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-FOURTH,

FOR 1918.

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MCMXIX.

List

OF THE

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Elected February 15th, 1918.

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No. 294—July 9th, 1919.
No. 295—September 5th, 1919.
No. 296—November 25th, 1919.

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EDITED BY

THE PERMANENT SECRETARY.

[With Eleven Plates, illustrating the Paper by Prof. E. J. Garwood & Miss Goodyear & Dr. A. Holmes's Paper.]

May 6th, 1919.

LONDON:

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ORDINARY MEETINGS OF THE GEOLOGICAL SOCIETY TO BE HELD AT BURLINGTON HOUSE.

Session 1918–1919.

1919.

Wednesday, May .... 7 —21*
,, June .... 4 —25*

[*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 1917–18.

November 7th, 1917.

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

The List of Donations to the Library was read.

A Lecture on 'The Nimrud Crater in Turkish Armenia' was delivered by FELIX OSWALD, B.A., D.Sc., F.G.S,

The Nimrud volcano, one of the largest volcanic craters in the world, is situated on the western shore of Lake Van, and was surveyed and investigated geologically for the first time by the speaker in 1898. The western half of the crater is occupied by a deep lake of fresh water, while the eastern half is composed of recent augite-rhyolites, partly cloaked in white volcanic ash. The crater-wall is highest on the north (9903 feet), rising in abrupt precipices over 2000 feet above the lake (7653 feet). The southern wall is also precipitous, but only reaches the height of 9434 feet (the south-eastern part). A large slice of the crater-wall has slipped down on the south-west, so as to form a narrow shelf, 800 feet above the lake. The crater is nearly circular, 8405 yards from west-south-west to east-north-east, while the transverse axis is 7905 yards. The lowest points lie on the long axis, reaching only 8139 feet on the western, and 8148 feet on the eastern rim.

The crater-wall has an external slope of 33° on the south and east, where it consists exclusively of overlapping lenticular flows of augite-rhyolite and obsidian. On the south-west, west, north-west, and north these are capped by thin sheets of cindery basalt which must have possessed great fluidity, extending for many miles to form wide fertile plains of gentle slope down to Lake Van on the east and into the Plain of Mush on the west. These basalt-flows dammed up the north-east to south-west valley between the Bendimahi and Bitlis rivers, and thus brought Lake Van into being.

The history of the Nimrud volcano may be summarized as follows from the speaker's observations:—

1. Its forerunner was the Kerkur Dagh on its southern flank,—a denuded mass of grey augite-trachyte, rising to 9000 feet, and crowned by many peaks. It was probably erupted in the Pliocene Period, subsequently to the folding of the Armenian area, in which the latest folded rocks are of Miocene (Helvetian–Tortonian) age, occurring north of the Nimrud Dagh and consisting of limestones with corals (*Cladocora articulata*, *Orbicella defrancei*, etc.), *Lithothamnion*, foraminifera (Lepidocycline *Orbitoides*, *Amphistegina*, etc.), beds of *Pecten* (*P. urmiensis*, etc.) and of oysters (*Alectryonia virleti*). Nimrud and the other numerous volcanoes of Armenia came into existence at a period when the sedimentary rocks could no longer be folded, but were fractured along definite lines, and Nimrud is situated on the great fracture transverse to the Armenian folds at the apex of their bending round from the Antitauric (west-south-west to east-north-east) to the Persian (north-west to south-east) direction. It also marks the point of intersection of this fracture with a great north-east to north-west fracture (Caucasian direction), which delimits on the south Lake Van and the faulted depression of the Plain of Mush, abruptly cutting off the Tauric horst of pre-Devonian marbles and mica-schists.

2. Numerous flows of augite-rhyolite built up the vast cone of the Nimrud Dagh, and the increasing pressure on the central vent became relieved by extrusions of augite-trachyte along radial fissures, forming the present promontories of Kizvag, Zighag, and Karmuch.

3. A presumably long period of inactivity was followed by violent explosions destroying the summit of the cone, and from this crater (smaller than the present one) vast lava-flows of a very fluid basalt (crowded with phenocrysts of labradorite, pale-green augite, and some olivine) flooded the country, filling up the Bitlis and Akhlat valleys, which have since then been eroded a little below their former depth. The Sheikh-Ora crater of basic tuff (now breached by Lake Van) probably belongs to this period.

4. Further explosions widened the crater, in which a large lake was formed; while the eastern half of the crater became filled by a succession of outflows of augite-rhyolite, in which numerous blow-holes were drilled, bringing to the surface large blocks of basaltic agglomerate, and also affording sections that show the transition downwards from obsidian, spherulitic obsidian, and spherulitic rhyolite to banded augite-rhyolite (with sanidine and green augite in a micropœcilitic ground-mass).

5. The last eruption was recorded in 1441 by a contemporary Armenian chronicler, and resulted in the extrusion of a very viscous augite-rhyolite along a north-to-south zone of weakness, both inside

the Nimrud crater, where it separated off part of the large lake to form the shallow, so-called 'hot lake,' and also north of Nimrud, where it rose up through fissures and in a small crater.

6. A violent earthquake in 1881, which destroyed the village of Teghurt, at the eastern base of the crater-wall, was the last sign of activity: but earthquakes are still frequent in the Plain of Mush, at the western foot of the Nimrud Dagh, and recent fault-scarps are clearly visible along the borders of this faulted depression.

The speaker mentioned that he had presented his model of the crater to the Museum of Practical Geology (Jermyn Street) and the rock-specimens and microscope-slides to the British Museum (Natural History), where his fossils from Armenia are already preserved.

A short discussion followed, and the thanks of the Fellows present were accorded to Dr. Oswald for his lecture.

Lantern-slides of many unpublished photographs and drawings of the Nimrud Crater and its surroundings, a model coloured geologically on the scale of 1 inch to the mile, and a series of rock-specimens and rock-sections were exhibited by Dr. Oswald, in illustration of his lecture.

A Geological Survey map of the Maclean-Umtata district, Cape Province, Sheet 27, scale: 1 inch=3·75 miles, 1917 (presented by the Geological Survey of the Union of South Africa), was also exhibited.

November 21st, 1917.

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

The List of Donations to the Library was read.

The following communication was read:—

'The Shap Minor Intrusions.' By James Morrison, B.A., B.Sc. (Communicated by Dr. Herbert Lapworth, Sec.G.S., M.Inst.C.E.)

Diagrams, rock-specimens, and microscope-sections of the Shap minor intrusions were exhibited by Mr. Morrison, in illustration of his paper.

A Geological & Topographical Atlas of the Gympie Goldfield and Environs, in 36 sheets, scale 1 : 4752, 1910–1911 (presented by the Queensland Geological Survey) was also exhibited.

December 5th, 1917.

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

Thomas Robert Ablett, Pembroke Lodge, Outram Road, Addiscombe (Surrey); John Albert Bullbrook, 15 Abercromby Street, Port of Spain, Trinidad (B. W. I.); Charles Herbert Henry Gore, 69 Eastcott Hill, Swindon (Wiltshire); George Thomas Heal, A.M.Inst.M.M., care of the High-Speed Steel Alloys, Ltd., Tavoy (Burma); William Blomfield Hume, B.Sc., United B. W. I. Petroleum Syndicate, Port of Spain, Trinidad (B. W. I.); Francis Sear Jolly, 14 Allerton Road, Stoke Newington, N. 16; William McDonald, 53 Dalzell Street, Moor Row (Cumberland); Stephen Miall, LL.D., B.Sc., 28 Belsize Grove, N.W. 3; Evan John Morris, Llwyncelyn, Bangor (North Wales); Clive Edward Effingham Pargeter, A.M.Inst.M.M., Westbrook House, Hounslow (Middlesex); Sir John Frecheville Ramsden, Bart., Bulstrode, Gerrard's Cross (Buckinghamshire); Albert Ernest Thomas, M.Inst.M.M., Oak House, Minsterley, Shrewsbury; and Arthur Elijah Trueman, M.Sc., 598 Berridge Road, Nottingham, were elected Fellows of the Society.

The List of Donations to the Library was read.

A Demonstration on the Application of X-Rays to the Determination of the Interior Structure of Microscopic Fossils, particularly with reference to the Dimorphism of the Nummulites, was given by EDWARD HERON-ALLEN, F.L.S., F.G.S., Pres.R.M.S., and J. E. BARNARD, F.R.M.S.

Mr. HERON-ALLEN said that, in the year 1826, Alcide d'Orbigny published among the innumerable, and for many years unidentified, nomina nuda that compose his 'Tableau Méthodique de la Classe des Céphalopodes' the name *Rotalia dubia*. This species was left untouched by Parker & Jones in their remarkable series of articles on the 'Nomenclature of the Foraminifera.' The French naturalist G. Berthelin was the first investigator to unearth and make use of the 'Planches inédites' which had been partly completed by D'Orbigny for the illustration of his great work upon the Foraminifera, a work that was never published. Working with Parker & Jones's paper, Berthelin made for his own use careful tracings of 246 of A. d'Orbigny's unfinished outline-sketches. These sketches were never elaborated by D'Orbigny upon the 'Planches,' which are still preserved in the Laboratoire de Paléontologie under the care of Prof. Marcellin Boule; among them was found the sketch of *Rotalia dubia*. On the death of Berthelin the tracings passed into the possession of Prof. Carlo Fornasini of Bologna, who reproduced them all in a valuable series of papers published between the years 1898 and 1908. Fornasini's opinion was that the organism depicted by D'Orbigny was doubtfully of Rhizopodal nature, and that it was probably referable to the Ostracoda. The speaker said that he had examined the D'Orbigny type-specimens in Paris in 1914, and had noted that *Rotalia dubia* was a worn and unidentified organism, resembling an ostracod.

There the matter rested, until Mr. Arthur Earland and the speaker, while examining the material brought by Dr. J. J. Simpson from the Kerimba Archipelago (Portuguese East Africa) in 1915, discovered one or two undoubted foraminifera of an unknown type, which resembled Berthelin's tracing. Prof. Boule kindly sent the D'Orbigny type-specimen to London, and the Rhizopodal nature of *Rotalia dubia* was established. It is not a *Rotalia*, and it must await determination until more specimens are obtained: it has been named provisionally *Pegidia papillata*. There were two or three forms of the organism, but only one perfect specimen of the D'Orbigny type; and it was undesirable to risk destruction by cutting a section of it. In these circumstances Mr. Barnard was approached, and he experimented with the object of ascertaining the interior structure of the shell by means of the X-rays. His results were extraordinarily promising, and led to further experiments.

The speaker showed on the screen photographs of the common and dense foraminifer *Massilina secans* (D'Orbigny), followed by a skiagraph of the same. A skiagraph of the still denser test of *Biloculina bulloides* D'Orbigny shows the arrangement of the earlier chambers as clearly as it is indicated in Schlumberger's beautiful sections. The application of X-rays to the dense imperforate shells of *Cornuspira foliacea* (Philippi) produced skiagraphs showing the dimorphism of the shells, both megalo- and microspheric primordial chambers being clearly distinguishable. Such results led to the extension of the experiments to the agglutinated arenaceous forms, of which sections are made with extreme difficulty. The skiagraph of *Astrorhiza arenaria* Norman shows the internal cavities that contained the protoplasmic body. Two arenaceous forms, *Botellina labyrinthica* Brady and *Jaculella obtusa* Brady, that are almost identical in external appearance, are distinguished at once by their respective skiagraphs, the one exhibiting a simple tubular cavity, the other appearing labyrinthic.

Mr. Barnard subsequently experimented on still more difficult material. The massive *Operculina complanata* Defrance, the umbilical portion of which is obscured by a mass of secondary shell-substance, furnished a clear skiagraph that showed some curious distortions of the internal septa. Similar results were obtained in the case of *Orbiculina adunca* (Fichtel & Moll), another species overladen with shell-matter. *Cyclammina cancellata* Brady is an arenaceous form, composed of softer mud and sand, studded with coarse sand-grains which make section-cutting almost an impossibility. The skiagraphs, however, reveal the primordial chamber, and establish the character of this form.

The determination of the Nummulites, depending as it does on a knowledge of the internal structure of the test, is greatly facilitated by the application of X-rays, which removes the necessity of splitting the test or cutting sections through it.

The speaker showed ordinary photographs and skiagraphs, made at slightly varying azimuths, of *Nummulites lævigata* and *N. variolaria*, forms that strew the shores of Selsey Bill. A particularly notable result was obtained in the case of *N. gizehensis*, an organism that forms the dense masses of Nummulitic Limestone of which the Pyramids of Egypt and the Citadel at Cairo are built.

Mr. Barnard said that, although the utilization of X-rays to determine the internal structure of various bodies was well known, he was not aware that the method had been successfully applied to small objects, such as foraminifera. After he had begun his experiments he found that M. Pierre Goby had done some work in this direction in France, but the method as Goby described it is surrounded with considerable mystery and elaboration of apparatus, which appear quite unnecessary. The speaker's results were arrived at independently; in fact, they are really a side issue.

His original experiments were directed rather towards the use of X-rays in obtaining magnified images, altogether apart from the usual skiagraphic methods in which a shadowgraph is, in fact, all that can be produced. The primary object has not yet been achieved, although there is some reason to hope that it may ultimately come to pass. The results shown by Mr. Heron-Allen are obtained by quite simple means. A very narrow beam of X-rays, such as would be termed 'a parallel beam' when speaking in terms of ordinary light, is allowed to impinge on the object, the latter being in contact with the photographic plate. The negative produced is, therefore, of the same size as the object. Photographic enlargement is then resorted to, and the result had been shown on the screen.

There are two points that require careful attention if success is to be achieved. The quality of the X-rays must be suited to the object. In nearly all cases of small objects, what are known as 'soft' X-rays must be used, and the degree of softness is the *crux* of the whole matter. The photographic plate must be of exceedingly fine grain, otherwise the amount of enlargement that can be obtained is very limited. Difficulties in this direction have been overcome, and Mr. Heron-Allen states that the results are of considerable biological value.

A short discussion followed, and the thanks of the Fellows present were accorded to Mr. Heron-Allen and Mr. Barnard for their demonstration.

Dr. A. Smith Woodward, F.R.S., V.P.G.S., exhibited a radiogram of the original slab of lithographic stone containing the skeleton of *Archæopteryx*, made for the British Museum by Dr. Robert Knox in 1916. It was evident that the penetrability of the fossil bones to the X-rays was the same as that of the surrounding matrix. The only portions of the skeleton visible in the radiogram were those more or less raised above the general surface of the slab. This result accorded with that obtained by Prof. W. Branca, when he similarly experimented with the Berlin specimen of *Archæopteryx*.

December 19th, 1917.

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

The List of Donations to the Library was read.

The following communication was read:—

'The Chellaston Gypsum-Breccia considered in its Relation to the Gypsum-Anhydrite Deposits of Britain.' By Bernard Smith, M.A., F.G.S.

Lantern-slides, rock-specimens, and polished slabs of alabaster were exhibited by Mr. Bernard Smith, in illustration of his paper.

January 9th, 1918.

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

The List of Donations to the Library was read.

The following Resolution of the Council was unanimously approved by the Fellows present. It was further resolved that a copy be forwarded to the Prime Minister:—

> The Council of the Geological Society has learned with surprise and regret of the proposal of the War Cabinet and the Office of Works to dismantle the British Museum at Bloomsbury and its Natural History Branch at South Kensington, in order to convert the buildings into ordinary public offices. It desires to protest most strongly against this unfortunate blow to the cultivation and progress of learning in the Empire, and earnestly hopes that the Government's intention may be reconsidered. The Geological and Mineralogical Collections, of which the Geological Society has special knowledge, are continually needed for reference concerning numerous problems that arise in the present crisis, and they cannot be rendered inaccessible without danger to their preservation.

The following communication was read:—

'The Highest Silurian Rocks of the Clun-Forest District (Shropshire).' By Lawrence Dudley Stamp, B.Sc., A.K.C.L. (Communicated by Dr. A. H. Cox, F.G.S.)

Specimens of rocks and fossils from the Silurian of the Clun-Forest district were exhibited on behalf of Mr. L. D. Stamp, in illustration of his paper.

January 23rd, 1918.

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

Frederick George Jones, 33 Royal York Crescent, Clifton, Bristol; Sir Douglas Mawson, D.Sc., B.E., The University, Adelaide (South Australia); Nagardas Purushottam Gandhi, M.A., B.Sc., A.R.S.M., D.I.C., Wolfram Mines, Tavoy (Burma); George Turner Reeve, M.A., 79 St. John's Avenue, Bridlington (Yorkshire); Alfred Ulrich Max Schlæpfer, Doctor of Technical Science (Zurich, Switzerland), 12 Arlington Gardens, Chiswick, W. 4; and Lawrence Dudley Stamp, B.Sc., A.K.C.L., Passey's House, Eltham, S.E. 9, were elected Fellows of the Society.

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: R. Mountford Deeley, M.Inst.C.E., and Bernard Smith, M.A.

The following communication was read:—

'On a Flaked Flint from the Red Crag.' By Prof. William Johnson Sollas, M.A., Sc.D., LL.D., F.R.S., V.P.G.S.

A specimen of a flaked flint from the Red Crag of Messrs. Bolton & Company's Pit at Ipswich was exhibited by Prof. W. J. Sollas, in illustration of his paper.

February 6th, 1918.

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

James Arthur Butterfield, M.Sc., 59 Barrett Street, Shipley (Yorkshire); and Lieut. Frederick Stretton Wallis, 9 Wolferton Road, St. Andrews, Bristol, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'Some Considerations arising from the Frequency of Earthquakes.' By Richard Dixon Oldham, F.R.S., F.G.S.

Diagrams were exhibited by Mr. R. D. Oldham, in illustration of his paper.

ANNUAL GENERAL MEETING.

February 15th, 1918.

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

Report of the Council for 1917.

During the year under review, 32 new Fellows were elected into the Society (2 less than in 1916) and 3 Fellows were re-admitted after payment of arrears. Of the Fellows elected in 1917, 23 paid their Admission Fees before the end of that year, and of the Fellows who had been elected in the previous year 6 paid their Admission Fees in 1917, making the total accession of new Fellows during the past year amount to 29 (5 less than in 1916).

Allowing for the loss of 43 Fellows (8 resigned, and 35 deceased), it will be seen that there is a decrease of 11 in the number of Fellows, as compared with a decrease of 32 in 1916.

The total number of Fellows is, therefore, at present 1220, made up as follows:—Compounders 216 (10 less than in 1916); Contributing Fellows 989 (1 less than in 1916); and Non-Contributing Fellows 15 (the same as in 1916).

Turning now to the Lists of Foreign Members and Foreign Correspondents, the Council has to regret the loss during the past year of Dr. H. E. Sauvage and Dr. W. B. Clark, both Foreign Correspondents. It will be remembered that, in the List of Foreign Members at the end of 1916, there were four vacancies, and six in that of Foreign Correspondents; and, as no elections were held to make up the numbers during the past year, there are, at present, four vacancies in the List of Foreign Members and eight vacancies in that of Foreign Correspondents.

With regard to the Income and Expenditure of the Society during 1917, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £676 12*s.* 5*d.* brought forward from the previous year) amounted to £2966 10*s.* 8*d.*, being £413 10*s.* 8*d.* more than the estimated Income.

On the other hand, the Expenditure during the same year, including the outlay of £475 for £500 5 % War Loan, amounted to £3581 1*s.* 6*d.*, being £553 1*s.* 6*d.* more than the estimated Expenditure, and the year closed with a Balance in hand of £62 1*s.* 7*d.*

Early in the year the Council decided to recommend the expenditure of the proceeds of the Sorby and Hudleston Bequests in fitting up the Meeting-Room Annexe as a Map-Room. Plans were prepared, and estimates obtained; but, on the advice of the

Architect of H.M. Office of Works, the work was postponed until after the War.

With regard to the publications of the Society, the Council has to announce the completion of Vol. LXXII of the Quarterly Journal (1916). No. 20 of the Society's 'Record of Geological Literature' (1913) is now in the printers' hands.

In accordance with the provisions of the modification of Bye-Law Section VI, Art. 4, sanctioned at the Special General Meeting of March 10th, 1915, the Council has, on the motion of the Treasurer, remitted the contributions of 49 Fellows serving with His Majesty's Forces (18 more than in 1916).

During the past year the Apartments of the Society have been used for General and for Council Meetings by the Institution of Mining Engineers, the Institution of Mining & Metallurgy, the Institution of Water Engineers, the Institution of Municipal & County Engineers, the Society of Engineers, the Mineralogical Society, the Palæontographical Society, the Ray Society, the South-Eastern Union of Scientific Societies, and the Geological Physics Society.

Dr. A. Strahan and Prof. W. G. Fearnsides have continued to act during the year as our representatives on the Conjoint Board of Scientific Societies.

The fifteenth Award from the Daniel Pidgeon Trust Fund was made on March 28th, 1917, to Arthur Holmes, B.Sc., who proposed to conduct researches in connexion with the Geology of the Dartmoor Border around Okehampton and Belstone.

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

The Wollaston Medal is awarded to Dr. Charles Doolittle Walcott, in recognition of his 'Researches concerning the Mineral Structure of the Earth,' especially in connexion with the Stratigraphy and Palæontology of the Oldest Fossiliferous Rocks.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Mr. Joseph Burr Tyrrell, in recognition of the value of his explorations in the less accessible regions of Canada, and of his researches on the Geology of Gold Deposits in that country.

The Lyell Medal, together with a sum of Twenty-Five Pounds, is awarded to Mr. Henry Woods, as an acknowledgment of the value of his researches in Palæontology, more particularly on the Fauna of the Cretaceous Period.

The Prestwich Medal is awarded to Prof. William Boyd Dawkins, in recognition of his important studies in Pliocene and Pleistocene Geology, connected more especially with the Mammalia of those Periods.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. Albert Ernest Kitson, in recognition of his contributions to our knowledge of the Geology and Mineralogy of Australia and Africa.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. Thomas Crook, in acknowledgment of the value of his work on the Separation and Identification of Minerals, and on the Mineralogy of our Colonies in general.

A Moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Vincent Charles Illing, as a mark of appreciation of his work on the Lower Palæozoic Rocks of Warwickshire, and to stimulate him to further research.

A second Moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. William Kingdon Spencer, as an acknowledgment of the value of his work on the Cretaceous Asteroidea, and to encourage him to extend his studies to Asteroidea from other formations.

Report of the Library Committee for 1917.

The accessions during the year are approximately the same in number and importance as those of the last two years, but the number of books borrowed has increased by 30 per cent. For purposes of reference the Library has been freely used by certain of the Government Departments requiring information. A large number of books has been bound, and the binding is now as complete as it can be at present. The contents of many of the shelves in the top gallery of the Upper Library have grown in the last few years to such an extent that overcrowding has resulted; and this presents a problem that must be taken in hand as soon as circumstances permit.

The principal task of the year was the completion of the compilation of No. 20 of the 'Record of Geological Literature,' and despite the fact that much time has been taken up with enquiries, this has now been placed in the printers' hands. The preparation of No. 21 (for 1914) of this Record should not take so long, for only about half the usual amount of foreign literature was received in that year, and much time will be saved by the system of registration instituted at the commencement of that year.

The Donations number 17 Volumes of separately published Works, 203 Pamphlets, and 8 detached Parts of Works, also 114 Volumes and 156 detached Parts of Serial Publications, 14 Volumes and 143 detached Parts of the publications of Geological Surveys and other public bodies, and 8 Volumes of Weekly Periodicals.

The total number of accessions by Donation amounts, therefore, to 153 Volumes, 203 Pamphlets, and 303 detached Parts.

Among the books and pamphlets already mentioned in the foregoing paragraph, especial attention may be drawn to the following works:—

'Volcanic Studies in Many Lands: being Reproductions of Photographs taken by the Author, Tempest Anderson'; second series, text by T. G. Bonney, 1917; 'The Banket—a Study of the Auriferous Conglomerates of the Witwatersrand & the Associated Rocks,' by R. B. Young, 1917; 'Italian Mountain Geology (Piémont, Liguria, & Western Tuscany, including Elba),' by C. S. Du Riche Preller, 1917; E. W. Berry's monograph on the 'Lower Eocene Floras of South-Eastern North America' (Professional Paper 91, U.S. Geological Survey, 1916); Mr. T. Sheppard's Account of 'William Smith: his Maps & Memoirs' (Proc. Yorkshire Geol. Soc. vol. xix, 1917); the Report published by the Egyptian Survey Department on the Oilfield Region of Egypt, by W. F. Hume, with map by J. Ball, 1916; the memoir on the 'Structure of the Himalayas & of the Gangetic Plain as elucidated by Geodetic Observations in India,' by R. D. Oldham (Mem. Geol. Surv. India, vol. xlii, 1917); and the 2nd editions of the Geological Survey's Special Reports on the Mineral Resources of Great Britain, dealing with Barytes & Witherite (vol. ii) and Fluorspar (vol. iv), 1917.

Numerous works have been also received from the various Colonial Geological Surveys; and those of the States of Australia have presented several of economic importance.

The number of Maps received shows an increase; there has been presented during the year 36 sheets from the Geological Survey of Queensland, 12 sheets accompanying Dr. A. Wade's report on Petroleum in Papua, 4 sheets from the Geological Survey of Sweden, 4 sheets from that of the Union of South Africa, 2 sheets from that of Scotland, and one each from the Geological Surveys of England and Ireland. Mention should be made also of the acquisition of William Smith's map of the Hackness Hills (1832), and of the manuscript map of the Federated Malay States prepared by Mr. J. B. Scrivenor from all sources, and representing all that was known of the geology of that region up to the end of 1916.

Mr. Thomas Sheppard has been engaged in cataloguing the Maps of the British Isles. The catalogue of the Society's collection of separately-published maps is practically completed, and contains about 300 items. It includes an unrivalled series belonging to Greenough and a large number of valuable manuscript maps, which are described in detail. In addition to these loose maps, all those contained in serial publications will be dealt with, and for this purpose the publications of the various British Geological Societies and Associations, as well as most of the local scientific societies' Transactions, and the various Geological Survey Memoirs have been examined and catalogued. Mr. Sheppard does not propose to include maps published by the Geological Survey. The bulk of the catalogue is now in manuscript, and the number of entries already exceeds 3000, but there still remains a great number of pamphlets and miscellaneous publications which must be examined before the catalogue can be regarded as really representative of all the geological maps of the British Isles. Much of this work has to be done away from London; but Mr. Sheppard hopes to devote some time in the Library during the next summer, in order to complete the catalogue.

The Donors during the preceding year included 101 Government Departments and other Public Bodies, 104 Societies and Editors of Periodicals, and 88 Personal Donors.

The Purchases included 33 Volumes and 22 detached Parts of separately published Works, and 17 Volumes and 22 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 and Periodicals	15	19	2
Binding and Map-mounting	116	3	10
Catalogue Cards	28	5	7
Total	£160	8	7

Mr. C. D. Sherborn reports steady progress with the Card-Catalogue of the Library. He has incorporated all the geological papers contained in the fifteenth volume of the Royal Society's Catalogue of Scientific Papers, and has edited the whole of the Catalogue so far as the letter L. Four new cabinets have been added to the Catalogue.

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, Government of the Commonwealth of. Melbourne.
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.).
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).—Académia 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.
——. Imperial Geological Survey. Tokyo.
Kingston (Canada).—Queen's College.
Leeds, University of.
London.—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.
——, Royal 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.
Quebec.—Department of Colonization, Mines, & Fisheries.
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.
Southern Rhodesia.—Geological Survey, Salisbury.
Stockholm.—Kongliga Svenska Vetenskapsakademi.

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.
United States.—Department of Agriculture. Washington (D.C.).
——. Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, Royal University of.
Victoria (Australia), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Washington (D.C.).—Smithsonian Institution.
——. Geophysical Laboratory.
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.—British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.

London.—Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Institution of Water Engineers.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Magazine.'
——. '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.

Adye, E. H.
Allen, E. T.
Arber, E. A. N.

Baker, H. A.
Basedow, H.
Beard, R. E.
Belisario, B. S.
Bolton, H.
Boswell, P. G. H.
Bowen, N. L.
Brooks, C. E. P.
Brown, C. Barrington.
Buckman, S. S.

Cantrill, T. C.
Chakho, I. C.
Chapman, F.
Chauvet, G.
Choffat, P.
Cockerell, T. D. A.
Cole, G. A. J.
Crick, G. C.
Crum, J.

Davies, A. M.
Day, A. L.
Depéret, C.
Du Toit, A. L.

Evans, J. W.

Gardiner, C. I.
Garrard, J.
Gibson, W.
Green, J. F. N.
Gregory, J. W.
Guareschi, I.
Guébhard, A.

Haughton, S. H.
Heinrick, M.
Herdsman, W. H.
Heron-Allen, E.
Holmes, A.
Hooley, R. W.
Hopkinson, J.
Hume, W. F.
Hutchinson, H. N.

Johnston, J.

Katô, T.
King, W. Wickham.

Lacroix, A.
Lamplugh, G. W.
Leach, A. L.
Lemoine, P.
Lisboa, A.

Means, P. A.
Mellor, E. T.
Merrill, G. P.
Miller, W. G.

Newton, R. B.
North, F. J.

Oldham, R. D.

Park, J.
Perret, F. A.
Pringle, J.

Reed, F. R. C.
Robarts, N. F.
Robinson, W. I.

Sawyer, A. R.
Schuchert, C.
Sheppard, T.
Sjögren, A.
Smith, G.
Sosman, R. B.
Speight, R.
Stainier, X.
Stanley, E. R.
Stevenson, J. J.
Stobbs, J. T.

Thomas, H. H.
Thomson, J. Allan.
Trueman, A. E.

Uttley, G. H.

Wade, A.
Walford, E. A.
Washington, H. S.
Webb, F.
Welsch, J.
Wherry, E. T.
Whitaker, W.
Wilson, E. M.

Zealley, A. E. V.

Comparative Statement of the Number of the Society at the Close of the Years 1916 and 1917.

	Dec. 31st, 1916.		Dec. 31st, 1917.
Compounders	223	....	216
Contributing Fellows	990	....	989
Non-Contributing Fellows	15	....	15
	1228		1220
Foreign Members	36	....	36
Foreign Correspondents	38	....	36
	1302		1292

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1915 and 1916.

Number of Compounders, Contributing, and Non-Contributing Fellows, December 31st, 1916 ...		1231
Add Fellows elected during the former year and paid in 1917		6
Add Fellows elected and paid in 1917		23
Add Fellows reinstated after payment of arrears.		3
		1263
Deduct Compounders deceased	12	
Contributing Fellows deceased	23	
Contributing Fellows resigned	8	
	—	43
		1220
Number of Foreign Members and Foreign Correspondents, December 31st, 1916	74	
Deduct Foreign Correspondents deceased	2	
	72	
	—	72
		1292

Deceased Fellows.

Compounders (12).

Bell, R. [elected 1865.]
Cotton, T. [el. 1874.]
Crick, C. G. [el. 1881.]
Cross, J. [el. 1906.]
Dewick, E. S. [el. 1873.]
French, H. H. [el. 1885.]
Poole, H. S. [el. 1866.]
Rosales, H. [el. 1877.]
Stephenson, J. G. L. [el. 1887.]
Tiddeman, R. H. [el. 1869.]
Trechmann, C. O. [el. 1882.]
Woodward, H. P. [el. 1883.]

Resident and other Contributing Fellows (23).

Anderson, C. W. [elected 1904.]
Boyle, R. [el. 1911.]
Bradshaw, C. [el. 1913.]
Brown, C. B. [el. 1879.]
Burton, R. C. [el. 1911.]
Carroll, F. J. [el. 1904.]
Fowler, F. [el. 1910.]
Fowler, J. C. [el. 1880.]
Franks, G. F. [el. 1890.]
Green, U. [el. 1889.]
Hague, A. [el. 1880.]
Hawksley, C. [el. 1898.]
Howard, F. T. [el. 1892.]
Hughes, T. McK. [el. 1862.]
Kennedy, H. T. [el. 1913.]
Latham, B. [el. 1876.]
Lawn, J. G. [el. 1896.]
Leeds, A. N. [el. 1893.]
Parrott, T. S. [el. 1907.]
Paul, F. P. [el. 1905.]
Pilkington, H. [el. 1916.]
Pretyman, F. R. [el. 1914.]
Roberts, J. [el. 1896.]

Fellows Resigned (8).

Cobbe, H. N. G.
Gordon, H. A.
Griffiths, Sir John N.
Heaton, E. W.
Hutchings, W. M.
Pomeroy, A. G.
Wakelam, H. T.
Wray, C.

Foreign Correspondents Deceased.

Clark, W. B. [elected 1904.]
Sauvage, H. E. [el. 1879.]

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 :—

(1) That the thanks of the Society be given to Dr. Alfred Harker, retiring from the office of President.

(2) That the thanks of the Society be given to Mr. E. T. Newton and Dr. A. Smith Woodward, retiring from the office of Vice-President and also from the Council, and to the other retiring members of the Council: Prof. C. G. Cullis, Dr. Walcot Gibson, and Prof. T. F. Sibly.

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.—1918.

PRESIDENT.

George William Lamplugh, F.R.S.

VICE-PRESIDENTS.

R. Mountford Deeley, M.Inst.C.E.
Alfred Harker, M.A., LL.D., F.R.S.
Prof. William Johnson Sollas, M.A., LL.D., Sc.D., F.R.S.
Sir Jethro J. Harris Teall, M.A., D.Sc., LL.D., F.R.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.

James Vincent Elsden, D.Sc.

COUNCIL.

Charles William Andrews, D.Sc., F.R.S.
Francis Arthur Bather, M.A., D.Sc., F.R.S.
Prof. John Cadman, C.M.G., D.Sc., M.Inst.C.E.
Arthur Morley Davies, D.Sc., A.R.C.Sc.
R. Mountford Deeley, M.Inst.C.E.
James Vincent Elsden, D.Sc.
Prof. Edmund Johnston Garwood, M.A., Sc.D., F.R.S.
Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.
John Frederick Norman Green, B.A.
Alfred Harker, M.A., LL.D., F.R.S.
Finlay Lorimer Kitchin, M.A., Ph.D.
George William Lamplugh, F.R.S.
Herbert Lapworth, D.Sc., M.Inst. C.E.
Major Henry George Lyons, D.Sc., F.R.S.
Prof. John Edward Marr, M.A., Sc.D., F.R.S.
Richard Dixon Oldham, F.R.S.
Robert Heron Rastall, M.A.
Prof. William Johnson Sollas, M.A., Sc.D., LL.D., F.R.S.
Prof. Henry Hurd Swinnerton, D.Sc.
Sir Jethro J. Harris Teall, M.A., D.Sc., LL.D., F.R.S.
Herbert Henry Thomas, M.A., Sc.D.
Samuel Hazzledine Warren.
Prof. William Whitehead Watts, M.A., Sc.D., LL.D., F.R.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1917.

Date of Election.

1884. Commendatore Prof. Giovanni Capellini, *Bologna.*
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.*). (*Deceased.*)
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, *Petrogråd.*
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.* (*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.*
1911. Prof. Baron Gerard Jakob de Geer, *Stockholm.*
1911. M. Emmanuel de Margerie, *Paris.*
1912. Prof. Marcellin Boule, *Paris.*
1913. 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. Alexis Petrovich Pavlow, *Moscow.*
1914. Prof. William Berryman Scott, *Princeton* (*New Jersey*).

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1917.

Date of Election.

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.*
1900. Prof. Federico Sacco, *Turin.*
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1902. Prof. Samuel Wendell Williston, *Chicago, Illinois* (*U.S.A.*). (*Deceased.*)
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.*). (*Deceased.*)

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. Harris 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. Prof. John Edward Marr.
1915. Prof. T. W. Edgeworth David.
1916. Dr. A. P. Karpinsky.
1917. Prof. A. F. A. Lacroix.
1918. Dr. Charles D. Walcott.

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.
1917. Prof. Percy G. H. Boswell.
1918. Mr. Albert Ernest Kitson.

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 P. Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.
1913. Mr. George Barrow.
1914. Mr. William A. E. Ussher.
1915. Prof. William W. Watts.
1916. Dr. Robert Kidston.
1917. Dr. George F. Matthew.
1918. Mr. Joseph Burr Tyrrell.

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 E. L. Dixon.
1914. Mr. Frederick Nairn Haward.
1915. Mr. David Cledlyn Evans.
1916. Mr. George Walter Tyrrell
1917. Dr. William Mackie.
1918. Mr. Thomas Crook.

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. Prof. 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.
1917. Dr. Wheelton Hind.
1918. Mr. Henry Woods.

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.
1917. Prof. A. Hubert Cox.
1917. Mr. Tressilian C. Nicholas.
1918. Mr. Vincent Charles Illing.
1918. Mr. William Kingdon Spencer.

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. Harris Teall.
1891. Dr. George Mercer Dawson.
1893. Prof. William J. Sollas.
1895. Dr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. Edgeworth David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.
1905. Prof. John Walter Gregory.
1907. Dr. Arthur W. Rogers.
1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.
1913. Sir Thomas H. Holland.
1915. Dr. Henry Hubert Hayden.
1917. Mr. Robert G. Carruthers.

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.
1918. Prof. William Boyd Dawkins.

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. Scientific instruments for Capt. E. F. 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' sarsens on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. { Mr. Bernard Smith. / Mr. John Brooke Scrivenor. }
1915. Mr. Joseph G. Hamling.
1917. Mr. Henry Dewey.

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. Prof. Percy G. H. Boswell.
1915. Mr. E. Talbot Paris.
1916. Dr. John K. Charlesworth.
1917. Dr. Arthur Holmes.
1918. Mr. James A. Butterfield.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions	70	0	0			
Arrears of Admission-Fees	50	8	0			
Admission-Fees, 1918	138	12	0			
				259	0	0
Arrears of Annual Contributions	160	0	0			
Annual Contributions, 1918	1690	0	0			
Annual Contributions in advance	39	18	0			
				1889	18	0
Sale of the Quarterly Journal, including Longmans' Account				100	0	0
Sale of other Publications				5	0	0
Miscellaneous Receipts				15	0	0
Interest on Deposit-Account				17	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			
Dividends on £500 5 per cent. War Loan 1929–1947	25	0	0			
				376	16	0
				£2662	14	0

the Year 1918.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House-Expenditure:						
Taxes		15	0			
Fire- and other Insurance	26	4	0			
Electric Lighting and Maintenance	38	0	0			
Gas	15	0	0			
Fuel	50	0	0			
Furniture and Repairs	10	0	0			
House-Repairs and Maintenance	10	0	0			
Annual Cleaning	15	0	0			
Washing and Sundry Expenses	40	0	0			
Tea at Meetings	20	0	0			
				224	19	0
Salaries and Wages, etc.:						
Permanent Secretary	360	0	0			
,, half Premium Life-Insurance	10	15	0			
Librarian	200	0	0			
Clerk	103	0	0			
Deputy Clerk	130	0	0			
Junior Assistant	54	12	0			
Library Assistant	91	0	0			
House-Porter and Wife	91	14	0			
Housemaid	55	4	0			
Charwoman and Occasional Assistance	18	0	0			
Accountants' Fee	10	10	0			
				1124	15	0
Office-Expenditure:						
Stationery	15	0	0			
Miscellaneous Printing	45	0	0			
Postages and Sundry Expenses	65	0	0			
				125	0	0
Grant to Conjoint Board of Scientific Societies				20	0	0
Library (Books and Binding)				100	0	0
Library Catalogue:						
Cards	10	0	0			
Compilation	50	0	0			
				60	0	0
Publications:						
Quarterly Journal, including Commission on Sale	630	0	0			
Postage on Journal, Addressing, etc.	80	0	0			
Abstracts of Proceedings, including Postage	100	0	0			
Record of Geological Literature	150	0	0			
List of Fellows	48	0	0			
				1008	0	0
				£2662	14	0

JAMES VINCENT ELSDEN, *Treasurer.*

February 5th, 1918.

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1917	59	3	10			
,, do. do. Deposit Account	600	0	0			
,, Balance in the hands of the Clerk at January 1st, 1917	17	8	7			
				676	12	5
,, Compositions				70	0	0
,, Admission-Fees:						
Arrears	37	16	0			
Current	138	12	0			
				176	8	0
,, Arrears of Annual Contributions				158	11	0
,, Annual Contributions for 1917:—						
Resident Fellows	1629	10	0			
,, Annual Contributions in advance	39	18	0			
				1669	8	0
Annual Contributions remitted 1917 (to be refunded)				10	10	0
,, Publications:						
Sale of Quarterly Journal: *						
,, Vols. i to lxxi (less Commission £4 14*s.* 6*d.*)	65	13	9			
,, Vol. lxxii (less Commission £3 12*s.* 3*d.*)	39	18	2			
				105	11	11
,, Other Publications (less Commission)				4	4	6
,, Miscellaneous Receipts				11	0	6
,, Interest on Deposit				22	15	11
,, Dividends (less Income-Tax):—						
£2500 India 3 per cent. Stock	56	5	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	11	5	0			
£2250 London & North-Western Railway 4 per cent. Preference Stock	67	10	0			
£2800 London & South-Western Railway 4 per cent. Preference Stock	84	0	0			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	39	9	11			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	6	0	4			
£500 5 per cent. War Loan 1929–1947	19	13	9			
				284	4	0
,, Income Tax recovered (two years to April 1917)				129	9	1
				£3318	15	4

* A further sum is due from Messrs. Longmans & Co. for Journal-Sales, etc. ... £49 15 0

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire- and other Insurance	26	3	10			
Electric Lighting, Installation and Maintenance	38	1	3			
Gas	15	3	5			
Fuel	76	14	6			
Furniture and Repairs	23	12	9			
House-Repairs and Maintenance	22	8	6			
Annual Cleaning	22	19	5			
Washing and Sundry Expenses	51	17	3			
Tea at Meetings	22	2	1			
				299	18	0
,, Salaries and Wages:						
Permanent-Secretary	360	0	0			
,, half Premium Life-Insurance	10	15	0			
Librarian	170	0	0			
Library Assistant	91	0	0			
Clerk	98	0	0			
Deputy Clerk	117	0	0			
Junior Assistant	54	12	0			
House-Porter and Wife	91	14	0			
Housemaid	53	4	0			
Charwoman and Occasional Assistance	18	7	6			
Accountants' Fee	10	10	0			
Extra Assistance	1	16	6			
War bonuses	49	12	0			
				1126	11	0
,, Office-Expenditure:						
Stationery	56	17	6			
Miscellaneous Printing	48	5	10			
Postages and Sundry Expenses	77	13	6			
				182	16	10
,, Library (Books and Binding, etc.)				147	16	5
,, Library-Catalogue:						
Cards	28	17	10			
Compilation	50	0	0			
Map-Catalogue (Expenses)	40	10	0			
				119	7	10
,, Grant to Conjoint Board of Scientific Societies				20	0	0
,, Publications:						
Quarterly Journal, Vol. lxxii, Paper, Printing, and Illustrations	646	15	9			
Postage on Journal, Addressing, etc.	83	17	0			
Abstracts, including Postage	105	13	5			
List of Fellows	48	17	6			
				885	3	8
,, Purchase of £500 5 per cent. War Loan 1929–47 (cost)				475	0	0
,, Balance in the hands of the Bankers at December 31st, 1917	45	0	3			
,, Balance in the hands of the Clerk at December 31st, 1917	17	1	4			
				62	1	7
				£3318	15	4

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

R. MOUNTFORD DEELEY, } *Auditors.*
BERNARD SMITH. }

JAMES VINCENT ELSDEN, *Treasurer.*

February 5th, 1918.

Statements of Trust-Funds: December 31st, 1917.

'WOLLASTON DONATION FUND.' TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	28	0	8	By Cost of Medal	10	10	0
" Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	24	2	10	" Award from the Balance of the Fund	17	10	8
" Income Tax recovered (two years to April 1917)	12	17	4	" Balance at the Bankers' at December 31st, 1917	37	0	2
	£65	0	10		£65	0	10

'MURCHISON GEOLOGICAL FUND.' TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	19	1	10	By Cost of Medal		11	0
" Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	30	0	2	" Award to the Medallist	10	10	0
" Income Tax recovered (two years to April 1917)	14	6	9	" Award from the Balance of the Fund	23	0	11
				" Balance at the Bankers' at December 31st, 1917	29	6	10
	£63	8	9		£63	8	9

'LYELL GEOLOGICAL FUND.' TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	46	16	7	By Cost of Medal		15	0
" Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	52	15	4	" Award to the Medallist	20	0	0
" Income Tax recovered (two years to April 1917)	28	2	8	" Award from the Balance of the Fund	39	5	5
				" Balance at the Bankers' at December 31st, 1917	67	14	2
	£127	14	7		£127	14	7

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	19	13	9	By Grant	24	19	1
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	10	10	8	,, Balance at the Bankers' at December 31st, 1917	10	5	11
,, Income Tax recovered (two years to April 1917)	5	0	7				
	£35	5	0		£35	5	0

'Bigsby Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	8	12	2	By Cost of Medal	10	19	5
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	4	14	6	,, Balance at the Bankers' at December 31st, 1917	4	17	8
,, Income Tax recovered (two years to April 1917)	2	10	5				
	£15	17	1		£15	17	1

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	34	4	0	By Grant	2	2	0
,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	3	2	8	,, Balance at the Bankers' at December 31st, 1917	36	18	2
,, Income Tax recovered (two years to April 1917)	1	13	6				
	£39	0	2		£39	0	2

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£ s. d.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	76	14	11	By Balance at the Bankers' at December 31st, 1917.				
,, Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock	15	15	0	Current Account	43 5 10			
,, Income Tax recovered (two years to April 1917)	8	8	0	On Deposit	60 0 0			
,, Interest on Deposit	2	7	11			103	5	10
	£103	5	10			£103	5	10

'Daniel Pidgeon Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	14	0	4	By Award	25	9	7
,, Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	22	18	6	,, Balance at the Bankers' at December 31st, 1917	23	13	10
,, Income Tax recovered (two years to April 1917)	12	4	7				
	£49	3	5		£49	3	5

SPECIAL FUNDS.

Hudleston Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	64	19	7	By Balance at the Bankers' at December 31st, 1917:						
,, Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	28	2	6	Current Account	63	18	0			
,, Income Tax recovered (two years to April 1917)	14	0	0	On Deposit	45	0	0			
,, Interest on Deposit	1	15	11					108	18	0
	£108	18	0					£108	18	0

Sorby Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.	£	s.	d.
To Balance at the Bankers' at January 1st, 1917	64	19	7	By Balance at the Bankers' at December 31st, 1917:						
,, Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	28	2	6	Current Account	63	18	0			
,, Income Tax recovered (two years to April 1917)	14	0	0	On Deposit	45	0	0			
,, Interest on Deposit	1	15	11					108	18	0
	£108	18	0					£108	18	0

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

JAMES VINCENT ELSDEN, *Treasurer.*
February 5th, 1918.

R. MOUNTFORD DEELEY, } *Auditors.*
BERNARD SMITH, }

Statement relating to the Society's Property: December 31st, 1917.

	£	s.	d.	£	s.	d.
Balance in the Bankers' hands, December 31st, 1917	45	0	3			
Balance in the Clerk's hands, December 31st, 1917	17	1	4			
				62	1	7
Due from Messrs. Longmans & Co., on account of the Quarterly Journal, Vol. LXXII, etc.	49	15	0			
Arrears of Admission-Fees (estimated)	66	3	0			
Arrears of Annual Contributions (Estimated to produce £160 0*s.* 0*d.*)	568	15	6			
				684	13	6
				£746	15	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 $2\frac{1}{2}$ per cent. Perpetual Preference Stock	1850	19	6			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250	0	0			
£2000 Canada $3\frac{1}{2}$ per cent. Stock	1982	11	0			
£500 5 per cent. War Loan (1929–1947)	475	0	0			
				£14191	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, 1917, amounted to* £8057 7*s.* 11*d.*]

JAMES VINCENT ELSDEN, *Treasurer.*

February 5th, 1918.

Award of the Wollaston Medal.

In handing the Wollaston Medal, awarded to Dr. Charles Doolittle Walcott, F.M.G.S., to Mr. William H. Buckler, Attaché to the Embassy of the United States of America in London, for transmission to the recipient, the President addressed him as follows:—

Mr. Buckler,—

The Wollaston Medal, the highest honour at the disposal of this Society, is conferred upon Dr. Charles Doolittle Walcott in recognition of his eminent services to Geology and Palæontology, more particularly among the older fossiliferous rocks of North America. While his administrative work, both on the United States Geological Survey and at the Smithsonian Institution, has done much for science in his own country, his personal researches have excited interest and admiration wherever Geology is cultivated.

He has made important contributions to the history of the Algonkian formations, and his discoveries lead us to hope that the less altered of those ancient sediments may ultimately yield more abundant and definite relics of pre-Cambrian life. His detection of fish-remains in the Ordovician rocks of Colorado, again, carried back by a stage the earliest appearance of vertebrates in the succession of life-forms. But it is in the Cambrian strata that Dr. Walcott has found chief scope for his labours, which, pursued principally upon the American continent, have often had a world-wide importance. Realizing the dual part which the exponent of Palæontology is called upon to sustain, he has illuminated that science alike in its geological and in its biological aspect. Under the former head should be mentioned the determination and collation of the stratigraphical sequence in numerous districts, and the light thrown thereby upon the problems of Palæophysiography. In particular, Dr. Walcott's study of the geographical distribution of the Cambrian faunas, establishing the existence of two distinct provinces, marked a signal advance in this field. On the biological side his work has been no less fruitful in results. It is sufficient to recall the series of memoirs dealing with the Trilobites, in which he greatly elucidated the organization of that important group, and again his two handsome volumes on the Cambrian Brachiopoda.

In recent years, with energy which a younger man might envy, he has pushed his researches into the Rocky Mountains of Canada, amidst scenery which his beautiful photographs have made known to many. There he has been rewarded by the bringing to light of two richly fossiliferous horizons in the Middle Cambrian succession, including in one an assemblage of fossils marvellous for the perfect preservation of their detailed structure. The preliminary account of the discovery has aroused keen interest, and palæontologists eagerly await the full description by a master hand of this unique collection.

If by his official status, joined with his personal record, Dr. Walcott is in some sense representative of American geology, with its large opportunities so ardently embraced, the occasion may remind us that community of scientific interests is perhaps not least among the links which unite your country to ours. I have much pleasure, Sir, in placing this Medal in your hands for transmission to its recipient, and trust that his future career may include achievements no less brilliant than those which we commemorate to-day.

Mr. Buckler replied in the following words:—

Mr. President,—

Mr. Page greatly regrets that a long-standing engagement prevents him from receiving this medal in person. He has asked me to convey to you Dr. Walcott's deep appreciation of the honour awarded by your Society and to assure you that this feeling is shared by our fellow-countrymen. Let me thank you, not only for this high distinction conferred upon American Geology in the person of one of its leading representatives, but also for the wishes which you have expressed, and in which all Americans will heartily join, for Dr. Walcott's future labours.

As a former President of the Baltimore Society of the Archæological Institute of America, I may mention that Dr. Walcott presides over the Washington Society of that Institute, a fact reminding us that his wide interests include Archæology, the younger sister of Palæontology.

In these times and on such an occasion one cannot but recall—as you, Sir, have said—the community in scientific, as in literary and political, activity which exists between the English-speaking peoples on both sides of the Atlantic. It is significant that of the two American Institutions in which Dr. Walcott has served as Secretary, the Smithsonian was founded by an Englishman, the Carnegie by a Scotsman. The partnership in arms, which now as never before unites our peoples, cannot fail in the coming years to strengthen and to extend that scientific comradeship of which your tribute to Dr. Walcott is a signal recognition.

Award of the Murchison Medal.

In handing the Murchison Medal, awarded to Joseph Burr Tyrrell, M.A., to the Hon. Sir George Halsey Perley, K.C.M.G., High Commissioner for the Dominion of Canada, for transmission to the recipient, the President addressed him as follows:—

Sir George Perley,—

The Murchison Medal has been awarded to Mr. Joseph Burr Tyrrell in recognition of the value of his many services to Geological Science. In the breadth of their scope, in the pioneer element which has so largely entered, in the practical benefits which have often followed, those services may stand as typical of Canada's contribution to Geology.

During more than thirty years Mr. Tyrrell has been frequently engaged in exploring wide tracts of the little-known Barren Lands of Northern Canada, making prolonged journeys of a kind which demands no ordinary resolution and endurance. Besides thus adding largely to geographical knowledge by his own efforts, he has done much to make known the results of earlier explorers in the North. While helping very materially to develop the mineral resources of the Dominion, he has at the same time gathered much valuable information touching the older rocks of the region; and, uniting in his own person the geologist and the prospector, he has often shown by example how science and enterprise may go hand in hand, to the great advantage of both.

On the side of pure science, however, his most notable researches have been in the domain of Glacial Geology, where his extensive acquaintance with the country has enabled him to arrive at conclusions of a large order. Prior to 1894 it was generally held that the ice which once overspread Canada, east of the Cordillera with its mountain-glaciers, emanated from a single centre of dispersal. Mr. Tyrrell first demonstrated the existence and approximate limits of a great ice-sheet, which he named the Keewatin, centreing in the country west of Hudson Bay and distinct in origin from the Labradorean ice-sheet on the east. To these two he subsequently added a third, under the name of the Patrician Glacier, which had its gathering-ground to the south of Hudson Bay. His development of this thesis, involving a discussion of the relations in time and space of the ice-sheets radiating from different centres, must rank among the most important contributions to the Glacial history of North America.

In forwarding to Mr. Tyrrell this token of recognition from the Council of the Geological Society, I beg, Sir, that you will add to our congratulations upon what he has already accomplished our hope that many years of activity still remain to him; and this wish will, I am sure, be echoed by his numerous friends on both sides of the Atlantic.

Sir George Perley replied in the following words:—

Mr. President,—

I am very happy to come here to-day and receive this Medal on behalf of Mr. Tyrrell, and I only regret that he is not here himself for that purpose. He was in London for some time last year, but unfortunately had to return to Canada last month, so that he has missed the pleasure of being with you to-day. As I live in Ottawa, I have known Mr. Tyrrell for a long time. He is a native-born Canadian, and was for many years connected with the Canadian Geological Survey. He showed much resource and energy in his work, and it is very fitting that he should be recognized by your Society in this way.

I may say that, in our Dominion, we are proud of our Geological Survey and of what it has done. We have a large country with great undeveloped mineral resources, which the Geological Survey has done a great deal to discover and utilize. Fortunately, Canada has been able to assist more than could have been expected in providing minerals and metals during the war. Many supplies from enemy countries have been cut off, and higher prices have encouraged enterprise. In consequence, we have not only provided large quantities of nickel, but we have developed our copper, lead, and zinc industries to a very considerable extent. Even so, I feel sure that our mineral and metal products will be greatly increased in the future, and we believe that our resources in that direction have been hardly scratched. To exemplify this, I would remind you that the wonderful argentiferous deposits at Cobalt, in Ontario, were only discovered by chance, although lumbering had been carried on over that district for a great many years. The Ontario Government built a line of railway from the Canadian Pacific into the North country, and in so doing crossed this great silver deposit, which is still producing heavily.

As representing Canada, I am proud to receive this Medal on account of our Dominion, as well as on account of Mr. Tyrrell personally. It seems peculiarly appropriate at this time that this honour should be given by this old and important Society to a Canadian, and we appreciate the same greatly.

I accept the Medal on behalf of Mr. Tyrrell with grateful thanks, and it will give me much pleasure to forward it to him and communicate the very kind words with which you, Mr. President, have accompanied it.

Award of the Prestwich Medal.

The President then handed the Prestwich Medal, awarded to Prof. William Boyd Dawkins, F.R.S., to Dr. A. Smith Woodward, for transmission to the recipient, addressing him as follows:—

Dr. Smith Woodward,—

The Prestwich Medal has this year been awarded to Prof. W. Boyd Dawkins, and there will appear, I think, a peculiar fitness in the choice which links together these two names. Much of the geological work which here receives recognition is such as would especially appeal to the Founder of this Medal, and did in his lifetime engage his lively interest.

During fifty-six years Prof. Dawkins has contributed nearly thirty papers to the Quarterly Journal of this Society, in addition to numerous works published elsewhere. His researches in British cave-deposits and in Mammalian Palæontology have long been well known and highly valued. He has shown that mammalian remains can be used in the classification of the Tertiary strata, and in many ways has cast light upon some interesting chapters in the later geological history of Europe. In another direction he has made important additions to our knowledge of the geology of the Isle of Man. His long connexion with the Victoria University and the support which he has given to the Manchester Geological Society have done much to promote the study of geology in Lancashire, and his well-known publications 'Cave Hunting' and 'Early Man in Britain' met the needs of a wide circle of readers.

Even more, perhaps, will the name of Prof. Dawkins be always associated with the discovery of the Kentish Coalfield, in which he guided to a successful issue an enterprise that had already exercised the mind of Prestwich himself. The site of the boring at Dover was selected after a careful survey of the district, and much patient labour was expended on the examination of the cores and the identification by their fossils of the several geological horizons pierced. Apart from the material success realized, there was in this way accumulated a body of information, which has important applications to the stratigraphy and tectonics of South-Eastern England.

On behalf of the Council, I ask you to transmit this Medal to Prof. Boyd Dawkins in token that he has indeed, in the words of the Founder, 'done well for the advancement of the science of Geology.'

Dr. Smith Woodward replied in the following words:—

Mr. President,—

I have much pleasure in receiving this Medal on behalf of Prof. Boyd Dawkins, on whom it has been so worthily bestowed. He desires me to express his regret that an unavoidable engagement in Manchester prevents him from being present to-day to return his thanks in person.

He writes:—

'I feel deeply the honour that the Council have conferred upon me. It is specially valuable to me from my long friendship with Prestwich, and because my scientific life has been mainly spent in following up the lines of enquiry which he made his own—the range of the Coal-Measures under the Secondary and Tertiary strata of South-Eastern England, the classification of the European Tertiaries, and the problem of the antiquity of Man in Britain. With regard to the first, it may be noted that the South-Eastern Coalfield is now clearly defined, and ranks among the assets of the Nation. With regard to the second, the classification by the evolution of the higher mammalia, originally intended for Europe, is found to apply to the whole of the world.

It is now being used by the American geologists (Prof. Osborn and others) to define the complicated subdivisions of the Tertiaries of the New World. With regard to the third, the problem remains now very much as it was in the days of Prestwich, and the zeal of the antiquarians and anthropologists to discover the presence of Man in deposits older than the Pleistocene Period, has been met by the caution of the geologists, with the net result, that the Piltdown remains stand as the oldest in the geological record of Great Britain; and that the alleged occurrence of traces of man in the Pliocene, and older strata, is put to a suspense account.

'I value, however, the Medal more particularly, as a mark of regard on the part of the Society, to which I have been able to contribute but little for many years, owing to my duties in other directions.'

Award of the Lyell Medal.

In presenting the Lyell Medal to Henry Woods, M.A., F.R.S., the President addressed him as follows:—

Mr. Woods,—

The Council of the Geological Society has selected you for distinction as one who 'has deserved well of the Science,' and I think that none who has watched your career and is acquainted with your work will dissent from that verdict. Your communication to the Society, in 1896, on the Mollusca of the Chalk Rock, set a standard of skilful and accurate diagnosis and description, which has been maintained in all your subsequent work, including the important monograph on the Cretaceous Lamellibranchia, published by the Palæontographical Society. That the philosophical side of Palæontology has also engaged your study is sufficiently proved by such papers as that on the evolution of the genus *Inoceramus*; while that dealing with the igneous rocks of Builth shows that your interests are not wholly comprised within one branch of our science. Your Text-book of Palæontology, based upon practical experience at Cambridge, is valued by other teachers, and your knowledge has always been, as I am well able to testify, generously placed at the disposal of fellow-workers.

It will be, I trust, an encouragement to you, as it is certainly a source of gratification to your friends, that so long a record of good work, faithfully pursued for no private end, does not go unrecognized; and, as an old colleague, I am pleased that it falls to my lot to place the Lyell Medal in your hands as a tangible mark of appreciation.

Mr. Woods replied in the following words :—

Mr. President,—

Twenty years ago the Council gave me great encouragement by awarding to me the Lyell Fund. The present award also comes at a time when encouragement is welcome; not that I feel any loss of interest in my work—far from it. But in these times one cannot help regretting, amongst other things, that one's special work in the past has little if any bearing on matters which are now of practical importance. It is, therefore, encouraging to find that the Council have taken a longer view, and have continued their traditional policy of giving recognition to any and every branch of Geology whether it has any obvious practical use or not.

One of the things that struck me most at the beginning of my palæontological work was the generosity and good nature of those with whom that work brought me into contact, and that pleasant experience has continued all through; whether I have had to do with officials in charge of museums, with professional or amateur geologists, or with that useful person sometimes spoken of disparagingly as the mere collector, all have most freely given me the benefit of their experience and the use of their collections; much as I should like on such an occasion as this to mention their names, I must refrain from doing so—the list is far too long, and I regret that it now includes the names of not a few who are no longer living.

Whilst it gives me great pleasure to receive this mark of the Council's approval of my work, it gives me a further pleasure to regard it as a distinction for the Cambridge School of Geology. To those with whom I have been associated in that school I owe much—to some of them I am deeply indebted.

I thank the Council most sincerely for this Medal, and you, Sir, for your kind words.

AWARD FROM THE WOLLASTON DONATION FUND.

The PRESIDENT then handed the Balance of the Proceeds of the Wollaston Donation Fund, awarded to ALBERT ERNEST KITSON, to Dr. H. LAPWORTH, Sec.G.S., for transmission to the recipient, addressing him as follows:—

Dr. LAPWORTH,—

The Balance of the Proceeds of the Wollaston Donation Fund has been awarded to Mr. ALBERT ERNEST KITSON, in recognition of his valuable contributions to Geology in Australia and West Africa.

Beginning in a clerical capacity on the staff of the Department of Mines of Victoria, he qualified himself for scientific investigation, and became ultimately Senior Field Geologist on the Survey of that State. Besides taking an active part in the geological mapping, he wrote numerous papers on the geology of Victoria, and seized opportunities to extend his researches to New South Wales, Tasmania, and New Zealand. In 1906, on the recommendation of his former chief, Prof. J. W. Gregory, Mr. Kitson was placed in charge of the Mineral Survey of Southern Nigeria. With characteristic energy, in a tropical climate, he traversed the Protectorate in every direction, and, in addition to other services, was chiefly responsible for the discovery and investigation of the Udi-Okana Coalfield, containing vast supplies of coal, the more valuable for its geographical situation. This Survey was suspended in 1911, and in 1913 Mr. Kitson received the appointment, which he now holds, of Director of the Geological Survey of the Gold Coast. His reports on that country have not yet been published; but it is perhaps permissible to mention the discovery of fossiliferous Palæozoic rocks of considerable geological interest, and of deposits of manganese-ore and of bauxite which have great economic importance.

That so notable a record of good work should receive recognition from this Society must gratify all who are interested, either in the advancement of geological knowledge, or in the mineral resources of the British Empire.

Award from the Murchison Geological Fund.

In presenting the Balance of the Proceeds of the Murchison Geological Fund to Thomas Crook, Assoc.R.Coll.Sci., the President addressed him as follows:—

Mr. Crook,—

In awarding to you the Balance of the Proceeds of the Murchison Geological Fund the Council wishes to recognize the value of your contributions to Petrology and Mineralogy, more particularly with reference to the mechanical analysis of rocks and also to the mineralogy of the British Colonies. The former of these subjects engaged your attention while you were at the Royal College of Science in Dublin, and you have since pursued it with success, especially in perfecting the use of the electro-magnet for the separation of minerals. As a member of the staff of the Imperial Institute you have during recent years made many additions to our knowledge of the minerals of the more remote parts of the British Empire, the results of your work appearing partly in papers published in your own name, but largely in the pages of the Bulletin of the Institute. Your petrological publications include some interesting observations on 'Dedolomitization' and a suggestive paper on 'The Genetic Classification of Rocks and Ore-Deposits.' In addition, you have collaborated with Prof. Cole in an important memoir on a collection of rock-specimens dredged off the coast of Ireland, showing how these may be made to yield information concerning the submarine geology of the British seas. This Award, so well deserved, will, I hope, be an encouragement to you in your future work, whether official or extra-official.

Awards from the Lyell Geological Fund.

The President then presented a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Vincent Charles Illing, M.A., addressing him as follows:—

Mr. Illing,—

The Council has awarded to you one moiety of the Balance of the Proceeds of the Lyell Geological Fund, to mark its appreciation of your admirable work among the Lower Palæozoic rocks of Warwickshire. Since its discovery by Prof. Charles Lapworth in 1882, the Cambrian inlier of Nuneaton has claimed the attention of numerous geologists; but it was reserved for you to show how complete a development of the whole Cambrian succession is there exhibited. In a paper communicated to this Society in 1914 you mapped out the various subdivisions which you had recognized, and correlated them with the parallel sequence in other areas. Of the Abbey Shales, representing in small compass a large portion of the Middle Cambrian, you made a full palæontological study, describing critically the rich trilobitic fauna and making known a number of new species. That this important memoir was professedly only a first instalment, warrants us in hoping that you will find in the present Award stimulus to the completion of your projected work.

In presenting the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to WILLIAM KINGDON SPENCER, M.A., the PRESIDENT addressed him in the following words:—

MR. SPENCER,—

A moiety of the Balance of the Proceeds of the Lyell Geological Fund has been awarded to you by the Council as an acknowledgment of the value of your palæontological work.

Starting with the advantage of a zoological training at Oxford, you have devoted the intervals of a busy official life to researches in the palæontology of the Echinoderms. You began by applying Prof. Sollas's method of serial sections to elucidate the structure of the Palæozoic forms *Palæodiscus* and *Agelacrinus*. You then devoted some years to the study of the Cretaceous starfishes, the results of which appeared in a Monograph upon the British examples and a paper, contributed to the Royal Society, upon 'The Evolution of the Cretaceous Asteroidea.' Therein you showed, among other conclusions, that the starfishes are of zonal importance, and that different lineages were evolved along parallel lines. More recently you have been investigating with great skill that difficult group of fossils, the Palæozoic Asterozoa, and your Monograph, not yet completed, has already brought to light many new facts relative to the morphology and phylogeny of those early Echinoderms. It is our hope that this recognition may encourage you to persevere in the same path.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

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

The list of Fellows removed by death during the year now past includes not a few familiar names, which have long held a place on the roll of the Society. Half of the Fellows whom I have selected for brief notice had passed the age of threescore and ten. I have received kind help from Prof. Marr, Dr. H. Woodward, Dr. Smith Woodward, Prof. J. B. Harrison, Dr. J. W. Evans, Prof. Cullis, and Mr. Lake, to whom I tender my thanks.

Henri Émile Sauvage, who died on January 3rd, 1917, in his seventy-fifth year, had been a Foreign Correspondent of the Geological Society since 1879. He was always interested in fishes, and, after some preliminary researches as a student and independent worker, he began his official scientific career in 1875 as Assistant-Ichthyologist in the Paris Museum of Natural History, where he remained until 1883. In the latter year he founded the Station Aquicole at Boulogne-sur-Mer, which he directed almost until the end. He also assumed charge of the Municipal Museum at Boulogne, and took a foremost place in the intellectual activities of the Boulonnais. While engaged in studying existing fishes, both from the purely scientific and from the economic point of view, he continually devoted his leisure to the interpretation of the fossil remains of extinct fishes, and made many important contributions to Palæontology and Stratigraphical Geology. Besides smaller papers on fish-remains from the Secondary and Tertiary formations of France, Dr. Sauvage prepared two large memoirs on the fishes of the French Carboniferous and Permian formations in connexion with the survey of the coalfields. He also wrote on Tertiary fishes from Sicily and Algeria, and on Jurassic fishes from Northern Spain. He was likewise interested in fossil reptiles, and described several important specimens (especially from the Jurassic of the Boulonnais). A complete list of his papers up to 1893 was published in that year at Boulogne. Dr. Sauvage was an indefatigable worker, whose enthusiasm for his science never flagged, and, even when waning power prevented him from doing much original research, he continued until the end to compile useful abstracts of current literature for the 'Revue de Paléozoologie.' He was an attractive personality, whose loss is mourned by a large circle of devoted friends. [A. S. W.]

William Bullock Clark was born at Brattleboro (Vermont), in 1860. His tastes early inclined him to Geology, and in particular to Palæontology, and he studied under Zittel at Munich, where he graduated in 1887. From there he went to Johns Hopkins University, Baltimore, where he was subsequently appointed Professor of Geology. He was the author of numerous reports and papers, dealing mainly with the geology and palæontology of the Cretaceous and Tertiary formations in the Atlantic States. After contributing to the publications of the Geological Survey of New Jersey and of the United States Geological Survey, he was in 1897 appointed State Geologist on the newly established Geological Survey of Maryland. He was interested also in meteorology and climatology, and held the office of Director of the Maryland State Weather Office. His services to geology were recognized by this Society when he was elected a Foreign Correspondent in 1904. He died on July 27th, 1917, aged 57.

A link with the past is severed by the death of Thomas McKenny Hughes, for forty-four years Woodwardian Professor at Cambridge. Since his predecessor, Adam Sedgwick, was elected in 1818, the two tenures covered nearly a century, a period which has seen the whole growth of modern Geology. Born at Aberystwith in December, 1832, Hughes was the son of the Rev. Joshua Hughes, afterwards well known as Bishop of St. Asaph, and he was named after his maternal grandfather, Sir Thomas McKenny, Bart., who had taken a prominent part in Catholic Emancipation in Ireland. From school at Leamington and Llandovery he went to Trinity College, Cambridge, and, like many of his contemporaries, came under the influence of Sedgwick. After taking his degree, he was attached for a time to the British Consulate at Rome during the eventful days of 1860–61. He seems at this time to have contemplated a diplomatic career, but the attractions of Geology prevailed, and he returned to England to join the Geological Survey under Murchison. He was engaged first in the South-Eastern Counties, and afterwards in Westmorland and on the borders of the West Riding.

Upon the death of Sedgwick in 1873 he became a candidate for the vacant Chair. The election was at that time in the hands of the Electoral Roll, and the choice fell upon Hughes, for whom the duties of his office became thenceforward the work of his life. Although he made numerous contributions to various branches of

Geology, and likewise to Archæology, it is as Professor that he will be chiefly remembered. Under his active direction there grew up at Cambridge a large and flourishing school of geology, and many of his old students have gone forth to occupy chairs in other Universities, or to recruit the ranks of geological surveys at home and beyond the seas. A certain youthfulness of spirit, which remained with him to the last, enabled him to be on easy terms with junior and senior alike, while those who were more closely associated with him in the work found unfailing consideration at his hands. As a lecturer he had a remarkably ready and fluent delivery, and never failed to make his subject clear to every one of his audience. Loyalty to his own old teacher was strong in him, and sometimes led him to revive controversies which had lost something of their interest to a new generation. A more important work, which engaged him for some years, was the biography of Sedgwick; but this eventually proved too heavy a task for one immersed in professorial duties, and after long delay was relegated to another hand. Causes of a different kind long deferred the progress of an undertaking which was even closer to Hughes's heart, the erection of the Sedgwick Memorial Museum. Completed at last in 1904, this building stands as a worthy memorial of a great man, while to those who know Cambridge it is a witness likewise to the energy and devotion of his successor.

Hughes had married in 1882 Mary Caroline, daughter of Canon G. F. Weston, a lady of wide culture, artist and naturalist. Mrs. Hughes from the first entered thoroughly into her husband's career, accompanying him on his travels and sharing all his activities, scientific and social. Her great charm of manner, with the Professor's heartiness and genial humour, made their house a very pleasant resort, where students were hospitably made welcome, and those who revisited Cambridge were sure to find themselves remembered.

Hughes was a Fellow of this Society from 1862, served frequently on the Council, and was a Vice-President in 1888–90. In 1891 the Lyell Medal was awarded to him. He was elected to the Royal Society in 1889, and was also Corresponding Member of the principal geological societies of Europe. From Italy he received the honour of Chevalier of the Order of SS. Maurice and Lazarus. In his later years he was not often seen at our meetings. University duties absorbed most of his energies, and, while his spirit remained the same, his bodily vigour was somewhat abated. The unexpected death of his wife in July, 1916, came upon him as a heavy blow, and it was followed by a severe illness. From this he rallied for a time; but, in the summer of 1917, the return of an old malady necessitated an operation which exhausted his strength, and he died on June 9th in his eighty-fifth year. Of his three sons the eldest was killed ten days ago in France, while the others are still serving in the Army.

In Edward Hull we have lost another of the older generation of geologists. Born in the town of Antrim on May 21st, 1829, he went in due course to Trinity College, Dublin, to be educated for the profession of engineering. By the influence of the Professor, Thomas Oldham, however, he was diverted to the study of geology, and in 1850 joined the staff of the Geological Survey under De la Beche. During the forty years which he spent in this service, he was engaged first in Wales, next in England, then in Scotland as District Surveyor, and finally in Ireland as Director from 1869 until his retirement in 1891. With the Directorship he held also the Professorship of Geology in the Royal College of Science at Dublin. More than once, too, he undertook special commissions abroad. In this way he visited Hungary in 1873, and in 1883 took part in investigations for the Palestine Exploration Fund, in association, among others, with Major Kitchener, afterwards Lord Kitchener of Khartum. In 1886 again Hull visited America, to report on some large mineral properties in Tennessee.

Much of his work was concerned with coal. His principal separate publication, 'The Coalfields of Great Britain,' has passed through five editions, and he was a member of the Coal Commission of 1901. His original contributions to societies and journals were very numerous, and those dealing with physical geology were often suggestive.

Until advancing age subdued his energy, Hull was a well-known figure at geological gatherings. With all the good-nature, he had some of the combativeness proverbially attributed to his countrymen; but he is well described by one of his old colleagues as

'a leal-hearted friend, who through a long life maintained the honour of a gentleman, and carried with him cheerfulness and goodwill wherever he went.'

He died on October 18th, 1917, in his eighty-ninth year.

Richard Hill Tiddeman was born on February 11th, 1842. On leaving Llanrwst Grammar School he entered at Oriel College, Oxford, and during his residence at the University came under the influence of Prof. Phillips. After graduating he joined the Geological Survey in 1864. He was chiefly occupied with the survey of the Carboniferous rocks of North Lancashire, West Yorkshire, and Westmorland, but also worked in North Wales, and, previous to his retirement in 1902, was engaged in mapping the rocks of South Glamorgan. He contributed to many of the Survey Memoirs explanatory of the geological maps, and also wrote a memoir on the Water-Supply of Oxfordshire.

He was elected a Fellow of this Society in 1869, and served on the Council from 1905 to 1910. In 1911 the Council awarded to him the Murchison Medal in recognition of his original contributions to our science. His election to the Presidency of the Yorkshire Geological Society in 1914 was a fitting recognition of all that he had done for Yorkshire geology and geologists. He had married in 1889 Margaret Florence, younger daughter of W. H. Spencer, M.D., of St. Leonard's-on-Sea, by whom he had two daughters. He died on February 20th, 1917, aged 75.

Tiddeman's contributions to geological literature are not voluminous, for he was reluctant to publish his results until he had fully satisfied himself of their accuracy. What he did publish is of high value, and throws much light on various geological problems. In addition to his official work, he wrote a series of papers on four subjects of great interest: the evidence for an ice-sheet in North Lancashire and its neighbourhood; the problems of the Victoria Cave at Settle; the remarkable structures in the Lower Carboniferous rocks of West Yorkshire which he designated 'reef-knolls'; and the pre-Glacial raised beach of the South Welsh coast.

The memoir on the North Lancashire Ice-Sheet, published in the Quarterly Journal of the Geological Society in 1872, is a record of high importance, and was tersely described by Carvill Lewis as 'an admirable paper, all of which is true.' The series of reports and papers on the Victoria Cave attracted much attention at the time of their appearance, on account of the occurrence of a supposed human fibula in a deposit claimed as anterior to the last occupation of the district by ice. Tiddeman was in no way responsible for the erroneous determination of the bone: his own work had reference to the relationship of the various deposits of the cavern. The origin of the remarkable 'reef-knolls' is not yet decided. To Tiddeman is due the credit of discovering their nature and recording numerous important facts connected with them.

The paper on the raised beach of South Wales directed attention to a phenomenon which is now recognized as of very high importance.

Of Tiddeman's personality little need be said: words addressed to his friends would be unnecessary, and to others inadequate. Suffice it to say that in him an absolutely upright character was combined with singular charm of manner, and that those who knew him loved and respected him whole-heartedly. [J. E. M.]

George Alexander Louis Lebour was the son of French parents, his father, Alexander Lebour, being an artist of distinction. He himself was born in France, at St. Omer, in 1847; but at the age of two years, owing to a pending revolution, his parents brought him to England, where they settled, and he was educated as an English boy. Even in his childhood he was an enthusiastic collector of fossils, and it was his great ambition to become a geologist. After he left school he was for some time employed at a mercantile house in the City; but the work was so entirely distasteful to him that at last he was allowed to follow his natural bent, and he entered the Royal School of Mines, where he came under the influence of Ramsay. In 1867 he obtained an appointment upon the Geological Survey, and was sent to join William Topley at Morpeth in Northumberland. His work upon the Survey lay for the most part in that county, and it was this circumstance that determined the whole course of his future career.

David Page, who was at that time Professor of Geology at the newly-founded Durham University College of Physical Science in Newcastle-on-Tyne, had become so infirm that it was necessary to provide him with some assistance; and in 1873 Lebour was appointed Lecturer in Geological Surveying. But, from the first, more of the work than the title implies fell to his share, and, on the death of Dr. Page in 1879, he became Professor of Geology, a post which he held for the remainder of his life. During that period of nearly 39 years he took a large part in the development of the institution from its small beginning to its present position, under the name of the Armstrong College, as one of the largest and best-equipped of the provincial Colleges; and since 1902 he had been Vice-Principal.

His published papers number more than a hundred; but they are widely scattered through many periodical publications, both English and French, and only two appear in the Quarterly Journal of this Society. The majority of them deal with the Carboniferous System or with the geology of Northern England. He also wrote a useful book on the Geology of Northumberland & Durham, which has passed through more than one edition; and the geological article in the Victoria County History of Durham is from his pen. But his interests were not confined to this side of the subject. He was an active member of several important committees of the British Association, among which may be mentioned the committees on Underground Temperatures and on the Conductivity of Rocks. A large proportion of the work of the latter committee was carried out at Newcastle under his supervision and that of his colleague, the late Prof. A. S. Herschel. Another question to which he devoted a considerable amount of attention in his earlier years was the influence of geology on public health; and on this he wrote several articles, including one on the distribution of goître.

But it is not by his published work that his students will chiefly remember him. He was an admirable lecturer and a most genial and sympathetic teacher, whose pupils became his friends and remained his friends for life. In his later years an affection of the foot, characteristically disregarded as of no moment, at length compelled an operation which left him lame, and incapacitated him for fieldwork, but his cheerfulness remained unimpaired. His last illness was long, lasting for several months, and he died at his home at Corbridge on February 7th, 1918, in his 71st year.

He had become a Fellow of the Society in 1870, and the Murchison Medal was awarded to him in 1904. [P. L.]

The veteran American geologist Arnold Hague had been a Fellow of this Society since 1880. In the early days of his career he took part in Clarence King's Exploration of the Fortieth Parallel and in other pioneer work in the West, and he also carried out special missions for the Governments of Guatemala and China From 1879 he was attached to the United States Geological Survey, and took a leading part in geological investigations in the Western States. His most important works are the 'Geology of the Eureka District, Nevada' (1892) and the 'Geology of the Yellowstone National Park' (1899), the latter written in collaboration with a number of colleagues. Hague's kindly disposition and personal qualities gained for him a large circle of friends. He was President of the Geological Society of America in 1910, and, among other honours, the degree of Doctor was conferred upon him by Columbia

University and by Aberdeen University. In his later years he suffered in health, and lived rather in retirement. He died in his 77th year, leaving a widow but no children.

The death of Robert Bell removes one of the oldest and best-known of Canadian explorers and geologists. His life was passed in the service of the Geological Survey of Canada, which he joined so long ago as 1857, and of which he ultimately became Acting Director. Much of his work was of the pioneer kind, and covered extensive areas about Hudson Bay, Great Slave Lake, and other outlying parts of the Dominion. His early studies at McGill University and at Edinburgh had included medicine as well as natural science, and he was able to act as surgeon as well as geologist on exploring expeditions. His interest was mainly, as might be expected, in Archæan and Glacial Geology. Bell became a Fellow of this Society in 1865 and of the Royal Society in 1897. He received the degree of Sc.D. from the University of Cambridge, and was also the recipient of medals from the Royal Geographical Society and the American Geographical Society. He died at Ottawa on June 19th, 1917, aged 76.

Godfrey Firth Franks was born at Cambridge on July 6th, 1853, and was educated at Balliol College, Oxford. In 1879 he went out to Barbados as classical master at Harrison College, and from there was transferred in 1893 to be second master at the Queen's College of British Guiana. Soon after his arrival at Barbados he had begun to study the fauna of the West Indian coral-reefs, both recent and fossil. He took part also in the fieldwork carried out by the late A. J. Jukes-Browne and Prof. J. B. Harrison on the geology of Barbados, the results of which appeared in a series of papers published by this Society. Soon after he had been elected a Fellow of the Society in 1890, he discovered thick beds of *Globigerina* Marls at Bissex Hill in Barbados, and in succeeding years worked out the upward succession from these deep-water deposits through shallower-water foraminiferal accumulations to basal reef-rocks and coral-limestones. A sketch only of these results was published in collaboration with Prof. Harrison in 1898. Franks also recognized the same characteristic succession in Trinidad.

While stationed in Barbados he made a study of the volcanic rocks of the Windward and Leeward Islands, and after his removal to British Guiana he made several geological explorations into the little-known interior of that colony. His work was, however, interrupted by failing health, and, after a long illness, he died on July 29th, 1917, aged 64.

Franks was beloved by all who had the privilege of his friendship, and only his modest nature and retiring disposition prevented his work and character from being more widely recognized. It is much to be regretted that a large part of his scientific results remained unpublished; but much of his material and his records have been left in the hands of his lifelong friend Prof. J. B. Harrison, and some part at least may yet see the light.

George Charles Crick was born at Bedford on October 9th, 1856, and was educated in the Modern School in that town. From there he went to the Royal School of Mines, where his career was an exceptionally brilliant one. From 1881 to 1886 he acted as Clerk and Assistant-Secretary to the Royal Commission on Accidents in Mines, but he also worked as a volunteer in the Geological Department of the British Museum, and subsequently became one of the regular staff. The Fossil Cephalopoda were assigned to his charge, and to these he devoted more than thirty years of patient and accurate investigation. He soon became recognized as an authority in this branch, and collections of belemnites, ammonites, and nautiloids from many parts of the world were referred to him as a specialist. In addition to official publications, he was author or joint-author of numerous contributions to scientific societies and journals, and his latest work still remains to be published.

Crick's modest and kindly disposition made him a general favourite, and he will be missed by many. His health was never good, and he died suddenly on October 18th, 1917, aged 61.

Harry Page Woodward, eldest son of Dr. Henry Woodward and grandson of Samuel Woodward of Norwich, belonged to a family of geologists. Born at Norwich on May 16th, 1858, he was educated at University College School, and received his geological training under Prof. Judd at the Royal College of Science. In 1883 he was appointed Assistant Government Geologist in South Australia, and later served as geologist on the Boundary Commission between that Colony and New South Wales. After a year spent in metallurgical study in London, he returned to

Australia in January 1888, having been appointed Government Geologist for West Australia. It was here that his most important work was done, especially in the exploration of the rich goldfields of the Colony. In addition to numerous official reports and a geological sketch-map, issued in 1894, he published in the same year a 'Mining Handbook to the Colony of Western Australia,' which proved of great service. His investigations also led to the discovery of artesian water in the country west of the Darling Range. In 1895 he quitted the Government service; but, after practising for some years as a consulting geologist in Perth and Coolgardie, he rejoined the Survey in 1906 as Assistant Government Geologist. He died at Perth in his fifty-ninth year, on February 7th, 1917, leaving a widow and three sons.

Although the name of the New Zealand geologist Alexander M'Kay is unknown to many, it is highly honoured by those who can estimate the importance of his original contributions to science. Beginning as a fossil-collector, he subsequently became attached to the Geological Survey of the Colony under Sir James Hector, and spent twenty years in the field. A self-taught man, and owing little to books, he was led to study the structural geology of the country, and to form for himself opinions far in advance of the times. His views concerning the part played by block-faulting in the evolution of the mountain-system of New Zealand received scant regard, and have only been brought into prominence by others in later years. Had M'Kay possessed the power of presenting his conclusions more clearly and enforcing them more cogently, his merits as an original thinker would have been generally recognized.

Upfield Green was one whose services to science are not to be adequately measured by the volume of his published work. Although he had been a keen geologist throughout a long and varied career, and had made many observations both at home and abroad, it was not until his 70th year that he began to make public his results. Cornwall was his chosen field, and his paper 'On the Geological Structure of Western Cornwall,' produced in 1909, brought his work into notice, and earned for the author the Bolitho Gold Medal. Other papers on the same area followed, including two written in collaboration with Mr. Davies Sherborn; and, although brief and appearing sketchy, they doubtless embody a large amount of careful work. Green was long a member of the Geologists' Association, and had many friends among London geologists. He died in his 83rd year on May 31st, 1917.

Charles Otto Trechmann, who died on June 29th, 1917, aged 66, was the author of numerous mineralogical papers. On geology he wrote little, though interested in its petrological side and a Fellow of this Society since 1882. It was he who showed that the so-called 'hypersthenite' of Carrock Fell is more truly a gabbro.

Alfred Nicholson Leeds belonged to a type of amateur to which Geology has owed much. Born at Eyebury, near Peterborough, where he spent his life, he devoted much of his leisure during nearly fifty years to collecting the reptilian and fish-remains of the Oxford Clay of the neighbourhood. Patiently disinterred and skilfully reconstructed by his own hands, his specimens furnished the material for numerous important memoirs by specialists, and a large part of them may now be found in the National Collection. Although he was content to leave to others the description of his finds, Leeds had himself acquired a good knowledge of Vertebrate Palæontology, and throughout his life he maintained an interest in scientific matters. He died on August 25th, 1917, in his 71st year.

Baldwin Latham, a Fellow of this Society for more than forty years, died on March 13th, 1917, in his 81st year. He was by profession a sanitary engineer. He was also interested in Meteorology, and contributed several papers to the Journal of the Royal Meteorological Society, of which he was President from 1890 to 1892. During a long residence at Croydon he made a study of the intermittent stream known as the Bourne, the movements of which he was able to predict from observations of the levels of wells.

William Albert Parker, a schoolmaster at Rochdale, did much to foster an interest in science in that part of England. He was an enthusiastic geologist and archæologist, and his investigations, carried on usually in collaboration with like-minded friends, often led to results of importance. Chief among the contributions to geology of this Rochdale group was the working-out of the Middle Coal-Measure shales of Sparth and the discovery therein of a rich collection of fossils, including numerous interesting crustacea, besides arachnida and insects. Parker died in his 64th year on January 14th, 1918.

Robert Boyle, born at Auchinleck (Ayrshire) in 1883, studied engineering at the University of Glasgow, and practised the profession first at Glasgow and subsequently under the Commissioners for the Port of Calcutta. He was interested in geological research, and contributed papers to the Geological Society of Glasgow, including one on the composite sill of Lugar. The Council of this Society awarded to him a grant from the Daniel-Pidgeon Fund in 1910, and in the following year he was elected a Fellow. About the end of 1916 he went to Western Australia for the sake of his health, and died there on May 22nd, 1917, aged 34.

The War has again levied its toll upon the ranks of the Society. In Alexander Moncrieff Finlayson we have lost one who bade fair to attain a high place as a mining engineer. From New Zealand, where he received his early training, he came to London with an 1851 Exhibition Scholarship, and spent two years in research work at the Royal College of Science. In 1910 he took up an important appointment in Burma as oil technologist, but on the outbreak of war he returned to England, and joined the Army. As lieutenant in the South Lancashire Regiment, he was wounded in France, and, returning to active service, again received a wound, from the effect of which he died on July 23rd, 1917.

For so young a man, he had accomplished a large amount of geological work. Before coming to London he had carried out researches on the goldfields, the scheelite deposits, and the nephrite of New Zealand, besides contributing to the geology of the Sub-Antarctic Islands. While in England he made a comprehensive study of the British ore-deposits, and endeavoured to classify them with reference to their geological age. His results were embodied in two papers read before this Society in 1910. He also visited Spain, and made important contributions to our knowledge of the pyritic deposits of Huelva. His death is deeply deplored by those who enjoyed the privilege of his friendship.

Horas Tristram Kennedy was one of the most promising of our younger geologists. After winning a First Class in the Natural Sciences Tripos at Cambridge, he joined the staff of the Geological Survey of Ireland in 1913, and was engaged on the revision of the Leinster Coalfield. He had been detailed to resurvey the Lower Palæozoic rocks of the West of Ireland, when war broke out, and Kennedy joined the Army. As lieutenant in the Royal Scots Fusiliers he took part in heavy fighting in 1916, and at the close of that year was attached to the Field Survey of the Royal Engineers, a service which afforded scope to his scientific aptitudes. He was killed in Flanders on June 6th, 1917, aged 28.

Frank Remington Pretyman was an Associate of the Royal School of Mines. After visiting Mexico and Canada as a mining engineer, he joined the Geological Survey of Wisconsin. Upon the outbreak of war he returned to this country, enlisted in the Royal Engineers, and subsequently obtained his commission and became a lieutenant in that regiment, doing good service in sapping work in France. Later he exchanged into the Scots Guards, and he was killed in action on July 4th, 1917, aged 26.

I propose now to offer some reflections of a general kind upon the present position and outlook of the study of metamorphism in rock-masses.

For more than one reason the petrologist stands to-day in face of exceptional opportunities, and may hope to record important advances in the near future. In addition to the steady growth of material which accrues, here as in other departments of knowledge, from research directed along established lines, valuable aid is tendered from other quarters. This, of course, is no new thing. Indeed geology is best defined by its aims rather than by its methods; and it is possible to regard it, not as a distinct science apart, but as the application of all the sciences to certain ends. None the less, the development of physical chemistry during recent years, deriving its impetus from the recognition of the Phase Rule and its consequences, means so much for petrology that it must be considered as marking for us a distinct epoch. This has been recognized by the chemists themselves, especially in the establishment at Washington of a laboratory with the object of attacking the main problems of petrology directly from the experimental side. Again, experiment as applied to petrology is not in itself a new departure. What is new, and is for the first time possible, is the conduct of experiments under conditions quantitatively known and continuously controlled, so that the investigation rests upon a strict scientific basis. Work of this character has already, in a few years, yielded important results. Their immediate application, so far, is mainly to the evolution of igneous rocks and the genesis and alterations of ore-deposits; but the practical difficulties which embarrass investigation at high pressures and the study of systems including a volatile phase have been in part conquered, and some of the problems of metamorphism are already brought within the scope of laboratory research. Moreover, apart from actual experimental results, a clear formulation of the principles involved may do much towards clearing the way, and here, too, the chemists have rendered useful service. If then we would realize truly the present standing of the study of metamorphism, we must note that field-observation, microscopic study, and chemical analysis are now being reinforced by a new and powerful weapon of attack.

These and kindred considerations warrant, I think, a new orientation towards the subject as a whole. More accurately, it is a reversion to a point of view which has passed too much into abeyance, for in the early days of modern geology the merely descriptive standpoint and the rational or genetic were sufficiently sharply opposed. To the one school the crystalline schists, with gneisses and allied rocks, became simply a class, coordinate with the igneous rocks and the sedimentary, with peculiar characters to be observed and described. This view does not, of course, preclude further inquiry touching the origin of the rocks; but in fact such inquiry has only recently and partially entered in such a way as to affect the progress of the study, and it remains broadly true that we have here the last surviving relic of the Wernerian system of geology. The rival school was concerned less with metamorphosed rocks as a class than with metamorphism as a process, which may operate upon rocks of all kinds. Unfortunately, from this logical starting-point little progress was made, and the failure must be ascribed mainly to disregard of chemistry. Even the leading British geologists of the time are not free from this reproach; while for some of their followers metamorphism became a wizard's wand, by which one rock was transformed to another quite irrespective of composition. After these extravagances had provoked a reaction, some real steps in advance were made, especially by those petrologists who urged the importance of the dynamic factor in metamorphism; but any systematic study on genetic lines was still impossible, in default of fuller physical and chemical knowledge. The situation is now changed, and some petrologists, abroad and at home, have perceived that this disability need no longer be admitted.

Should this wider mode of vision become general, some arbitrary limitations and inconsistencies which have hampered progress will automatically disappear. By regarding metamorphism, not as a peculiar state exemplified in certain groups of rocks, but as a process or class of processes, we shall more definitely recognize that it is something progressive, and, as estimated by its results, a matter of degree. In particular, the earlier stages or lower grades of metamorphism may be expected to throw much light upon some important questions, and they undoubtedly merit more attention than has hitherto been bestowed upon them. In the purely descriptive treatment as commonly followed, the rocks dealt with are such as have lost all trace of their former mineralogical and textural characters, save only the occasional recognition of residual or 'palimpsest' structures. By excluding the connecting links any determination of the original nature of the rocks metamorphosed is often rendered impossible, and accordingly in a classificatory scheme such as that of Grubenmann rocks of very different origin, one igneous and another sedimentary, are grouped together if, after total reconstitution, they have a like chemical composition.

It may be remarked that, for the study of progressive metamorphism, British petrologists enjoy exceptional opportunities. Owing to the dome-like disposition of the whole, the belt of less metamorphosed rocks bordering a large metamorphic region is of relatively narrow width. As a belt of weakness it is liable to be cut out by later dislocations, and as the margin of a mountain-tract it is likely to be concealed by the overlap of later sediments. Gradations of metamorphism are in this way often obscured, and the idea is fostered of some radical difference between 'regional' and 'local' metamorphism. In the case of the Scottish Highlands, however, the overthrusting and faulting along the Highland Border have in great part spared the marginal belt, and the Old Red Sandstone, which once spread far up over the country, has been stripped away. In this element of completeness, as in some other respects, the Highland area may serve as a model metamorphic region; while the study of it in this aspect is rendered possible by the admirable detailed survey of the ground which is now well advanced towards completion.

It is essential to what I have styled the genetic point of view, that a discussion of the transformations suffered by rock-masses compels regard to the proximate causes of these transformations. Metamorphism is the response to changed conditions in respect of temperature and stress, and a logical treatment of the subject should proceed with direct reference to these agents of metamorphism, the thermal and the dynamic. One main difficulty, on the physico-chemical side, arises from the interaction of these two factors, which makes the conditions controlling metamorphism a function of two seemingly independent variables. The general case, however, must clearly include the particular cases in which one of the factors is predominant and the other negligible; and it is in accordance with scientific method that these two special cases of pure thermal metamorphism and pure dynamic metamorphism should be exhaustively studied as preliminary to attacking the general problem. It might seem needless to vindicate a proposition so elementary, had it not been habitually obscured by the practice of approaching the subject from the end rather than from the beginning. In almost all discussion of the crystalline schists and gneisses, what is commonly termed 'local' or 'contact' metamorphism has been explicitly ruled out. It is doubtless true that pure thermal metamorphism can never be developed on a very extended scale, since, when any large tract of rocks suffers rise of temperature, expansion necessarily sets up internal stresses, and the dynamic factor is automatically brought into play. But, in a consideration of causes and effects, the question of extension is not primarily relevant, and this divorce between so-called 'regional' and 'local' metamorphism is seen as a gratuitous narrowing of the field of view.

A like remark applies to pure dynamic metamorphism at low temperatures. This too is typically localized, especially near faults and overthrusts in the shallower levels of the Earth's crust. The chemical changes here are of the nature of degradation, and indeed the products are largely the same as the constituents of residual clays resulting from weathering. The amount of heat set free and dissipated in the complete chemical breakdown of a crystalline rock is very considerable, probably greater than the latent heat of fusion. Pure thermal and pure dynamic metamorphism thus present a strong contrast, in that the reactions are endothermic in the former and exothermic in the latter. Although we cannot reason strictly to the more general case, in which both thermal and dynamic factors enter, it is clear that a certain compensation may be assumed. The energy-change under the complex conditions will be either positive or negative, and often of small magnitude. Here we may perceive a kind of economy in nature, which helps to explain the vast extension sometimes attained by metamorphism of this type.

This consideration is to be borne in mind in connexion with the so-called 'metamorphic cycle'—a conception which has come down to us from the days of Lyell. If we begin, for clearness, with crystalline igneous rocks, the ideal cycle consists, in the language of Van Hise, of a phase of catamorphism followed by one of anamorphism. The large quantity of energy liberated during the former phase passes for the most part into a form in which it is irrecoverable, and, if the complementary phase is to close the cycle by restoring the original igneous rocks, very heavy drafts must be made upon the Earth's internal store of energy. We see, however, that no such extravagant demand is involved in the extensive conversion of sediments to crystalline schists by the joint agency of heat and mechanical stress. We may reasonably adopt the conclusion of Leith and Mead that the cycle is in general an incomplete one; and that, in so far as the conditions for regional metamorphism have been recurrent in geological time, there has been an increasing accumulation of metamorphic at the expense of igneous rocks. This seems to accord with geological evidence. After taking account of the very interesting phenomena described in particular districts by Sederholm and others, I can find little support for the belief that the subcrustal fusion which should close the hypothetical cycle is in general realized.

One admonition brought home to us by the recent work of chemists is, not merely the slowness of many of the operations of Nature—an idea to which the geological mind is well habituated,—but their incompleteness, from the point of view of the establishment of chemical equilibrium. We know, for instance, that many common rock-forming minerals may persist under conditions far outside their theoretical range of stable existence; that many of them indeed have no stable existence, but are metastable forms wherever found; and that chemical reactions, no less than changes of state, may be indefinitely retarded or suspended because the rate of change is so slow as to be insensible. This has far-reaching consequences of a positive as well as a merely negative kind. Thus it appears from the researches of Bowen and others that the manner of evolution of a series of igneous rock-types from one primitive magma is governed largely by the formation of zoned crystals of such minerals as pyroxenes and felspars, and, if there were continual adjustment of chemical equilibrium throughout the process, differentiation would follow quite other lines.

Some features of metamorphosed rocks, such as the comparative rarity of zoned crystals, suggest that equilibrium is more promptly attained, or more closely approached, here than in a crystallizing magma. Goldschmidt indeed assumes equilibrium when, by direct application of the phase-rule, he lays down the law that the number of different minerals in a metamorphosed rock is not greater than the number of components in the system. This rule, however, does not seem to be justified by the facts; and it may also be remarked that some characteristic minerals of metamorphism, such as andalusite and enstatite, quoted by Goldschmidt as illustrations, are themselves merely metastable forms. We shall certainly err if we suppose that the minerals and mineral-associations actually found necessarily represent a stable arrangement, either under the conditions of their formation or under existing conditions. Indeed, it is only in virtue of the non-establishment of equilibrium that many products of the higher grades of metamorphism now exist to be studied. Even in reactions strictly reversible the lag-effect is much greater with falling than with rising temperature, and thus minerals formed at high temperatures, instead of reverting to other products as the temperature falls, may survive to indicate, as it were, the high-water mark of metamorphism.

Nor shall we justly appreciate some of the phenomena of metamorphism, especially in its earlier stages, unless we recognize that the rocks are in many cases far from being initially in a state of chemical equilibrium. Those argillaceous sediments which are of the nature of residual clays probably do represent approximately the ultimate degradation of the crystalline rocks from which they come. In these, therefore, metamorphism may be supposed roughly to start from equilibrium, and successive reactions will come into play as the temperature rises, subject only to a greater or less lag-effect. Accordingly, it is in rocks of this type, and in them only, that we can trace from the beginning successive zones of metamorphism, characterized by the first appearance of distinctive new minerals. In sediments of mixed origin no such nicely-graduated series of stages is observable. In particular, we see here the reason of the peculiar behaviour of partly calcareous sediments, which afford a typical example of 'false equilibrium' as between the two kinds of constituents, silicate and carbonate. Here, so soon as with rising temperature the rate of possible reactions becomes sensible, the reactions proceed with a rapidity limited only—since they are endothermic—by the supply of heat. It is well known that in the field the transition from a seemingly unaltered sediment of this type to a rock composed wholly of new minerals is often strikingly abrupt, and, again, beds of this nature intercalated among simple argillaceous sediments, still in the first stages of alteration, afford the best examples of the so-called 'selective' metamorphism. The relatively low temperature at which complete reconstruction is effected sets very narrow limits to the interchange of material within the rock, and the result is seen in the exceedingly fine texture of many lime-silicate rocks originating in this way. The complex mineralogical constitution of many of these rocks is significant in the same sense. It is easy to believe that total reconstruction so hastily effected does not always result in a theoretically stable association of products, and the number of distinct minerals found in some of these lime-silicate rocks is clearly in excess of that allowed by Goldschmidt's rule.

The recrystallization of rock-masses and the various chemical reactions comprised in their metamorphism all presuppose solution of the material; and the part played by solvents becomes therefore of fundamental importance in the chemistry of metamorphism. The nature of the most common solvents is scarcely in doubt. It is sufficiently indicated by examination of the metamorphosed rocks themselves, where some part of these substances has often entered finally into the composition of certain of the new minerals. Water is doubtless the most abundant of these substances, though others, such as boric and hydrofluoric acids, are more potent. Others again, such as carbon dioxide, may acquire importance in particular cases. Now these are precisely the volatile bodies which we know to be present in plutonic magmas, and to be given out after fulfilling their functions in the crystallization of plutonic rocks. Various petrogenetic considerations show that the quantity of these gases in an intruded magma is very considerable, and almost the whole must pass into and through the rocks invaded. This is true of all kinds of magmas, even when the resulting igneous rocks, such as peridotites, preserve no direct evidence of the fact. There can be, I think, no doubt that the solvent medium which is essential to metamorphism is to be ascribed ultimately to a magmatic source. Since, however, metamorphism can evidently go on far from any igneous intrusion, we are to conceive a pervading medium, doubtless of extreme tenuity in general but attaining a greater concentration in the neighbourhood of newly-intruded igneous rocks. Numerous facts suggest that other volatile bodies besides water do permeate the earth's crust at large, if only in an exceedingly dilute state. For instance, Carnot's observations go to show that fossil bones undergo in the course of geological ages a slow enrichment in fluorine, until the phosphate attains to the composition of apatite.

The diffusion of the volatile solvent here premised can become effective, despite the extreme slowness of the process, because it is perennially in progress. Diffusion of dissolved material, on the other hand, can take place only during the time of metamorphism: that is, while the requisite conditions of temperature, etc. are maintained; and it is in consequence restricted within very narrow limits. We find that in a banded sediment composed of different thin seams—argillaceous, calcareous, and gritty—metamorphism does not confuse the whole to one average type. The several bands remain distinct, each represented by its own association of new minerals, even when a dozen such bands are included in the field of the microscope. Apart from the effects of mechanical disturbance, phenomena indicative of segregation, such as garnet-lenticles and streaks of quartz sillimanitisé, are found only in the highest temperature-grade of metamorphism. Here, too, a coarser grain of the recrystallized rocks points to a somewhat enlarged amplitude of diffusion, the diffusion-constant being of course a function of temperature. The free circulation which is essential to the filling of mineral veins and to metasomatic changes like dolomitization, has no part in metamorphism proper, the fluid medium acting only as a solvent, not in general as a carrier. It will be observed that I reject the much wider definition of metamorphism adopted by Van Hise. The problem would be greatly complicated, were we to include rocks which are undergoing some arbitrary or unknown change in total composition.

Since the critical temperature is 374° for water and in general much lower for the other volatile substances in question, the solvent medium in any high grade of metamorphism must be gaseous. Concerning the properties and chemical behaviour of gases at high temperatures and under great pressures we possess at present little information, though the systematic study of a system involving silicate compounds with a volatile phase has already been brought within the scope of laboratory methods. Although I have used the words 'solvent' and 'solution,' I do not mean to imply that the action is of a merely physical kind. Doubtless water in many cases and *a fortiori* the more active substances take part in chemical reactions, which are of a cyclical kind in this respect, that the solvent is released to repeat the process upon a new portion of the material. How in this way a very small quantity of the solvent may serve to bring about little by little the reconstitution of the whole mass, is well illustrated in the lower grades of thermal metamorphism. Especially instructive are the 'spotted' slates, which so often mark the beginning of change in argillaceous sediments, since in these we see the process arrested at an early stage. Such studies as those of Hutchings make it clear that the spots (of this kind) are merely patches of glass or partly devitrified glass. We see that the process has begun at isolated points by the solution of small portions of the rock-substance; but, in this case, the recrystallization which should have followed has been checked by fall of temperature. Vitrification of the rock in mass is found only at an actual contact, where a more abundant supply of solvent was furnished directly from its source, and is found there only under conditions which ensured an intense heating and a relatively rapid cooling. The intrusive rock in such a case is always of thoroughly basic or ultrabasic nature, implying a high temperature of intrusion, and it is a dyke or sheet of small volume, which would soon cool down.

Here again the semi-calcareous sediments afford an instructive contrast, for it is not uncommon to find them converted to a coarsely crystalline aggregate of garnet or of diopside in contact even with a dyke of moderate width. Such rocks, until they have been wholly reconstituted, have the special peculiarity of providing their own solvent in the form of carbon dioxide set free in the reactions, a property obviously conducive to that rapidity of metamorphism on which I have already remarked. It is further of importance that the loss of this constituent implies a shrinkage of the solid rock, which may often amount, according to Barrell's calculation, to 30 or 40 per cent. of the volume. This estimate, of course, ignores the pressure to which the rock may be subjected during the process; but it is clear that the effect must be to enhance its permeability in the first place by the gaseous solvent and later, when cooling has sufficiently progressed, by liquid solutions. In illustration may be cited the 'garnet-contact-zones' which have acquired some importance in recent years as ore-deposits of iron, copper, and zinc. The phenomena point to a pneumatolytic origin of the ore-material, and even the garnet may owe something to the same source, for, as Kemp has pointed out, it often approaches andradite rather than grossularite in composition.

I refer to such instances as these, chiefly in order to emphasize their exceptional nature as depending upon a special kind of composition of the original rocks affected. I cannot concur in the large demands made by some geologists upon extensive and radical metasomatism as, not merely a special incident, but a general factor in metamorphism. This is not the place to discuss so large a question, more especially since it turns in particular cases upon the interpretation of field-evidence. I would observe, however, that, when the appeal is to liquid solutions emanating from igneous intrusions, speculation should be controlled by regard to the known chemistry of crystallizing magmas. The adinole transformation, for example, presents no obvious difficulty on this score, since we know that the final residual magma of an igneous rock may be very rich in albite. The case is different when magnesian solutions of magmatic origin are invoked to explain the dolomitization of a limestone, or the production in it of such minerals as biotite and hornblende.

What most of all characterizes the recrystallization of rocks in metamorphism, and differentiates it from the crystallization of an igneous magma, is that it takes place, not freely in a fluid medium, but in the heart of a solid mass. Hence the nascent and growing crystals, as well as the rest of the rock, are subject to more or less complex stresses. A clear understanding of all that this implies is among comparatively recent developments. It could not be appreciated while geologists were content to speak vaguely of the effects of 'pressure,' without discriminating between uniform and non-uniform pressure. If, following the general analysis of Thomson and Tait, we resolve any stress at a point within a rock-mass into, first, simple uniform pressure, related to change of volume, and second, shearing stress, related to change of shape, it is not difficult to assess for our purpose the relative significance of the two elements. In all transformations or reactions involving a gaseous phase simple pressure is important, and may be a determining factor. The thermal metamorphism of the pure carbonate-rocks affords a good illustration. Under different pressures dolomite either recrystallizes without change, or is dissociated and its magnesian part decarbonated; but calcic carbonate, which has at corresponding temperatures a lower dissociation-pressure, is never decomposed. Apart from changes of the class indicated, hydrostatic or equal pressure seems to be in general of small moment. Calculation and experiment alike show that, as regards the displacement caused in a balanced reaction, a very great change of pressure is no more effective than a very few degrees change of temperature. It is only at great depths, therefore, where enormous pressures prevail, that the 'volume law' comes to have any noteworthy consequence in metamorphism; and certain mineralogical characters of deep-seated metamorphic rocks, such as the increasing prominence of garnets in certain types, may be interpreted in this sense. With this growing importance of pressure goes a decline in the efficacy of shearing stress, since the high temperature which necessarily rules diminishes the resistance of the rocks to shearing. In the more general case, however, and certainly for typical crystalline schists, we may without serious error consider metamorphism as controlled by the two factors temperature and shearing stress, and treat simple pressure as a relatively small correction.

A true appreciation of the problems of metamorphism was long retarded by the tacit assumption that the rocks play a merely passive part in the operation. Despite such familiar phenomena as the splitting of rocks by frost, the powerful mechanical force which can be exerted by crystals growing in a solid medium was ignored. So lately as 1903 Becke first approached the subject in a brief but important note dealing with the microstructure of the crystalline schists as dependent upon crystal growth in the solid and upon a competitive struggle between the crystals of different minerals. A stricter analysis would discriminate between effects due merely to a solid environment and those connected with externally impressed forces; but this distinction is necessarily obscured when the crystalline schists are treated as a peculiar class of rocks, and 'regional' is severed from 'contact'-metamorphism.

That the force which growing crystals are capable of exercising implies a definite specific property, seems to be proved by the more or less fixed order of precedence which Grubenmann has termed the 'crystalloblastic series,' and it may some day be possible to measure this property for different mineral species. Hitherto the only recorded attempt in this direction is the experiment of Becker & Day, in which a crystal of alum, growing in a saturated solution, was caused to lift a superincumbent weight. Since the crystal was loaded above but free at the sides, it was subjected to shearing stress. The stresses developed by crystal growth within a rock-mass must also be mainly of this type. There is in general little change of total volume in metamorphism, and consequently, in so far as each crystal grows at the expense of material in its immediate neighbourhood, the constraint which it encounters is in respect of shape, not of volume. The alum experiment would seem to indicate that the internal stresses thus spontaneously set up may be of the same order as the crushing strength of the crystals themselves, and therefore comparable in magnitude with the stresses which are called into play by orogenic forces. It is certain, however, that in a rock which has no parallel structure the shearing stresses of internal origin, having all directions at random, must be in great measure neutralized by mutual compensation.

The stresses set up in reaction against external forces do not tend to compensate one another, since they have a common direction imposed from without. They can, however, be reduced or partly annulled by setting off against them the stresses due to crystal-growth; and the various types of foliated and schistose structures are merely Nature's devices for compassing this end. We find accordingly that only very strong minerals, like garnet, assert their normal crystal-habit under the conditions premised. The crystals of weak minerals, such as quartz, tend to lenticular and flattened shapes by growing out chiefly in directions perpendicular to the maximum pressure, as did the alum in the experiment. Moreover, many of the minerals of metamorphism have an advantage not possessed by alum or by garnet, in that their normal habit is tabular or columnar, owing to more rapid growth in certain crystallographic directions. This habit is exaggerated when the growth takes place in a solid rock; and, if the rock is under definitely oriented stresses, the habit is further exaggerated in those crystals which lie more or less nearly along the plane perpendicular to the maximum pressure. Any shearing deformation of the rock-mass, besides affording direct relief, rotates existing crystals more nearly into this favourable posture, and—what is of greater importance—new crystals, originating under the stress-conditions indicated, set themselves in the same plane.

The laws governing the growth of crystals in a solid rock have much more than a theoretical interest. In particular, the distinction between strong and weak minerals, as expressed in the crystalloblastic series, concerns the field-geologist no less than the petrologist; and disregard of it may lead to erroneous conclusions concerning the mutual relations of rocks and the geological history of a district. For example, an eclogite intercalated among well-foliated rocks is not to be set down as an intrusion later than the foliation, merely on the ground that it does not share in that structure. Nor again do flakes of ilmenite or ottrelite scattered through a mica-schist, without conforming to the parallel arrangement, afford evidence of a second epoch of metamorphism. It would be easy to pick out in geological literature passages which call for revision in the light of these and kindred considerations.

The student of metamorphism must realize how radically some simple physical and chemical principles become modified when applied to bodies in a condition of internal stress; and, moreover, of stress which varies from place to place and from time to time. Our conceptions of the relations between solids and liquids—crystallization, fusion, solution, chemical reaction—are naturally based on the behaviour of bodies under uniform pressure, such as that of the atmosphere; and a considerable readjustment of ideas becomes necessary before we can acquire a clear understanding of what happens in dynamic metamorphism. Petrologists, on their side, have hitherto made but little enquiry into the effects of non-uniform stress in rocks, other than effects of a purely mechanical kind. It is true that Sorby, in an address delivered from this Chair in 1879, pointed out that an unequal distribution of 'pressure' within a rock-mass must cause differences in solubility, and illustrated the consequences from the microstructure of some limestones; but this remained as one of numerous suggestions thrown out by that versatile genius, and left for others to follow up. About the same time Willard Gibbs was discussing on thermodynamic principles the equilibrium-relations between a liquid and a solid under stress of any kind; but his results were presented in so highly generalized a form that it was long before all their implications were perceived.

One consideration of moment to the geologist is that, when pressure is applied to a mass consisting of crystals with interstitial liquid, the additional pressure is borne by the crystals and not, or in much less degree, by the liquid. It follows that, whereas equally distributed pressure would cause in general an elevation of melting-points, unequal pressure (that is, unequal as between crystals and liquid) causes always a lowering of melting-points, and that of much greater amount. Johnston & Adams have applied this principle to Tresca's well-known experiments on the flow of metals, maintaining that the effects are due to actual fusion, local and temporary, in the interstices of the crystalline mass. However this may be, it cannot be doubted that the same principle has an important bearing upon the fluxional deformation of rocks under unequal stress, and so upon the origin of certain gneissic and foliated structures. Here, of course, we have to do, not with simple fusion, but with solution, which is subject to precisely the same law. We gain a new light upon the action whereby material is dissolved from those parts of a crystal or grain which bear greater pressure, to be concurrently deposited upon those parts where the pressure is less. This action, observed by Sorby in calcareous rocks, has undoubtedly a wider application, notably to the flattened and sometimes sinuous shapes assumed by such a mineral as quartz in some types of crystalline schists. It affords still another method by which the unequal stress set up by external forces is minimized or relieved.

There is, of course, much more than this. Even when a single mineral suffers such differential solution, that which recrystallizes may not be the same as that which dissolves, but a dimorphous form more stable under the actual conditions. In the more general case, where solution affects a number of minerals simultaneously, the products which crystallize out will often be new minerals, and ideally such as are stable under the immediate conditions. That the stress-condition is indeed often a determining factor is sufficiently clear from petrographical evidence, but a systematic interpretation of the observed mineral-associations remains a task for the future. Johnston & Niggli have set forth in convenient terms some general principles relative to the influence of unequal pressure, but the application of those principles demands data which are yet to seek. Upon all reactions involving a liquid or gaseous phase the influence is paramount, always favouring the production of the liquid or gas. To transformations and reactions between solid bodies alone the conception of unequal pressure is manifestly inapplicable, and it seems to be assumed that shearing stress in itself is of no direct effect. It is admitted, however, that reaction between solid bodies, which is negligible in other circumstances, may become effective with shearing movement, which has the result of bringing fresh particles continually into contact with one another.

Even on so brief a presentation of the case, it appears that the chemistry of bodies under unequal stress is in some important degree a new chemistry, different from that of the laboratory. One class of transformation-points may be greatly displaced, while another class—such as the inversion-point between two dimorphous forms—is unaffected. Consequently the range of stability of a particular compound, or a particular form of a dimorphous compound, may be either extended or contracted. A place may be made for some form which has no stable existence under any conditions of temperature and uniform pressure, or again another form may have its range of stable existence wholly cut out.

The facts of observation which await elucidation on these lines are sufficiently familiar to geologists, Shearing stress manifestly favours the production of sericite and the chlorites, of albite among the felspars, of the epidote-zoisite group, of amphiboles as opposed to pyroxenes, of cyanite and staurolite, chloritoid and talc, hæmatite and rutile. These may conveniently be styled stress-minerals. Some of them—cyanite, anthophyllite, gastaldite, jadeite, lawsonite, antigorite—are so exclusively associated with crystalline schists that we may reasonably infer shearing stress to be necessary for their production. On the other hand numerous minerals, such as anorthite and the potash-felspars, augite, olivine, and andalusite, known as common products of simple thermal metamorphism, are rare or absent in proportion as the dynamic element has entered, and they may be distinguished as anti-stress minerals. Of special interest are those cases in which members of the two contrasted categories are dimorphous forms of the same compound. Thus anthophyllite is a characteristic mineral of crystalline schists, while enstatite appears as a metamorphic product only in districts, like that of Christiania, where shearing-stress has been absent. Similarly, cyanite is a typical stress-mineral, while andalusite belongs to rocks metamorphosed under no considerable shearing stress. It is to be remarked that the four minerals named are all metastable forms under ordinary laboratory conditions. We must infer, either that cyanite and anthophyllite have each a real stability-range under stress-conditions, or alternatively that shearing stress may invert the relative stability of two metastable dimorphous forms. Observe that there is no question here of pressure and the volume-law: for, of the two forms of magnesium metasilicate mentioned, the pyroxene is denser than the amphibole. Cyanite, it is true, is denser than either andalusite or the stable sillimanite, and, in accordance with this, it is the form found in deep-seated metamorphic rocks like eclogites, although these may have crystallized under no very intense shearing stress. It is clear, however, that any reasoning *a priori* must be inconclusive, since we do not possess at present the requisite data. It would be impossible, for instance, to predict, what we find to be the fact, that soda-felspar remains stable under shearing stress down to quite low temperatures, while the potash- and lime-felspars under like conditions are destroyed. We can only await the results of experimental research in a field as yet unexplored.

Shearing stress, then, is a factor of first importance, coordinate with temperature, governing mineralogical changes in solid rocks. Even when uniform pressure is disregarded, the conditions of metamorphism are a function of two independent variables, and this may seem to imply a range of possibilities which will greatly complicate a systematic study. Grubenmann has evaded this difficulty by supposing that both temperature and shearing stress, as well as pressure, are roughly functions of depth beneath the surface. To some degree of approximation all the conditions controlling metamorphism will then be determined by a single variable. The assumption in its entirety is one to which I must certainly demur. We can conceive ideally a globe in which the temperature, like the pressure, increases steadily downwards; but it is of the essence of metamorphism that it is related to a very notable disturbance of this ordered state of things in some part of the Earth's crust. In such a disturbed tract, and especially when igneous intrusion intervenes, temperature may vary greatly in a manner having no connexion with depth, and the same may be premised of shearing stress. While, however, the assumption is unsound, the classificatory scheme erected upon it by Grubenmann does in fact provide places for the great majority of regionally metamorphosed rocks. The reason is not very recondite. Although shearing stress may vary independently of temperature, it has a maximum value which is a function of temperature, since this determines the elastic limit of the material. The maximum stress, and with it the possible range of stress, diminishes with rise of temperature; and it is accordingly at low temperatures that the inadequacy of Grubenmann's simplified treatment becomes most apparent. The elastic limit, and consequently the maximum shearing stress, will be very different for different materials; and it is to be noted that in the empirical classification cited the dividing lines between the three zones of depth are not supposed to be the same in different classes of rocks.

If now the external forces be everywhere sufficient to maintain the shearing stresses at their maximum, stress does become a function, not indeed of depth, but of *temperature*, and the main conditions controlling metamorphism in rocks of a given type will therefore be determined by a single variable. Doubtless this case is often closely realized, where metamorphism takes place upon an extensive scale. It is this which renders possible the mapping of successive zones of metamorphism, as worked out by Barrow over a large part of the South-Eastern Highlands: the lines laid down are at once isothermals and isodynamics. To assign the corresponding temperatures in degrees may some day be found possible, but the data will be very scanty. As Johnston & Niggli have pointed out, the inversion-points of enantiotropic forms seem to be the only points on the 'geological thermometer' which remain true in a tract subjected to shearing stress.

While metamorphism of the most general type, in which the thermal and dynamic factors have cooperated, is usually developed upon a regional scale, the strict localization of such effects, which may sometimes be observed, presents some points of special interest. It seems clearly attributable to the mechanical generation of heat by the crushing of rocks. The fact that notable instances are exceptional, proves that crust-movements are in general too slow to bring about a local rise of temperature from this cause. The classical area is that of the Ardenne, where Gosselet has demonstrated belts of special metamorphism along faults and overthrusts and in the cores of small anticlines. In some cases the thermal element is much more in evidence than the dynamic, shearing stress having apparently been effectively relieved before the recrystallization of the rocks. Some of Gosselet's 'cornéites' indeed are identical with types of 'hornfels' familiar to us in metamorphic aureoles. Our own country too affords examples of metamorphism of a more or less high grade localized in evident relation with tectonic accidents. The belt of maximum metamorphism in the Isle of Man follows a horizon of special mechanical disturbance, and seems to be strictly comparable with some cases in the Ardenne. It is, however, in crystalline rocks, which offer more resistance to crushing, that we should rather look for effects depending upon the mechanical generation of heat. Some special features of the Lewisian tract in the North-West might be cited, and especially the sharply bounded east-and-west belts of reconstruction which traverse the old gneiss and its dykes in common. They are evidently bound up with displacements of the nature of 'tear-faults,' at some epoch between Archæan and Torridonian.

To some geologists, whose concern has been with wide tracts of crystalline schists and gneisses, these minor incidents may seem to have little significance; but it is my main thesis that metamorphism, in all its manifestations, is to be envisaged as a single problem, though a very intricate one: namely, the reconstitution of rock-masses under varying conditions of temperature and stress. To the solution of this general problem data of a large and of a small order may equally contribute, and each will have value in proportion as it tends to bring the facts of observation into touch with known physical principles.

I now relinquish the office which I have been privileged to hold for two years. Thanks to the consideration which I have at all times received, my tenure of it has been not only an honour warmly appreciated, but a pleasant memory to be cherished. My path has been made smooth by the forethought and promptitude of my fellow-officers and the loyal support of the Council. To all these I wish to record my thanks; as also to the permanent officials of the Society, whose help has always been zealously rendered despite many difficulties incident to these troublous times. You have chosen as my successor one whose high qualifications, both as a geologist and as a man of affairs, are well known to all, and into his capable hands I confidently resign my trust.

February 20th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'The Geological Aspects of the Coral-Reef Problem.' By Prof. William Morris Davis, For.Corr.G.S.

March 6th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Harold Downes, M.B., F.L.S., F.R.M.S., Ditton Lea, Ilminster (Somerset); Thomas Wilson Ogilvie, 44 Irish Street, Whitehaven (Cumberland); and Joti Parshad, B.A., care of the Geological Survey of India, Calcutta, were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. John Frederick Norman Green delivered a Lecture on the Igneous Rocks of the Lake District. He first drew attention to some of the manuscript 6-inch maps of the Lake District, prepared nearly fifty years ago, by the Geological Survey, and pointed out that, although undoubtedly most accurate, they appeared to differ greatly in the volcanic area from his own. He suggested that the reason was, that there was a fundamental difference in the classification of tuffs and lavas. A large proportion of the Lake-District rocks were brecciated, and had been supposed to be altered tuffs: with the unbrecciated rocks into which they passed they had been mapped as ashes. A number of specimens and photographs were shown, indicating that the brecciation and apparent bedding were due to flow. Specimens were also shown of explosion-breccias, of the normal tuffs (which the Lecturer believed to be mainly the result of erosion between eruptions), and of rocks simulating true tuffs, but actually sandstones and conglomerates, composed of detrital igneous material. Attention was drawn to the criteria for distinguishing the various types. Manuscripts in the possession of the Geological Survey proved that W. T. Aveline, whose maps were extraordinarily accurate and detailed, had anticipated by thirty years the Lecturer's separation from the volcanic rocks of the basal beds of the Coniston Limestone Series.

When re-mapped on this basis, the Borrowdale Series appeared as a simple and regular sequence, strongly folded and cropping out in long bands. An interesting history of vulcanicity was revealed, beginning in many places with explosion-tuffs followed by a great series of pyroxene-andesites over the whole district. Then there was a pause during which fine-grained andesite-tuffs, with a tendency to produce true slates, accumulated. This was succeeded by a vast outpouring of andesites, of great thickness in the central mountain-region, but dying out southwards and eastwards. Next a series of peculiar mixed tuffs, of special value in mapping, was covered by another mass of andesites dying out south-westwards. After this, soda-rhyolites covered the whole district, nothing later being preserved—with one possible known exception. These volcanic rocks were intersected by a varied series of intrusions.

The solfataric phenomena were of interest, including the production of garnet and graphite, and a remarkable 'streaky' structure in the rhyolites.

An important question related to the age of the large acid intrusions associated with the volcanic rocks. Were they of the same age as, or later than, the Devonian folding? A sketch was given of the evidence on which the Lecturer assigned the Eskdale and Skiddaw granites to the Ordovician volcanic episode, and it was suggested that the great Skiddaw anticline was not due to regional folding, but a local structure connected with the vulcanicity.

Lantern-slides of Lake-District country were shown, and the manner in which the volcanic rocks entered into the scenery was pointed out.

A short discussion followed, and the thanks of the Fellows present were accorded to Mr. Green for his Lecture.

Rock-specimens and manuscript 6-inch maps were exhibited by the Director of H.M. Geological Survey.

A series of volcanic rocks from the Eifel District was exhibited by James Francis, F.G.S.

March 20th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Harry Muller, 12 West Park, Eltham (Kent), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The President referred with sorrow to the death, on March 18th, of Dr. George Jennings Hinde, F.R.S., who had served the Society for many years as a Member of the Council. The President also recorded the loss of Capt. Lewis Moysey, M.B., R.A.M.C., who was on board H.M. Hospital Ship 'Glenart Castle,' torpedoed in the Bristol Channel on February 26th, 1918. It was stated that the Council had sent resolutions of condolence to the relatives of both these Fellows.

The PRESIDENT announced that the Council had awarded the Proceeds of the Daniel-Pidgeon Fund for the present year to JAMES ARTHUR BUTTERFIELD, M.Sc., F.G.S., who proposes to conduct researches in connexion with the Conglomerates and Sandstones underlying the Carboniferous Limestone Series in the North-West of England.

Dr. WILLIAM FREDERICK SMEETH delivered a lecture on the Geology of Southern India, with particular reference to the Archæan Rocks of the Mysore State. With the aid of a map, prepared by the Geological Survey of India, the Lecturer pointed out the general character of the geological formations of Southern India, which consist, very largely, of a highly-folded and foliated complex of Archæan gneisses and schists, followed by some considerable patches of pre-Cambrian slates, limestones, and quartzites; with these are associated basic lava-flows and ferruginous jaspers. The remaining formations consist of remnants of the Gondwana Beds (coal-measures of Permo-Carboniferous age), a few patches of Cretaceous rocks, some Tertiary and Pleistocene deposits, and recent sands and alluvium, all situated along the coastal margins of the Peninsula. He contrasted the scanty post-Archæan record of Southern India, the apparent non-submergence of the greater portion of the area, and its freedom from great earth-movements since Archæan times, with the widely-extended formations of Northern India which recorded oft-repeated movements of depression and elevation, culminating in the rise of the Himalaya in Tertiary times, and accompanied by igneous activity on a gigantic scale, as proved by the outpourings of the Deccan Trap.

In discussing the Archæan complex, the Lecturer traced the history of the various views which had been held. Newbold (1850) regarded the complex as formed of Protogene schists and gneisses intruded into by granites. Bruce Foote (1880) separated the schists (to which he gave the name 'Dhárwár System') from the gneisses, and regarded them as laid down unconformably upon the gneisses and granites which, for many years thereafter, were embraced in the term 'Fundamental Gneissic Complex.' He regarded the Dhárwár System as transition-rocks between the old gneisses and the older Palæozoic rocks (Cuddapa, etc.). Holland (1898) differentiated the Charnockites, showing that they formed a distinct petrographical province with intrusive relations to the main members of the gneissic complex. In 1906 he proposed to regard the Cuddapa System as pre-Cambrian, and separated by a great Eparchæan Interval from the Dhárwár System, which, together with the gneissic complex, he classed as

Archæan. In 1913, Holland added a group of post-Dhárwár eruptive rocks, and produced a classification of the pre-Cambrian rocks of India which exhibits a remarkable parallelism with that given by Lawson (1913) for the pre-Cambrian of Canada.

The work of the Mysore Geological Survey from 1899 to 1914 had gradually eliminated the Fundamental Gneissic Complex, and shown that within the area of the Mysore State—representing some 29,000 square miles of the Archæan complex—the oldest rocks were the Dhárwár System, which had been intruded into by at least four successive granite-gneisses, namely: the Champion Gneiss, the Peninsular Gneiss (forming the greater part of the area), the Charnockites, and the Closepet Granite Series. If we compared this succession with Holland's 1913 classification, without assuming any real correlation with the Canadian rocks, but viewing the Dhárwár rocks as Huronian, as suggested by Holland, then his post-Dhárwár eruptive series (Algoman) included the whole of the gneisses of Mysore, while equivalents of the Laurentian and Ontarian formations were wanting. On the other hand, if the Dhárwár rocks were regarded as Keewatin, then the gneisses of Mysore might represent Laurentian and, possibly, Algoman formations, while representatives of the Huronian would be non-existent. Obviously, therefore, the Mysore Archæan succession was either very incomplete, or it did not fit in with the classifications of Holland and Lawson. It was to be remembered that Holland's classification dealt with a much wider area than Southern India, and the essential problem appeared to be whether his 'Bundelkund Gneiss' (Laurentian) and the Bengal gneisses (Keewatin) were really older than, and unconformable to, the Dhárwár System—as represented by him—, or whether they were post-Dhárwár eruptives corresponding to portions of the Mysore gneissic complex. In favour of the latter view it was noted that observers acquainted with both have appeared to recognize the Bundelkhand and Bengal types of gneisses in and around Mysore, and that all of these gneisses have, until recently, been regarded as forming part of the great Fundamental Gneissic Complex of India.

The Lecturer then described the map of Mysore, which, on a scale of 8 miles to the inch (1 : 506,880), presented a simplified summary of the work of the Mysore Geological Survey. On lithological grounds the Dhárwár System was divided into an Upper and a Lower Division. The former was composed largely of basic flows and sills with their schistose representatives. Whether some of the chloritic schists, slates, phyllites, and argillites were of secondary origin was still doubtful. In the series as a whole, chlorite predominated, and hornblende was subordinate. The presence of carbonate of lime, magnesia, and iron was a strikingly prevalent feature. The Lower Division was composed of dark hornblendic epidiorites and schists, which were distinguishable from the greenstones of the Upper Division by their dark colour and by the practical absence of chlorite. Many of the greenstones and schists of the Upper Division appeared to resemble Keewatin rocks of Lake Superior, such as the Ely Greenstone Series (save that augite is conspicuously absent in the Mysore rocks), and it had been suggested that the dark epidiorites, which naturally crop out between the rocks of the Upper Division and the intruding gneisses, might be merely metamorphosed portions of the greenstones and chlorite-schists. This might be true in some cases, but the independent existence of the dark hornblendic rocks of the Lower Division was supported by the fact that they do not exist in many places where the gneisses come into contact with the greenstones; that many of the former retain original igneous structures, which would be unlikely to survive the chloritization and the subsequent change to epidiorite; and, finally, that the amphibolitization of the rocks of the Lower Division appears to have been complete before the intrusion of the earliest of the gneisses which, with its associated pegmatites and quartz-veins, has developed secondary augite in the hornblendic rocks along intrusive contacts.

The Lecturer referred briefly to the autoclastic conglomerates which were usually associated with intrusions of the Champion Gneiss; to the intrusive character of some of the quartzites or quartz-schists; and to the evidence that the limestones were, partly if not wholly, due to metasomatic replacement of other rocks by carbonates of lime and magnesia.

The Dhárwár schists of Mysore contain a widely-extended series of banded quartz-iron-ore rocks, very similar to those of the Lake-Superior region, the origin of which has been the subject of much discussion, and is still highly perplexing. Some of the earlier American geologists considered them to be directly igneous in origin; but these views are now discredited, and replaced by an interesting and ingenious theory of chemical precipitation from liquids associated with subaqueous lavas. The Lecturer suggested that some of these rocks might be pegmatitic intrusions of quartz and magnetite, and that some might be the metamorphosed relics of igneous rocks composed, in great measure, of highly-ferruginous amphiboles (such as cummingtonite) or other chemically-allied minerals.

A short discussion followed, and the thanks of the Fellows present were accorded to the Lecturer.

Rock-specimens and microscope-sections of rocks from Mysore were exhibited by Dr. W. F. Smeeth, M.A., A.R.S.M., F.G.S., in illustration of his Lecture.

April 17th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'The Evolution of the Liparoceratidæ.' By Arthur Elijah Trueman, M.Sc., F.G.S.

Lantern-slides and specimens of Ammonites were exhibited by Mr. A E. Trueman, in illustration of his paper.

May 1st, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Capt. Rupert William Palmer, M.C., M.Sc., 10 Mayfield Road, Kersal, Manchester; and Arthur James Pickering, Abbeycraig, Hinckley (Leicestershire), were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. Arthur Hubert Cox delivered a Lecture on the Relationship between Geological Structure and Magnetic Disturbance, with especial reference to Leicestershire and the Concealed Coalfield of Nottinghamshire.

Before the Lecture, at the request of the President, Dr. A. Strahan, F.R.S., Director of the Geological Survey, briefly outlined the circumstances that had led to an investigation into a possible connexion between geological structure and magnetic disturbances. The magnetic surveys conducted by Rücker and Thorpe in 1886 and 1891 had proved the existence of certain lines and centres of disturbance, but those authors observed that 'the magnetic indications appear to be quite independent of the disposition of the newer strata,' and he (the speaker) had not been able to detect any obvious connexion with the form and structure of the Palæozoic rocks below. In 1914–15 a new magnetic survey was made by Mr. G. W. Walker, who confirmed the existence of certain areas of disturbance. It was suggested that the effects might be due to concealed masses of iron-ore, and the matter was referred to the Conjoint Board of Scientific Societies, who appointed an Iron-Ores Committee to consider what further steps should be taken. The Committee recommended that attention should be concentrated on certain areas of marked magnetic disturbance, and that a more detailed magnetic survey of these areas, accompanied by a petrological survey and an examination of the magnetic properties of the rocks of the neighbourhood, should be made. He (the speaker) had been approached with a view to the petrological work being undertaken by the Geological Survey, and it had been arranged by the Board of Education, with the consent of H.M. Treasury, that a geologist should be temporarily appointed as a member of the staff for the purposes of the investigation. Dr. Cox had received the appointment, and the lecture which he was about to deliver would show that results of great significance had been obtained by him. The new magnetic observations had been made by Mr. Walker, and the examination of the specimens collected, in regard to their magnetic susceptibility, had been conducted by Prof. Ernest Wilson.

Dr. Cox then described the selected areas, which lay on Lias and Keuper Marl between Melton Mowbray and Nottingham, and in the neighbourhood of Irthlingborough, where the Northampton Sands are being worked as iron-ores. The Middle Lias iron-ores, consisting essentially of limonite, which crop out near Melton Mowbray, have been proved incapable, by reason of their low magnetic susceptibility, of causing disturbances of the magnitudes observed, while the distribution of the disturbances showed no correspondence with the outcrop of the iron-ores. Nor was any other formation among the Mesozoic rocks found capable of exerting any appreciable influence. It appeared, therefore, that the origin of the magnetic disturbances must be deep-seated.

Investigation showed that the disturbances were arranged along the lines of a system of faults ranging in direction from north-west to nearly west. The faults near Melton Mowbray have not been proved in the Palæozoic rocks, and, so far as their effects on the Mesozoic rocks are concerned, they would appear to be only minor dislocations. But farther north, near Nottingham, faults which take a parallel course, and probably belong to the same system of faulting as those near Melton Mowbray, are known from evidence obtained in underground workings to have a much greater throw in the Coal Measures than in the Permian and Triassic rocks at the surface. It appears therefore that movement took place along the same lines at more than one period, the earlier and more powerful movement being of post-Carboniferous but pre-Permian age, the later movement being post-Triassic. Accordingly, it is probable that the small dislocations in the Mesozoic rocks indicate the presence of important faults in the underlying Palæozoic.

The faults can only give rise to magnetic disturbances if they are associated with rocks of high magnetic susceptibility. It is known from deep borings that the concealed coalfield of Nottinghamshire extends into Leicestershire, but how far is not known. Deep borings have proved that intrusions of dolerite occur in the Coal Measures at several localities in the south-eastern portion of the concealed coalfield and always, so far as observed, in the immediate vicinity of faults. It has been established that dolerites may exert a considerable magnetic effect; and the susceptibility of those that occur in the Coal Measures is above the general average. Further, no other rocks that are known to occur, or are likely to occur under the area, have susceptibilities as high as the dolerites found in the Coal Measures. These facts suggest the possibility of the occurrence of dolerites intrusive into Coal Measures beneath the Mesozoic rocks of the Melton-Mowbray district.

The distribution of the dolerites actually proved, and of those the presence of which is suspected by reason of the magnetic disturbances, appears to be controlled by the faulting. Moreover, whereas the character of the magnetic disturbances is such that it would not be explained by a sill or laccolite faulted down to the north, in the manner demanded by the observed throw of the principal fault, it would be explained by an intrusion that had arisen along the fault-plane. The faulting itself is connected with a change of strike in the concealed Coal Measures, and the incoming of doleritic intrusions in the concealed coalfield, in contrast with their absence from the exposed coalfield, appears to depend upon the changed tectonic features. The change of strike is apparent, but to a less degree, in the Mesozoic rocks which, in the neighbourhood of Melton Mowbray, have suffered a local twist due to the development of an east-and-west anticlinal structure.

In view of the evidence that later movements have, in this district, followed the lines of earlier and more powerful movements, it appears possible and even probable that this post-Jurassic (probably post-Cretaceous) anticline is situated along the line of a more pronounced post-Carboniferous but pre-Permian anticline. In this connexion the isolated position of Charnwood Forest has a considerable significance. The Forest is situated on the prolongation of the east-and-west line of uplift, and just at the point where this uplift crosses the line of the more powerful north-westerly and south-easterly (Charnian) uplift. Where the two lines of uplift cross the elevation attains its maximum, and the oldest rocks appear.

The main line of faulting and of magnetic disturbance is parallel with and on the northern side of the east-and-west anticline, and the faulting is of such a nature that it serves to relieve the folding while accentuating the anticlinal structure. It is possible that this belt of magnetic and geological disturbance marks the southern limit of the concealed coalfield. The results obtained by joint magnetic and geological work have thus served to emphasize the real importance of a structure which, when judged merely from its effects on the surface-rocks, appears to be of only minor importance.

A further series of observations was carried out on the Jurassic iron-ores of the Irthlingborough district of Northamptonshire. The ores occur in the form of a nearly horizontal sheet of weakly-susceptible ferrous carbonate, partly oxidized to hydrated oxides. They give rise to small magnetic disturbances which are quite capable of detection, and these may be of use in determining the boundaries of the sheets in areas not affected by larger disturbances of deep-seated origin.

The results obtained by the joint magnetic and geological work in the two areas show that this method of investigation may be used to extend our knowledge of the underground structure. It appears also that an extension of the method to other parts of the country would yield information of considerable scientific and economic importance.

A short discussion followed, and the thanks of the Fellows present were accorded to Dr. Cox for his Lecture.

Geological maps were exhibited by Dr. A. Hubert Cox, M.Sc., F.G.S., in illustration of his Lecture.

A model of a 'Sop' of iron-ore worked at the Park Mines, Dalton-in-Furness, was exhibited by the Director of the Geological Survey, to whom it was presented by the Barrow Hæmatite Steel Company. Mr. Bernard Smith, F.G.S., described the model, and discussed the origin of the ore-body. The model was prepared by Messrs. David & Herbert Lawn.

May 15th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Albert Stanley Harding, B.Sc., Brighton Villas, Abertillery (Monmouthshire), was elected a Fellow of the Society.

The List of Donations to the Library was read.

A Lecture on 'The Geology of the Italian Front' was delivered by Prof. Edmund Johnston Garwood, M.A., Sc.D., F.R.S. It was illustrated by lantern-slides, geological maps and sections, and tables of strata.

The President expressed to the Lecturer the thanks of the Fellows present.

June 5th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Kelestominæ, a Sub-Family of Cretaceous Cribrimorph Polyzoa.' By William Dickson Lang, M.A., F.G.S.

2. 'The Geology and Genesis of the Trefriw Pyrites Deposit.' By Robert Lionel Sherlock, D.Sc., A.R.C.Sc., F.G.S.

Lantern-slides of Cretaceous polyzoa were exhibited by Mr. W. D. Lang, in illustration of his paper.

Rocks, minerals, and fossils were exhibited by Dr. R. L. Sherlock, in illustration of his paper.

June 19th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Alfred Joseph Bull, B.Sc., 16 Vincent Road, Croydon; Capt. Edward Lionel Johnson, R.E., 91 Bruce Street, Swindon (Wiltshire); and William McPherson, Masons Arms Hotel, Muirkirk (Ayrshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

A Lecture on Some Features of the Antarctic Ice-Cap was delivered by Major Sir Douglas Mawson, D.Sc., F.G.S. In the course of his lecture, which was illustrated by a large series of lantern-slides, Sir Douglas Mawson said that the ice-mantle of the south formerly involved the sub-Antarctic Islands, Patagonia, Southern New Zealand, and the higher mountains of Tasmania and of the neighbouring portions of Australia, but it retreated to its present confines—a circum-Polar Continent—at a time apparently concurrent with the disappearance of the extensive Pleistocene ice-sheets of the Northern Hemisphere.

The existence of a great land-mass situated on the face of the globe just where the sun's rays fall most obliquely has the effect of intensifying the Polar conditions. This result is achieved by reason of the elimination of the ameliorating influence of the ocean and as a result of the acceleration of the circulation of the moist atmosphere from the surrounding sea to the land, owing to the wide difference in temperature pertaining over the one and the other. Thus the presence of extensive land at the Pole, in contradistinction to ocean, results, under present cosmical conditions, in increased refrigeration, and consequently in greater extension of the Polar ice-cap. This in turn reflects on the average temperature of other regions of the globe, for an ice-surface absorbs but a relatively-small proportion of the sun's radiant heat. The existence of the Antarctic Continent must, therefore, have some bearing on the climate of the Northern Hemisphere, and be reckoned with as a factor contributing to the refrigeration thereof.

The Lecturer laid great stress upon the work of the outflowing surface-winds in developing the domed form of the ice-cap. These winds, owing to their persistence and violence, strip the surface of much of the newly-fallen snow, and otherwise ablate the marginal zone, thereby considerably reducing the volume of ice that would otherwise reach the sea by glacial flow. Crevasses in the ice-cap, observed far inland at 'The Nodules,' indicate that the ice of the hinterland is in motion.

In the seaward termination of the ice-sheet at Cape Denison, a basal zone, attaining as much as 50 feet in thickness, bearing englacial drift, is a well-marked feature.

The shelf-ice formations, including the Ross Barrier and the Shackleton Shelf were specially referred to: mention was made of their growth and decline, of a method of determining their depth below water, and of the probability of specialized life existing beneath such formations.

The President expressed to Sir Douglas Mawson the thanks of the Fellows and Visitors for his Lecture.

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1. *On the* Geology *of the* Old Radnor District, *with special reference to an* Algal Development *in the* Woolhope Limestone.

By Edmund Johnston Garwood, Sc.D., F.R.S., Yates-Goldsmid Professor of Geology in University College, London, and Edith Goodyear, B.Sc. (Read June 6th, 1917.)

[Plates I–VII.]

Contents.

I. Introduction.

The district which forms the subject of this communication has received but scanty attention in geological literature since the time of Murchison. Only one edition of the 1-inch Geological Survey map has been issued, namely, that published in 1840, and no explanatory memoir has yet appeared.[1] Two of the horizontal sections published[2] by the Geological Survey, however, pass through the district, and these throw some light on the views adopted by the officers of the Survey regarding its general structure at the time when the district was mapped.[3] They regarded the rocks of Old Radnor Hill as altered May Hill Sandstone, and the surrounding limestone, together with that which occurs at Nash Scar 3 miles away to the north-east, as altered Woolhope Limestone.

Murchison, as shown by his description in 'Siluria,' considered the district to be one of especial interest.[4] He draws attention to the differences exhibited by the limestone at Nash Scar and Old Radnor, when compared with the normal Woolhope Limestone and Shale at Corton and Haxwell, and remarks,

'between these two . . . . lies the large and loftier rock of Nash Scar, in which the same limestones, whether thick-bedded or nodular, have been run together into one amorphous mass, in which the stratified character has been destroyed, and the shale driven off. . . . . In tracing the strata southwards along this axis, other masses of limestone, more or less amorphous, are seen near Old Radnor, which, in proportion as they approach the eruptive masses of Stanner and Hanter rocks, and Ousel Hill, or the highly metamorphosed rock of Old Radnor and Yat Hill, are themselves subcrystalline, and unbedded, with coatings of serpentine upon the surfaces of the joints. On the other hand, on receding westwards from that line of eruption and metamorphism, into the Vale of Radnor, to the south-east of Harpton Court, the limestone begins to resume its bedded character, resting on the pebbly Caradoc conglomerates which range by Old Radnor Church and Yat Hill.'

After referring to the geological section of the Government Survey exhibiting the igneous rocks of Hanter Hill, he continues:

'It is also suggestive of the fact, that another body of igneous rocks lies subjacent to the Caradoc conglomerate and crystalline limestone of Old Radnor and Yat Hill, where the coatings of serpentine and brecciated and altered features of the stratified rocks are, in the eye of the geologist, conclusive evidences in favour of such relations.' (*Op. cit.* p. 104.)

Although Murchison admitted that the change in the character of the limestone at Old Radnor must have been in a great measure due to original deposition, he still considers that

'its amorphous and massive condition at Nash Scar and Old Radnor was doubtless caused by the action of heat issuing along a line of former linear fissure, which, in some places, evolved the hypersthenic rocks and greenstones of Stanner, Ousel, and Hanter upon the line in question, fused the stratified limestone and the calcareous nodules of the shale into amorphous and heterogeneous masses, more or less crystalline, leaving coatings and films of serpentine on their faces and joints.' (*Op. cit.* p. 105.)

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[1] The only published references appear to be a note, in the abstract of a paper by A. Ramsay & W. T. Aveline, entitled 'Sketch of the Structure of Parts of North & South Wales' Q. J. G. S. vol. iv (1848) p. 296; and in a paper by Ramsay, entitled 'On the Physical Structure & Succession of some of the Lower Palæozoic Rocks of North Wales & Part of Shropshire' Q. J. G. S. vol. ix (1853) p. 174.

[2] Sheet 56, S.E. New Radnor, Kington, etc.

[3] Sheet No. 27, 1852, & Sheet 58, 1860.

[4] 'Siluria' 1st ed. (1854) pp. 103 *et seqq.*

In 1850 J. E. Davis gave a list of fossils collected from the limestone at Nash Scar, with the view of determining the age of the limestone.[1] Of this collection Murchison remarks

'All the fossils which have been found in the limestone of this tract, whether by Mr. Edward Davis, who discovered most of them, and specially assisted me in studying them, or subsequently by the Government Surveyors, are truly Wenlock and Upper Silurian forms.' ('Siluria' 1st ed. 1854, p. 105.)

Unfortunately, the present whereabouts of Mr. Davis's collection is unknown, and only a very few specimens from this locality are preserved in the Museum of Practical Geology, Jermyn Street.

Since Murchison's time only one writer has dealt with the Old Radnor district.[2] In the Quarterly Journal for 1900[3] Charles Callaway briefly described the grits and limestones of Old Radnor Hill and Yat Hill, and suggested for the first time a Pre-Cambrian (Longmyndian) age for the grits. He based his conclusions on

(1) The resemblance which he traced between the Old Radnor grit and the rocks of the Longmynd; (2) the similar trend exhibited by the rocks in the two districts; and (3) an unconformity which he noticed between the limestone and the underlying 'Caradoc' Sandstone of Murchison.

This paper did not come to our knowledge until some time after we had begun work in the district; but, although it anticipates the conclusions at which we had arrived regarding the Pre-Cambrian age of the grits, we think that it may be worth while to record our observations in this connexion. These observations not only confirm Callaway's general contention, but, as they include the discovery of several additional rock-types, they render it possible to discuss more fully the particular group in the Longmyndian of Shropshire, to which the Old Radnor series appears to belong.[4]

Our attention was first called to this district at the Birmingham meeting of the British Association by Prof. Charles Lapworth, who suggested that the geographical conditions which had given rise to the algal development in the Ordovician rocks of Girvan, described by one of us in the Presidential Address to Section C,[5] most probably existed at the same time also in Shropshire, and might even have extended as far south as the borders of Radnorshire. He suggested that an investigation of the limestone in the latter area might possibly reveal the presence of beds of Caradoc age beneath the Wenlock rocks of the district, and that these

[1] Q. J. G. S. vol. vi (1850) p. 437.

[2] The igneous rocks of Stanner, which are described by Prof. G. A. J. Cole, Geol. Mag. dec. 3, vol. iii (1886) p 219, are not included in the scope of the present paper.

[3] 'Longmyndian Inliers at Old Radnor & Huntley' Q. J. G. S. vol. lvi (1900) p. 511.

[4] The statement in Mr. T. C. Cantrill's paper 'On a Boring for Coal at Presteign' Geol. Mag. dec. 6, vol. iv (1917) p. 490, that C. Callaway records a Longmyndian conglomerate at Old Radnor, is not correct; perhaps Mr. Cantrill was unwittingly thinking of our statement to this effect when the present communication was read in June 1917.

[5] Rep. Brit. Assoc. (Birmingham) 1913, p. 453.

might have been accumulated under similar lagoon conditions during a period of subsidence. Although the investigation of the district has revealed no rocks of Ordovician age, a careful examination of the Wenlock deposits has shown that they include a special reef facies of the Woolhope Limestone, a facies which constitutes by far the most remarkable development of algal limestone yet recorded from British rocks.

During the progress of this investigation we have had the advantage of discussing many of the problems which arose with Prof. Lapworth, who had himself previously visited and partly mapped the district; and we are glad of this opportunity of acknowledging our indebtedness to him, not only for the kind and stimulating interest which he has taken in the progress of the work, but also for many valuable suggestions and criticisms.

We are also indebted to Dr. F. R. Cowper Reed, who has examined our collection of trilobites and brachiopods from the Woolhope Limestone, and has determined many of the species: we wish here to tender to him our sincere thanks for so kindly placing his intimate knowledge of the Wenlock fauna at our disposal.

To Dr. Herbert H. Thomas we are under special obligation for his kindness in examining microscopic sections of the Pre-Cambrian sediments and for the notes with which he has furnished us.

In conclusion, we have to acknowledge the courtesy of the managers of the Old Radnor Trading Company and the Radnorshire Coal & Lime Company for permission to examine the extensive limestone-workings in the neighbourhood.

II. The Old Radnor Inlier. (Map, Plate VII.)

The general structure of the Old Radnor Inlier is an elongated dome, having a longer axis of a mile and three-quarters running in a general north-easterly direction. The northern half of the inlier is occupied, chiefly, by Pre-Cambrian rocks, which form the core of the dome, while the main limestone-mass occurs in the southern and south-western portions of the inlier. Narrow strips of limestone, however, also occur on the eastern and north-eastern margins, while a small lenticular 'faulted outlier' runs southwards from the northern margin towards the centre of the dome, having been faulted down and preserved in the midst of the Pre-Cambrian rocks. It is probable, therefore, that the limestone once extended over the whole of the inlier, and has been removed from the northern and central portions by denudation, except where certain blocks have been let down and preserved by faulting. According to the Geological Survey map the inlier is surrounded by Wenlock Shale, but there are only three sections where the contact with the limestone is exposed, and in each case the junction is a faulted one. The whole district is much crushed and dislocated by earth-movements.

(*a*) The Pre-Cambrian (Longmyndian) Rocks.

These rocks occupy the greater portion of the northern half of the inlier. They form the whole of Old Radnor Hill (Pl. II) with the exception of the north-western, southern, and south-eastern margins, where narrow strips of limestone have been let in by faults. They also occupy the district north and west of St. Stephen's Church, and extend southwards as far as the fault which runs immediately north of Yat Farm. South of this fault the outcrop continues with an average width of about 200 yards in a south-westerly direction, through the eastern portion of Yat Wood, to the railway, where a further exposure of Pre-Cambrian rocks emerges from under the limestone north and west of the station. The beds reappear on the south side of the line, and occupy the lower slopes of the rising ground which forms the elevations known as Dolyhir and Strinds, whence they can be followed round along the eastern side of Dolyhir Quarry. Several small patches are also met with on the north side of Strinds Quarry, where they have been thrust up into the limestone, and a similar thrust-block has recently been exposed by quarrying operations in the north-western corner of Yat-Hill Quarry, north of the railway. The rocks consist of pink and green greywackés and grits, together with occasional bands of coarse conglomerate, the series being essentially a sedimentary one throughout. The apparent strike of these Pre-Cambrian rocks is roughly parallel to the longer axis of the inlier, that is, north-north-eastwards, with a high but variable dip to the west and west-north-west—that is to say, the grain of the country runs in this direction. If, however, an attempt is made to map the different rock-types, it is not found possible to follow any individual band continuously for more than a short distance, and this is usually true of the conglomerates as well as of the finer-grained deposits. The group, as a whole, really represents a crush-breccia on a large scale, although some of the fragments are of considerable size. The conglomerate-bands, as might have been expected, have yielded less readily to pressure than the finer sediments, and also offer greater resistance to weathering; they can, therefore, be more readily traced than the finer sediments. These conglomerates, however, include layers of finer material, and this fact enables the dip and strike of the individual outcrops to be ascertained with a fair degree of certainty. In this connexion it is noteworthy that, with one exception (namely, the faulted patch immediately north of Stone's Farm), all the conglomerate outcrops strike in a general northerly direction. This dominant direction of the grain of the country is obviously the result of the last important set of movements that have taken place in the district, though the rocks had evidently undergone considerable crushing at a much earlier period.

It is impossible, therefore, to draw up a table of the beds, or to be certain of the true order of succession in any portion of the district. The dip, when it can be ascertained, appears to be in a general westerly direction, although there is always the possibility that the beds may be inverted, especially in the northern half of the district, where the apparent dip is often 70° or more. The problem is further complicated by the presence of a series of faults which traverse the district in a more or less easterly direction, rendering it difficult to correlate beds in the northern portion of the district with those in the south.

A visit to the quarry below the Harp Inn or, still better, to Gore Quarry, at the north-eastern end of the district, where the shattered character of the rocks is well displayed, shows the impracticability of attempting to trace the individual beds of the series for any distance.

The grits and greywackés.—The bulk of the deposit is composed of grits and fine-grained greywackés, true conglomerates being subordinate and only of local occurrence. In places, however, the grits become coarse, and may then contain a few small pebbles, but these coarse grits do not differ essentially from the material which forms the matrix of the true conglomerates.

The typical pink grits are well exposed in the outcrops round St. Stephen's Church and on the west side of Harp-Inn Quarry. They are much shattered, and often assume a brecciated appearance, the angular fragments being set in a fine dark paste which contains a considerable proportion of ferruginous material. The finer greywackés vary considerably in colour. The prevailing tints of the fresh rock are various shades of pink and green; the rocks, however, frequently weather to a buff colour, owing to the hydration of the iron oxides to limonite. Occasionally, fine bands of a bright crimson tint occur, which owe their colour in part to the presence of manganese salts; one such band may be seen cropping out on the track that leads past the quarry beside the Harp Inn. The presence of these highly-coloured bands is interesting, as similar rocks have been mapped by Prof. Charles Lapworth in the Bayston Group of the Longmyndian Series, in the type-district farther north.

A rather different kind of rock occurs in the old quarries below Yat Wood, close to Dolyhir Station. Here the beds dip at 50° west-north-westwards, and consist of compact green micaceous greywackés interbedded with layers of crushed shale. The mica-flakes are arranged in parallel layers along the bedding-planes of the deposit, and the finer shale-bands resemble very closely the Stretton Shales of the Longmynd area. Some purple layers also occur, which, in addition to mica-flakes, contain a few included flat pellets of a red-brown mudstone lying parallel to the bedding-planes. These layers are identical in appearance and structure with rocks exposed in Sharpstone Quarry, near Bayston. A further exposure of red mudstones, containing abundant mica-flakes, also associated with micaceous green greywackés, occurs in Gore Quarry. The rocks, however, are so crushed and broken that their true dip cannot be determined here.

Dr. H. H. Thomas has kindly furnished us with the following notes on the structure of these rocks as exhibited in thin slices:—

All these grits and greywackés are linked together by their general felspathic character and angularity of grain.

Microscopically they consist of a closely-packed aggregate of quartz, grains of quartzite, and igneous rocks rich in soda-felspars. The quartz is of two kinds, one practically devoid of strain and originating most probably in quartz-porphyries or quartz-keratophyres, and the other highly strained and probably derived from pre-existing sedimentary rocks that have been subjected to shearing stresses. In addition, broken crystals of albite are of common occurrence, and these are certainly derived from soda-granites and soda-aplites, or from porphyritic keratophyric rocks, fragments of which are occasionally met with.

All these rocks, whether collected from the north of Dolyhir Station, from Harp-Inn Quarry, or from Gore Quarry, present characters that are quite distinctive but yet unite them closely with the matrix of the conglomerates described below, and the small pebbles that are of frequent occurrence in the grits are identical with, or of rock-types similar to, those found in the coarser deposits.

Locally the rocks become highly micaceous. The mica is arranged with well-defined parallelism, and is obviously detrital in character. In some of the rocks it is mainly muscovite; but usually, as in the green grits north of Dolyhir Station, it is an intimate parallel intergrowth of muscovite and chlorite, the chlorite being pseudomorphous after biotite.[1] In some bands a pale leek-green pleochroic mica is met with, similar to that which is so abundant in certain beds of the Lower Old Red Sandstone of the Welsh Borders.

From the general abundance of minute detrital garnets in all these rocks, and especially so in those containing much mica, it is probable that the micas had their origin in a series of garnetiferous schists or granulites.

The conglomerates.—Although the shattered condition of the Pre-Cambrian rocks makes it difficult to correlate the different outcrops one with the other, or to assign them to any definite horizons in the series, a study of the constituent pebbles shows clearly that at least two distinct types of conglomerate occur. Of one of these we may speak as the 'pink' conglomerate, and of the other as the 'grey' conglomerate.

The pink conglomerate is characterized by its prevailing red tint throughout; the majority of the pebbles are composed of bright-pink quartzite and dull-red felsite, some of the latter being visibly banded in hand-specimens; among them occur also a few pebbles of dark-grey granitoid rocks, which are stained red to a depth of about $\frac{1}{16}$ inch from the surface. The matrix is deeply impregnated with hæmatite, which gives it a uniform tint, except where it has been bleached by surface-weathering. The pink quartzite-pebbles are fairly uniform in size, of a blunt ovoid form, with well-smoothed surfaces; they have an average longer diameter of $1\frac{1}{2}$ to 2 inches, and exhibit a bright lustre on freshly fractured surfaces. The felsite-fragments are usually more elongate, with approximately circular cross-sections; and the same is often the case with the granitoid rocks. A few small well-rounded pebbles of grey and

[1] C. Callaway, Q. J. G. S. vol. lvi (1900) p. 513, regards the mica in these rocks as authigenous, but its nature and arrangement militate against this view.

white quartz also occur. The matrix, which forms only a small proportion of the rock, is fairly coarse, and consists of smaller and more angular fragments of pink felsite and quartz set in a sandy ferruginous paste.

The best exposures of this conglomerate are found at two points near the northern margin of the inlier. The northernmost of these outcrops occurs in a field about a third of a mile due west of Stockwell Farm, and about 150 yards south of the mound known as 'Castle Nimble,' at a spot marked 'boulders' on the 6-inch map. The second outcrop lies about 300 yards south of this, and some 280 yards west of the church; it forms a conspicuous feature on the north side of the cart-track leading from Old Radnor to Stone's Farm. These two outcrops both strike a little to the east of north, and have a similar dip of 70° west-north-westwards; they both consist of two layers of conglomerate separated by a bed of pebbly grit, and appear to form portions of a continuous band lying at a definite horizon in the series. The exposure of this conglomerate in Stone's-Farm Lane is cut off abruptly at its southern end by an east-and-west fault; but it reappears at the surface about 200 yards away to the west, immediately north of Stone's Farm.

Dr. H. H. Thomas, who has kindly examined thin sections of these conglomerates, reports as follows:—

As has already been stated, the matrix of the conglomerates is practically identical with the material that forms the grits and greywackés; but, owing to the greater size of the rock-fragments, these conglomerates afford a better opportunity than the finer-grained deposits for determining the types of rock undergoing denudation at the time. The bulk of the pebbles are quartzitic and felsitic in character, but coarser granitoid rocks, microlithic acid eruptive rocks, and even basalts are of frequent occurrence. Quartzite is present in two distinct varieties, one pink and the other grey to white in colour. The pink quartzite which predominates in this conglomerate, has a fine even texture, and a characteristic red staining throughout its whole mass—a staining which was undoubtedly completed before the denudation of the rock and its formation into pebbles. Another characteristic feature is the occurrence in some instances of minute but highly conspicuous rhombs of chalybite, scattered through the rock, though generally altered, completely or in part, to ferric oxide. The grey quartzite is of similar texture, but appears to have suffered in general some slight deformation. It is often stained superficially; yet the staining never extends far into the rock, and is evidently subsequent to the formation of the pebbles. The felsitic rocks are present in great variety, and present striking microscopic structures. The result of an examination of an extensive series of pebbles collected from the pink conglomerate of Castle Nimble indicates that soda-rhyolites, in the form of devitrified rocks with small porphyritic crystals of quartz and albite, constitute a prevalent type. Microscopically they often show strong fluxion-banding, and in some cases a beautiful perlitic structure has been retained.

Among the coarser igneous pebbles, rocks ranging from albite-granite to what may be termed soda-aplites and quartz-albite-porphyrites, are well represented. The soda-granites and aplites are closely related, and consist essentially of albite and albite-perthite with quartz, often in pœcilitic relationship, together with occasional subordinate muscovite. In some instances the structure approaches hypidiomorphic, and if quartz be present the rocks approximate to what may with propriety be termed quartz-albite-porphyrites.

One rock from this same locality calls for special mention, indicating as it does a tourmaliniferous granite of great antiquity. This iron-stained pebble when sliced showed interlocking crystals of albite, perthite, quartz, and subordinate muscovite, together with big well-developed crystals of greenish-blue tourmaline.

Pebbles of detrital rocks other than the characteristic quartzites are not of frequent occurrence; but well-foliated quartz-schists, fine-grained micaceous sandstones, as well as a garnetiferous arkose, are represented.

The grey conglomerate is characterized by an abundance of well-rounded grey and white quartz-pebbles, although a few pebbles of pink quartzite also occur; but the red felsite-pebbles, so conspicuous in the pink conglomerate, are rare. A few pebbles of crystalline schists have also been collected from rocks of this type, in the exposures on Old Radnor Hill (Pl. II). This grey conglomerate is well exposed in a small field on the north side of the road running from Old Radnor to Walton, immediately west of Stockwell Farm, where it forms a prominent feature. It can be traced into the road, but appears to be cut off south of it by the dislocation which brings down the limestone immediately to the east. The small outcrops of conglomerate which occur along the edge of the wood, east of the Old Castle mound, may, however, represent fragments of the same bed. North of the road the conglomerate is cut out by another dislocation, and disappears before reaching the old quarry on the south side of Wellin Lane. This fault is evidently a continuation of that which has already been mentioned as running along the lane to Stone's Farm, and the isolated outcrops of grey conglomerate which occur in the field north of Stockwell Farm are therefore, in all probability, the Stockwell-Farm bed shifted eastwards by this fault. A similar grey conglomerate also occurs in several isolated outcrops round the southern margin of Old Radnor Hill, immediately north of Hillhouse Farm; and again in two exposures in the triangular field below the farm, on the east side of the Dolyhir-Radnor road. These outcrops all have a general north-north-westerly strike, and are cut off abruptly on the south by an east-and-west fault which brings in the limestone on the southern margin of the hill. Whether these exposures represent faulted outcrops of the same bed, as suggested on the map, is difficult to determine; but their general similarity in composition and the parallelism of their strike renders it probable that this is the case.

Dr. Thomas reports as follows:—

The pebbles of the grey conglomerate are similar to those of the pink conglomerate, but the beds of this horizon differ from the pink conglomerate chiefly in the relative proportions of the rock-types represented. Here again we meet with the same suite of albitic rocks. The white to grey superficially-stained quartzite and other fine-grained quartzose sedimentary rocks are relatively abundant, while the pink quartzite so characteristic of the pink conglomerate is less frequently met with.

A red-stained albitized basalt, with well-shaped microporphyritic pseudomorphs after olivine, occurs in one of the outcrops of the conglomerate on Old Radnor Common.

The green felsitic and keratophyric rocks occur perhaps in slightly greater force than in the pink conglomerate; but, taken as a whole, there is strong evidence for the view that both the pink and the grey conglomerates have been derived from common sources.

No conglomerates have been met with in the micaceous grits which crop out at the southern end of Yat Wood on the north side of the railway; but south of the line a grey quartz-conglomerate occurs beneath the Woolhope Limestone on the east side of Dolyhir Quarry (see inset-map, Pl. VII), while a similar rock, probably a portion of the same bed, crops out round the northern margin of Strinds Quarry, and is well exposed beside the footpath leading from the quarry to Strinds Cottage. Fragments of this conglomerate are also included in the thrust masses of limestone and Pre-Cambrian rocks which are exposed along the north-eastern face of the quarry (D). A further fragment is exposed in the old quarry, below the bend in the road north-east of Strinds Farm, where it has been brought in by the north-and-south fault which brings up the Pre-Cambrian rocks on the east. Pebbles of the grey quartz have here been torn from the conglomerate, and plastered along the face of the fault-plane to form a derived thrust-conglomerate (Pl. III).

The materials of which these Pre-Cambrian sediments are composed appear to have originated from several sources, including as they do various types of sedimentary, igneous, and metamorphic rocks. In their general characters these Pre-Cambrian deposits differ from the typical marine sediments of later formations, and appear to resemble more nearly certain lenticular detrital deposits, such as the Nagelfluh of the Alps, to which a fluvio-lacustrine origin has usually been assigned.

In concluding this description of the Old Radnor Pre-Cambrian rocks, we may add that no traces of organisms have been met with in any of the rocks of the series.

(*b*) The Position of the Old Radnor Rocks in the Longmyndian Series.

From the above description of the grits and conglomerates of Old Radnor, it is obvious that Murchison's view, adopted also in the Geological Survey map, that this series represents the May-Hill Sandstone or *Pentamerus* Grit of the Presteign district, metamorphosed by subterranean intrusions of igneous rocks, cannot be sustained, and that Callaway's suggestion[1] that the series represents a mass of Longmyndian rock jutting up amid Silurian strata, is correct. The question still remains whether this Old Radnor series can be correlated definitely with any portion of the Longmyndian of the Bayston area. The presence of, at least, two different types of conglomerate intercalated in the red and green grits, taken together with the occurrence of micaceous greywackés and bands of fine crimson mudstone, gives a definite character to the Old Radnor series, which recalls very clearly certain portions of the normal Longmyndian succession. Prof. Charles Lapworth, as the result of his work in mapping the Longmyndian rocks of

[1] Q. J. G. S. vol. lvi (1900) p. 514.

Shropshire, has separated the Western Longmyndian, or Wentnor Series, from the Eastern Longmyndian or Stretton Series, and has further subdivided the Wentnor Series into two sub-groups, the Ratlinghope Group and the Bayston Group. The latter of these two groups is well displayed near Bayston Hill, and also on Lyth Hill. It consists of red and grey grits with the three zonal conglomerates of Stanbach, Darnford, and Haughmond, the last-mentioned being rich in pebbles of volcanic rocks.[1]

During the progress of our work in the Old Radnor district an opportunity occurred of discussing with Prof. Lapworth the probable position of the Old Radnor series in the Longmynd sequence, and also of examining the typical Shropshire exposures under his personal guidance, and we owe to him the suggestion that the Old Radnor rocks might well represent some portion of his Bayston Group. Further detailed investigation of the rocks of the district has only served to confirm his conclusion that the Old Radnor series represents the southern continuation of the Bayston Group. The southernmost outcrop of this group, in the Longmynd range, occurs near Asterton, but Dr. A. H. Cox has recently given reasons for including the grits and pebble-beds exposed between Brampton Bryan and Pedwardine, some 12 miles south of Asterton, in the Longmyndian[2]; and Prof. Lapworth has called attention to the resemblance of these beds to the Stanbach Conglomerates of the Bayston Group.

We have examined the outcrop of these beds displayed in Brampton-Bryan Park, and have been impressed by their resemblance to the grey conglomerates and grits of the Old Radnor series. The two districts lie only some 9 miles apart, and, in both, the rocks have a definite north-eastward trend; their apparent dip also, in both cases, is about 70° in a general westerly direction.

If we compare in detail the Old Radnor series with the typical Bayston Beds of Yat Hill, the close resemblance between the two is strikingly apparent. Practically every type of rock that is characteristic of the series on Lyth Hill is represented at Old Radnor. The conglomerates of Old Radnor resemble very closely the Stanbach and Darnford Conglomerates of Lyth Hill, the former showing abundant fragments of grey and pink quartz, the latter having a preponderating red tint and innumerable fragments of pink quartzites and red rhyolites. Even the double character of the Darnford rock is duplicated in the outcrop of pink conglomerate west of Old Radnor Church, while the various shades of pink, green, and buff-coloured grits and greywackés may be closely matched in the two series; even the bright crimson bands so conspicuous on the path leading from Lyth Hill to Windmill Hill are represented at Old Radnor by similar streaks of fine mudstone

[1] C. Lapworth & W. W. Watts, 'Shropshire' in 'Geology in the Field' 1910 (Jubilee vol. Geol. Assoc.) chapt. xxx, p. 748.

[2] 'On the Inlier of Longmyndian & Cambrian Rocks at Pedwardine (Herefordshire)' Q. J. G. S. vol. lxviii (1912) p. 364.

which crop out in front of the Harp-Inn Quarry. Again, the micaceous greywacké which appears near Dolyhir Station may be matched by the rocks of Sharpstone Quarry, east of Bayston, with their included pellets of purple mudstone. Lastly, the matrix filling the cracks and joints of the middle portion of the Bayston Group on Lyth Hill is characterized by the presence of black ferruginous and bituminous material, and the same phenomenon is conspicuous in the grits at Harp-Inn and Gore Quarries.

In summing up the results of the comparative study of the rocks in thin sections in the two areas, Dr. Thomas remarks:—

A microscopical study of the rocks of the two regions reveals the fact that the respective rock-types are comparable even in their minutest detail, and their similarity may be reasonably accepted as an indication of practically identical origin, mode of deposition, and geological age.

The greywackés and grits north of Dolyhir Station and in Gore Quarry not only have their green and red tints and general texture repeated in the rocks of the Longmyndian of Lyth Hill and Bayston; but the deposits correspond in their mineral composition, and in the character of the rock-types represented by the larger included fragments. The highly-micaceous green and red grits with their curiously-flattened mud-pellets find an exact parallel in the Bayston Series of Sharpstone Hill. In these rocks the mica is of the same general type throughout, being detrital in character, and consisting of a minute intergrowth of chlorite, after biotite, with muscovite.

The ordinary speckled grits and greywackés, with their characteristic angular grains, abundant albitic and perthitic fragments, and plentiful detrital garnets, may be matched in the same two areas; they also present a close similarity to the speckled grits of the Broken Stones of the Horderley district.

They have undergone the same type of alteration: namely, veining with epidote and chlorite; while a general epidotic character is a common feature of the more compact varieties in both areas. Further, the occurrence of bituminous epidotic veins that mark incipient brecciation in some of these rocks, as at Lyth Hill and Old Radnor, again emphasizes the likeness that exists between the rocks of the two regions.

In the case of the coarser grits, in the composition of which rock-fragments play an important part, the analogy becomes still more striking: for now soda-rhyolites with good fluxion- and perlitic structures, microlithic keratophyres, fine-grained quartzites, and albitized basalts may be recognized. Many of these rock-fragments from the grits of Old Radnor have such definite characters that it would be easy to recognize them should they occur in rocks of any other district; it is thus interesting to find an exactly similar assemblage, with the characteristic types well represented, in the grits of the Bayston Series of the Longmynd and Lyth Hill. From Prof. Cox's description of the Brampton-Bryan deposits it would appear that those rocks have been derived from sources similar to (or identical with) those that furnished the material to the other areas.

As has already been stated, the coarse grits of the district under description are practically identical in composition with the matrix of the conglomerates. It will follow, therefore, that if the grits are identical with those of the Longmynd and of other adjacent areas of Longmyndian rocks, we shall find the same close (or an even closer) similarity in the pebbles forming the associated conglomerates in the respective districts. This has proved to be the case. The pink conglomerate that crops out south of Castle Nimble, with its characteristic pink quartzite, soda-granites, soda-aplites, red-banded rhyolites, and keratophyric rocks, may be matched with the middle (Durnford) conglomerate of Lyth Hill, which contains practically the same assemblage of rock-types. Basaltic rocks of like texture and similarly albitized are met with in both cases; but on Lyth Hill basalt-pebbles appear to be more plentiful and of slightly greater dimensions. Again, the pink conglomerate of Castle Nimble may be compared with the conglomerate exposed near the summit of the Longmynd, beside the Ratlinghope road. In the latter exposure the pebbles are, for the most part, of types similar to those described above: even the pink quartzite with the characteristic rhombs of chalybite is represented; but the pebbles of green devitrified rhyolite, sparingly met with at Castle Nimble, occur more plentifully in the Ratlinghope exposure, as also fragments of a superficially ironstained quartz-schist.

It is interesting to note that in the conglomerate passed through in the boring for coal at Folly Farm, near Presteign, the same assemblage of rock-types was encountered, including the pink quartzite with chalybite-rhombs.[1] It is thus more than probable that this conglomerate may be correlated with the pink conglomerate of the district to the south-west.

The grey conglomerate, so well shown on Old Radnor Hill, has many points in common with the uppermost conglomerate of Lyth Hill.

It appears, therefore, from the foregoing statements, that these arenaceous sedimentary rocks, both as a whole and individually, may be assigned with certainty to the Longmyndian, and correlated more particularly with the Bayston Group of that region.

It is interesting, in passing, to reflect upon the fact that these rocks indicate the widespread denudation of an area of still more ancient sedimentary rocks, rocks that had in many instances suffered considerable alteration before their disintegration began. Further, that these sediments were associated with a remarkable series of contemporaneous lavas of both an acid and a basic composition, more especially the former. In all probability, they were invaded by plutonic and hypabyssal rocks characterized by the dominance of soda-felspar. These igneous rocks were brought within the influence of denuding agencies, and thus it is clear that unconformable relationship of great magnitude must be inferred to exist between the newer and the older sedimentary deposits.

(c) The Woolhope Limestone.

The basement conglomerate.—The junction between the Pre-Cambrian rocks and the limestone is, in general, a faulted one; several exposures, however, do occur which show the original relations of the two formations. Callaway mentions one locality where this may be seen: namely, in an old quarry on the north-eastern margin of the main limestone outcrop, about 300 yards south-west of Yat Farm (Quarry K, in the map, Pl. VII). This section shows several feet of conglomerate at the base of the limestone, dipping gently north-westwards. The beds here rest upon a fine-grained green greywacké, which can be seen cropping out in the wood on the other side of the fence, a few yards farther east.

Fragments of this basement-bed have also been met with in the elliptical block of limestone which has been faulted down to the north of the Harp Inn, showing that the limestone here also originally rested unconformably on Pre-Cambrian rocks on the western flank of Old Radnor Hill; the former line of junction, however, is now complicated by faulting. Similar evidence of the original presence of a basement conglomerate is seen at the southern end of

[1] Geol. Mag. dec. 6, vol. iv (1917) p. 489.

Yat Hill in the floor of the old quarry immediately north of Dolyhir Station, where the limestone has been worked down to the surface of the Pre-Cambrian rocks (Quarry G). These basement-beds should therefore crop out continuously between these two points through the middle of Yat Wood, as indicated on the map, but no exposures can now be seen. On the south side of the railway the junction may again be observed, beside the path leading from the level-crossing to Strinds Cottage (Quarry B). Here, again, although the beds can still be traced, they have been almost entirely quarried away. The best exposure showing this unconformity, however, occurs at the present time in the new Dolyhir Quarry (Quarry D). This quarry is divided into two portions by a vertical north-and-south fault, which throws the limestone down about 50 feet to the west. On the upthrow, or eastern side of the fault, the Pre-Cambrian rocks are exposed in a small cliff close to the tram-line. This exposure shows an admirable section of the basement-beds of the limestone resting unconformably on the Pre-Cambrian rocks, which here consist chiefly of fine grit, but include also one of the bands of coarse grey conglomerate described above. The limestone rests partly on the grit and partly on the conglomerate, the latter being well seen at the southern end of the exposure.

The basement conglomerate here reaches a thickness of 5 feet, and consists of angular and subangular fragments of Pre-Cambrian grit, ranging in size from small grains to pieces 4 inches in diameter. It contains, in addition, a few rounded pebbles of quartz derived from the underlying conglomerate (Pl. I). The angular fragments of grit appear to have been derived by subaërial weathering directly from the Pre-Cambrian rocks, since many of them show little or no sign of attrition by wave-action. This fact would appear to point to the conclusion that the Pre-Cambrian rocks had already been shattered and brecciated in Pre-Silurian times.

The section is complicated in places by the presence of an irregular line of thrusting, which occurs near the junction of the two formations. Along this line the surface of the Pre-Cambrian rocks has been torn and broken, giving rise to a crush-conglomerate composed of quartz-pebbles embedded in a fine green rock-paste. The beds along this line are impregnated with copper salts, which include numerous small crystals of copper pyrites and specks of chessylite and malachite. The basement-beds of the limestone contain numerous tabular colonies of *Favosites* measuring several inches across, which lie in the position of growth among the fragments of Pre-Cambrian grit, and mark the bedding-planes. The whole deposit is cemented by a coarse matrix, composed of crinoid ossicles embedded in secondary calcite. The conglomerate also shows evidence of crushing, the planes of movement being again impregnated with copper salts. This basement conglomerate dips at about 12° eastwards, and is immediately overlain by white crystalline limestone containing abundant remains of *Solenopora*.

The limestone.—The main mass of the limestone is well exposed in the extensive workings on both sides of the railway, close to Dolyhir Station. Its original thickness cannot now be determined, as the beds are nowhere seen in their natural relation to the succeeding formations; while the surface, at present exposed to view, has evidently undergone extensive denudation.[1] The actual thickness of the beds still remaining in the district is also difficult to ascertain, because of the crushing and dislocation to which they have been subjected, and this difficulty is further increased by the general absence of stratification in the mass of the limestone above the basement-beds. The unstratified character of the limestone is probably due primarily to the mode of origin of the deposit; but any stratification which originally existed would now be largely obliterated by the general crushing and recrystallization which the rock has undergone. In the large quarry on Yat Hill and in the old quarry east of it, the beds, apart from the actual lines of thrusting, appear to lie generally in a more or less horizontal position. This horizontal disposition of the beds can be seen in the lowest beds of the limestone in the old quarry occupied by the railway siding, and again on the south side of the line in the downthrow portion of Dolyhir Quarry, already mentioned. In Strinds Quarry, however, the bedding has been almost entirely obliterated by the numerous planes of crushing which here traverse the limestone. Elsewhere, the beds dip usually at moderate angles in the neighbourhood of the dominant north-and-south faults. In the old quarries at the northern end of Yat Wood, the stratification is less obscured, and the beds show a fairly uniform dip of 15° north-westwards. Combining these different observations, we shall not be far wrong if we assign to the deposit a thickness of about 80 feet, and estimate the original minimum thickness at 100 feet. This agrees closely with the section of the limestone exposed at Nash Scar (where, however, the upper beds have been mostly quarried away); it is greatly in excess of the normal thickness of the Woolhope Limestone near Presteign and elsewhere, and in itself indicates that the Dolyhir and Nash-Scar Limestones were accumulated under somewhat special conditions. The alteration of the deposit by igneous intrusions, as postulated by Murchison, however intense, could not account for this remarkable increase in thickness.

The typical rock is a bluish-grey crystalline limestone, locally iron-stained, but weathering to a pale grey or even white. It is remarkably pure and, apart from one thin bed of shale, is free from argillaceous matter.

According to local records, the limestone has been worked for some 300 years: on account of its purity, the rock is found to be admirably suited for a flux in iron-smelting, and also as a gas-purifier and for general agricultural purposes.

[1] The small patch of Wenlock Shale (Pl. V, fig. 1) seen on the south side of Dolyhir Quarry, let down by the fault already mentioned, may perhaps lie conformably on the limestone, but its position close up against the fault makes its relationship to the limestone difficult to ascertain.

We tabulate here two chemical analyses of the rock:—

	New Dolyhir Quarry.	Yat Hill Quarry.
	Per cent.	Per cent.
Calcium carbonate	99·46	99·11
Magnesium carbonate	trace	trace
Ferrous oxide and alumina	do.	do.
Silica	0·20	0·10
Phosphoric acid	trace	trace
Sulphuric acid	do.	do.
Totals	99·66	99·21

Fauna and flora.—The fauna consists chiefly of bryozoa, corals, and brachiopods, crinoid-remains being inconspicuous (except in the basement conglomerate). Good specimens can only be extracted from certain portions of the deposit, as the rock has been subjected to a considerable amount of solution and recrystallization. The most interesting feature of the deposit, however, is the presence of abundant remains of calcareous algæ, especially *Solenopora*, which, in places, constitutes fully half of the rock. This organism occurs in the form of irregular nodular growths, varying in size from that of a pea up to masses 17 centimetres in diameter. In the freshly quarried portions of the rock these nodules are of a deep purple colour, and might easily be overlooked; but, after exposure, they gradually lose their colour, and appear on weathered surfaces as conspicuous white spots, scattered through the deposit. The typical porcellanous structure so characteristic of this organism is well seen on freshly fractured surfaces, and differentiates it from the surrounding coarsely crystalline rock.

Callaway appears to have noticed portions of *Solenopora* in his thin sections, but evidently considered the structure to be inorganic, for he remarks:

'Some of it displays a compound polygonal structure, suggesting a *Favosites*. I think, however, that this is only mimicry, and that it is really concretionary, consisting of aggregations of tubular bodies. That it is not organic appears from its relation to the fossils.'[1]

Good specimens may be seen in the local buildings, as, for example, at the railway station and at Yat Farm; and a very fine slab of this algal limestone has been erected in Old Radnor Churchyard, in memory of the late Sir Edmund Herbert Frankland Lewis.[2] A fine example of the rock is preserved in the geological museum at University College, Gower Street.

[1] Q. J. G. S. vol. lvi (1900) p. 517.

[2] A descendant of Sir T. Frankland Lewis, who, as stated by Murchison, with his son Mr. George Lewis, 'first urged me to put together all my geological documents respecting this region,' and thus form the work afterwards called 'The Silurian System.' See 'Siluria' 1st ed. (1854) p. 104.

FOSSILS OF THE WOOLHOPE LIMESTONE, OLD RADNOR DISTRICT.

Sphærocodium gotlandicum Rothpletz.
Solenopora gracilis, sp. nov.

Saccammina sp.

Cystiphyllum cylindricum Lonsdale.
Lindstrœmia (Cyathaxonia) cf. *siluriensis* M'Coy.
Streptelasma europæum Rœmer.
Streptelasma (Cyathophyllum) pseudoceratites M'Coy.
Streptelasma (Palæophyllum) aggregatum Nicholson.
Streptelasma (Palæophyllum) cf. *rugosum* Billings.
Arachnophyllum diffluens Edwards & Haime.
Favosites aspera A. d'Orbigny.
Favosites fibrosa M'Coy.
Favosites gotlandica Fougt.
Favosites hisingeri Edwards & Haime.
Halysites escharoides Lamarck.
Plasmopora tubulata Lonsdale.
Thecia swindernana Goldfuss.

Clathrodictyon striatellum D'Orbigny.

Crinoid-stems.

Athyris (?) depressa Sowerby.
Atrypa imbricata Sowerby, var.
Atrypa reticularis Linnæus.
Atrypa, sp. nov. (cf. *marginalis* Dalman).
Atrypina barrandi Davidson.
Cyrtia exporrecta Wahl.
Leptæna rhomboidalis Wilckens.
Leptæna sp.
Meristina tumida Dalman.
Orbiculoidea forbesi Davidson.
Orthis (Dalmanella) elegantula Dalman.
Orthis (Rhipidomella) rustica Sowerby.
Orthis (Rhipidomella) sp.
Pentamerus (Barrandella) linguifer Sowerby.
Pentamerus (Conchidium) knightii Sowerby.
Plectambomites transversalis Dalman.
Rhynchonella (Anastrophia) deflexa Sowerby.
Rhynchonella (Camarophoria) borealis Schlotheim.
Rhynchonella (Wilsonia) wilsoni Sowerby.
Rhynchonella (Rhynchotreta) cuneata Dalman.
Spirifer crispus Hisinger.
Strophomena antiquata Sowerby.
Strophomena applanata Salter.
Strophomena (Schuchertella) pecten Linnæus.
Strophomena (Stropheodonta) semiglobosa Davidson.

Batostoma.
Cœnites repens Wahl.
Fenestella sp.
Graptodictya sp.
Hemiphragma sp.
Mesotrypa sp.
Pachydictya sp.
Phylloporina sp.

Ambonychia sp.
Mytilus mytilimeris.

Holopella sp.
Horiostoma funatum Sowerby.
Horiostoma rugosum Sowerby.
Horiostoma sp.
Pleurotomaria limata Lindstrœm.
Pleurotomaria cf. *biformis* Lindstrœm.
Pleurotomaria sp.
Platyceras haliotis Sowerby.
Platyceras disciforme Lindstrœm.
Trochus sp.

Orthoceras annulatum Sowerby.
Orthoceras angulatum Hisinger.
Orthoceras excentricum Sowerby.
Orthoceras sp.

Acidaspis coronata Salter.
Bronteus signatus Phillips.
Illænus barriensis Murchison.
Proetus sp.

The fauna, as a whole, is fairly uniformly distributed in the limestone, but one or two horizons occur which are marked by special forms. In the basal conglomerate occurs a small species of *Favosites* (*F. hisingeri*), which appears to be especially abundant at this horizon. A short distance from the base we meet with a striking reef-like development of bryozoa, the mass of the reef being composed of branches of *Cœnites repens*, a form especially characteristic of the Upper Silurian of Gotland and also of Russia and North America.[1] This form includes the two species *C. juniperinus* and *C. intertextus* mentioned in Murchison's 'Siluria.' The branches are frequently encrusted with growths of calcareous algæ, notably *Sphærocodium gotlandicum* Rothpletz (Pl. VI, fig. 3). This organism appears in thin sections under the microscope, in the form of chain-like growths having two distinct forms of cell. The smaller of these have an average diameter of 29 μ, while in the larger form of cell the diameter may exceed 300 μ. Many of the sections show the digitated expansions characteristic of the genus (Pl. VI, fig. 4). This lower bryozoa-bed is well exposed beside the path running along the south-eastern margin of the inlier, immediately south of the stile and close to Weythel Brook, and again in the floor of Dolyhir Quarry, and also in the old quarry opposite containing the railway-siding. Associated with this lower bryozoan reef occurs a band characterized by the abundance of the large brachiopod *Stropheodonta semiglobosa*.

Near the summit of the limestone we find another conspicuous development of bryozoa. In this case it is associated with abundant remains of *Favosites* and *Halysites*, and is succeeded by a compact band, a few inches thick, containing numerous specimens of *Orthoceras*, belonging to three species, of which the large form *O. angulatum*, with its characteristic reticulate surface, is the most conspicuous; with it occurs *O. excentricum*, which was originally figured by Murchison from the Old Radnor limestone. A good exposure of this *Orthoceras* bed was until recently visible at the summit of the western end of Strinds Quarry, but this has now been almost entirely quarried away.

(*d*) The Included Shale-Band.

Though the mass of the Woolhope deposit is essentially calcareous, traces of a thin shale-band are found in several of the sections. Everywhere, where it is present, the shale has formed a line of weakness along which movement has taken place, so that it cannot be traced continuously for more than a short distance; wisps of it may, however, sometimes be seen, caught up and teased out along the thrust-planes. As a result of this the shale does not, at first sight, appear to occur at any definite horizon in the limestone, and might easily be mistaken for a fine layer of crushed rock, developed along lines of movement. A careful study, however, of the shale shows that it is definitely confined in all the exposures to the horizon of the lowest bryozoa-bed and the associated *Stropheodonta* band, near the base of the succession. It is well

[1] A. Hennig, 'Gotlands Silur-Bryozoer: II' Arkiv för Zoologi, K. Svensk. Vetensk. Akad. vol. iii, No. 10 (1906) p. 27.

seen near the floor of the old quarry at the end of the railway-siding, below the large Yat-Hill Quarry (Quarry E), and again beside the footpath which runs round the south-east side of the inlier, close to the stile, about 100 yards north of the outcrop of Wenlock Shale in Weythel Brook. It also occurs in Dolyhir Quarry, where it has been removed during quarrying operations, though fragments may still be found on the floor of the quarry. Traces of the same shale also occur in the old quarries near Yat Farm. The bulk of the shale is much crushed and is very friable: it contains a fair abundance of greenish cementstone concretions, which have been formed round local accumulations of crinoid-stems and young brachiopods. This shale contains, on the whole, a fauna distinct from that of the limestone, and is remarkable for the number of trilobites, gastropods, and small cup-corals which it contains, and especially for the abundant remains of *Illænus (Bumastus) barriensis*.

The following is a list of the fossils which have been collected from this deposit:—

Streptelasma sp., single form, abundant.
Favosites forbesi Edwards & Haime.
Athyris ? depressa Sowerby.
Atrypa reticularis Linnæus.
Leptæna rhomboidalis Wilckens.
Platyceras prototypum Phillips, abundant.
Bronteus signatus Phillips.
Calymene blumenbachii Brongniart.
Cheirurus bimucronatus Murchison.
Dalmanites caudatus Bronn.
Deiphon forbesi Barrande.
Illænus barriensis Murchison, abundant.
Lichas (Corydocephalus) hirsutus (?) Fletcher.
Lichas (Dicranopeltis) salteri Fletcher.

The trilobites in the foregoing list, with the exception of *Calymene*, appear to be confined to this shale-band, and the same may be said of the small cup-corals. The collections of gastropods and brachiopods, as well as of trilobites, are notable for the number of young forms which they include. The fauna, taking it altogether, is distinctly Middle Silurian in character, and confirms the view arrived at from a study of the limestone as to the Wenlock age of the deposit generally.

This shale appears to mark a period early in the subsidence of the area, when the growth of the bryozoan reef gave rise to shallow lagoons: in these fine silt was quietly deposited, and they served as a nursery for numerous young forms.

(*e*) The Wenlock Shale.

According to the Geological Survey map the inlier is entirely surrounded by Wenlock Shale, but its contact with the rocks of the inlier is only seen at the present day in the section in Weythel Brook already mentioned. Two small patches of this shale, however, occur in the inlier itself: one in Dolyhir new quarry, and the other in the old limestone-workings north-east of the Harp Inn. In the former case the shale has been let down and preserved on the west side of the north-and-south fault which traverses this quarry. Its relation to the Woolhope Limestone is complicated by the presence of the fault and by a covering of Boulder Clay which overlaps from the shale on to the surface of the limestone on the west (Pl. V, fig. 1). The shale here appears to be the same as at Sandbanks, near Presteign: it contains similar concretions enclosing characteristic trilobites (*Calymene blumenbachii*, *Dalmanites caudatus*), and it may here be lying conformably on the limestone.

The second patch, near the Harp Inn, has been much obscured by quarry-tips now almost entirely grassed over; but the traces of fossils found are sufficient to identify it as Wenlock Shale. These occurrences suggest that the inlier was once completely covered by deposits of Wenlock Shale.

III. The Nash-Scar Limestone.

The reef-facies of the Woolhope Limestone of the Old Radnor district, described above, reappears at the surface about 3 miles away to the north-east near Woodside, where it may be studied in several old quarries. Still farther north-eastwards it forms the picturesque feature of Nash Scar, where it has been extensively quarried along the face of the escarpment for a distance of 600 yards, and where (according to J. E. Davis [1]) it appears to have originally reached a thickness of at least 100 feet. At the northern end of the Scar it is cut off by a fault which brings in a small patch of Wenlock Shale against the face of the limestone. Immediately north of this, no sections are seen until we reach an exposure of the *Pentamerus* Grits dipping steeply off the hill on the west side of the road to Presteign. The general sequence of the rocks in this district is fully discussed in J. E. Davis's paper cited above. At the time when his paper was written, however, it must be remembered that the *Pentamerus* Grit was still considered to be the equivalent of the Caradoc Sandstone. The limestone of Nash Scar is, in every respect, similar to that seen at Dolyhir and Old Radnor; it contains the same abundant nodules of *Solenopora*, the same reef-like development of bryozoa, frequently encrusted with *Sphærocodium*, also the same general fauna of corals and brachiopods (including a few rare examples of *Cyrtina exporrecta* and *Conchidium knightii*), and there can be no doubt that it was deposited contemporaneously with the beds of Old Radnor. The only difference exhibited between the limestones in the two districts is found in connexion with their stratigraphical relationships to older formations. At Nash Scar the limestone dips, to all appearance, conformably off the Upper Llandovery Grit; while in the Old Radnor district the latter beds are entirely absent, and the limestone was accumulated directly upon the Longmyndian rocks. No actual junction, however, is seen at Nash Scar; and the grits at

[1] 'On the Age & Position of the Limestone of Nash, near Presteign' Q. J. G. S. vol. vi (1850) p. 434.

their nearest point of outcrop to the limestone, in Caen Wood, are unfossiliferous. There is, however, one small exposure in the gully immediately north of Haxwell at the southern end of the Scar, where a small anticline of limestone is seen overlying grit. This grit is quite devoid of fossils, but does not differ essentially from the unfossiliferous portion of the *Pentamerus* Grits occurring farther north. According to Murchison, this section was formerly much better exposed, and included a layer of normal Woolhope Limestone and Shale between the grit and the Nash-Scar Limestone.[1] At the present day, the section is much overgrown, and no trace of these beds can be seen. Davis, on the other hand, remarks:

'It [the Nash-Scar Limestone] undoubtedly, however, rests immediately on the sand and grit beds. The connexion may be traced to within a few feet, leaving at the utmost merely room for the intervention of a thin bed of shale.' (Q. J. G. S. vol. vi, 1850, p. 434.)

The Wenlock Shale is only seen in contact with the limestone at the northern end of the Scar, close to the farm, and their junction here, as already mentioned, is a faulted one. The eastern boundary of the limestone appears also to mark a line of dislocation, which forms a conspicuous feature along the east side of the road, between Haxwell and Corton. It is evidently a continuation of the Stretton line of disturbance, and links this with the faults bounding the eastern margin of the Old Radnor Inlier.

One important point in connexion with the Nash-Scar district remains to be considered: namely, the fact that an outcrop of the normal type of Woolhope Limestone and Shale occurs at the 'Sandbanks' near Corton, a mile south of Presteign, and about the same distance from the typical reef-development at Nash Scar. The old workings here are almost entirely overgrown; but, according to J. E. Davis (*loc. jam cit.*), the section in 1850 showed a thin band of highly-crystalline limestone about 8 feet thick dipping 50° north-north-eastwards, and separated from the sand- or grit-beds by a few feet of shale which also overlay it to a greater depth. At the present day the overlying nodular shale can still be seen, and the narrow trench from which the limestone has been extracted, and in one place a small outcrop of dark bituminous limestone, can yet be traced. A few years ago a boring for coal was put down in the Wenlock Shale at this spot. We have not had the opportunity of examining the complete core; but, if we may judge from fragments of the core found on the spot, the boring penetrated a coarse conglomerate which closely resembles the Longmyndian conglomerates of the Bayston Group and the grey conglomerate of Old Radnor: this suggests the presence here of Pre-Cambrian rocks forming a southward continuation of the Longmyndian ridge that underlies the Llandovery grits of Caen Wood. This sudden and remarkable change from the thick reef-facies of the limestone at Nash Scar to the thin band of normal Woolhope Limestone and Shale at the 'Sandbanks' in a distance (at the

[1] 'Siluria' 1st ed. (1854) p. 103.

present day) of less than a mile, appears to be only explicable on the supposition that the beds at the 'Sandbanks' were deposited in direct connexion with the open Woolhope sea; while the reef-like development at Nash Scar and Old Radnor was accumulated round the islands of a slowly-subsiding archipelago, in lagoons sheltered from the open sea and free from the detrital deposits of rivers.

This reef-facies of the Woolhope Limestone at Old Radnor and Nash Scar, with its well-developed bryozoan growths and abundant calcareous algæ, is most nearly paralleled by the algal and reef developments of Wenlock and Lower Ludlow age in Southern Gotland, as described by Dr. H. Munthe.[1]

Here two horizons occur, characterized by a profuse algal development, notably *Solenopora gotlandica* Rothpletz and *Sphærocodium gotlandicum* Rothpletz: the Lower or *Sphærocodium* Marl, and the Upper or *Sphærocodium* Limestone. The former, which stretches across the southern part of the island from Burgsviken to Bandelundaviken, and occurs also in Tofta, is correlated by Dr. Munthe with the Wenlock Limestone; while the sandstone, oolite, and Upper *Sphærocodium* Limestone which overlie it, are considered to represent the Lower Ludlow. Of these beds, as a whole, Dr. Munthe remarks that they

'are a closely-related series, both palæontologically and also, in part, lithologically. They are all shallow-water deposits, and were, in part, formed upon a shore.' (*Op. jam cit.* p. 1415.)

In several places reef-limestones replace the *Sphærocodium* Limestone, often abruptly, and in the formation of these *Stromatopora* and bryozoa play an important part. On the whole, then, although a somewhat younger series, the Gotland beds were formed under conditions very similar to those under which the algal limestone of Old Radnor and Nash Scar were deposited, and the species of *Solenopora* and *Sphærocodium*, so abundant in the limestone of the Welsh Border, may be looked upon as the direct ancestors of those which contributed so largely to the algal reefs of the Middle Silurian of Southern Gotland.

IV. Movements in the District.

Post-Longmyndian and Pre-Silurian.—That the Pre-Cambrian rocks had undergone considerable crushing before Silurian times is evident from a study of the beds in the field. The present distribution of the conglomerates, their want of continuity, and the restricted character of the exposures, are not easily explicable as the result of the post-Silurian movements alone. The grits and greywackés are again everywhere cracked and brecciated, even at some distance from the post-Silurian faults and thrusts, and, as previously stated, appear to have been already in this condition when

[1] 'On the Sequence of Strata within Southern Gotland' Geol. Fören. Stockholms Förhandl. vol. xxxii (1910) p. 1397.

they were being disintegrated and incorporated in the basement-beds of the Woolhope Limestone. The marked unconformity with which that limestone rests upon the older rocks, sometimes on grit and sometimes on conglomerate, also testifies to considerable disturbance and denudation of the Pre-Cambrian rocks in Pre-Silurian times. With regard to the age and direction of these older movements, we have no definite evidence, as they have been obscured by later disturbances.

Post-Silurian movements.—The main lines of disturbance at the present time run in a general north-easterly direction, and there can be little doubt that these lines represent the south-westward continuation of the dislocations which have produced the characteristic scenery of the country between Church Stretton and Lilleshall, brought up the old rocks at Pedwardine, and formed the striking escarpment of Nash Scar. These have almost certainly all been produced by the same set of movements, and they all have a definite Caledonian trend. As in the Longmynd area, the movements seem to have taken place at more than one period. The latest formation affected in the Radnor district is the Old Red Sandstone, so that the disturbances in this case have most probably taken place in post-Devonian or post-Carboniferous times. These latter dislocations appear to be in the nature of rejuvenated faults which acted along lines of weakness established at an earlier period, as they are confined to the neighbourhood of the Pre-Cambrian ridge, and do not extend into the Old Red Sandstone country on the east and south.

The Old Radnor Inlier is bounded along its eastern margin by one of these main lines of dislocation which brings the Wenlock Shale, in places, against the Woolhope Limestone, and, in places, against the Pre-Cambrian rocks. This faulted junction is clearly exposed in Weythel Brook about 150 yards below the ford, and some 300 yards south-west of the railway. Here the Wenlock Shale can be seen, crushed against a smooth slickensided face of the limestone which stands up as a vertical wall, forming the left bank of the stream. North of the railway this fault divides into two branches. The more easterly branch apparently forms the boundary of the inlier round the east side of Old Radnor Hill (Pl. II) passing close to Gore Quarry. Although this fault is nowhere seen, the fact that Wenlock Shale lies against the limestone along the southern portion of this line and against the Pre-Cambrian farther north, precludes the possibility of a natural junction. This fault is presumably the southern extension of the fault which runs along the eastern flank of Nash Scar farther north-east. The more westerly branch of the fault, starting near the Mission Room, runs parallel to the road, a little to the west of it, as far as Yat Farm, where it crosses the road and forms a distinct feature along the western slope of Old Radnor Hill as far as the Old Castle mound. To the north of this, it lets down a lenticular strip of limestone among the Pre-Cambrian rocks, marked by the old workings behind the Harp Inn and Stockwell Farm. The

Fig. 1. Section through Quarries south of the railway.

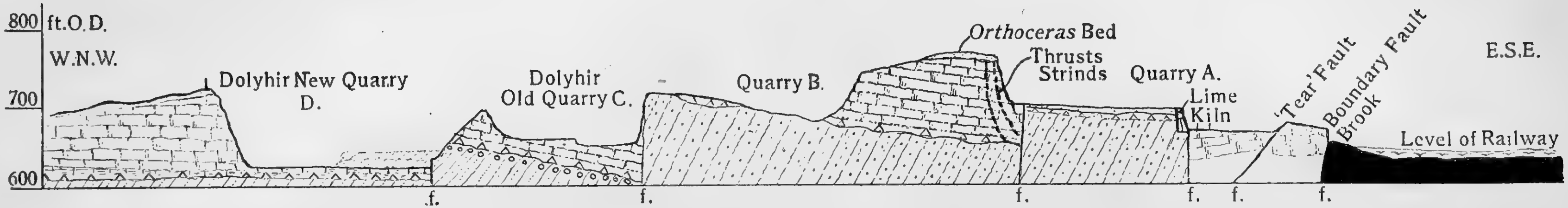
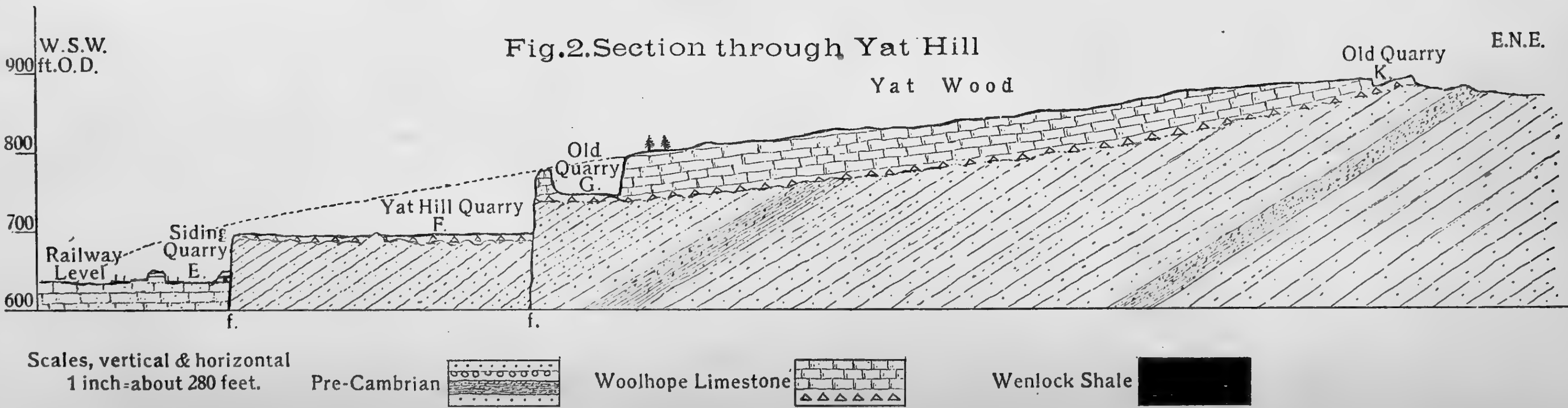


Fig. 2. Section through Yat Hill



eastern boundary of this limestone outlier may still be seen where it is faulted against the Pre-Cambrian conglomerates, at the eastern margin of the old workings, about 200 yards from the Harp Inn; and fragments of the basement Woolhope Conglomerate have been found here turned up against the fault.

With regard to the southern and western boundaries of the inlier, there is no direct evidence in proof of their faulted character. There is, however, ample evidence of faulting among the rocks of the inlier near its western and north-western margins, as shown in the accompanying map (Pl. VII). Two main faults have here been traced running in a general east-north-easterly direction. The southernmost of these faults, which skirts the western edge of Yat Wood, trends gradually more and more towards the south as it approaches the western margin of the inlier, as though influenced by a line of movement along that margin; while a north-and-south fault runs southwards from the boundary at the corner of Stone's Coppice.

In addition to the two main north-north-east and south-south-west faults described above, several others, having a generally similar trend, traverse the southern portion of the district. These are well seen on the south side of the railway, where they have been exposed by quarrying operations. In all cases the downthrow is to the west, so that the Pre-Cambrian rocks, underlying the limestone, are brought up on the east, and the higher beds of the limestone are absent on this side, owing to denudation (see figs. 1 & 2, p. 24). These fault-planes, therefore, mark the limit to which the limestone can be profitably worked, and consequently they form the eastern boundary of several of the quarries. This is the case in the new Dolyhir Quarry (D), in the smaller old quarry (C) to the east of it (Pl. III), and in Yat-Hill Quarry (F) on the north side of the railway, and also, though to a less extent, in Strinds Quarry (A). In all these cases the downthrow is to the west.

In addition to these normal faults, a number of other lines of movement traverse the district. These are in general too numerous and too complicated for description; but, out of the tangle of shear-planes and thrusts, two main directions of movement may be discerned. One of these has a general north-and-south trend, and may be connected with the faults just described. Along this line occur a series of sub-parallel curved thrust-planes hading steeply westwards and having their concave faces directed eastwards. A group of these are well seen along the northern and western margins of Strinds Quarry. Their general effect has been to pile up slices of the Pre-Cambrian rocks among the limestone, and also to bring fragments of the lower layers of the limestone among the upper beds so as to form a confused mass of crush-breccia. The phenomenon is rendered more conspicuous by the presence here of a quartz-conglomerate in the Pre-Cambrian rocks, pebbles from this conglomerate having been teased out along the thrust-planes.

The second set of planes of movement runs nearly at right angles to these thrusts, and appears to be of the nature of 'tear'-faults, along which blocks of rock have separated and moved forward along the thrust-planes independently. The view that these represent 'tear'-faults is strengthened by the character of the slickensiding seen on the faces of the faults, the striæ running almost horizontally, and also by the fact that the thrust-planes do not cross these faces, but appear to end against them. A good example of one of these 'tear'-faults may be seen in the south-western corner of Strinds Quarry[1] (Pl. V, fig. 2).

One other direction of movement occurs in the south of the district, namely, along the floor of the valley through which the railway runs past Dolyhir Station. This direction is roughly west-north-west and east-south-east, or exactly at right angles to the major axis of the inlier. Only one other fault, parallel to this direction, has been observed in the district: namely, that which lets down the limestone south of Hillhouse Farm, and it is possible that this latter fault was once continuous with the railway valley-fault, and has been shifted north-eastwards by the dislocation which follows the Old Radnor road, already described.

This fault along the Dolyhir Valley is not actually seen, as the valley-floor is covered by tip-heaps and quarry-débris. There are, however, several facts which indicate its existence. In the first place, the line of the valley coincides with the direction of an anticlinal axis in the limestone, as shown by the dip of the basement conglomerate on each side of the valley. In the second place, the base of the limestone on the north side of the railway, exposed in the old quarry at the southern end of Yat Wood (Quarry G), is at a distinctly higher level than the outcrop on the south side, when it reappears in the old working in Quarry B. In the third place, the Archæan rocks which crop out on the north side, do not agree with those exposed on the south of the railway: thus the pebble-conglomerate, which forms so conspicuous a feature round the northern edge of Strinds Quarry, is totally unrepresented north of the railway, where we find instead massive green greywackés. But the most conclusive evidence for this fault lies in the relative positions of the base of the limestone in Yat-Hill Quarry and in the old quarry below, now occupied by the railway-siding, there being a difference in height between them of some 50 feet. This is evident from the occurrence of portions of the Pre-Cambrian grits exposed in the floor of Yat Quarry, showing that the limestone has here been worked down to the base; while, in the railway-siding quarry below, the workings have only reached to the level of the lower bryozoan reef some 20 feet above the base—this would indicate the presence of a south-east and north-west fault running past the entrance to Yat-Hill Quarry, somewhere in the neighbourhood of the limekiln, with a downthrow of some 60 feet to the south.

It is doubtless the line of weakness produced by this fault that

[1] These faults are similar to those described by Suess as 'Blätter.'

originally gave rise to the valley now followed by the railway, although the present gorge may well owe its existence to an overflow stream from one of the numerous post-Glacial lakes, relics of which form conspicuous features in the district.

V. Description of *Solenopora gracilis*, sp. nov. (Pl. VI, figs. 1 & 2.)

This species differs from all other known examples of the genus *Solenopora*, on account of the massive character of the thallus (some specimens measuring more than 17 cm. in diameter) and the minute size of its cells. It occurs in the usual nodular form characteristic of the other species of the genus; but, in many cases, the outer surface has been destroyed by the solution and crushing which the limestone in the Old Radnor district has undergone. The internal structure is too minute for any trace of the cells to be observed in hand-specimens, even with a good lens; occasionally, however, indications of the concentric lines of growth may be traced. Freshly-fractured surfaces display the porcellaneous texture characteristic of this genus.

Specimens extracted from the heart of the limestone are of a deep indigo or purple colour; some, however, are blotched with patches of a paler tint where they have been partly bleached by percolating water, and they then exhibit irregular concentric banding. When exposed to weathering, the whole of the thallus becomes bleached, and these organisms then appear as conspicuous white spots on the surface of the limestone.

Under the microscope, longitudinal sections show a series of closely-set sub-parallel tubes, or cell-threads, having an average diameter of 17 μ. The walls of these tubes are straight and thin, but the specimens in the Old Radnor limestone have undergone such complete recrystallization that their detailed structure is not always easy to ascertain. The length of the cells averages 25 μ. In places where the organism is in contact with a foreign body, the cells are wider; they tend to be more irregular in their disposition, and may then reach a diameter of 20 to 25 μ. Rothpletz[1] differentiates the portions of the thallus characterized by these two classes of cells into 'perithallium' and 'hypothallium' respectively. In our species the larger cells are not limited to the first-formed layers of the thallus, but are liable to occur wherever the growth of the organism is interrupted by the introduction of a foreign body (Pl. VI, fig. 2).

These longitudinal sections also exhibit numerous concentric lines of growth, which occur at irregular intervals, and are frequently marked by a discontinuity in the growth of the cell-threads on each side of them. They appear to mark periods when the growth of the organism was interrupted, and there is

[1] 'Ueber die Kalkalgen aus dem Obersilur Gotlands' Sver. Geol. Undersökn. Ser. Ca No. 10 (1913) p. 7.

often a tendency towards an increase in the diameter of the cells along this junction-line, similar to that which characterizes the basal layer of the thallus.

Occasionally, small elongated fusiform spaces (Pl. VI, fig. 1) occur in the thallus, filled with crystalline calcite; these lie with their longer axes parallel to the direction of the cell-threads—they vary in length from mere specks up to 300 μ, and their greatest width is about 50 μ. Similar spaces have been described by Rothpletz in *S. gotlandica* as sporangia, but it is very doubtful whether such an interpretation can be placed on these spaces in the Old Radnor species; they suggest, rather, spaces due to the irregular solution of portions of the cell-walls, since the cavities interrupt the continuity of the cell-walls and are not definitely enclosed by them.

In cross-sections the structure appears as closely-packed polygonal cells, having a nearly uniform diameter of 17 μ. This species resembles most closely *S. gotlandica* Rothpletz from the *Sphærocodium* Limestone of Southern Gotland—an horizon considered by Dr. H. Munthe to be the equivalent of the Aymestry Limestone of this country. The cells in *S. gotlandica* are, however, much larger, measuring from 25 to 35 μ, while the thallus seldom attains a greater diameter than 3 cms. The size of the cells in *S. gracilis* approaches very closely to those of some species of *Lithothamnion*, in which they range from 6 to 20 μ.

EXPLANATION OF PLATES I–VII.

Plate I.

The base of the limestone, Dolyhir Quarry, showing included angular fragments of Pre-Cambrian grit and tabular growths of *Favosites*. The higher beds show white nodules of *Solenopora*, as also the blocks in the foreground.

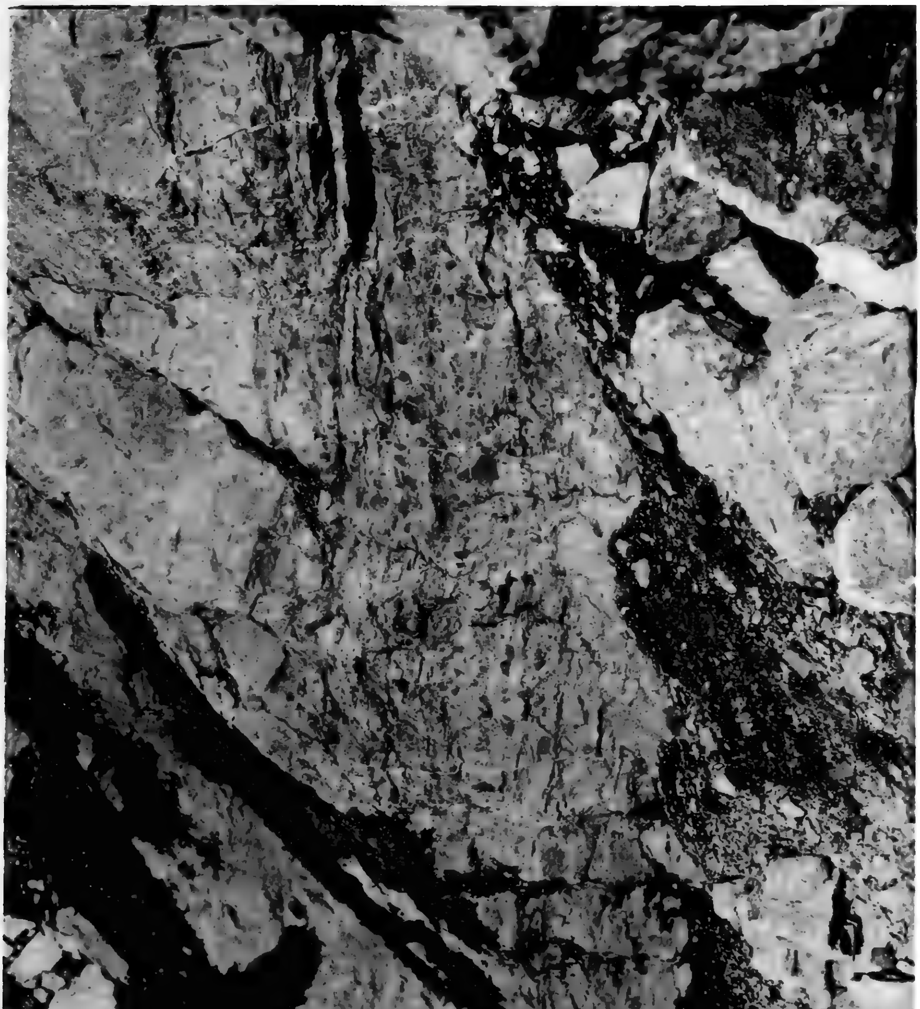
Plate II.

View of Old Radnor Hill, looking north-eastwards across the railway from the south side. The plantation on the right of the road in the centre of the picture marks the old limestone-quarry, at the back of which runs the east-and-west fault. The Pre-Cambrian conglomerate outcrops are seen on the slope behind Hillhouse Farm.

F.F. = Boundary-faults.
T. = Thrust-plane in limestone.
S.R. = Northern end of Stanner Rocks.
Str. = Entrance to Strinds Quarry.
R.R. = Railway.
H. = Hillhouse Farm.
Y. = Pre-Cambrian Quarry, Yat Wood.

Plate III.

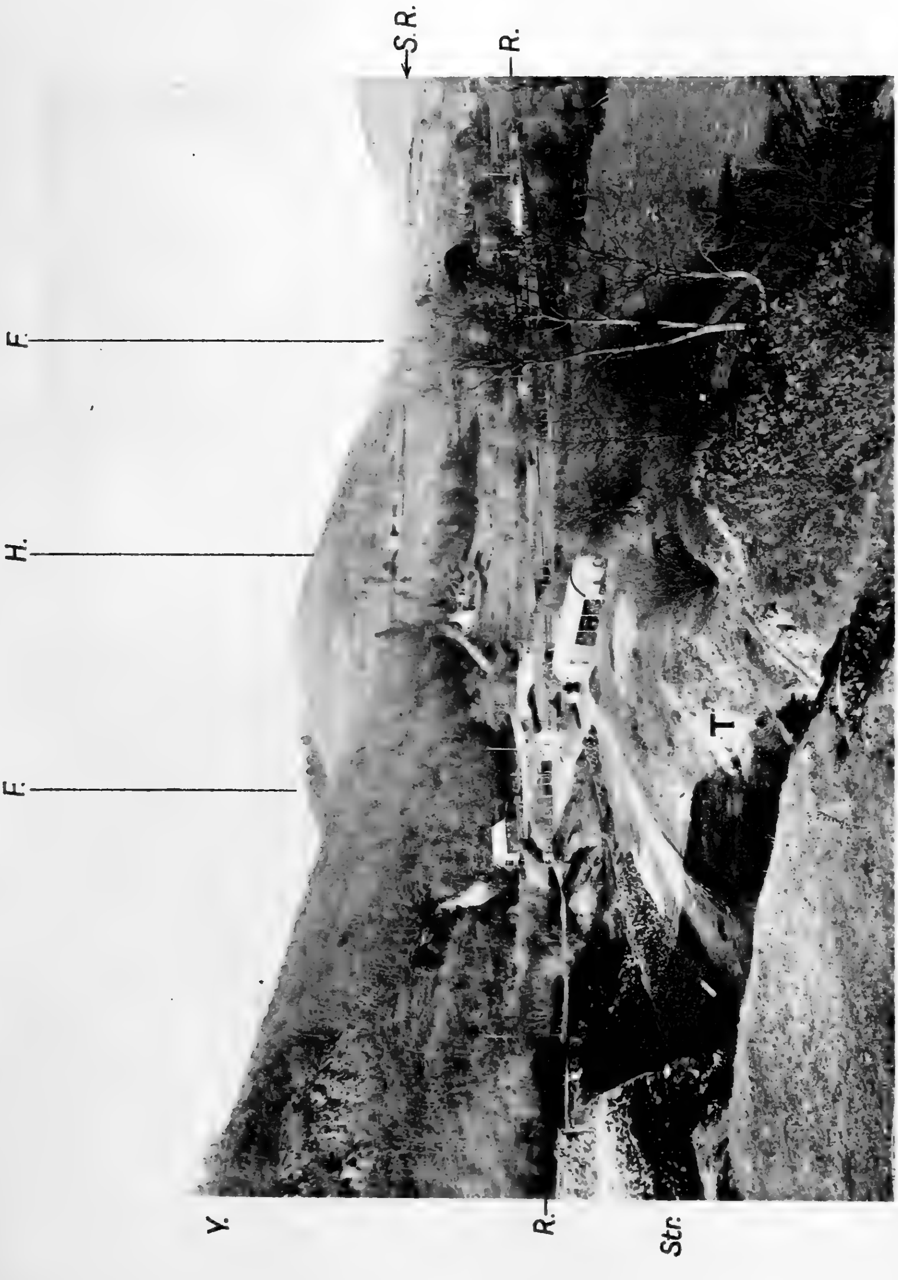
View of Yat-Hill Quarries, looking north-north-westwards from the road to Strinds Farm, behind the old quarry, Dolyhir, showing the fault-plane bounding the eastern side of the quarry. One of the parallel thrust-faces, bringing up a patch of Pre-Cambrian grit in Yat Quarry, is seen on the left in the distance.



E.J.G., Photo.

Bemrose, Collo., Derby

Conglomerate with Favosites, Base of Woolhope Limestone, Dolyhir Quarry.



E.J.G., Photo.

Bemrose, Collo., Derby

Old Radnor Hill, showing Boundary-Faults, F, F.

E.J.G., Photo.

Bemrose, Collo, Derby.

Yat Hill, from the old Dolyhir Quarry, showing Fault-Face.

E.J.G., Photo.

Bemrose, Collo, Derby

Fault-Plane forming the Eastern Boundary of Yat Quarry.

Fig. 1.– Fault (*ff*) letting in Wenlock Shale (WS), Dolyhir Quarry.

E. G., Photo.

Fig. 2.– Tear-Fault: Horizontally-Striated Fault-Face, Strinds Quarry.

E. J. G., Photo.

Bemrose, Collo., Derby

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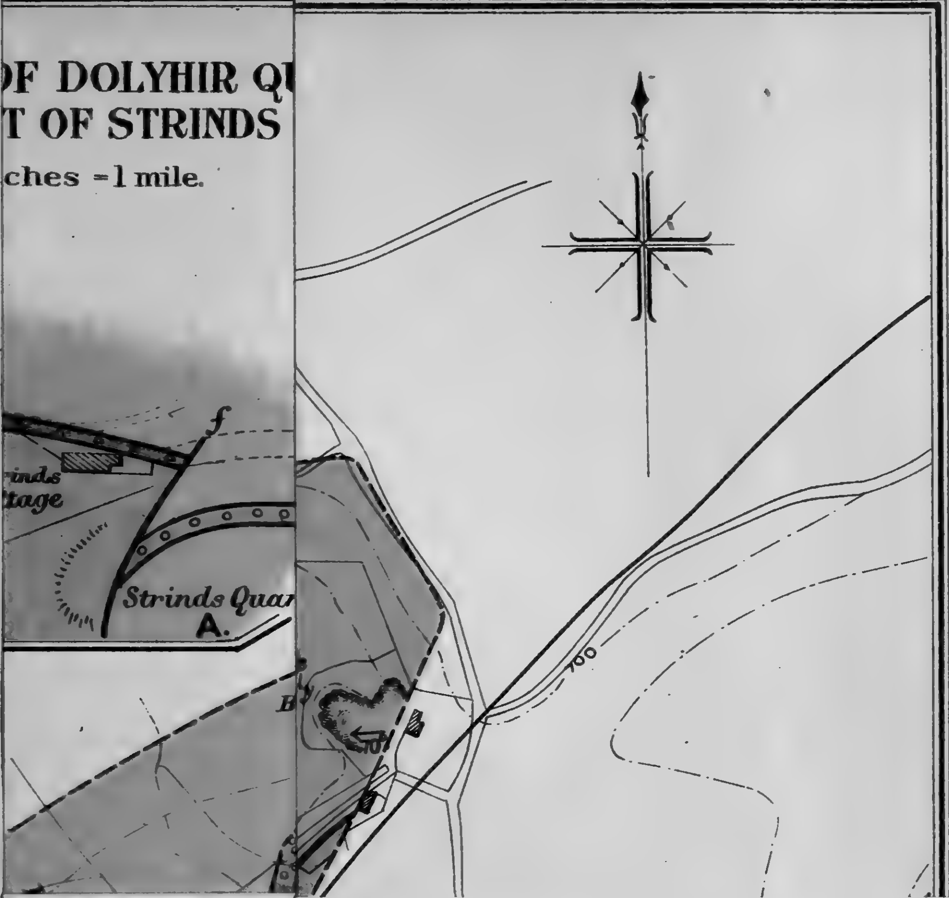
E. J. G., Photomicro.

Bemrose, Collo. Derby

Calcareous Algæ, Woolhope Limestone, Old Radnor.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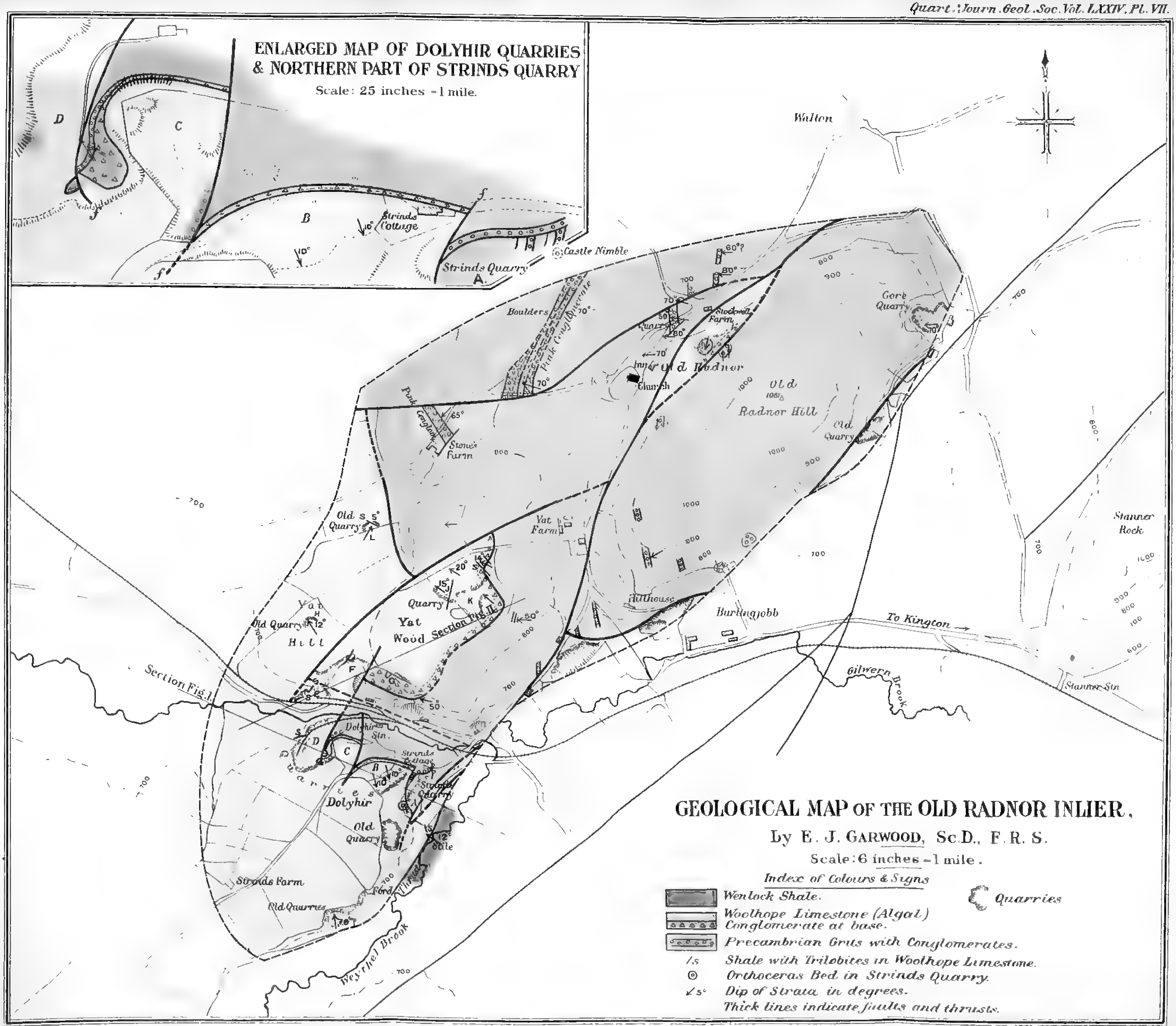

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Plate IV.

View, looking northwards, of the fault-plane forming the eastern end of Yat Quarry. This fault brings up the Pre-Cambrian rocks on the right, from the top of which the limestone has been removed by quarrying. (This old quarry is shown on the sky-line in Pl. III, a little to the right of the centre of the picture.) One of the curved north-and-south thrust-planes is seen on the left.

Plate V.

Fig. 1. View looking southwards, showing the main fault which traverses Dolyhir Quarry in a north-and-south direction. This fault has thrown down the limestone on the west, which is there worked at a lower level. A patch of Wenlock Shale (W.S.) is also let down against the fault, and can be seen in the centre of the picture near the top of the cliff.

2. One of the east-and-west 'tear'-faults, showing a horizontally-striated surface, Strinds Quarry.

Plate VI.

Calcareous algæ from the Old Radnor Limestone.

Fig. 1. *Solenopora gracilis*, sp. nov. × 25. Longitudinal section, showing lines of growth and pseudosporangia.

2. *Solenopora gracilis.* × 25. Showing enlargement of cells in contact with a foreign body.

3. *Sphærocodium gotlandicum* Rothpletz, coating surface of bryozoa. × 10.

4. *Sphærocodium gotlandicum*, showing traces of branched cell-threads. × 45.

Plate VII.

Geological map of the Old Radnor Inlier, on the scale of 6 inches to the mile or 1 : 10,560, with an inset-map of the Strinds-Quarry area, on the scale of 25 inches to the mile or 1 : 2535.

Discussion.

Dr. J. V. Elsden said that he had recently been over the ground described in the paper, and one of the Authors had been good enough to show him the critical sections upon which their conclusions had been based. The evidence was clear and incontrovertible so far as the main facts were concerned, and he could suggest no alternative reading. Earlier workers had been mistaken, both as to the age of the rocks and as to the structure of the district. Some of their errors might conceivably have been due to the absence of good exposures. Quarrying had been in active progress in this area for many years, and evidence available at any particular time might be subsequently buried beneath the quarry-tips. For that reason it was gratifying that this paper had been brought before the Society, and that a detailed record of existing evidence would now be preserved. With regard to the alleged metamorphism described by earlier writers, too much importance had clearly been ascribed to the proximity of the igneous intrusions of Stanner and Hanter Hill. There was, so far as the speaker knew, no evidence of any igneous intrusions in the Old Radnor Inlier. The abundance of algal remains in the Woolhope Limestone was a revelation, and he had been greatly impressed by the important part played by these organisms as rock-builders. He congratulated the Authors upon the valuable work which they had done in a district that had been too long neglected.

Dr. A. H. Cox remarked on the great interest with which he had listened to the paper, in view of certain resemblances between the district under discussion and the Pedwardine or Brampton-Bryan district, some 10 miles north-east of Old Radnor, an area that he himself had investigated a few years previously. He had then suggested that the Brampton-Bryan rocks were of Longmyndian age, and that they belonged to the 'Bayston Group' of Prof. Lapworth. This view gained additional support from the fact, now established as the result of the Authors' examination of Old Radnor, that there also the rocks were Longmyndian, and still further, that they were to be referred to the Bayston Group. While working at Brampton Bryan the speaker had paid a brief visit to Old Radnor, and he concluded that the Old Radnor rocks were Longmyndian, but, if anything, a little lower than the conglomerates of Brampton Bryan. Now the Authors had discovered at Old Radnor conglomerates that matched in every respect the conglomerates of Brampton Bryan, and of Stanbach in the main Longmynd area. There appeared, consequently, to be little room for doubt that the correlation of the rocks of the three areas was correct. The speaker had further suggested that at Brampton Bryan the Longmyndian had been thrust eastwards horizontally over Cambrian. He was accordingly very pleased to see actual photographs from Old Radnor showing Pre-Cambrian rocks thrust horizontally over Silurian, giving more definite information as to the age of the movements than was to be obtained at Brampton Bryan. It was extremely fortunate that the investigation of the algæ had led the Authors to the examination of a district that yielded such good results.

Prof. G. A. J. Cole enquired as to the general strike of the Longmyndian rocks of Old Radnor, which seemed, by the trend of the conglomeratic bands, to be northward on the whole. The north-easterly and south-westerly direction of the axis of the mass, as now exposed, appeared to be due to the cutting-up of the district by the faulting.

Prof. E. J. Garwood, on behalf of the Authors, thanked those who had taken part in the discussion for their appreciative remarks. In reply to Prof. Cole, he said that the strike of the Archæan rocks, so far as the individual beds were concerned, was difficult to trace for more than a short distance—the direction of the longer axis of the inlier and the trend of the boundary-faults were in a general north-easterly direction: that was, in a line with the Caledonian trend of the Longmynd range. The Nash-Scar Limestone, described in the paper, was shown to be identical with the algal development at Old Radnor.

2. *The* Pre-Cambrian *and* Associated Rocks *of the* District *of* Mozambique.

By Arthur Holmes, D.Sc., D.I.C., A.R.C.S., F.G.S. (Read June 20th, 1917.)

[Plates VIII–XI.]

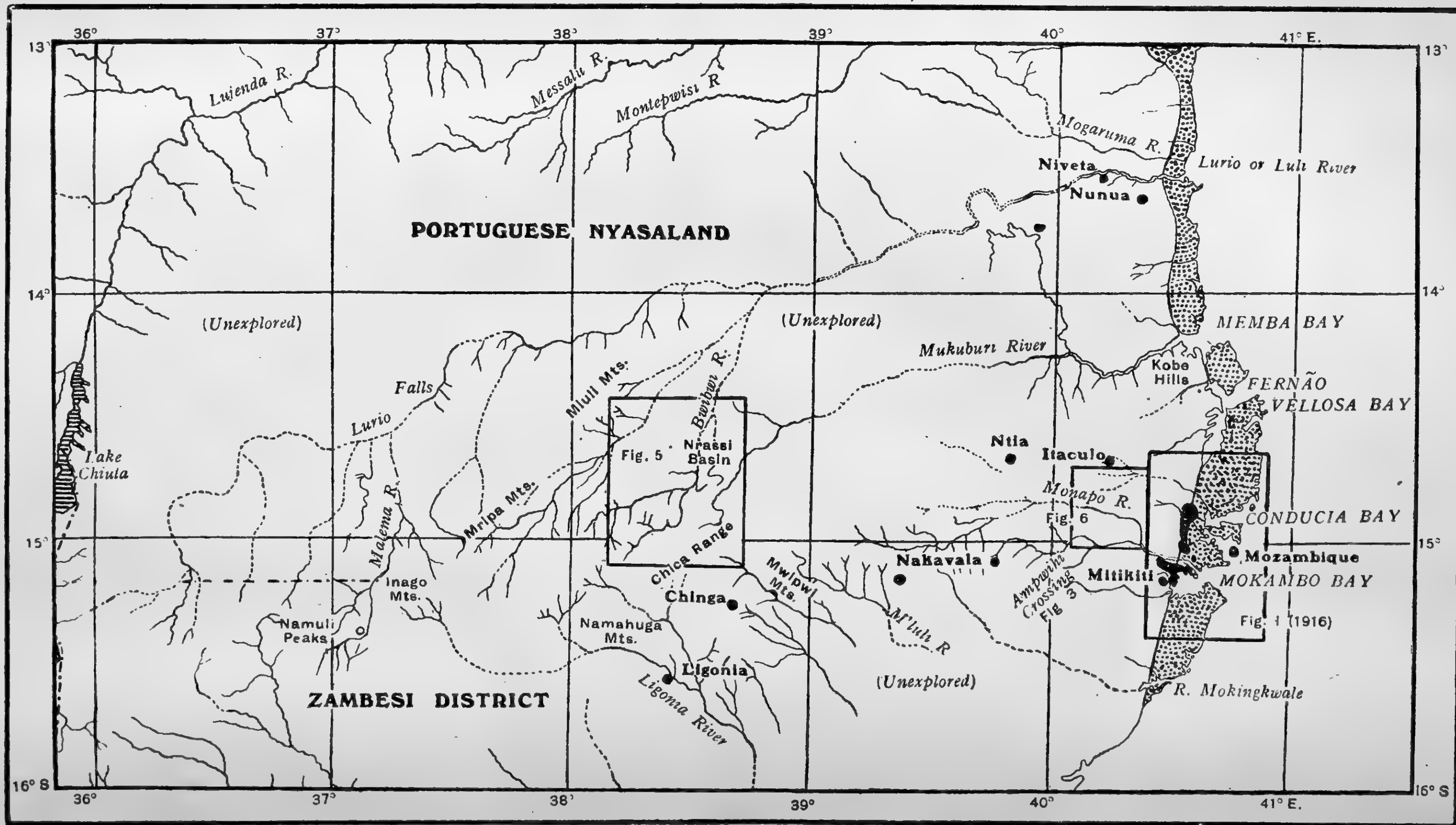
Contents.

I. General Description of the Area.

Beyond the coastal and volcanic belts of Mozambique—already described in a previous contribution [1]—the country assumes the

[1] A. Holmes, 'The Tertiary Volcanic Rocks of Mozambique' Q. J. G. S. vol. lxxii (1916–17) pp. 222–79. In this paper a brief account of the exploration of Mozambique was given, together with a bibliography and other preliminary matters. A further introduction to the subject-matter of the present contribution is considered, therefore, to be unnecessary.

Fig. 1.—*Index-map of the District of Mozambique.*



The dotted coastal area is mainly occupied by Cretaceous sediments, flanked on the east by Tertiary sediments in certain areas. The volcanic belt, so far as it has been explored, is shown in black between Conducia and Mokambo Bays.

[Fig. 3 of the above map is Fig. 4 on p. 38. Fig. 5 of the above map is Pl. XI.
Fig. 1 (1916) of the above map refers to p. 226 of the Q. J. G. S. vol. lxxii (1916–17).]

form of a gently undulating plateau that gradually rises towards the west. As one proceeds inland its surface becomes increasingly diversified by inselberge and clusters of abrupt hills until, west of Ribawe, where the plateau reaches an elevation of nearly 2000 feet, the scenery becomes more typically of a highland character and the stretches of unbroken plateau less extensive. Throughout the whole area traversed by the staff of the Memba Minerals Ltd. (after the Cretaceous and Tertiary formations had been left behind) no rocks were found that were not of igneous or metamorphic origin, or that, like laterite,[1] could not be traced immediately back to an igneous or metamorphic parent-rock or to solutions percolating through such rocks. (See index-map, fig. 1, p. 32.) The dominant rock of the country, persistent to a degree that often becomes monotonous, is a grey biotite-gneiss. Interfoliated with the gneiss are occasional lenticular masses of hornblende-gneiss and amphibolite, and with these, smaller bands and lenticles of crystalline limestone are sometimes intimately associated. Elsewhere the gneisses become coarse and garnetiferous, and in some places eclogites and basic granulites occur.

Schists were found very sparingly, and the known exposures are limited to three areas: the north-east of the territory behind the broadened coastal plain in the neighbourhood of the mouth of the Lurio, the district around Memba, and the central coastal region between the Mitikiti River and Sokoto Hill. In the latter district, the schists are probably older than the gneisses that enclose them: for the gneisses are mainly, though perhaps not wholly, foliated granites, and therefore of igneous origin. This important but difficult question will be discussed in detail in § V, pp. 63–65. Into the gneisses, later granites of at least two different periods have penetrated, riddling them with enormous numbers of small intrusions, lit-par-lit injections, tongues, apophyses, and dykes of pegmatite and aplite.

As a general rule, the foliation or banding of the schists and gneisses is well defined in parallel uncontorted planes, which thus make possible observations of dip and strike. The strike is most commonly along, or a little north of, a north-east to south-west direction; though, in the Ribawe district and near the coastal belt, it swings round to a nearly north-and-south direction. Near the coast the predominant direction of dip is away from the sea. Farther west this statement ceases to hold; but, except locally where the rocks are contorted by later intrusions or faulted, or in the neighbourhood of certain inselberge, the dips show no tendency to rapid variation, the same direction being maintained over large areas, and the angles, usually low, changing but slowly. Sometimes, however, the structures revealed on the wind-swept slopes of the inselberge indicate a striking divergence from the comparative uniformity displayed across the plateau. In certain cases, it is

[1] A. Holmes, 'The Lateritic Deposits of Mozambique' Geol. Mag. dec. 6, vol. i (1914) p. 529.

seen that the strike swings round the contours of the hills, and that the foliation dips away from their summits in every direction, occasionally even to the extent of being practically coincident with the actual surface.[1]

Proceeding westwards, we note that the country slowly changes in character. Within the first 50 or 60 miles, isolated hills and linear series of hills of the inselberg type rise up abruptly from the plateau. Climbing one of these precipitous peaks—if a precarious footing can be found on its steep and often convex slopes—one beholds a magnificent panorama displayed from the smoothly-domed summit. The bare rounded inselberg of gneiss stands alone, like an island in an undulating sea of vegetation. On the east the forest-clad plateau stretches unbroken to the horizon, or drops to the coastal plain and the sea, but on the west it is bounded by the dark-blue outlines of an increasingly mountainous country. Here and there detached peaks, culminating in gracefully-curved domes, fantastic knobs, or unscalable pinnacles, rise into the sunshine above the gloom of the tropical forest. Rolling across the plain one sees regular alternations of level: low elevations and corresponding shallow depressions—marked by a brighter green—run side by side like the corrugations of a galvanized iron roof, following a direction that is parallel to the foliation and banding of the gneisses. Farther west the low ridges broaden into long series of turtlebacks, elongated along the strike of the rock-structures. The small inselberge increase in height and numbers, and grow together in imposing linear series and towering mountainous clusters, all of which afford unrivalled vertical and horizontal sections for the study of the detailed structures and inter-relations of the rocks, gneissose and granitic, which enter into their architecture.

The characteristic domed outlines of the peaks and their smoothly-curved surfaces are obviously due to chemical denudation. Sharp corners tend to be more rapidly worn away than rounded surfaces, and the dome-topped form that is ultimately attained offers therefore a superior resistance to weathering, and maintains a higher degree of permanency. The rounded surfaces are further developed by exfoliation. Owing to wide daily variations in temperature, the rocks split along planes parallel to the surface, and almost any inselberg exhibits gently-curved shells of gneiss lying on its steep sides in readiness to fall away so soon as they are liberated by the growth of radial cracks.[2] Occasionally concentric shells lie one over the other like the tiles on a roof, making an ascent difficult, and in some cases even impossible.

Livingstone stated in 1865 that near Lake Nyasa the rocks,

[1] For other examples of this type of structure see F. D. Adams & A. E. Barlow, 'Geology of the Haliburton & Bancroft Areas' Mem. No. 6, Geol. Surv. Canada, 1910, p. 14; and F. E. Studt, 'Outline of the Geology of South Central Africa' Trans. Geol. Soc. S. Africa, vol. xvi (1913) p. 92.

[2] J. W. Evans, 'The Wearing-down of the Rocks' Proc. Geol. Assoc. vol. xxiv (1913) pp. 245–49.

rapidly cooling after sunset, frequently split with a loud report.[1] In the Ribawe Mountains, where the base-camp of the Memba Minerals Expedition was situated in 1911 (surrounded on three sides by high peaks rising 2000 feet above the valley), the report of a splitting rock and the noise of its fall was noticed during the night on several occasions.

Where the peaks lack a simple outline, and are capped by irregular knobs, the latter can generally be explained as an additional breaking-away of the rocks along foliation-planes, and along joint-planes inclined to them. A peak in the Kobe Hills, near Memba, provides an admirable illustration (figs. 2 & 3, p. 36). Seen from the south the summit is smoothly rounded, the convex sides dropping steeply to the plain below and truncating the banding of the gneiss, which is here nearly horizontal. From the east, however, the profile is very different, and shows an overhanging rectangular block that has been formed by fracture along joint-planes.

The plateau-surface rises almost uniformly until it culminates in the Namuli district, 300 miles from the Indian Ocean, at a height of 3000 feet. Similarly, the inselberge and mountain-blocks steadily increase in altitude towards the west. Within 50 miles of the sea few of the peaks attain 1000 feet. West of Nampula the Mwipwi Mountains and the Namahuga Range approach 3000 feet above sea-level, or 2000 feet above the plateau. The Chica Range reaches 4000 feet, the highest of the Ribawe peaks 5000 feet, while many of the peaks of the Mrupi, Mluli, and Mripa mountains exceed that figure. The highest summit of Inago rises to 6490 feet, and that of Namuli, the highest peak in Portuguese East Africa, to 8050 feet, 5000 feet above the broad and fertile valley of the Malema.

The river-systems are closely related to the structural directions of the country, nearly all the streams and the watersheds between them being either parallel or perpendicular to the foliation directions of the gneissose granites.[2] The basins of the Mukumburi, the Monapo, and the Mluli Rivers fall entirely within Mozambique, and the rest of the territory is watered by the border rivers, the Lurio and Ligonia, and by their tributaries from the south and north respectively. All the larger rivers and their important tributaries, except the Monapo, rise in the high mountain-groups of the interior. The upper courses are fed continuously throughout the year; but the middle and lower tracts become wide and shallow, and, except for a few stagnant pools, they dry up during several months of the year. Recent rejuvenation is indicated by the gullies cut through thick deposits of sand and gravel, and by small hanging valleys which are sometimes seen among the mountains. A corresponding uplift is demonstrated along the coast by the existence of raised beaches and coral-reefs.

[1] 'Expedition to the Zambesi, &c.' p. 492.

[2] See A. Holmes & D. A. Wray, Geogr. Journ. vol. xlii (1913) map on p. 145.

Fig. 2.—*Mount Kobe, Memba: profile seen from the south.*

Fig. 3.—*Mount Kobe, Memba: profile seen from the east.*

II. Succession and Classification of the Rocks.

(a) The Coastal Districts.

The Archæan succession in Mozambique, so far as it is developed, bears a close resemblance to that of other African localities, and many of its features are similar to those of the Archæan areas of India, Ceylon, Fennoscandia, and Canada. Representatives of the oldest rocks of the territory are found underlying part of the coastal belt between Mitikiti and Ibrahimo. They consist of a series of micaceous quartz-schists and paragneisses interfoliated with granite-gneisses that appear to have been injected between successive bands of an older sedimentary formation. No original basement on which the schists could have been laid down as sediments can be found. Granulitic granites and pegmatites, predominantly grey or nearly white, traverse the schists and gneisses; and a later red granite, accompanied by coarse-grained pegmatites free from any trace of granulitic structure, cuts through all the members of the older complex.

A similar succession is observed south of the Lurio, between Nunua, 12 miles from the coast, and Fort Naparara. Here are numerous bands of crystalline limestone interfoliated with the gneisses, and accompanied by thin belts of hæmatite-schist. As the crystalline limestones are approached, the normal biotite-gneiss gradually changes to hornblende-gneiss and amphibolite, and much plagioclase appears in place of the usual alkali-felspars. Mica-schists have not been recorded from this district, nor indeed from any part of Mozambique other than that mentioned above. Graphite ores associated with quartz-veins are said to occur near Nunua, but nothing is known of their mode of origin or position in the sequence. At Niveta, and in the hills west of Naparara, there are small intrusions of a grey granulitic granite which is sometimes porphyritic. Red felspathic pegmatites of later age have been traced near Niveta, into quartz-veins which carry considerable quantities of galena.

West of Memba crystalline limestones and hornblende-schists are interfoliated with the gneisses, which in many places are highly garnetiferous. Thus it happens that deep-red garnets, often an inch in diameter, are thickly sprinkled among the gravels of the Mukuburi River. Due north of Memba a heavy dark-green eclogite is interbanded with the garnet-gneisses of the Muendazi Valley. Tourmaline-granites and pegmatites belonging to the coarse-grained later type are strongly developed around Memba, and in the town itself the post-office is built on an outcrop of quartz-tourmaline rock. For allowing me to make use of his notes on the Memba district, I am indebted to my former colleague, Mr. D. Alexander Wray.

(*b*) The Ampwihi Crossing.

Almost due west of Mozambique Island, at a distance of 42 miles from the sea, the military road from Mosuril to Nampula crosses the Ampwihi River, the chief tributary of the Monapo. Near the crossing (see figs. 4 & 5) a welcome diversion

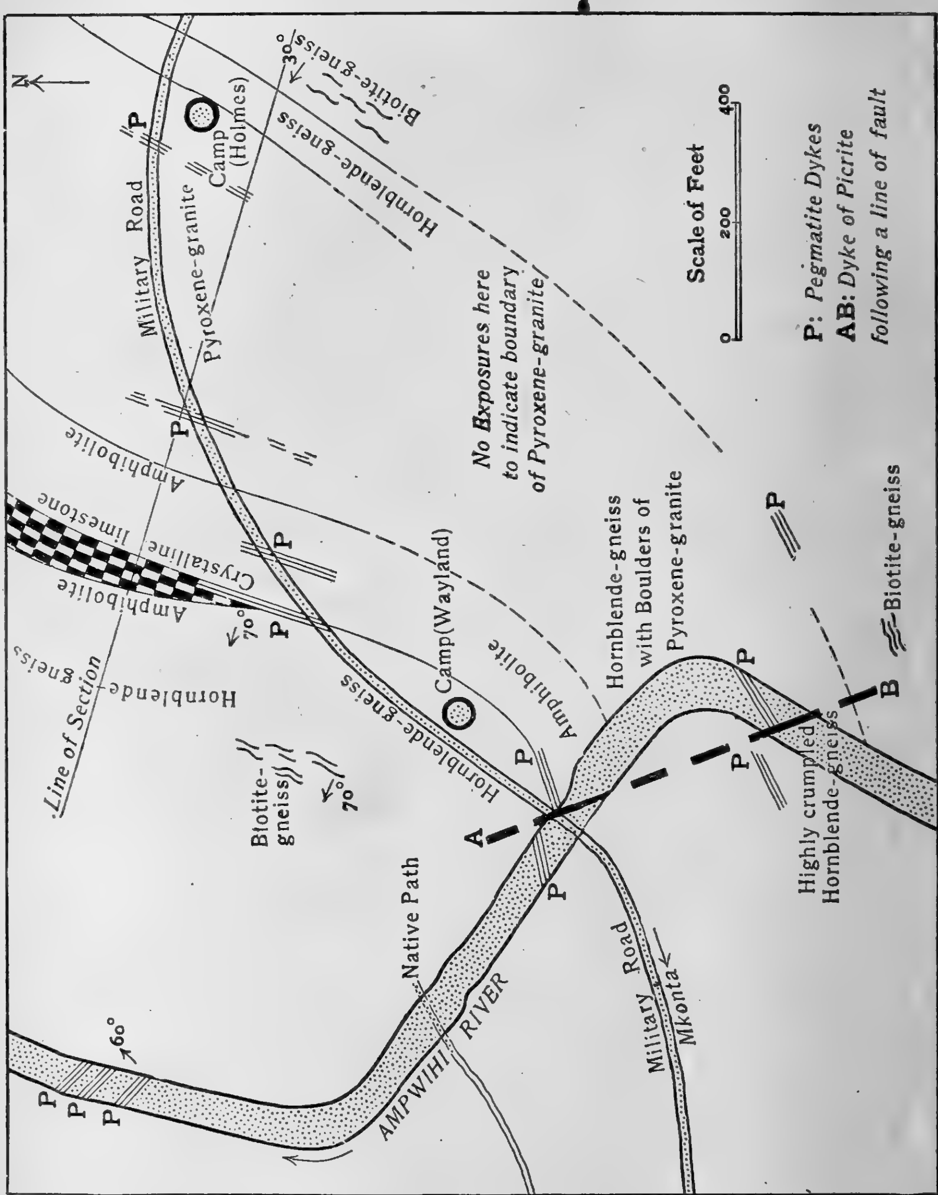
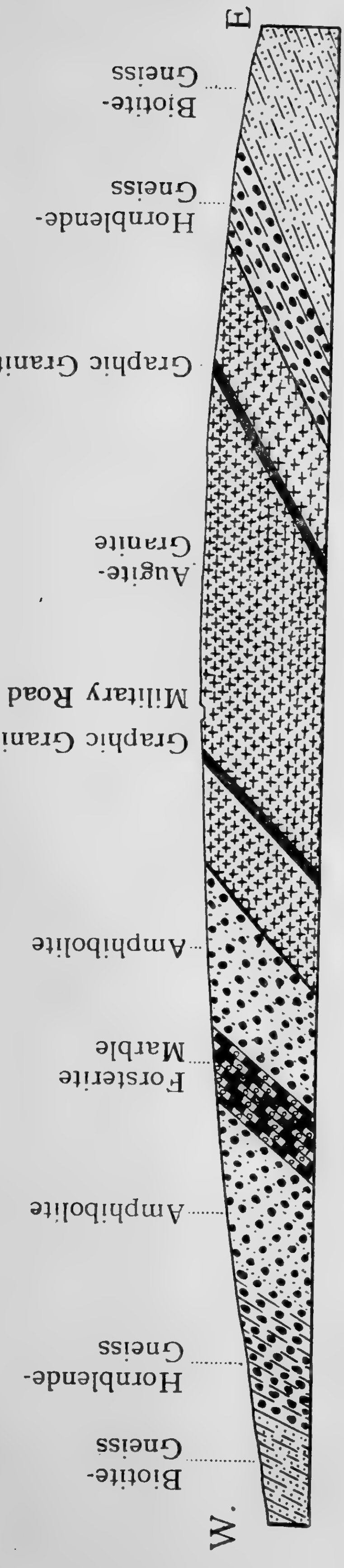


Fig. 4.—*Geological sketch-map of the Ampwihi Crossing.*

from the monotony of biotite-gneiss is introduced by the appearance, in successive belts from north-west to south-east, of hornblende-gneiss, amphibolite, crystalline limestone, amphibolite, pyroxene-granite, and hornblende-gneiss, the whole series being penetrated by numerous dykes of graphic granite and by one or two coarse-grained dykes that carry large crystals of magnetite

Fig. 5.—*Horizontal section across fig. 4 (Ampwihi Crossing) on the scale of 200 feet to 1 inch*



and ilmenite. The hornblende-gneisses and pyroxene-granite enclose small pockets of calcite, and near the boundaries of the crystalline limestone many interesting contact-minerals are developed. The hornblende-gneisses pass imperceptibly into the surrounding biotite-gneiss and are almost certainly of the same age, the incoming of hornblende and plagioclase being attributed to interchange of material between the biotite-gneiss and the crystalline limestone. According to this reading the succession in order of age is (*a*) crystalline limestone (forsterite-marble), (*b*) biotite- and hornblende-gneisses, (*c*) pyroxene-granite, (*d*) graphic granite and other pegmatites. At the junction of the river and the road, a dark compact picrite-dyke about 10 feet thick appears on the right-hand side of the river-bed, and crosses obliquely to the other bank, taking a north-north-westerly to south-south-easterly direction across the strike of the older rocks. The Ampwihi makes a sudden bend about 70 yards to the south-east so that it returns towards the dyke, which is again exposed across its sandy floor. The dyke is clearly the latest rock of the district, and is intruded along a line of fault—for in two cases pegmatite-dykes seen on the eastern side are broken across, and reappear on the western side with a well-marked northward displacement.[1]

On the northern slopes of the Monapo Valley, south-east of Mount Tibwi, the late R. L. Reid found a large mass of nearly pure crystalline limestone, embedded in hornblende-biotite-gneiss and intruded upon by muscovite-bearing pegmatites.

[1] A. Holmes, Geol. Mag. dec. 6, vol. iv (1917) p. 150.

(c) The Ribawe Mountains.

No schists nor crystalline limestone have yet been detected in the gorges and precipitous slopes of the Ribawe Mountains (see map, Pl. XI). The chief rock is a biotite-gneiss, dipping gently northwards and passing locally into a grey porphyritic granite. There are, however, bands of hornblende-gneiss, and later intrusions of augite-granite, in the neighbourhood of certain curious caves which may have once been occupied by crystalline limestone that has since been dissolved away.[1] The other intrusions in this district are pink and grey granulitic gneisses, while the youngest rocks are coarse pegmatites (some of which carry tourmaline and topaz, and others magnetite and ilmenite) associated with red biotite-granite containing large phenocrysts of orthoclase.

(d) The Nrassi Basin.

North-east of the Ribawe Mountains the upper waters of the Nrassi River and its tributaries flow through a basin-like area surrounded almost everywhere by linear series and clusters of peaks (see map, Pl. XI). In one of the small gullies, which in the wet season carry the drainage from the peaks of Ericola to the Nrassi, bands of crystalline limestone are exposed, again interfoliated with hornblende-gneiss that merges on each side into biotite-gneiss. In the Mwima range the last-mentioned rock passes into an unfoliated grey granite with little biotite. As in other districts where limestone occurs, there are small intrusions of augite-granite, which in this case is associated with adamellite and diorite. Here, again, are granulitic pegmatites, sometimes carrying hæmatite, and associated in the isolated line of peaks north of Ribawe with a pink and grey speckled biotite-granite. This rock constitutes the main mass of some of the Karji and Koldwi peaks, and in it Mr. E. J. Wayland was fortunate in finding enclosed

[1] For illustration, see 'The Lateritic Deposits of Mozambique' Geol. Mag. dec. 6, vol. i (1914) pl. xxxvii, facing p. 529. In that paper I wrote: 'On each side of the [Sawa] valley the mountains rose up precipitously, and the foliation of the gneiss could be plainly seen dipping away at a gentle angle to the north. On the eastern side the nearly vertical face of the gneiss was eaten away here and there into caves, the entrances to which ran along the "dip." Those which we explored widened and narrowed in the most remarkable way, defying explanation. In each case a steady drip of water trickled from the roof and from narrow fissures which penetrated the rock parallel to the foliation, thus demonstrating that a considerable drainage of water percolated northwards down the "dip" through the apparently impermeable gneiss. The roofs of the caves were lined with a thick highly-polished deposit of limonite, which also covered the upper parts of the walls, gradually becoming thinner as the floor was reached and giving place to bright pink rhodochroisite and black pyrolusite.'

Since writing that paper, it has occurred to me that if, as is frequently the case, hornblende-gneiss and augite-granite indicate the proximity of crystalline limestone bands, these remarkable caves may represent pockets of crystalline limestone that were not completely absorbed by the invading magmas.

fragments of the older biotite-gneiss. In the Nrassi Basin itself, there are many coarse pegmatites, some of which are rich in tourmaline. Of still later age are a few north-and-south pyroxenite dykes, which (like the crystalline limestones) are exposed in a gully east of Ericola.

(*e*) Fort Chinga District.

Passing now to the plateau south-east of the Chika range, we find (along the disused Portuguese road that runs from Chinga towards the isolated peak of Mushima) bands of garnetiferous gneiss among the normal biotite-gneisses. The gneisses here are thickly threaded with grey granulitic pegmatite, and intruded into locally by extremely coarse pegmatite-dykes, in some of which individual crystals of red felspar occupy the whole width of the dyke and extend for several feet. Some of these pegmatites carry tourmaline, and near the surface yellow-green crystals of autunite are occasionally present.

(*f*) West of Ribawe.

I am indebted to Mr. D. A. Wray for permission to use a series of notes on the rocks encountered by him during his journeys from the Memba Minerals base-camp at Sawa to the Inago and Namuli Mountains in the west, and to the Luli Valley and Mluli Mountains in the north-west. In the district north of the Norray Peaks, the biotite-gneisses are accompanied by bands of hornblende-gneiss, garnet-gneiss, eclogite, and garnet-pyroxene-scapolite rocks, the whole series dipping at a high angle towards the north-west and striking uniformly along a north-east and south-west direction. In the same line of strike, 40 miles away to the south-west, garnet- and hornblende-gneisses again appear, exposed in the Mrayho Hills. The complex north of the Norray Peaks is riddled as usual with grey granulitic pegmatites, and has been penetrated at a later date by coarse tourmaline-bearing pegmatite. Farther north, in the valley of the Namikati River (draining the south-eastern slopes of the Mluli peaks), there are also composite garnetiferous and hornblende-gneisses in which large crystals of tourmaline and magnetite occur.

The Mrupi peaks are made up almost entirely of coarsely-banded hornblende-gneiss, remarkable in the fact that the dip of the banding is almost vertical, while the surrounding biotite-gneisses—generally fine-grained—have a nearly horizontal foliation, a feature that characterizes them all along the Luli Valley as far west as the Falls near Vattiva, where the gneisses are highly contorted and again very coarse in structure.

The huge peaks of the Inago Mountains consist of a grey biotite-granite showing fluxion-structure, which passes peripherally into gneiss containing a much higher percentage of biotite. The Namuli Peaks, though seen only from a distance, appear to

TABLE I.—SUCCESSION OF THE ROCKS IN VARIOUS PARTS OF THE DISTRICT OF MOZAMBIQUE.

Between Mitikiti and Ibrahimo.	*Memba Bay District.*	*District South of the Lower Lurio.*	*Ampwihi Crossing.*	*Ribawe Mountains.*	*Nrassi Basin.*	*Between Chinga and Mount Mushima.*	*North of the Norray Mountains.*
—	—	—	Dyke of picrite.	—	Dykes of pyroxenite.	—	—
Red biotite-granite; graphic granite; and coarse felspathic pegmatites.	Tourmaline-granite and coarse pegmatites.	Coarse red felspathic pegmatites and quartz-veins.	Graphic granite; pegmatites carrying magnetite and ilmenite.	Porphyritic granite; pegmatites, with magnetite, ilmenite, topaz, and tourmaline.	Coarse grey pegmatites, with tourmaline.	Coarse red felspathic pegmatites, with tourmaline and autunite.	Coarse pegmatites carrying tourmaline and magnetite.
Grey granulitic biotite-granites; and pegmatites.	No record.	Grey granulitic biotite-granites; porphyritic granites; and pegmatites.	Augite-granites and pegmatites.	Augite-granites; granulitic biotite-granites; and pegmatites with hæmatite.	Augite-granites; granulitic granites and pegmatites with hæmatite.	Grey granulitic pegmatites.	Grey granulitic pegmatites.
Biotite-gneiss.	Biotite-gneiss; hornblende-gneiss; garnetiferous gneiss; eclogite.	Biotite-gneiss; hornblende-gneiss.	Biotite-gneiss; hornblende-gneiss; amphibolite.	Biotite-gneiss passing into porphyritic granite; hornblende-gneiss.	Biotite-gneiss passing into porphyritic granite; hornblende-gneiss; amphibolite.	Biotite-gneiss; garnetiferous gneiss.	Biotite, hornblende, and garnetiferous gneisses. Garnet-pyroxene-scapolite-granulite. Eclogite.
Micaceous quartz-schists; sediment- or para-gneisses.	Hornblende-schist. Crystalline limestone.	Hæmatite-schist. Crystalline limestone.	Crystalline limestone.	—	Crystalline limestone.	—	—

consist of similar rocks, a fact already observed by Mr. J. T. Last in 1887.[1]

The rocks of the Malema Valley are chiefly biotite-gneisses, which become coarsely banded and injected with granulitic pegmatitic veins in the neighbouring peaks. South of Makalia, Mr. E. J. Starey found a number of magnetite-bearing pegmatites. North of Makalia graphite deposits (like those of Nunua near the coast) have been found; but here again their position in the sequence is obscure.

Elsewhere to the west of Ribawe, biotite-gneisses, sometimes coarsely banded, sometimes so finely-grained as to become almost schistose, occasionally passing into hornblendic varieties, and in the mountains becoming less foliated, are everywhere the predominant rocks; as indeed they are throughout the whole District of Mozambique beyond the narrow coastal belt.

(*g*) General Sequence and Classification.

In Table I (p. 42) the sequences of rocks in eight of the better-known areas are summarized. The implied correlations are only put forward tentatively. It is thought probable that all the rocks of each horizontal series are younger than those of the series below, but it is less probable that all the rocks placed in any one horizontal series are of identical age throughout the country. Within these broad limits, however, the evidence seems to justify a classification of the rocks in the following order:—

Table II.

Ultra-mafic Dykes.	Pyroxenites. Picrite.	§ VIII, p. 80.
	Intrusive Contact.	
Granites and massive pegmatites.	Biotite- and muscovite-granites. Graphic granite and other pegmatites. Quartz-veins.	§ VII, p. 76.
	Intrusive Contact.	
Granulitic granites, pegmatites, and associated rocks.	Biotite-granites. Pegmatites. Pyroxene-granites, adamellites, and quartz-diorites. Rutile-bearing rocks. Granulitic norite.	§ VI, p. 67.
	Intrusive Contact.	
Gneisses and associated rocks.	Biotite-gneisses and gneissose granites. Hornblende-gneisses. Amphibolites. Garnetiferous gneisses, granulites, and eclogites.	§ V, p. 52.
	Intrusive Contact.	
Crystalline schists and limestones.	Forsterite-marble and other crystalline limestones; (including products of contact-metamorphism).	§ IV, p. 46.
	....	
	Sediment-gneisses. Quartz- and mica-schists. Quartz-magnetite-schists. Hornblende-schists. Hæmatite-schists.	§ III, p. 44.

[1] See A. Holmes & D. A. Wray, Geogr. Journ. vol. xlii (1913) p. 148.

III. The Crystalline Schists.

About 4 miles north of Mitikiti, in the banks of a stream that drains into the Mitikiti River, bands of gneissose rock that are undoubtedly of sedimentary origin are exposed. The foliation is nearly due north-east and south-west, and is parallel to that of the biotite-gneisses with which the sediment-gneisses are associated. In hand-specimens the rock is seen to be composed of irregular interlocking bands that are rich in quartz and biotite alternately. For this reason the formation has a drawn-out and coarsely-speckled appearance in the field, and is structurally a sediment-gneiss rather than a mica-schist.

No. 186[1].—Under the microscope, the rock still retains in part the aspect of an arenaceous sediment, the clastic structure being astonishingly well preserved. Angular fragments of quartz free from any traces of distortion or recrystallization, and subangular fragments of felspar (chiefly orthoclase or microcline, with occasional examples of oligoclase) which have suffered little, if any, distortion, are the most abundant minerals present. Around the borders of these, shreds of biotite have developed, maintaining on an average a parallel orientation which alone has determined the foliation. In places there are similar streaks of muscovite; while grains of epidote and garnet and specks of iron-ores are distributed sparsely among the other minerals (Pl. VIII, fig. 1). Quartz and felspar exhibit no tendency towards elongation in the direction of foliation, and are remarkably uniform in their dimensions, the average diameter being about 0·15 millimetre.

Nos. 181–83.—In the Monapo bed (between Mitikiti and Murimatigri), a number of pebbles of quartz-magnetite-granulites and schists were collected by Mr. Wayland; but, despite a close search for their parent rocks, nothing at all resembling them was found *in situ*.

No. 183 is a finely-foliated dark-grey rock, which in thin section is seen to consist mainly of a fine-grained mosaic of recrystallized quartz. A few grains of orthoclase, with inclusions of apatite, are also present. Both the quartz- and felspar-grains are roughly equidimensional, and it is to the arrangement of the other minerals that the foliation is due. Irregular small masses of magnetite are very numerous throughout the rock, and along certain bands rounded grains of epidote, badly-terminated crystals of kyanite, and elongated prisms of andalusite are also abundant.

In *No. 181* recrystallization appears to have proceeded much farther, for the quartz-felspar mosaic is made up of individuals having average diameters of 0·3 millimetre, instead of 0·15 mm. as in the preceding types. The mineral composition is the same as that of No. 183; but, as in this case the crystals of magnetite are drawn out into long lath-shaped masses which are not conspicuously parallel, the rock is granulitic rather than schistose.

No. 182 is even coarser in texture, irregular patches of quartz reaching 1·0 or 1·2 mm. in their largest dimensions. Very little felspar is present; but magnetite, in drawn-out crystals and short rounded stumpy grains, makes up about 20 per cent. of the rock. Andalusite and kyanite are absent. (See Pl. VIII, fig. 2.)

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[1] The numbers refer to specimens in the collection of the Mozambique rocks studied by the Author. That collection has now been presented to the Mineralogical Department of the British Museum (Natural History).

Immediately north of Murimatigri quartz-mica-schists are again found *in situ*, the direction of foliation, which is also that of the enclosing gneisses, being now more nearly north and south.

No. 172 is a cream-coloured to pink rock, faintly streaked with sinuous shreds of pale-green biotite. Under the microscope, quartz proves to be the chief mineral present, associated with felspars which have suffered extreme granulation. The quartzes, too, are generally granulated around the periphery, and the unbroken cores show evidence of straining by their undulose extinctions. Small granules of epidote, garnet, and apatite, generally enclosed within the biotite-shreds, are also present. (See Pl. VIII, fig. 3.)

No. 171 was found near Ibrahimo, where the schists or granulites are cut in places by coarsely-felspathic tourmaline-bearing pegmatites. It is a glassy-looking quartz-granulite, spangled with parallel flakes of muscovite. In thin section, the rock is seen to be completely recrystallized to a coarse mosaic of quartz, penetrated by lath-shaped crystals (seen in one direction as elongated plates) of muscovite, which are remarkably straight and parallel. Apatite and small crystals of tourmaline are also present as inclusions.

The rocks described above are clearly of detrital origin, and the fact that they exhibit unequal degrees of metamorphism is perhaps due to the circumstance that the region has suffered at least three periods of intimate penetration by granitic magmas. It is of even greater interest that they represent a differentiated series of deposits, including argillaceous, felspathic, micaceous, and ferruginous sandstones. These formations, laid down before the gneisses were intruded, indicate that in those early times denudation and deposition had already begun the regular course that is revealed to us by the records of the later formations. Moreover, not only were the processes similar, but the rocks which suffered decay by their activities—rocks of which only a few clastic grains now remain—must also have been closely akin to those exposed in Mozambique to-day; that is, they were of granitic composition.

No. 176. In the Mukumburi Valley, due west of Memba, a dark-green hornblende-schist containing irregular bands of quartz and felspar is found interfoliated with the gneisses.

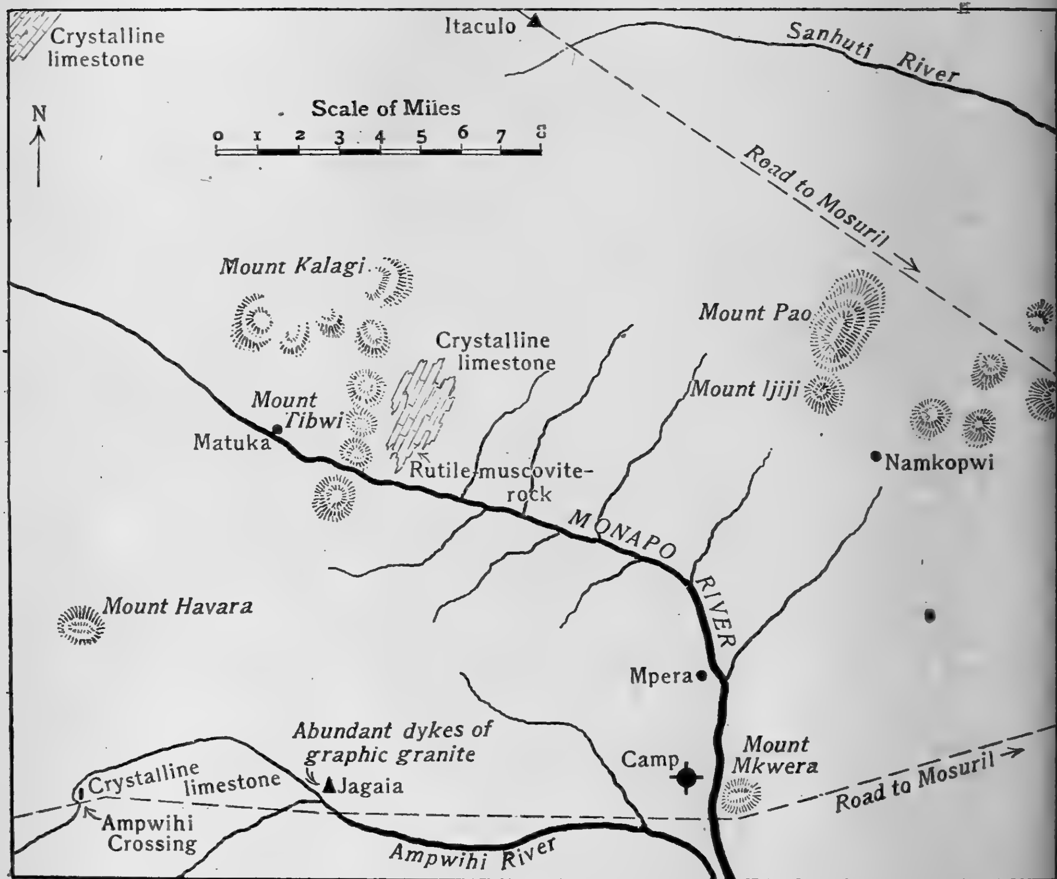
In thin section (Pl. VIII, fig. 4) it is seen that hornblende predominates along certain bands, while between the latter occur lenticular areas in which the chief constituents are, in some cases, distorted quartz, in others quartz and felspar, and sometimes felspar without quartz. The felspar is usually oligoclase, but some orthoclase is also present, and both types are conspicuously elongated in the direction of foliation. Between the dark and light bands, granular clusters of epidote, and occasionally of sphene, are present; and these minerals, especially epidote, are also arranged in sinuous lines throughout the rock, but more particularly among the felspars. Minute apatites are included in hornblende and felspar, and both quartz and felspar contain blebs of calcite, which does not seem to owe its origin to weathering processes.

This rock may be of composite origin, due to the interaction of a granite magma with a dolomitic limestone; but, on the other hand, the mineral composition is precisely what one would expect to arise from the metamorphism of a basalt or dolerite. Augite would yield hornblende and quartz, leaving over a little lime; this with a lime-soda felspar would yield oligoclase, epidote, and more free quartz, while any further excess of lime interacting with ilmenite and the silica already provided, would readily produce sphene.

IV. The Crystalline Limestones.

On the northern side of the Monapo Valley, below the three peaks of Mount Tibwi (see fig. 6, below), Mr. R. L. Reid discovered a large mass of crystalline limestone surrounded by hornblende-

Fig. 6.—*Sketch-map of the Monapo District.*



gneiss that passes rapidly into the usual biotite-gneiss away from the contacts. The boundaries of the limestone are by no means well defined, for lenticular masses which are partly or completely separated from the main body appear among the surrounding gneisses, these having penetrated the limestone in a very irregular manner. Moreover, both gneisses and limestone are cut by small sill-like intrusions of a later microcline-granite.

The crystalline limestone (*No. 72*, from the interior of the mass) is a grey lustrous rock made up very largely of calcite. In thin section a few rounded grains of colourless unserpentinized forsterite are seen among the calcite-plates, accompanied here and there by a few similar grains of colourless diopside. Small flakes of graphite are sprinkled through the limestone, and it is to these that the rock owes its grey coloration.

At the south-eastern corner of the mass the limestone is bounded by a dyke or vein of extraordinary composition, which has inserted itself between the limestone and the enclosing gneiss. The specimen collected (*No. 74*) is made up almost entirely of a felt of pale-green muscovite in which there are granular streaks and rounded or lenticular aggregates of rutile, accompanied in places by granular intercalations of quartz (see p. 73 for a detailed description, and Pl. X, fig. 4, for a photomicrograph).

In the immediate neighbourhood of the muscovite-rutile vein, the limestone becomes much richer in silicate-minerals. Olivine disappears, and gives place to diopside; while muscovite becomes abundant, and titaniferous minerals begin to appear.

No. 73, collected between the muscovite-rutile vein and the purer limestone, consists mainly of calcite and granular aggregates of colourless diopside, with a considerable proportion of muscovite varying in colour from white to pale green. A small amount of interstitial quartz is present, and associated with the mica are occasional grains of rutile and larger masses of sphene.

The following table gives the mineral compositions of the crystalline limestone and the muscovite-rutile vein, for comparison with that of the contact-rock produced by their interaction.

Table III.

Minerals.	*Crystalline Limestone.* No. 72.	*Contact-Rock.* No. 73.	*Muscovite-Rutile Vein.* No. 74.
Calcite	80	36	—
Forsterite	12	—	—
Diopside	8	18	—
Sphene	—	8	—
Rutile	—	2	27
Muscovite	—	33	68
Quartz	—	3	5

On the eastern side of the Monapo Limestone the latter is cut by small intrusions of coarse-grained pegmatite containing perthitic orthoclase, oligoclase, and biotite as its chief constituents. In the specimens collected very little quartz is present. Immediately within the contact occur beautifully bladed crystals of actinolite, averaging an inch in length. Inside this zone is a band 3 or 4 inches wide composed of a fine-grained aggregate of tremolite and actinolite with intersertal felspar and calcite (*No. 91*). In a neighbouring locality the limestone has been cut by small intrusions of granite containing much quartz and a little biotite; and, in this case, diopside has been produced as the product of interaction in place of actinolite (*No. 92*).

These examples of contact-metamorphism illustrate the important principle that magnesia must be saturated with silica before lime. Where silica is abundant diopside is formed; but, when it is deficient, then tremolite or actinolite is produced. Mr. E. B. Bailey has recently exemplified the same principles in connexion with the contact-metamorphism of the Ballachulish Limestone.[1]

The crystalline limestone (*No. 221*) of the Ampwihi Crossing has already been mentioned in relation to its environment (p. 38, and figs. 4 & 5, pp. 38–39). The rock is evenly granulose in texture, and is composed of irregular grains of calcite averaging 5 mm. in diameter, with interstitial buff-coloured forsterite and a few dark blue-grey crystals (2 mm. in axial length) of spinel.

In thin section (Pl. VIII, fig. 5) the rock is seen to be made up chiefly of calcite and forsterite, the latter mineral occurring in rounded masses and small blebs that are serpentinized along cracks. Associated with the forsterite there are often yellow granules of chondrodite, pleochroic from orange-yellow to pale yellow or colourless. The maximum extinction-angle is about 30°, thus distinguishing the mineral from other members of the humite group.

Other minerals present are diopside, in colourless granules sometimes showing cleavage, and having an extinction-angle of about 40°; phlogopite, in golden spangles scattered sparingly through the rock; magnesia-spinel, colourless in thin section, with a refractive index of 1·72; and finally scapolite, in grains with elongated inclusions parallel to the length. This mineral is optically anomalous, giving a biaxial figure of negative character with a small angle between the optic axes, and slightly inclined extinction. The refractive index is nearly 1·6 and the specific gravity 2·72, so that the composition is about that of meionite.

A partial analysis of the forsterite gave the result set forth in column A of the following table. Other analyses of forsterite from crystalline limestones occurring in Ceylon and elsewhere are appended for comparison:—

Table IV.

Constituents.	A.	B.	C.	D.
SiO_2	41·93	42·55	42·82	41·85
Al_2O_3	—	0·23	—	—
FeO	2·71	2·36	1·47	1·07
MgO	53·19	51·97	54·44	56·17
CaO	1·37	1·43	0·85	—
Alkalies	n. d.	—	—	0·52
Loss on ignition	1·21	1·68	0·76	0·19
Totals	100·41	100·22	100·34	99·80
Specific gravities	3·23	3·14	3·21	—

A. Forsterite from Ampwihi Crossing, Mozambique. (An. A. Holmes.)
B. Forsterite from Hakgala, Ceylon. (An. G. T. Prior, Q. J. G. S. vol. lviii, 1902, p. 415.)
C. Forsterite from Bolton, Mass. (U.S.A.). (An. Brush.)
D. Forsterite from Monte Somma. (An. Micrisch.)
} 'Handbuch der Mineralogie' C. Hintze, vol. ii (1897) pp. 5–6.

[1] 'The Geology of Ben Nevis & Glen Coe' Mem. Geol. Surv. Scotland, 1916, p. 193.

The forsterite-marble has considerably influenced the later intrusive rocks which have come into contact with it, and these will be described in later sections. Two contact-rocks, however, may be described more properly in this place.

At the south-eastern termination of the limestone (near the dip-arrow on fig. 4), a skarn-like rock (*No. 193*) occurs between amphibolite and the limestone. The minerals of the rock (Pl. VIII, fig. 6) are chiefly garnet, scapolite, and quartz.

Garnet is the most abundant mineral, and in thin section is nearly colourless or of a pale pink. Qualitative tests indicate the presence of lime in considerable amount, with magnesia in less amount, and barely a trace of iron. The scapolite present has a birefringence about twice that of quartz, and has a much lower refractive index than the meionite of the crystalline limestone, the value being about 1·56. It is therefore a variety having the meionite and marialite molecules in about equal proportions. Other minerals present besides quartz are calcite, sphene (sometimes developed between calcite and ilmenite), ilmenite (somewhat altered to leucoxene), pyrite in small amount, and inclusions of zircon and apatite in scapolite. The complete absence of potash-felspar is a significant fact, and will be discussed later (p. 58). (For the quantitative mineral composition, see Table VI, p. 59.)

West of Memba, another quartz-garnet-scapolite rock occurs in contact with crystalline limestone. The rock is coarsely foliated, bands rich in pale-pink garnet and bright-green pyroxene alternating with colourless bands composed of scapolite and quartz. Sphene is an abundant accessory associated with the coloured minerals, and clusters of zircon in minute rounded grains are frequently present as inclusions in scapolite. A garnet-pyroxene-scapolite rock occurs north of the Norray Mountains, and is described with the other garnetiferous rocks of that district (p. 62).

Returning to the Ampwihi limestone, we may notice in fig. 4 (p. 38) that a pegmatite-dyke is shown cutting the limestone at the south-eastern corner. This pegmatite (*No. 223*) is composed of quartz and felspar (chiefly microcline, but with some oligoclase), with occasional flakes of muscovite and biotite, and numerous big crystals of titaniferous magnetite, many of them well-shaped.

The contact-rock (*No. 222*) between this magnetite-pegmatite and the limestone is a most interesting rock. It is composed very largely of black garnet, deep brown in thin section, with interstitial felspar of the same types as those of the pegmatite. Within the garnets, which are sponge-like in texture, numerous patches occur in which a deep-green augite predominates. Usually in these patches augite and magnetite (sometimes with sphene and garnet) are closely interlaced. Throughout the garnets inclusions of light-brown sphene are extremely abundant. In places apatite is present, and a few streaks or granular crystals of calcite still remain—generally near to, or associated with, the felspars. On the pegmatite side of the contact, quartz begins to appear and the garnet gradually dies out.

The garnet is a titaniferous andradite (melanite), and tested qualitatively it failed to give any indication of magnesium. Its mode of origin in association with sphene is suggested by an experiment of L. Michel Lévy,[1] who produced melanite and sphene

[1] C. R. Acad. Sci. Paris, vol. cxv (1892) p. 830.

by heating to 1200° C. a mixture of ilmenite, silica, calcium sulphide, and carbon. In the present case, the interacting compounds were probably titaniferous magnetite, quartz, and calcium carbonate. A possible equation illustrating the reaction is as follows:—

$$\underset{\text{Magnetite}}{FeO\,.\,Fe_2'''O_3} + \underset{\text{Ilmenite}}{FeO\,.\,TiO_2} + \underset{\text{Calcite}}{4CaCO_3} + \underset{\text{Silica}}{4SiO_2}$$

$$= \underset{\text{Andradite}}{Ca_3Fe_2'''(SiO_4)_3} + \underset{\text{Sphene}}{CaSiTiO_5} + 2FeO + 4CO_2.$$

In the presence of water or its equivalent at high temperature, some of the excess of ferrous oxide would probably be oxidized to magnetite (which is present) or to ferric iron, which could then make possible a further supply of andradite. In any case, some of the ferrous oxide would be required for the formation of augite, this mineral perhaps being produced by the interaction of ferrous oxide, silica, forsterite, and calcite, or of ferrous oxide and diopside (present in the limestone):—

$$\underset{\text{Ferrous Oxide}}{2FeO} + \underset{\text{Silica}}{7SiO_2} + \underset{\text{Forsterite}}{Mg_2SiO_4} + \underset{\text{Calcite}}{4CaCO_3}$$

$$= \underset{\text{Diopside}}{4Ca(Fe, Mg)(SiO_3)_2} + 4CO_2.$$

Any ferric oxide or alumina required for the actual composition of the augite would readily be forthcoming from constituents present in the interacting systems, such as magnetite and spinel.

The crystalline limestones of the district south of the Lurio, near its mouth, and that occurring along the military road about half-way between Itaculo and Ntia, call for no special description. As represented by the specimens collected, each is a pure-white saccharoidal marble with no minerals other than calcite, except for a few minute specks of pyrite in the Ntia-Itaculo example.

The crystalline limestone of the Nrassi Basin (*No. 93*) occurs in a long lenticular mass, that at first sight looks like a red felspathic pegmatite. The rock is a coarsely-granular dolomitic marble of pink colour, and contains in places small rusty cavities representing former pyrite-crystals. As in the case of the Monapo occurrence, the limestone has been cut by small intrusions of microcline-granite. In the neighbourhood of the limestone, the granite is characterized by numerous crystals of augite. A contact-specimen (*No. 94*) is largely composed of the same mineral in large, allotriomorphic, well-cleaved crystals, with which are associated calcite and oligoclase on the limestone side, and microcline, oligoclase, and quartz on the granite side.

In thin section the augite is seen to be bright green and free from the peripheral zone of hornblende that characterizes the augite of the associated granite. The maximum extinction $Z \wedge C$ observed is 44°; the mean refractive index, determined by the immersion method, is about 1·7; the maximum birefringence, measured by means of a quartz wedge in a slide of known thickness, is 0·025; and the optical character is positive.

A chemical analysis of the mineral gave the following results:—

Constituents.	Composition. Per-centages.	Composition. Molecular Proportions.	Constitution. Molecular Proportions.	Constitution. Per-centages.
SiO_2	51·10	852	$CaSiO_3$ = 378	43·85
Al_2O_3	3·77	37	$MgSiO_3$ = 274	27·40
Fe_2O_3	2·05	13	$FeSiO_3$ = 108	14·26
FeO	7·78	108	$NaFe(SiO_3)_2$ = 26	6·01
MgO	10·96	274		
CaO	21·21	378	$NaAl(SiO_3)_2$ = 4	0·81
Na_2O	0·91	15		
K_2O	trace	—	Al_2O_3 = 35	3·60
H_2O	0·87	—	TiO_2 = 3	0·21
H_2O at 110° C.	0·89	—	SiO_2 = 31	1·85
TiO_2	0·21			
				97·99
Total	99·75		Water	1·76
			Total	99·75

Specific gravity = 3·27.

The augite is thus mainly composed of diopside (85 per cent.), with a small excess of hypersthene and alumina that together constitute the hypothetical Tschermak molecule, and of ægirine (6 per cent.).

Origin of the Crystalline Limestones.

The occurrence of small and sparsely distributed bands of crystalline limestone interfoliated with gneisses that are apparently of igneous origin, at once raises a number of puzzling problems. Like the limestones of Ceylon,[1] the Mozambique examples are usually unassociated with schists of definitely sedimentary origin. Near Memba the association is with a hornblende-schist probably derived from a basic igneous rock. South of the Lurio the limestones occur with hæmatite-schists.

The probabilities are that the limestones are of exogenetic origin, for the gneisses are certainly intrusive into them, and have in places such a composition as to suggest that great but localized masses of limestone have been more or less completely assimilated. However, whether the limestones were vein-deposits or chemical or organic sediments, they must have been deposited in or on some other formation, and the main question is to determine where this formerly coexisting material is now to be found. A number of possibilities may be considered:—

(*a*) The materials of the rocks formerly coexisting with the limestones may have been above the present surface, and therefore now entirely removed by denudation, or they may be below the present surface, and therefore still unexposed.

(*b*) The materials of the coexisting rocks may be wholly or in part those actually exposed at the present surface; in which case the gneisses may be regarded either as the product of their refusion, or as composite rocks due to their assimilation by a granitic magma that advanced laterally from greater depths by a process of lit-par-lit injection.

[1] A. K. Coomaraswamy, Q. J. G. S. vol. lviii (1902) p. 424.

The last view is the one specially favoured, but further discussion will be reserved until the gneisses themselves have been described.

It remains to be considered why the limestones should persist at all. The probability is that argillaceous sediments are easily granitized; whereas limestones, by taking up a large amount of silica, become enclosed within a blanket of hornblende- or syenite-gneisses, or of less extensive contact-deposits no longer oversaturated[1] in silica, which preserve the interior of the limestones from further change. Limestone can always continue to exist, even at high temperatures, provided that the pressure of overlying rocks is greater than the dissociation pressure of calcium carbonate, and provided that free silica does not come into direct contact with it.[2]

V. The Gneisses and Gneissose Granites.

(1) Biotite-Gneisses and Gneissose Granites.

Biotite-gneisses are by far the dominant rocks of the country. The prevailing directions of foliation have already been stated, and attention has been drawn to the important fact that in certain inselberge the foliated structure gradually passes into granitic texture.

The essential minerals usually present are quartz, orthoclase, and microcline (sometimes perthitic), soda-lime felspar (generally oligoclase), biotite, and in rare cases muscovite. Accessory minerals are apatite, zircon, sphene, garnet, and iron-ores, including magnetite, ilmenite, and pyrite, and occasionally mispickel. Among the alteration-products, sericite derived from potash-felspar, and epidote derived from soda-lime felspar, are the chief; their distribution is purely local, and from a majority of the specimens collected they are absent. The rocks vary widely in structure, some being very coarsely banded, others finely foliated; occasionally augen-gneisses are found, and in other cases the disposition of the biotite is that expressed by Lœwinson-Lessing's term glomeroplasmatic.[3] By increase in the proportion of biotite, the gneisses pass locally into types that structurally are biotite-schists. By decrease in the proportion of biotite, accompanied by gradual loss of directive structure, the rocks pass into indubitable granites.

The following brief descriptions of characteristic types cover the whole range of specimens collected. For convenience, the percentage mineral compositions (determined by Rosiwal's method of micrometric analysis) are collected, together with the respective specific gravities and radium contents, in Table V, p. 53.

[1] S. J. Shand, Geol. Mag. dec. 5, vol. x (1913) p. 510.

[2] J. Johnston, Journ. Geol. Chicago, vol. xxiii (1915) p. 730, & J. Kœnigsberger, Econ. Geol. vol. vii (1912) p. 699.

[3] Trav. Soc. Nat. St. Pétersb. vol. xxx (1900) p. 208.

TABLE V.

MINERAL COMPOSITION AND RADIUM CONTENT OF BIOTITE-GNEISSES AND GNEISSOSE GRANITES (by Volume).

Minerals.	*Fine-grained.*	*Coarsely Banded.*			*Augen.*	*Glomero-plasmatic.*	*Granite.*	*Specific Gravities used for calculation.*
			Dark Band.	*Light Band.*				
	No. 49.	*No. 51.*	*No. 45 a.*	*No. 45 b.*	*No. 69.*	*No. 38 b.*	*No. 52.*	
Quartz	43	23	21	32	24	31	34	2·66
Microcline, perthite, and orthoclase	18	51	28	45	39	50	57	2·55
Oligoclase	27	9	16	10	21	6	2	2·65
Biotite	7	14	34	11	12	10	6	2·90
Muscovite	4	1	—	—	—	—	—	2·78
Accessories	1	2	1	2	4	3	1	3·8
Specific gravity:—								
Calculated	2·67	2·67	2·76	2·65	2·70	2·66	2·62	—
Determined	2·66	2·67	2·78	2·62	2·69	2·68	2·63	—
Radium in grms.$^{-12}$ per grm. of rock	n. d.	2·43	1·78	2·31	1·32	2·10	2·76	—

No. 49. 3 miles from Ibrahimo, on the Ibrahimo-Mosuril Road.
No. 51. 2 miles from Ibrahimo, on the road towards Mount Kwera.
No. 45. Bwibwi Valley, below the Namosa Hills.
No. 69. Ligonia River, below the Etipoli Hills.
No. 38 *b*. Slope of Mhala, Etipoli Hills.
No. 52. Slope of Mhala, above No. 38 *b*.

No. 49, from the Ibrahimo-Mosuril road, 3 miles from Ibrahimo, is a fine-grained, finely-banded gneiss, in which the foliation-planes are speckled with minute flakes of biotite that give to the rock in certain directions a characteristic 'pepper-and-salt' appearance. Under the microscope the minerals present are quartz, orthoclase (generally altered along cracks and cleavage-planes to sericite), microcline, oligoclase (holding secondary grains of epidote), biotite, and a little primary muscovite. Accessories are magnetite with rare examples of minute apatite and zircon. The rock has not suffered from granulation, and the minerals are free from strain-shadows. Either it received its foliation during crystallization, or it has been completely recrystallized since solidification. (See Table V, p. 53 and Pl. IX, fig. 1.)

No. 42 occurs immediately north of Murimitigri, where it alternates with quartz-mica-schists (see description of No. 172, on p. 45). The rock is almost identical with No. 49 in the hand-specimen, but in thin section it is seen to have the appearance of a micrographic granite that has crystallized from a viscous magma flowing under conditions of differential pressure. Long tongues of quartz, giving sharp extinction, alternate with a granular mosaic of microcline, of which the average grain is 2 mm. Neighbouring tongues of quartz extinguish together, or in some cases nearly together; but the microcline individuals show no such relationship. Evidently, the quartz was drawn out before its crystallization was completed. No. 172 shows the strikingly different effect produced by the same processes acting on a rock already in the solid state.

No. 54, from 2 miles west of Mitikiti, is another rock similar to No. 49 in the hand-specimen. It is, however, coarser in grain (average 4 mm.) and is richer in biotite. This rock is extensively riddled by narrow pegmatite-veins which make with it a composite gneiss. Similar rocks occur extensively around Yenyiga (*No. 43*).

No. 51, also from the neighbourhood of Ibrahimo (1¼ miles beyond Ibrahimo on the road towards Mount Kwera), illustrates the more coarsely-banded varieties of gneiss. Bands averaging a centimetre in width and composed mainly of quartz, microcline, and oligoclase, alternate with narrower bands in which biotite is the chief constituent. Muscovite is an accessory, and magnetite and apatite are also present. The microscopic texture is nearly granitic, differing only by the presence of occasional granulitic patches. (See Table V, p. 53.)

Nos. 41 & 53, from the Makwassi River, near its junction with the Bwibwi at the northern end of the Mtupa Pass, Ribawe Mountains, are still more coarsely-grained rocks, containing dark-green hornblende, and ilmenite associated with the biotite. The biotite-gneiss near the Ampwihi Crossing is an almost identical rock. No. 53 merges towards the 'augen' type by the swelling of the biotitic bands around islands of quartz-felspar aggregates.

No. 45, from the Bwibwi Valley, below the Namosa Hills, is a gneiss with bands excessively rich in deep-brown biotite. The mineral compositions of the micaceous and felspathic bands respectively are set forth in Table V (45 *a* & 45 *b*). The rock is quite fresh and, as in the case of most of the gneisses, the structure is slightly granulitic, while the biotites are elongated rather more than is usual in granites.

No. 69 is the best example of an 'augen-gneiss.' It occurs in the bed of the Ligonia River, opposite Fort Ligonia, and is a handsome rock, consisting of large pink felspathic 'eyes' and lenticles separated by dark-green streaks of biotite aggregates. Under the microscope the texture is distinctly seen to be more granular than are the banded varieties. The biotite aggregates are of a sage-green tint, and are associated with canary-yellow epidote granules, and rounded crystals of greenish-brown sphene. The epidote appears to be derived from a calcic plagioclase with oligoclase as the complementary product; for oligoclase crystals are abundant in the neighbourhood of the biotite streaks, and are invariably occupied by innumerable grains of similar epidote accompanied by wisps of muscovite. Orthoclase and microcline, in addition to quartz, make up the larger lenticles and 'eyes,' and are usually free from alteration, only a little secondary muscovite being occasionally present. (See Table V, p. 53.)

Augen-gneisses of the ordinary type are rare, the more common transition from coarsely-banded gneisses towards granites being through a series of types that may be described as glomeroplasmatic. In these rocks numerous clusters of small biotite-flakes are distributed through a granular mass of quartz and felspar. The biotite assemblages are generally so drawn out that the rocks have an irregular foliation. It is as though the darker streaks of the banded gneisses were broken up and distributed more evenly through the rock, the individual biotites still retaining a semblance of directive structure. By the loss of this structure, the rocks gradually pass into granulitic granites. Should porphyritic crystals of orthoclase be present, their alignment indicates the direction of flow, but otherwise the granites are almost devoid of the directive structures displayed by the gneisses.

No. 38 a, from the eastern slope of the Etipoli Hills, facing the Lalaua River, is a characteristic example of the glomeroplasmatic gneiss. It is noticeably less granulitic than the gneisses already described, and there are even patches in which the felspars (microcline) are idiomorphic. The biotite, like that of the Ligonia augen-gneiss, is a sage-green variety, and with it are associated hornblende of a darker green, greenish-brown sphene, and apatite. Quartz and oligoclase are also found near the biotite aggregates, while away from them the rock is almost exclusively composed of quartz and microcline, with occasionally a small flake of biotite. In the leucocratic parts of the rock rounded zircons are present as inclusions.

Similar rocks, but without hornblende, are found on the northern slopes of Mhala (*No. 38 b*), the middle member of the three peaks that constitute the Etipoli Hills; and they also occur on the southern slopes of those Hills, and on the south-western slope towards the Ligonia (*No. 70*). The same type of gneiss has also been found on the slopes of the Mwipwi Mountains, north-west of the Namieta River, and on the sides of Palalani Hill in the same neighbourhood.

No. 46 is an almost identical rock (somewhat richer in microcline) from another hill called Mhala, south of Nakavala's Kraal, near the source of the Ampwihi River. In the district north-east of the Ribawe Mountains the same rock-type was found in the Namosa and Ericola Hills, and on the southern slopes of the Muima Range.

To sum up, the glomeroplasmatic gneisses have been found only on the slopes of the hills and inselberge peaks. Towards the adjoining valleys or plains they merge outwards into banded gneisses that usually are conspicuously richer in biotite; while in the hills themselves, especially in the case of the larger mountain groups, they pass inwards into granites much poorer in biotite. These rocks will now be described.

No. 52 was collected from the upper slopes of Mhala (Etipoli Hills), where it occurs above the glomeroplasmatic gneiss *38 b*. It is a granulitic rock, pink to cream in colour, with occasional dark irregular patches containing flakes of biotite. Under the microscope these are seen to be of the same green as the flakes in *38 a* and *38 b*; but there is no alignment, and even the quartz-microcline mosaic that makes up the rest of the rock is devoid of any directive structure. The mineralogical composition is recorded in Table V (p. 53), and it shows in relation to the associated gneiss a marked deficiency in biotite and oligoclase. The accessories are mainly apatite and zircon, and a point of interest is that the biotites contain exceedingly dense pleochroic haloes.

No. 16 illustrates a granite, from the peak of Natupi (Namosa Hills, north-east of Ribawe), intermediate between the type just described and the glomeroplasmatic gneiss. The biotites are here in elongated groups, but otherwise the structure is that of an ordinary granite. Muscovite is present in addition to the usual minerals, and apatite and zircon are well represented as accessories.

A third example (*No. 66*) is provided by the rocks on the slope above the Base Camp at Sawa (Ribawe Mountains). This granite shows a slight foliation caused by the grouping of quartz and felspar (microcline and perthite) respectively in elongated aggregates. Biotite, however, does not make up more than 2 per cent. of the rock. Minute inclusions of zircon and rare apatite occur in the felspars, which are somewhat altered by kaolinization along cracks and cleavage-planes. Many of the cracks are also stained a deep red by the deposition in them of hæmatite.

The hillsides east of the Sawa Camp were too steep to be ascended, but large blocks which had fallen indicate that the granulitic type passes gradually into a grey porphyritic rock, having phenocrysts of felspar 2 to 5 cms. long in a coarse-grained (0·5 to 1 cm.) groundmass, which is granitic rather than granulitic. Grey porphyritic granites have also been recorded by Mr. D. A. Wray from the mountain groups farther west, such as the Inago and Mripa ranges, though he describes these peaks as consisting in the main of slightly-foliated biotite-granite passing into biotite-gneiss in the surrounding plains.

In Nyasaland, still farther west, Dr. A. R. Andrew & the late T. E. G. Bailey[1] described a similar passage from gneisses to granites :—

'Fine-grained gneisses with platy structure may be traced in the field through every gradation into augen-gneiss, which in turn is found to pass into slightly-foliated syenite or granite. . . . They [the foliated plutonic intrusions] consist, for the most part, of granite or syenite with well-developed porphyritic crystals of felspar. The granites rarely contain much quartz, and resemble the associated syenites in the abundance of microcline, and the occurrence, at times, of perthitic felspars.'

The Nyasaland gneissose granites appear to differ from those of Mozambique, only in the smaller proportion of quartz and in their greater areal extent.

Prof. J. W. Gregory & Mr. G. W. Tyrrell[2] have described gneisses from the Angola province of Benguella that bear a close resemblance to the biotite-gneisses of Mozambique described above. After describing the transition from orthogneisses to biotite-schists, Mr. Tyrrell writes (*op. cit.* pp. 538–39) :—

'Another mode of transition is into a group of gneisses with very pronounced cataclastic textures, showing all gradations to mylonite.'

Several specimens of the gneisses from the Mkwassi River district (along the northern borders of the Ribawe Mountains; see map, Pl. XI) illustrate the beginning of a similar phenomenon which recalls the 'trap-shotten' structure described by Sir Thomas Holland.[3]

[1] Q. J. G. S. vol. lxvi (1910) pp. 194–95.

[2] Trans. Roy. Soc. Edin. vol. li, pt. 3 (1916) pp. 495 & 537. For other references and descriptions of African gneisses and gneissose granites, see C. B. Horwood & A. Wade, Geol. Mag. dec. 5, vol. vi (1909) pp. 455, 497, & 543.

[3] Mem. Geol. Surv. India, vol. xxviii (1900) p. 198.

No. 53, already mentioned as a coarse-grained banded gneiss, has been severely crushed. The felspars are strongly cleaved, and the quartz is broken into angular or slightly-rounded fragments. Fractures, cleavages, and boundaries between adjacent minerals are marked by thick lines of dense black dust, the nature of which is not revealed by the microscope. In places, there are pockets of material entirely reduced to this same black substance.

Lines of mylonized material, however, such as are found west of Ochilesa in Benguella, have not yet been detected in Mozambique. It is interesting to notice that *No. 53* occurs in the Mkwassi Valley, where it is met by the fault that borders the eastern walls of Ribawe. Although no definite evidence was collected along the Mkwassi Valley itself, it seems probable, in view of the faulted boundaries of the eastern and southern walls, that the northern boundary, determined by the Mkwassi Valley, is also a faulted one.

(2) Heavy Residues from the Biotite-Gneisses.

During the course of prospecting work in Mozambique, considerable quantities of rocks of various kinds were crushed in a large iron mortar by native servants, and the crushed material was afterwards panned by Mr. E. W. E. Barton (the leader of the Expedition) or myself, in the hope of tracing minerals of economic value. Although we were generally unsuccessful in this particular quest, we never failed to obtain a residue rich in zircon, which has provided valuable material for an attempt to determine the age and correlation of the rocks concerned.

From the gneissose granite of Sawa the minerals obtained were magnetite and ilmenite in small quantity, the latter being more abundant; zircon in rounded grains with occasional sharply terminated prisms, small rounded prisms of apatite less numerous than zircon; and a few examples of sphene, epidote, garnet, and rutile.

The gneissose granite of the Etipoli Hills gave a similar but more abundant residue. Among the opaque minerals pyrites and mispickel were detected in small quantities, while apatite was more plentiful relatively to zircon than in the Ribawe rock.

From the biotite-gneisses the relative proportion of apatite, garnet, rutile, and sphene was greater than in the granitic facies, and microscopical examination shows that apatite and sphene are associated more particularly with the bands rich in biotite. The gneisses of the Ligonia and Lalaua rivers proved to be unusually rich in pyrites and mispickel, this being a feature already mentioned as characterizing the rocks of the Etipoli Hills which lie between these two rivers. Monazite, although a common constituent of the concentrates from many of the river-sands, has not been detected in the gneisses, despite the fact that it was specially looked for in view of its general widespread occurrence in granites.[1]

[1] O. A. Derby, Min. Mag. vol. xi (1897) p. 304.

(3) Hornblende-Gneisses and Amphibolites.

Attention has already been drawn to the association of hornblende-gneisses with crystalline limestones. The most complete case studied in the field was that of the Ampwihi district (figs. 4 & 5, pp. 38–39), in which a gradual transition from biotite-gneiss to hornblende-gneiss and garnetiferous amphibolite was traced as the limestone was approached from the west. The biotite-gneisses are of the coarsely-banded type, rich in microcline; and, as the limestone is approached, hornblende, accompanied by accessory sphene, makes its appearance among the streaks of biotite. As hornblende becomes more abundant, the rocks lose their banded and streaky appearance, and show only a slight foliation due to the elongation of some of the minerals in a common direction. Still nearer the limestone the rocks become heavy and granulose without distinct foliation, their dark surface, when freshly broken, presenting a speckled appearance due to the presence of minute grains of felspar. These rocks, which are neither schistose nor gneissose in structure, are referred to as amphibolites. Garnet appears in the amphibolites on the limestone side, and by increase of this mineral the rocks merge into quartz-garnet-scapolite rock (*No. 193,* described on p. 49).

No. 189 may be taken as a characteristic example of hornblende-gneiss, showing foliation by the elongation of its minerals. In thin section it is seen that the hornblende is slightly elongated parallel to the cleavages, and that in many cases the cleavages and twin lamellæ of the felspars are approximately parallel to the same direction. The hornblende is chiefly a brown variety, but it is very patchy in colour and passes through pale-green to a nearly colourless tint. Minute apatites are present as inclusions, but the chief accessory, around which the hornblende is frequently moulded, is sphene. The rest of the rock, with the exception of a few sparse shreds of biotite, is composed of rounded interstitial quartz and felspar, the latter being beautifully fresh. Two thirds of the felspar is a soda-lime variety approaching labradorite in composition, while the other third is perthitic orthoclase or microcline. (Pl. IX, fig. 2.)

No. 194 represents the granular non-foliated type, distinguished as amphibolite. The hornblende is of the same brown colour, but is more abundant and less patchy than in No. 189; and instead of sphene inclusions, titaniferous magnetite is present as the chief accessory mineral. Potash-felspars and biotite have now entirely disappeared, and the soda-lime felspar is labradorite, slightly more calcic than in 189. Another feature of interest is the incoming of a very pale-pink garnet which generally forms a narrow border between hornblende and felspar. The garnet is identical in appearance with that of the quartz-garnet-scapolite rock which intervenes between the amphibolite and the forsterite-marble. (Pl. IX, fig. 3.)

The mineral compositions of the chief rock-types, from biotite-gneiss to the quartz-garnet-scapolite rock, have been measured by the Rosiwal method and are set forth in Table VI (p. 59) with the specific gravities in each case, as also the radium-content where this has been determined.

The gradual loss of quartz and the disappearance of the potash minerals—orthoclase, microcline, and biotite, as the limestone is approached, are offset by the steady increase of the lime-bearing minerals: soda-lime felspars, hornblende, garnet, and scapolite. The loss of quartz is a necessary result of the interaction between a granitic magma and limestone, and calls for no further comment, except that it may be pointed out that the increase of quartz in the garnet-rich rock relative to the amphibolite is to be correlated with the fact that garnet is an orthosilicate and that hornblende is a metasilicate. Thus, if each rock had for its formation an equal supply of silica, the garnet would fix much less than the hornblende, leaving the garnet-rock relatively richer in free silica than the amphibolite. The disappearance of potash is more

TABLE VI.

MINERAL COMPOSITION (BY VOLUME) OF ROCKS FROM THE AMPWIHI DISTRICT.

(To illustrate the transition types between biotite-gneiss and crystalline limestone. See fig. 5, p. 39.)

Minerals present.	*Biotite-Gneiss.* *No. 196.*	*Biotite-Hornblende-Gneiss.* *No. 202.*	*Hornblende-Gneiss.* *No. 189.*	*Garnetiferous Amphibolite.* *No. 194.*	*Quartz-Garnet-Scapolite-Rock.* *No. 193.*	*No. 221.*
Quartz	27	24	12	9	13	*Crystalline Limestone.*
Orthoclase, Microcline	55	43	14	—	—	
Oligoclase	2	6	—	—	—	
Andesine, Labradorite	—	—	28	12	—	
Garnet	—	—	—	11	61	
Scapolite	—	—	—	—	16	
Calcite	—	—	—	—	3	
Biotite	14	17	2	—	—	
Hornblende	—	7	41	63	—	
Accessories	2	3	3[1]	5	7	
Specific gravities	2·68	2·71	3·04	3·10	3·18	
Radium in gms.$^{-12}$ per gm. of rock	2·61	1·77	2·13	n. d.	n. d.	trace

[1] *No. 189* was crushed and panned in the field, and the heavy residue collected is found to contain sphene as the most abundant mineral. Apatite is also plentiful, and garnet and epidote are well represented. Rutile and zircon are comparatively rare. The opaque constituents, which make up about a third of the whole residue, consist mainly of ilmenite together with a little magnetite.

significant. It is clear that the incoming of calcic plagioclase and garnet (and probably that of hornblende also) implies the addition of alumina as well as of silica. The chief source of such alumina is certainly to be found in the material in the magma that, away from the contact, crystallized as potash-felspar and biotite. Evidently, under the physico-chemical conditions that prevailed, calcium carbonate had a claim on alumina superior to that of potash. Whether orthoclase molecules or potassium-aluminate molecules had formed before the interaction with calcite, does not matter.

The constituents of these molecules were there, together with an excess of silica, and potash was driven out, just as in the fusion of a rock for alkali determinations by the Lawrence-Smith method the alkalies are liberated from their alumino-silica union by interaction with calcium carbonate at a red heat. The following equation indicates the kind of interaction that may have taken place:—

$$\underset{\text{Constituents of Orthoclase}}{2(K_2O \cdot Al_2O_3 \cdot 6SiO_2)} + \underset{\text{Calcite}}{11CaCO_3}$$

$$= \underset{\text{Grossularite}}{Ca_3Al_2(SiO_4)_3} + \underset{\text{Anorthite (for plagioclase)}}{CaAl_2(SiO_4)_2} + 7CaSiO_3 + 2K_2CO_3 + 9CO_2.$$

The figures in Table VI further suggest that, although the constituents of albite have undergone a similar change, it must have been to a less degree and also at a later stage. From Nos. 202 to 189 there is a considerable increase of the albite molecule, which is probably more apparent than real: that is to say, the increase is relative to quartz and orthoclase, and may not be an absolute increase. From Nos. 189 to 194 there is a marked decrease in albite, the change accompanying an increase of lime minerals. Clearly the lime took the place of potash before soda was appreciably displaced, and throughout the transition, sodic minerals do not entirely disappear until the forsterite-marble itself is reached. The selective preference of lime for soda is possibly related to the fact that these constituents form isomorphous compounds in the felspars and scapolites. There is, moreover, experimental proof that the selection takes place, and that soda is retained by limestone to a greater extent than potash. K. Endell[1] studied the interaction between molten soda-microcline and limestone immersed within the viscous mass. On cooling, the limestone was found to have been replaced by a yellow glass, which, when analysed, proved to be much richer in soda relatively to potash than the original felspar.

The changes accompanying the transition described above clearly result in the liberation of solutions rich in potash, and, to a less extent, in soda. Of the effects of these solutions there is now no evidence; but in other localities they may provide a clue towards solving the difficult problem of the origin of highly-potassic leucite-bearing lavas, such as those of the Bolsena-Vesuvius district.

In the Haliburton-Bancroft district of Ontario, F. D. Adams & A. E. Barlow[2] have described the formation of amphibolite by the interaction of granitic magma with the invaded Grenville Limestone; but there the relations are more complex, and the transitions are not so regular as that described above. They say:

> 'The crystalline limestone can be seen, under the influence of the granite intrusion, to have changed into a typical hornblende-felspar amphibolite, passing through the intervening stage of a pyroxene-scapolite-hornblende-felspar amphibolite (pyroxene-scapolite-gneiss).'

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[1] Neues Jahrb. vol. ii (1913) p. 152.

[2] Geol. Surv. Canada, Mem. No. 6, Pub. 1082 (1910) p. 104.

The authors also tabulate a series of analyses (*loc. cit.*) illustrating the transition, and these show a regular decrease in potash as the limestone is approached, while soda first increases and afterwards decreases even more rapidly than the potash. In a later study of the region, W. G. Foye[1] correlates the liberation of alkaline solutions by amphibolitization with the production of nepheline-syenites.

The hornblende-gneisses and amphibolites on the eastern side of the Ampwihi limestone are similar to those now described, except in the general absence of garnet from the specimens collected.

In none of the other localities where hornblende-gneiss and amphibolite were found was it possible to trace the transition from biotite-gneiss on the one hand, or towards crystalline limestone on the other, as completely as in the Ampwihi district.

Hornblende-gneiss occurs in the bed of the Nrassi River near the camp south of Ndrapo, associated on both sides with biotite-gneisses that have been thickly threaded by later pegmatites.

The rock (*No. 29*) is dark and heavy (S.G. = 3·07), and is slightly foliated owing to the elongation of the hornblende individuals and the arrangement of both white and coloured minerals in sub-parallel drawn-out aggregates. The hornblende is a dark greenish-brown strongly-pleochroic variety, in places, however, becoming nearly colourless. It is slightly more abundant than the felsic minerals, which are beautifully fresh, and consist of labradorite and quartz in the proportion of about two to one. The accompanying accessories are (in order of abundance) sphene, apatite, and zircon.

A similar rock (*No. 58*), but exhibiting less foliation and containing a little biotite in addition to hornblende, occurs in association with crystalline limestone (*No. 93*, p. 50) in a gully that carries part of the Ericola drainage to the Nrassi. Towards the limestone, the gneiss loses its distinctive foliation, and becomes a thoroughly massive amphibolite (*No. 59*) free from biotite.

On the steep slopes near the Sawa caves (east of Sawa base-camp), a coarsely foliated hornblende-gneiss (*No. 48*) occurs, cut by later sill-like intrusions of augite-granite. The minerals present are the same as in the Nrassi-River example, but hornblende is more abundant, making up about 70 per cent. of the rock. The specific gravity is 3·10. This rock closely resembles the hornblende-gneiss found by Mr. R. L. Reid in contact with the Monapo-River crystalline limestone (p. 46).

(4) Garnetiferous Gneisses and Eclogite.

The garnetiferous hornblende-gneiss of the Ampwihi district has already been described (p. 58), and two scapolite-bearing garnet-rocks occurring in the Ampwihi and Memba districts have been dealt with as products of contact between limestone and gneiss (p. 49). A third scapolite-bearing rock from the district north of the Norray Hills is described below: for, as crystalline limestone has not yet been found in that neighbourhood, its origin cannot demonstrably be referred to contact processes.

[1] Am. Journ. Sci. ser. 4, vol. xl (1915) p. 427.

The biotite-gneiss (*No. 96*) of the Norray district is a banded variety rich in brownish-green biotite, and containing a considerable amount of oligoclase. Quartz and microcline are the remaining essential constituents, and, seen in thin section between crossed nicols, these minerals exhibit extreme granulation along certain bands, oligoclase having suffered to a much smaller extent. Associated with this gneiss are garnetiferous rocks of three distinctly different types.

No. 97 is a garnetiferous biotite-gneiss differing mineralogically from the biotite-gneiss described above only in the presence of crystals (6 to 8 mm. in diameter) of pale-pink garnet, and of a plagioclase that has the composition of calcic andesine instead of oligoclase. Wisps of biotite are frequently moulded on the periphery of the garnets, and rounded crystals of biotite are sometimes present as inclusions. It is thus possible that biotite may have contributed the pyrope and almandine molecules of the garnet. A qualitative analysis of the latter indicated the presence of magnesia, iron, and also lime. In the absence of definite field evidence, it is unfortunately not possible to discuss further the origin of the garnet. The rock, as a whole, clearly differs chemically from the normal biotite-gneiss in being richer in lime-bearing minerals. (Pl. IX, fig. 4.)

The next rock to be described from this region is a dark and heavy skarn-like rock (*No. 78*) composed of pale-brown garnet and bright-green pyroxene with interstitial scapolite (near to meionite) and quartz. As in the scapolite found in the other garnetiferous rocks of Mozambique, the mineral contains rounded inclusions of zircon. (Pl. IX, fig. 6.)

Finally, a beautifully foliated eclogite (*No. 77*) is represented, composed of pale-pink garnet (wine-colour in the hand-specimen), green amphibole, and colourless pyroxene. Rutile is present as inclusions in all three minerals. (Pl. IX, fig. 5.)

The only other garnetiferous rock brought back [1] is a garnet-bearing gneiss collected on the old military road from Fort Chinga towards Mount Mushima. This rock contains alternating bands rich in quartz and microcline respectively, grains of deep-red garnet (pink in thin section) being distributed through both, though more abundantly in the quartz-rich bands, while biotite is confined almost entirely to the felspathic bands. In the neighbourhood of the garnets, magnetite and apatite are plentiful, together with occasional rounded grains of zircon, and the same accessories are present as inclusions. A curious feature of the garnets is the frequent presence around them of a narrow selvage of orthoclase. The garnets are frequently oval in shape, or embayed by quartz individuals, so that they send out stumpy arms with blunt terminations. The long axes of the oval arm-shaped sections are generally parallel to the foliation of the rock, and in these cases the orthoclase rims first thicken out as they approach the terminations and then come sharply to a point. This feature to some extent supports the surmise hinted above, that garnet may have derived its ferromagnesian constituents from biotite, for such a transformation would be accompanied by the liberation of the constituents of orthoclase.

[1] Several others were collected by Mr. D. A. Wray, but these unfortunately were lost on the homeward journey.

(5) Origin of the Gneisses.

The question of the origin of the gneisses, so far as it can be discussed here with the data available, reduces itself to that of the origin of the biotite-gneisses. The hornblende-gneisses and amphibolites, and some of the garnetiferous rocks, have already been interpreted as products of interaction between granitic magma and crystalline limestones. Other members of the garnetiferous rocks cannot yet be so readily disposed of. They may be in part composite rocks derived from the contact with, or assimilation of, limestones or former calcareous sediments which have not been seen, or of which no other relics remain. In others, the garnets may be derived in part by the action of high pressure[1] from biotite, and in the case of eclogite the rock may be due to high-pressure metamorphism of gabbro or other igneous rock of similar composition. In the absence of detailed field evidence, these possibilities cannot yet be profitably discussed. The biotite-gneisses, however, have been extensively studied, and, as they constitute the chief formation of the country, the question of their origin calls for some attention, even though a final conclusion cannot be arrived at with demonstrable certainty.

Summing up the facts already recorded in the preceding pages, we have the following data on which to build :—

(*a*) Near the coast the gneisses are interfoliated with schists and sediment-gneisses that are the representatives of ancient arenaceous rocks.

(*b*) Near the coast (in the north only) and in various localities inland, the gneisses are interfoliated with bands of crystalline limestones presumably of exogenetic origin.

(*c*) Except in the neighbourhood of certain inselberg peaks, the banding or foliation of the gneisses almost everywhere follows linear or broadly curving planes, neither strike nor dip (which is usually low) being generally subject to sudden variations.

(*d*) On the slopes of certain inselberge, the foliation sweeps round the hills in closed curves and dips quaquaversally from the summit.

(*e*) In a few cases it has been observed that the banding dies away as inselberg slopes are approached, the gneisses becoming glomeroplasmatic, and finally passing into gneissose granite (porphyritic or non-porphyritic), or into granulitic granite devoid of foliation, the change being accompanied by a marked loss of biotite.

(*f*) The biotite-rich gneisses are (so far as measurements have been made) poorer in zircon and radium than their leucocratic associates.

The presence near the coast of metamorphosed rocks that are referred to arenaceous sediments of various types, combined with the occurrence of limestones in the north and interior, suggests that, unless the land from which they were derived was of very different average composition from those of later periods, large quantities of argillaceous sediments must have been deposited concomitantly. The absence of any direct metamorphic representatives of such rocks at once raises the question whether they

[1] The condition suggested is one in which hydrostatic pressure is high, while shearing stress, which presumably would favour the continued existence or production of biotite, is relatively unimportant.

may not enter into the composition of the biotite-gneisses. The latter would then be composite rocks like the hornblende-gneisses, and their richness in biotite compared with the gneissose granites into which they pass, would thus find a simple explanation.

The distribution of radium in the gneisses helps to support this view. The general argument may be stated as follows[1]:—

On an average granites contain three times as much radium as argillaceous sediments and mica-schists; while gneisses, apparently of igneous origin, average only twice as much radium as schists—a fact which harmonizes with the possibility of their composite origin. In all these rocks a considerable proportion of the radium-content occurs in the biotite, but gneisses are generally richer in biotite than granite, thus implying that the biotites of granites are much richer in radium than those of gneisses and richer still than those of schists. Thus, if the biotites of gneisses are relatively rich in radium, a primary igneous origin is suggested; while on the other hand, if they are relatively poor in radium, a sedimentary or composite origin may be suspected. In neither case, however, does the evidence amount to actual proof.

For the Mozambique rocks, part of the radioactive evidence has been already given in Tables V & VI. The figures for Nos. 45 *a* & 45 *b* are particularly significant. The following averages bearing on the subject are given for completeness. In each case the radium-content is stated in grams per billion grams of rock or mineral, and, with the exceptions of averages 1–3 and 9, the materials examined were from Mozambique.

Table VII.

Average Radium-Content of Granites, Gneisses and Schists, and of Biotites separated from them.

			Grm. $^{-12}$ *per grm. of Rock.*
(1)	Granites	average	3·0
(2)	Gneisses	,,	2·0
(3)	Mica-schists	,,	1·0
(4)	Three specimens of sediment-gneisses and schists	,,	1·34
(5)	Fourteen specimens of biotite-gneiss	,,	1·87
(5 *a*)	Four specimens of biotite-gneiss	,,	2·11
(6)	Three specimens of gneissose granite	,,	2·64
(7)	Six specimens of granulitic granite (of later age than the preceding)	,,	3·24
(8)	Four specimens of biotite from gneissose granite	,,	8·00
(9)	Biotites from mica-schists	,,	2·00
(10)	Six specimens of biotite from biotite-gneiss	,,	2·63

[1–3. See J. Joly, Phil. Mag. ser. 6, vol. xxiv (1912) p. 694; A. Holmes, 'Science Progress' 1914, No. 33, p. 35. 4–10. Analyses published for the first time.]

In every case the results for gneisses—whether the gneisses themselves or their biotites are considered—fall between those for granites and mica-schists. The simplest explanation is that the

[1] Contribution to the discussion on Prof. G. A. J. Cole's paper on 'A Composite Gneiss near Barna' Q. J. G. S. vol. lxxi (1915–16) pp. 186–87.

radium-content of an invading granitic magma (now represented by the gneisses) was diluted by the intimate penetration of the magma into less radioactive rocks. The abundance of biotite in many of the gneisses, combined with the known existence of older arenaceous and calcareous rocks, leads to the conclusion that the rocks penetrated were probably mica-schists derived from argillaceous sediments.

If this view be correct, then we may interpret some of the inselberg peaks as foci of granitic intrusions, indicating, like the 'batholitic foci' of F. D. Adams & A. E. Barlow,[1] the axes of the greatest upward movement, and along which the magmas were most rapidly supplied. W. G. Foye has recently put forward a similar hypothesis in explanation of the gneisses and so-called 'batholiths' of the Haliburton-Bancroft area:[2]

> 'The granitic gases and fluids must have had their origin at certain definite points. At these points they were pushed upward and sideways along planes of easy parting and a pine-tree structure was produced. In general, the increase of material due to the addition of granite would produce a doming at the centre of intrusion with quaquaversal dips away from these points. However, the subsidence of the magma on cooling might very possibly cause a collapse of the dome, and irregular dips would result.'

A corollary from this conception of the mechanism of intrusion and composite nature of the gneisses, is that the foliation and banding of the latter are due essentially to intimate penetration or lit-par-lit injection, accompanied by complete recrystallization of the invaded formations. The frequent arrangement of inselberg peaks in linear series parallel to the prevalent strike of the foliation and themselves constituting gneissic anticlines (see map, Pl. XI), points to the existence of tangential pressure acting at right angles to the north-east and south-west or north-and-south directions, and sufficiently intense to cause the uprising magmas to elongate themselves along the direction of strike. This pressure, however, was not so severe as to prevent the local formation of closed curves of foliation due to the superior pressure of the upward flowing magmas. Crystals grow most rapidly in the directions at right angles to that of the pressure,[3] and thus biotite, which is the most conspicuously elongated mineral, generally follows the prevailing direction of strike controlled by moderate tangential pressure. In the neighbourhood of uprising magmas, however, the 'shouldering pressure' would assume control and lead to tangential elongation around the dome-shaped granite foci.[4] Moreover, if tangential pressure had been the only controlling influence, the biotite-flakes should be frequently in approximately vertical positions, so that the prevailing dips of the foliation-planes would be high. On the contrary, the dips over

[1] Geol. Surv. Canada, Mem. 6, Pub. 1082 (1910) p. 19.
[2] Journ. Geol. Chicago, vol. xxiv (1916) p. 790.
[3] G. F. Becker & A. L. Day, Proc. Wash. Acad. Sci. vol. vii (1905) p. 283.
[4] W. J. Miller, Journ. Geol. Chicago, vol. xxiv (1916) p. 596.

large areas of country are low, pointing to a lateral flow of the magmas from elongated regions of upward flow, and to the existence of a considerable pressure from above, which can have been caused only by the weight of superincumbent formations. The dips and strikes of the foliation-planes thus lead us to the conception of lateral interpenetration of schistose formations by granitic magma, fed from elongated regions of dominant upward intrusion.

However, the parallel structure of the gneisses may perhaps be otherwise explicable. It is possible that biotite-crystals, formed at an early stage in a viscous flowing magma, would be to some extent segregated and drawn out into long streaks, between which the later minerals would be obliged to crystallize. The richness of the gneisses in biotite would thus correspond with the more mafic character of the portions of the magma first to crystallize, as compared with the later parts, now represented by the leucocratic gneissose granites of some of the inselberg peaks. In addition, the later parts of the magmas generally are relatively enriched in 'mineralizing agents' or volatile fluxes,[1] and it is with the rocks the formation of which has been controlled by such fluxes that the more radioactive minerals are usually associated.[2] It might therefore be anticipated that the leucocratic facies of the gneiss should be richer in radium than the biotite-rich facies. Opposed to this view, which explains the structures by differentiation and viscous flow, is the fact that the granitic cores show no signs of having crystallized under the special influence of volatile fluxes. The textures are granulitic, and the minerals, except for porphyritic crystals, are small, and give the impression of having crystallized in a stiffening viscous magma that flowed with difficulty. Pegmatites, when present, are always of later age. Moreover, the hypothesis fails to throw any light on the peculiar association of the crystalline limestones with the gneisses.

Considering all the evidence and the probabilities of the case, it is thought possible that—

(1) the gneisses were produced by the concordant injection of granitic magma into a series of pre-existing sediments or their metamorphosed equivalents;

(2) the greater part of these sediments, being argillaceous, became granitized with such ease that, apart from the richness in biotite of some of the gneissic bands, they have left no recognizable traces of their former existence;

(3) when limestones or dolomites were encountered, the granite was partly desilicated, and formed hornblende-gneisses, amphibolites, and garnetiferous rocks, and in many instances these rocks preserved a core of crystalline limestone from the further attack of the magma;

(4) the gneisses may be interpreted as composite rocks in which, as a rule, the granitic element predominates.

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[1] On the other hand, C. N. Fenner (Journ. Geol. Chicago, vol. xxii, 1914, p. 594) believes that the mechanism of lit-par-lit injection depends on the fluxing power of pneumatolytic gases which go *in advance* of the main granite magma, and so prepare the way for its penetration.

[2] A. Holmes, 'Science Progress' 1914, No. 33, p. 19.

VI. The Granulitic Granites and Pegmatites.

The later granites of Mozambique never occur in large intrusions such as have been described from other African areas.

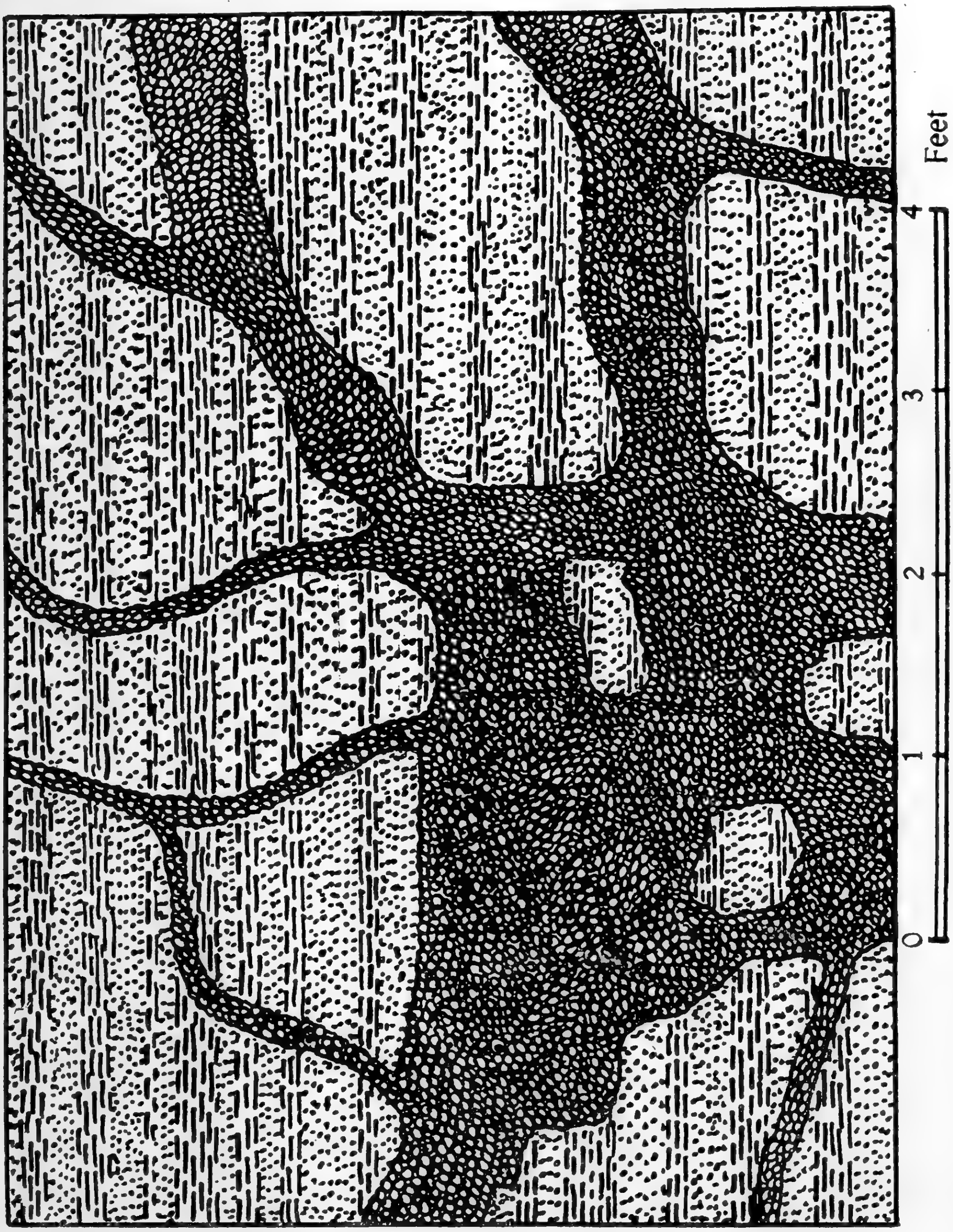


Fig. 7.—*Granite intrusion: vertical section exposed on the slopes of Mhala, Nakavala.*

Occasionally they form the cores of some of the inselberg peaks, and, although they may resemble very closely the granulitic facies of parts of the older gneissose granites, their relative age can generally be easily determined from the fact that they cut across the gneissic foliation, and often contain inclusions of the associated gneiss. Fig. 7 (p. 67) is a drawing of a granulitic granite-intrusion exposed on a vertical face of the western slope of Mhala, Nakavala. The entire hill is riddled with innumerable tongues and apophyses, sometimes parallel to the foliation, but often cutting across obliquely or at right angles. Only on the lower slopes is it possible to find greater masses of granite from which the long irregular arms have sprung, and even these greater masses are rarely more than a few feet across. In many places thin aplitic veins have been injected in lit-par-lit fashion along the foliation-planes, converting the rock into a banded composite gneiss. In other places, the tongues and apophyses thread the older rocks so abundantly that the foliation is extremely contorted, or becomes so confused that it almost ceases to exist.

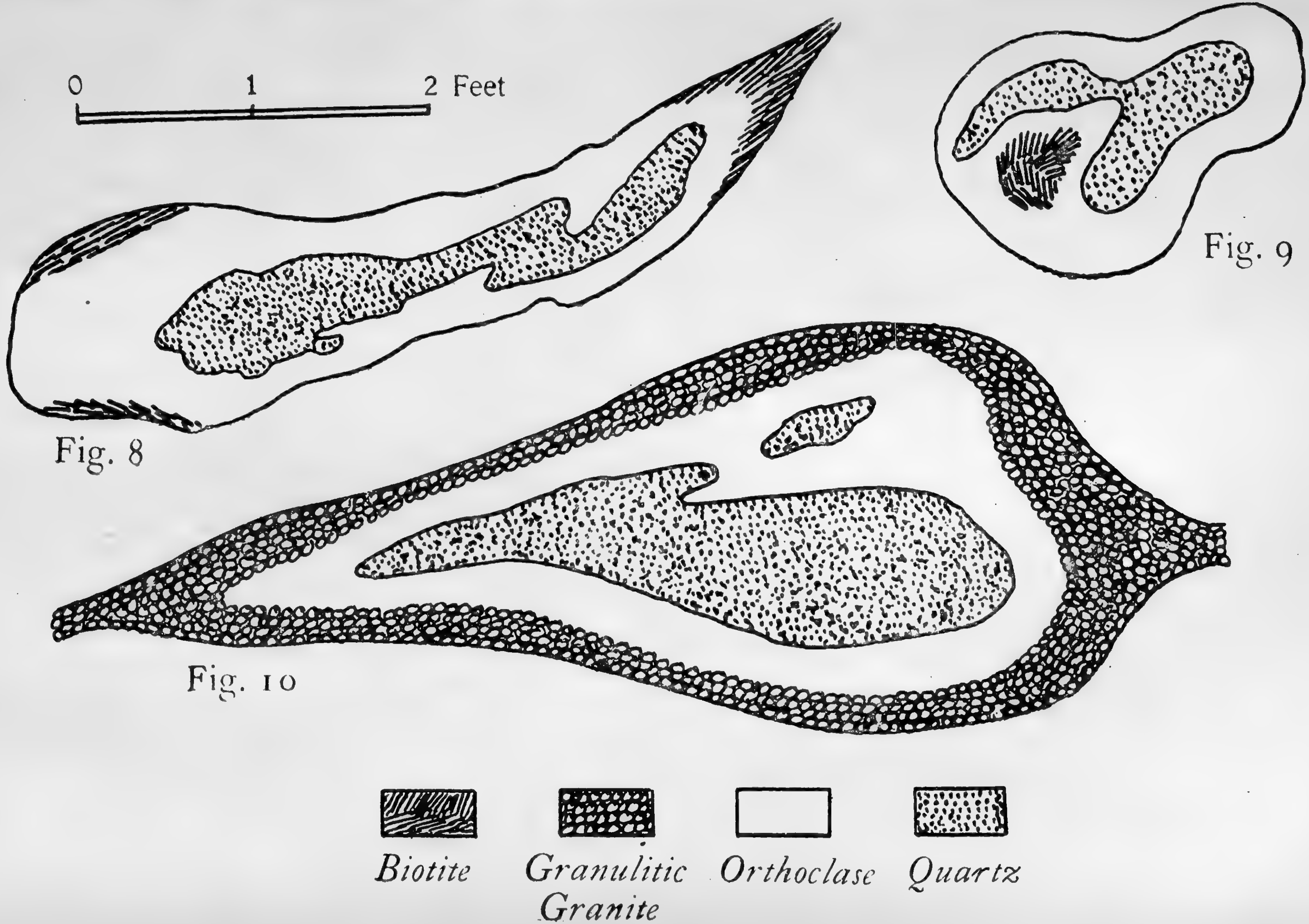
Farther west the intrusions become larger and more continuous. The augite-granite above the Ampwihi crossing (figs. 4 & 5, pp. 38–39) is a good example, and will be described below. North of the Ribawe Mountains, the Karji and Koldwi Hills are largely made up of an intrusive granulitic granite, though numerous inclusions of gneiss still remain. In the Ribawe Mountains themselves, occurs a biotite-granite with porphyritic crystals of perthitic orthoclase, and similar intrusions were noted in many of the hills surrounding the Nrassi basin. In the plains of the Nrassi, the granite is generally found in sill-like masses rarely exceeding 2 or 3 feet in thickness, or as larger intrusions having a laccolithic form.

It is a noteworthy fact that the smaller intrusions are nearly always free from biotite, although many of them carry small crystals of hæmatite. The larger intrusions have generally a small proportion of biotite, while those that have traversed hornblende-gneiss, or have come into contact with crystalline limestone, are characterized by the presence of augite as the chief coloured mineral.

(1) Pegmatites.

Pegmatites are frequently associated with the granulitic granites, from which they are distinguished by the tendency of minerals of the same kind to group themselves together in irregularly-shaped masses. Quartz, occupying the interior of the mass, is generally coarsely granulitic in texture, and felspar less so; while, if biotite be present, it occurs in pockets carrying large strongly-cleaved individuals, either enclosed within the felspar or arranged around the periphery of the intrusion, especially in the neighbourhood of angular terminations (see figs. 8 & 9, p. 69). Between the central quartz aggregates and the surrounding orthoclase, there is frequently a narrow granulitic zone composed of quartz and orthoclase in about the same proportions as in graphic granite. In other cases, a similar zone containing flakes of biotite arranged in haphazard fashion, surrounds the felspar (fig. 10, p. 69).

Figs. 8–10.—*Structures of pegmatites of irregular pipe-like habit: inclined sections exposed on the western slopes of Mhala, Nakavala.*



There can be no doubt that the pegmatites are of practically the same age as the granites with which they are associated. The peripheral and internal quartz-orthoclase zones have a texture identical with that of the tongues and apophyses of granulitic granite. Although the pegmatites are generally seen cutting gneiss, they may sometimes be observed, as on the lower slopes of Mhala (Nakavala), as 'contemporaneous veins' swelling and thinning in irregular fashion within the larger granite masses, but without definite contacts. The pegmatites are distinguished from those of later age—which occasionally cut the earlier ones—by their zonal structures and granulitic textures, and by their curious mode of occurrence. While the granulitic granite tongues are approximately of dyke- or sill-like habit, the pegmatites have often a pipe-like habit of constantly varying cross-section, sometimes oval, sometimes elongated, in places swelling out to a diameter of several feet, and in others almost disappearing. The axis of intrusion is generally more nearly vertical than horizontal, as though the magma had fluxed its path upwards. Supporting this view—and also indicating that the country-rock was itself moderately hot—is the fact that the foliation of the gneisses traversed by the pegmatites is turned upwards, so that within half or a quarter of an inch from the contact, it becomes nearly parallel to the outer surface of the pegmatite body. The later pegmatites cut the gneisses without deviating the foliation and exhibit a totally different habit, for they occur in broad dyke- or sheet-like bodies that can often be traced for considerable distances, both vertically and along level ground. Their minerals are either graphically intergrown on a coarse scale, or are segregated in large individuals, but without zonal arrangement.

(2) Granites and Biotite-Granites.

On the slopes near the foot of Mount Kwera (Monapo River, fig. 6, p. 46) occurs a grey porphyritic granite with a fine-grained granulitic ground-mass (*No. 57*). The phenocrysts are perthitic orthoclase, while in the ground-mass microcline is the most abundant felspar, the other minerals present being albite-oligoclase and quartz. No accessory minerals can be seen in thin section; but, as the result of crushing and panning, a few flakes of biotite and granules of hæmatite were found. In the specimen collected there are in places rusty holes that were formerly occupied by hæmatite. A similar rock (*No. 63*), but carrying crystals of hæmatite of about the size of a pea, occurs in sill-like masses on the slopes of Nhepa (north-west of Ribawe). In the rough country south-west of Sawa, the low domes and turtlebacks are frequently thickly threaded with this type of granite, and hæmatite masses often as big as a walnut lie sprinkled about the surface. These are greatly prized by the natives, who collect them for the making of spear-heads and knives. The granite from Mhala, Nakavala (*No. 32*), is of a type similar to those just described, but is free from hæmatite.

South of Mount Kwera a rather different type of granite occurs (*No. 28*). It is pink rather than grey, and is uniform and granulitic in texture. The same felspars are present, but biotite is more abundant, and the chief accessories are magnetite and rounded grains of zircon. Considerable quantities of the rock were crushed and panned, and a heavy residue collected. From this a considerable crop of zircon was obtained by the ordinary methods of separation, and the mineral was afterwards analysed for lead and uranium (see p. 87). A granite (*No. 56*) almost identical with that of Mount Kwera occurs west of the Etipoli Hills, near the Ligonia River. It differs mainly in having a little muscovite in addition to biotite, and in containing less magnetite. The biotites are rich in minute zircons, which are surrounded by strongly-developed pleochroic haloes. Similar rocks occur in the Sawa Valley (*No. 39*), in the Nrassi Basin (*No. 20*), and close to Ibrahimo Quartel (*No. 18*). A variety much richer in biotite, some flakes of which exhibit pleochroic haloes, is illustrated by an intrusion at Natashu (*No. 60*), north-west of the Etipoli Hills. The felsic minerals are, as before, microcline, albite-oligoclase, and quartz, while the accessories are apatite, zircon, and magnetite. A similar rock (*No. 35*) crops out on the road from Fort Chinga towards Mushima.

(3) Augite-Granites, Quartz-Augite Diorites, etc.

The augite-granites, with which are associated adamellites and quartz-diorites, may be described by reference to three important occurrences. Two of these, in the Ampwihi and Nrassi districts, are associated in the field with both crystalline limestones and hornblende-gneisses; while the third, from the slopes near Sawa Cave, is associated with hornblende-gneiss alone.

The Ampwihi specimens were collected near the road above the crossing (fig. 5, p. 39). The intrusion is by no means uniform throughout. The central portions are coarse-grained, and contain crystals of perthitic orthoclase and slightly-rounded dark-green augites embedded in a granulitic mosaic of microcline, albite-oligoclase, and quartz. In one specimen (*No. 207*) the proportion of oligoclase is not much less than that of the potash-felspars, so that the rock may be described as an augite-adamellite (Table VIII, p. 72). Towards the margin in both directions the phenocrysts of orthoclase gradually die out, as a conspicuous feature of the rocks; though perthitic orthoclase is still seen, in thin sections, in larger individuals than those of the surrounding minerals. At the same time the augites break down into feathery aggregates which are more or less parallel, so that the rocks take on a foliated appearance. Near the actual contact, the texture becomes finer, and a greater proportion of the minerals have rounded allotriomorphic forms. The augites, from being crystals 2 cm. long, are reduced to rounded grains 2 mm. in diameter, the total proportion of the mineral being now much higher than in the interior of the intrusion.

The minerals present are quartz, orthoclase, and microcline (including perthitic varieties), oligoclase, bright-green monoclinic pyroxene, dark-brown or green hornblende, straw-coloured biotite, apatite, sphene, zircon, magnetite, and calcite. The pyroxene is frequently bordered by a frayed edging of amphibole, which is sometimes brown, pleochroic in tints of brown and yellow, but more generally dark-green, pleochroic in tints of dark green, yellow-green, and blue-green. Along the cleavage-planes fibrous inclusions of the green variety are also developed, while the brown amphibole occurs in addition as ragged plates that tend to congregate around the margins of the pyroxene individuals. Biotite is rare, and is absent from many of the specimens. With the coloured minerals, the abundant accessories, sphene and apatite, are chiefly associated, while calcite in irregular blebs is present mainly as inclusions in the felspars. The form of the mineral, its presence in orthoclase and microcline, and the entire absence of any signs of alteration in the rocks, make it impossible to interpret the calcite as secondary. The association of the rocks with amphibolites and crystalline limestone leads one to suggest that the calcite represents a recrystallized residue of calcareous material picked up by the magma during its passage from below, the greater part of such material having been completely absorbed to form the pyroxene and amphiboles. It is significant that specimen No. 207, which contains less quartz than the other members of the series, is also richest in calcite and amphiboles.

TABLE VIII.

MINERAL COMPOSITION OF AUGITIC INTRUSIONS (BY VOLUME).

Minerals.	*Augite-Granite. Sawa Cave. No. 27.*	*Augite-Granite. Ampwihi Crossing. No. 208.*	*Augite-Adamellite. Ampwihi Crossing. No. 207.*	*Augite-Quartz Diorite. Nrassi Basin. No. 23.*
Quartz	22	18	14	7
Microcline, Perthite, Orthoclase	49	56	35	4
Oligoclase	18	8	32	—
Andesine	—	—	—	53
Pyroxene	9	14	12	31
Amphibole	—	1	3	—
Biotite	—	1	2	1
Accessories	2	2	2	4
Specific gravities.	2·67	2·67	2·70	2·78

The augite-granite of the Sawa caves occurs as a sill-like intrusion bounded by hornblende-gneiss, and cut by pegmatites rich in magnetite and ilmenite. As the mineral composition (stated on the preceding page) indicates, the rock is of the same type as the Ampwihi augite-granite. In texture it is more granular, and the minerals are equidimensional. Otherwise, the only difference lies in the absence of peripheral amphibole around the augites (Pl. X, fig. 1).

The Nrassi intrusions occur near the foot of Ericola, on the western side of the hornblende-gneiss and crystalline limestone exposures (see pp. 50 & 61; & Pl. XI). The augitic rocks do not form a single intrusion, but a number of sill- and dyke-like masses intrusive into biotite- and hornblende-gneisses. They are themselves cut by later dykes of pegmatite and pyroxenite. The rock-types represented vary from augite-granite, similar to that of the Ampwihi intrusion, though coarser in grain, through adamellite to quartz-diorite, by decrease in orthoclase or microcline, and quartz, and increase first in oligoclase and afterwards in andesine. Sphene, apatite, and zircon are the chief accessories, while magnetite and calcite occur as in the Ampwihi rocks, and pyrite is present in addition.

(4) Rutile-bearing Rocks.

One of the Nrassi sills, though clearly belonging to the series of rocks recorded above, is remarkable for the presence of rutile and pyrite and of other accessories in unusual abundance. The rock (*No. 21*) consists essentially of large crystals (2 cm. × 1 cm.) of green augite and oligoclase with smaller individuals of quartz; while between these constituents occurs a granulitic mosaic of quartz and orthoclase, with only a little oligoclase. Around some of the augites wisps of faded biotite are seen; but more commonly there is a granulitic periphery of green hornblende, sphene, apatite, and pyrite. In places the interstitial quartz-felspar mosaic is associated with, or entirely replaced by, aggregates of sphene, rutile, and apatite, riddled and penetrated by pyrite. In other parts of the rock, veins of granular apatite and rutile with smaller quantities of hornblende, sphene, and pyrite wrap round the larger felspars (Pl. X, fig. 3).

The rock may be regarded as a mineralized augite-adamellite, the sphene-rutile-apatite veins having been followed by pyrite. The occurrence recalls the 'krageröite' of W. C. Brögger.[1] In that rock rutile also occurs with oligoclase, and the neighbouring rocks are cut by veins of apatite and rutile.

Another Mozambique rock rich in rutile (*No. 74*), though of doubtful age, may appropriately be described here. It has already been mentioned on p. 47 as a vein or dyke cutting both the Monapo limestone and the enclosing gneiss at the south-eastern border of the former rock (fig. 6, p. 46). The rock is made up almost entirely of a felt of pale-green muscovite in which occur granular streaky masses, and rounded or lenticular aggregates, of vermilion-coloured rutile, the contrast in colour and texture giving to the

[1] Vidensk. Selsk. Skrifter Christiania, Dec. 2nd, 1903.

rock a striking and handsome appearance. In places, the rutile is bordered by minute grains of quartz; but the total proportion of the latter mineral in the specimen collected is not more than 6 per cent. (Pl. X, fig. 4).

The following table gives the mineral composition of the rock (by weight) as determined by the Rosiwal method, and also by heavy-liquid separation of the minerals:—

Minerals.	*Percentages of Minerals by weight.*		*Specific Gravities.*
	Separation Method.	*Rosiwal Method.*	
Muscovite	70·9	68	2·83
Rutile	23·3	27	5·12
Quartz	5·8	5	2·66
Specific gravity	Calculated. 3·11	Calculated. 3·21	Determined. 3·17

An analysis of the separated muscovite was made by Dr. H. F. Harwood, to whom I express my sincere thanks. The results are as follows:—

	Percentages.	*Molecular Proportions.*	
SiO_2	47·15	·786	
Al_2O_3	33·57	·329	·337
Fe_2O_3	1·35	·008	
FeO	0·32	·004	·007
MgO	0·45	·001	
CaO	0·14	·002	
Na_2O	1·04	·017	·405
K_2O	9·27	·099	
H_2O above 110° C.	5·20	·289	
H_2O below 110° C.	0·48	—	
TiO_2	1·31	·016	
F	0·05	·003	
MnO	none	—	
	100·33		
Less O for F	·02		
Total	100·31		

The molecular proportions indicate that the ordinary formula for muscovite does not adequately express the composition of this variety. The chief discrepancies are due to an excess of water and of silica. The latter may be explained by assuming that 2·5 per cent. of the mineral contains silica as trisilicate instead of the normal orthosilicate; but this assumption is probably unnecessary, as it seems more likely that a small quantity of quartz remained with the muscovite after separation. Microscopic examination of the analysed material revealed traces of both quartz and rutile, and the presence of about 1·8 per cent. and 1·3 per cent. respectively of these impurities would suffice to reduce the silica to the orthosilicate proportion, and to explain the amount of titanium dioxide recorded in the analysis. The excess of water is not so easily disposed of. If it be assumed that, in place of aluminium, the group (Al OH) is present in considerable proportion, then the muscovite is calculated to have the following approximate composition:—

$$\begin{cases} 55 \text{ per cent. of } R'_3Al_3(SiO_4)_3 \\ 45 \text{ per cent. of } R'_3(AlOH)_3Al(SiO_4)_3\,; \end{cases}$$

where R′ is K, Na, and H; Al partly replaced by Fe‴; (AlOH) partly replaced by Ca, Mg, and Fe″; and (OH) partly replaced by F.

(5) Granulitic Norite rich in Sphene.

A dark-grey finely-granulitic rock (*No. 37*) occurs as sill-like masses penetrating biotite-gneiss in the bed of the Namieta River, south of Peone Hill (Mwipwi Mountains). Under the microscope the rock is found to be composed of labradorite, pale greenish-grey augite, nearly colourless enstatite, and clove-brown sphene, with pyrite and magnetite as accessories (Pl. X, fig. 2). The texture is thoroughly granulitic and the range in dimensions is low, the average grain being about 2 mm. The pyroxenes are usually above average size, and by aggregation they form still larger groups; the rounded and elongated crystals of sphene are, on the contrary, below the average size. Like the rock as a whole, the felspar is perfectly fresh, and its optical properties indicate that its composition is approximately $Ab_{45}\ An_{55}$. A single small individual of quartz was seen in one section only.

The mineral composition by volume, determined by the Rosiwal method, is as follows:—

Quartz	trace
Labradorite	43
Pyroxenes	47
Sphene	6
Apatite	1
Pyrite	2
Magnetite	1
	100

Specific gravity:
Calculated = 3·07
Measured = 3·04

Radium-content:
in grms.$^{-12}$ per grm. of rock[1] = 0·54

This rock is the only one so far found in Mozambique that resembles in any way the rocks of the charnockite series of India,[2] or of the similar series which have been discovered in Ceylon,[3] the Ivory Coast,[4] and Benguella.[5]

[1] A. Holmes, 'The Age of the Earth' 1913, Appendix A, p. 183.
[2] T. H. Holland, Mem. Geol. Surv. India, vol. xxviii (1900) p. 124.
[3] A. K. Coomaraswamy, Q. J. G. S. vol. lviii (1902) p. 401.
[4] A. Lacroix, C.R. Acad. Sci. Paris, vol. cl (1910) p. 18.
[5] G. W. Tyrrell, Trans. Roy. Soc. Edin. vol. li, pt. 3 (1916) p. 539.

VII. The Granites and Massive Pegmatites.

The latest granitic rocks of Mozambique consist mainly of massive pegmatites, but occasionally small intrusions of granite are exposed, in which the minerals are more uniformly distributed, and the grain is less coarse, than in the pegmatites. The chief rock-types may be classified as follows:—

- Granites.
  - Biotite-granites.
  - Muscovite-granites.
- Pegmatites.
  - Graphic granite.
  - Coarse quartz-felspar pegmatites.
  - Pegmatites with hæmatite.
  - Pegmatites with magnetite.
  - Pegmatites with ilmenite.
  - Pegmatites with sulphide minerals.
- Tourmalinized rocks.

(1) Biotite- and Muscovite-Granites.

Between Mitikiti and the Monapo River there was found during a journey eastwards from Nambako, a broad dyke-like mass of red biotite-granite (*No. 6*). This rock consists of red perthitic orthoclase with interstitial smoky quartz, and in places small flakes of biotite. In thin section it is seen that idiomorphic crystals of oligoclase are present in small amount, wrapped round by the orthoclase. The biotite contains numerous pleochroic haloes around zircon inclusions, and a little muscovite is also present. The accessory minerals are apatite and zircon, with very little magnetite.

In the same neighbourhood occur numerous dykes and sheets of massive red felspathic pegmatite, with pockets of quartz and small sheaves of biotite. The detailed similarity between these minerals and those of the granite suggests a genetic connexion between the two groups of rocks.

A similar granite (*No. 3*), but with flesh-coloured phenocrysts of orthoclase (recalling the Shap Granite in its megascopic aspect), was found among the rock-débris occurring along the shore of Mosuril Bay near Ampense.

Near Fort Ligonia (Zambesia), on the south side of the Ligonia River, the complex of gneiss and granulitic granite is cut by numerous sheets, 2 or 3 feet thick, of muscovite-granite. The minerals (*No. 159*) are quartz, orthoclase (not perthitic, but including small hypidiomorphic crystals of oligoclase), and abundant muscovite. Accessories are rare, and only magnetite and zircon have been seen. The late R. L. Reid also recorded muscovite-granites and pegmatites from the neighbourhood of the Monapo Limestone.

(2) Graphic Granite and other Quartz-Felspar Rocks.

Among the rocks distinguished as pegmatites, graphic granite is by far the most abundant. Beautiful specimens can be picked up from many of the river-beds and from the gravel-strewn sea-flats of the coast. *In situ*, the rocks occur as narrow dykes and sheets from 1 inch up to about 2 feet thick. It is scarcely possible to record particular localities, for graphic granite is to be found in almost every square mile explored. However, in certain districts the rock is more abundant than in others, and Fort Jagaia, the Ampwihi Crossing, Ligonia, and the district south-west of Sawa, are thus worthy of mention.

The minerals present are quartz and orthoclase, the latter containing (in all specimens that were sliced) drawn-out perthitic inclusions of albite-oligoclase. The only other mineral visible to the naked eye is muscovite, which is rarely present; while in three cases panning the crushed rock failed to give any considerable residue of accessories, only a very few minute grains of magnetite, zircon, and apatite being left in the pan. Of these, only magnetite has been seen in thin section.

In the field I applied the Rosiwal method of mineral analysis to graphic granite *in situ*, measuring up with a millimetre-scale a metre or more of smooth surface at each locality. The following results (calculated to percentages by weight) were obtained :—

TABLE IX.

Locality.	*Quartz.*	*Felspar.*
Fort Jagaia	26·3	73·7 *
Ampwihi Crossing	27·9	72·1 †
Ligonia	25·3	74·7
Nrassi River................	25·6	74·4
South-west of Sawa.........	27·1	72·9 ‡
Chinga	24·2	75·8
Average (by weight)...	26·1	73·9
Eutectic proportions by weight (after J. H. L. Vogt)......................	25·75	74·25

* includes about 12 per cent. albite-oligoclase }
† Do. do. 10 do. do. do. } measured on thin sections.
‡ Do. do. 12 do. do. do. }

The range of variation is remarkably small, and the final average agrees closely with the figures given by J. H. L. Vogt[1] for

[1] 'Die Silikatschmelzlösungen' pt. 2 (1904) p. 113 (Vidensk. Selsk. Skrift Math.-naturv. Klasse).

Fig. 11.—*Pegmatite intrusion (red massive orthoclase with small pockets of quartz): seen in plan across the dry bed of the Mitikiti River.*

[Length of section = 10 feet. Average strike: 20° east of north. Dip: 50° eastwards.]

the eutectic proportions of quartz and orthoclase. For quartz and albite Vogt gives eutectic proportions of 25 per cent. and 75 per cent. respectively, consequently the presence or absence of albite as perthitic inclusions ought not greatly to affect the proportions of quartz and felspar.

Pegmatites made up of massive felspar (generally flesh - coloured or red) alternating with smaller masses of quartz, were encountered in many places. The pegmatite dykes and sills of the Mitikiti district have been already mentioned, and in fig. 11 a plan of one of these as exposed across the floor of the Mitikiti River is depicted. The sill in this case evidently fills an irregular fracture, for the two sides are parallel, and where the gneissic foliation is truncated on one side it appears again on the other.

Exceedingly coarse-grained pegmatites occur as dykes between Chinga and Mount Mushima, and some of these contain moonstone or amazonite. In a tributary of the Namieta, masses of flesh-coloured felspar, measuring up to 10 feet in length, by 6 feet in width, are exposed. These dykes contain small 'books' of biotite, between the folia of which green autunite[1] sometimes occurs in rosettes and irregularly-disposed flakes. This alteration-product was found in many of the biotite-bearing pegmatites of other localities, and also—though in much smaller quantity—in the older granulitic pegmatites. No primary radioactive minerals such as are elsewhere associated with autunite were found, although a careful search was made for any parent material from which the autunite might have been derived.

Other districts especially noteworthy for their felspathic pegmatites are Mhala (Nakavala), Ribawe, and Nrassi districts (map, Pl. XI), and around the Mluli Mountains. But, as in the case of graphic granite, it is almost invidious to choose special localities, for the rocks are everywhere represented to some extent, and the superficial gravels of the plateau are often thickly strewn with fresh cleavage-fragments of massive felspar.

(3) Pegmatites with Special Minerals.

Although the great majority of the pegmatites are composed in the aggregate of quartz and felspar with occasionally a little mica, others have been found in which hæmatite, magnetite, or ilmenite are abundant constituents.

Hæmatite occurs more particularly in the granulitic pegmatites; but at the northern end of the Chica Range, and between Mount Mataria and the Mavili Hills (south-west of Sawa), large rounded masses of hæmatite are also found in the later massive pegmatites.

Magnetite-bearing pegmatites are more common, and in them the magnetite often occurs in well-shaped octahedral crystals varying in axial length from 1 to 5 cm., while irregular masses of larger size are also frequently present. On the slopes of East Peak, Sawa, and between the Bwibwi and Sawa Rivers, such magnetite-rocks are very abundant in narrow dykes and sills. Despite the restricted width of the pegmatites, the crystallization is very coarse, large crystals of quartz, red perthitic orthoclase, oligoclase, and biotite being developed in irregular fashion. A precisely similar rock occurs at the south-eastern end of the Ampwihi limestone, and its contact-phenomena with the latter have been described in a previous section (p. 49). In this case the magnetite was found to be titaniferous. South of Mahalia, in the Malema Valley, pegmatites with large magnetite-crystals were found by Mr. E. J. Starey; and Mr. Wray has recorded the presence of the same type from the districts around Wampahua (Luli River) and Namkala (south-west of Mluli Mountains). In the rough rocky country south-west of the Ribawe Mountains (between the Bwibwi and the headwaters of the Makwassi),

[1] See A. Holmes, 'The Age of the Earth' 1913, p. 153, for the analysis of this mineral for lead and the discussion of its significance.

ilmenite is present in many of the pegmatites, and similar rocks occur in the north-eastern part of Mozambique around Niveta.

On the banks of the Nrassi River, due east of Ericola, Mr. Wayland found a felspathic pegmatite veined with pyrite and capped with bauxite. Pyrite and other sulphide minerals were also found by Mr. E. W. E. Barton, the leader of the Memba Minerals Expedition, in coarse pegmatite-dykes occurring near Nakota in the south of the territory.

Many of the pegmatites carry big crystals of black tourmaline, and in the coastal districts, tourmalinized rocks are especially abundant. Around Memba many of the pegmatites are rich in tourmaline and muscovite, and locally the rocks are made up almost entirely of these minerals. Others approach tourmaline-granite in their texture, while the Post Office at Memba is built on an outcrop of a typical schorl-rock. Near Ibrahimo, quartz-mica-granulite carries small crystals of tourmaline that have probably been introduced from tourmaline-bearing pegmatites which cut the older rocks. Black tourmaline also occurs in many of the pegmatites of the Nrassi, Ribawe, Fort Chinga, and Norray districts. Near Fort Ligonia, on the Zambesi side of the river, fragments of red and pink tourmaline associated with lepidolite were found in the débris overlying the muscovite-granites, but the parent rock was not seen.

(4) Quartz-Veins.

Veins of quartz varying from a few inches to many feet in thickness are widely distributed in the territory; but, apart from pyrite and accompanying rusty staining, they were, with one exception, free from mineralization. The exception refers to the quartz-veins of Niveta, in the north-east of Mozambique, which have been reported to carry considerable quantities of massive galena. These veins are directly connected with red felspathic pegmatites. A similar relationship was found on the north-western side of Mhala, Nakavala, where a quartz-vein 12 inches thick, was traced towards the hill, and found to become increasingly felspathic.

VIII. The Pyroxenite- and Picrite-Dykes.

(1) Pyroxenites.

In the Nrassi Basin (Pl. XI) occur a number of dykes of pyroxenite that follow a nearly north-and-south direction. In a gully draining into the Nrassi from the slopes of Ericola, and about half a mile from the base of the hill, two of these dykes (*Nos. 33 & 34*) can be seen cutting through the youngest pegmatites; and consequently they are demonstrably the youngest intrusions of the district. The dykes are generally 2 or 3 feet wide. They appear to resist weathering as well as the rock through which they have intruded, for they show no signs of alteration beyond an iron-stained selvage 2 mm. thick or less, and they make no feature on the ground, either positive or negative.

Hand-specimens have a greenish-grey colour, and are of uniform saccharoidal grain (about 1 mm.). The average specific gravity of three specimens is 3·21. Under the microscope the rocks are found to be all very similar, and *No. 33* may be taken as a type representative of the whole series (Pl. X, fig. 5).

Diopside, colourless or nearly so in thin section, is by far the most abundant mineral. It builds a roughly equidimensional mosaic of sub-rectangular or rounded individuals. Some of the diopsides are seen to have yellowish-green slightly-pleochroic inclusions. Under crossed nicols these patches give aggregate polarization, and may be referable to serpentine or chlorite. They probably represent the alteration-products of amphibole: for, in places, similarly shaped inclusions occur consisting of blue or greenish-blue amphibole, and passing into altered material at the edges. The amphibole has a maximum measured extinction of about 10°, and its pleochroic scheme is as follows:—

X = *a* yellowish-green.
Y = *b* greenish-blue.
Z = *c* indigo to violet.

In places a few rounded crystals of enstatite occur, distinguishable by their straight extinction, lower refractive index, and much lower birefringence. Neither olivine nor felspar has been detected.

In the Mluli Valley east of the Mwipi Range, are dykes of felspathic pyroxenite which may be conveniently described here, although their age is not known beyond the fact that they are of post-gneiss age. Colourless diopside is again the chief mineral present, and in places it constitutes practically the whole of the rock, which is of a uniform grey colour.

In thin section (*No. 184*) it is seen that a few granules and plates of calcic labradorite or bytownite are present. Swarms of minute granules of pyroxene occur in the plagioclase plates, which are thus reduced to a sponge-like skeleton. The only other minerals present are a few shreds of biotite (also carrying inclusions of granular pyroxene), occasional enstatites as in the Nrassi pyroxenites, and occasionally a rounded apatite.

Pyroxenite-dykes occur in Ceylon, and have been described by A. K. Coomaraswamy.[1] Although many of them differ markedly from the Nrassi type by the possession of phlogopite and several other minerals, others seem to be of identical type, for it is stated that

'a nearly colourless monoclinic pyroxene [is] the chief or only constituent of many of the most conspicuous varieties.'

A more remarkable point of resemblance lies in the position in the sequence. In Mozambique the pyroxenites follow the succession (1) gneisses, (2) granulitic granites, and (3) massive pegmatites; while in Ceylon they follow the similar succession (1) gneisses, (2) granulites (charnockite series), and (3) massive pegmatites.

[1] Geol. Mag. dec. 5, vol. ii (1905) p. 363.

(2) Picrite.

The only picrite encountered in the country was that of the dyke at the Ampwihi Crossing (fig. 4, p. 38). This rock (*No. 201*) has already been described in detail by the present writer, and analysed chemically by Dr. H. F. Harwood.[1] The following particulars are quoted from the paper here cited:—

'The specimens collected were from the margin—evidently chilled—of the transverse dyke, and have a dark-grey colour, mottled with nearly black glassy phenocrysts of olivine. Here and there are minute white amygdales, the infilling consisting of an isotropic material that is probably glass. The weathered surface is creamy-grey in colour, with rusty patches corresponding to the phenocrysts. The average specific gravity of three fragments of the fresh rock is 3·08.

'In thin section the rock is found to consist of corroded phenocrysts of olivine in a fine-grained ground-mass composed mainly of elongated grains of augite and enstatite, the former alternating with and sometimes intergrown with laths of soda-lime felspar. In places interstitial patches of pale brownish-grey glass appear, and where a minute amygdale is seen it is found to be composed of the same obscure material. (P. 151.)

'In order to determine the specific gravities of the various minerals, a diffusion column of methylene iodide and methylene iodide diluted with benzine was prepared so as to give a range from 3·3 to 2·3. Olivine and magnetite sank. A well-marked band of pyroxene formed between 3·1 and 3·2. Another band formed at 2·73 (labradorite), tailing out above and below owing to the difficulty of obtaining a clean separation from such fine-grained material. Finally, another layer formed at the level corresponding to 2·50.

'The results obtained are as follows:—

Mineral.	Percentage by Weight.	Specific Gravity.
Glass	8	2·50
Labradorite, An_{70}	17	2·73
Pyroxene	45	3·15 (average)
Olivine	29	3·45 (?)
Magnetite	1	5·17 (?)'
Total	100	Average 3·20 (P. 152.)

IX. Heavy Residues from Crushed Rocks and River-Deposits.

Accessory minerals obtained from a number of gneisses and granites by crushing and panning have already been described. The details are here repeated in tabular form, for comparison with the minerals of the heavy residues separated from river-sands and gravels. A large number of heavy residues were examined in the field during the course of prospecting work for gold and cassiterite, and many of these were preserved for more detailed examination in the laboratory.

The most interesting result is the discovery of monazite

[1] A. Holmes & H. F. Harwood, Geol. Mag. dec. 6, vol. iv (1917) pp. 150–57 & pl. xi.

(Pl. X, fig. 6) as a constant constituent of the sands of the Bwibwi and of those of its tributaries which were examined. Monazite is probably brought down in considerable abundance by the Matupa River and the Potela Mazi ('Tsetse Fly Water'), for in residues 4 & 5 the proportion of this mineral is much higher than in the upper parts of the Bwibwi. Monazite has not been found in any of the rocks examined, and as these include the gneisses and granulitic granites of the Ribawe Mountains and the Nrassi Basin, it seems probable that the main source of the mineral is to be found in the coarse pegmatites of the region.

The Sawa sands contain deep-red spinel, which was picked up by Mr. E. J. Wayland in fragments as big as a pea from pockets of gravel occurring in the gorge a few miles above the

TABLE X.

HEAVY RESIDUES FROM RIVER-DEPOSITS AND CRUSHED ROCKS.

Minerals.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Magnetite	c	c	c	c	c	a	c	c	c	c	c	c	r	a	c
Ilmenite	a	a	a	a	a	a	a	a	a	a	a	a	a	r	a
Garnet	r	r	r	r	c	r	c	r	c	r	r	r	c	—	—
Zircon	a	a	a	a	a	a	c	a	c	a	a	a	r	a	a
Rutile	r	r	r	r	r	r	c	r	c	—	r	r	r	—	r
Monazite	r	r	r	c	c	r	r	—	—	—	—	—	—	—	—
Spinel	r	r	r	r	r	—	—	—	—	—	—	—	—	—	—
Sphene	—	r	r	r	—	—	c	c	a	—	r	r	a	—	a
Apatite	r	r	r	r	r	r	c	r	r	c	c	a	a	c	c

[a = abundant; c = common; r = rare.]

River-Deposits.

1. Sawa River, between Base Camp and village.
2. Bwibwi River, below its confluence with the Sawa.
3. Do. below its confluence with a tributary from Mount Tipwi.
4. Matupa River, at the mouth of the Matupa Pass, Ribawe Mountains.
5. Bwibwi River, above its confluence with the Potela Mazi ('Tsetse Fly Water').
6. Nrassi River.
7. Do.
8. Monapo River, near Mpera.
9. Do. below the crystalline limestone near Mount Tibwi.
10. Ligonia River, near Fort Ligonia.

Rocks.

11. Gneissose granite, Sawa (contains also epidote; r.).
12. Do. Etipoli Hills (contains also pyrite and mispickel; r.).
13. Hornblende-gneiss, Ampwihi (contains also epidote; c.).
14. Granulitic granite, Mpera, Monapo River.
15. Augite-granite, below Ericola, Nrassi Basin.

Base Camp. The same mineral is a constant, though rare, accessory of the Bwibwi residues.

In almost every case ilmenite was found to be more abundant than magnetite, and this relation was reflected by the residues from rocks.

Pink or red garnet is present in all sands, and the examination of the rocks shows that it is derived from the gneisses.

Zircon is everywhere abundant or common, while rutile is generally a rare mineral. In two localities, however, rutile is common, and here neighbouring rocks rich in rutile also occur—the rutile-granite of Nrassi, and the rutile-muscovite pegmatite of the Monapo Limestone district.

Sphene is very variable in its distribution. It is most plentiful in the Monapo and Nrassi sand, where its relation to sphene-bearing hornblende- or augite-rocks is apparent. Apatite is noticeably more abundant in the residues from rocks than in those from the river-sands.

X. Correlation of the Gneisses and Granulitic Granites of Mozambique.

In a paper on 'The Measurement of Geological Time,' read before the Geologists' Association in 1915,[1] I suggested that the method of determining geological time by means of the lead-ratios of radioactive minerals might

> 'be used comparatively for the correlation of igneous intrusions in various parts of the world, and in particular for the correlation of the Pre-Cambrian rocks.'

I now propose to apply this method to the correlation of the Mozambique gneissose granites and of the later Nrassi, Monapo, and Ligonia granites, with corresponding rocks in other well-known Pre-Cambrian areas. It should be noticed that no assumption is here made as to the absolute age of the rocks; for such an assumption is in no way necessary to the argument. If, as has been suggested by Prof. Joly,[2] a proportion of the uranium atoms that formerly existed disintegrated more rapidly than do the uranium atoms still existing at the present time, then it follows that the ages calculated from lead-ratios, on the assumption that the rate of decay of uranium has not varied during geological time, must be too high. The detailed structure of pleochroic haloes provides some evidence in favour of this view; but, on the other hand, the thermal condition of the Earth speaks against it.[3] The only assumption made for purposes of correlation is that, if uranium produced lead at a certain rate in Mozambique at any given time,

[1] A. Holmes, Proc. Geol. Assoc. vol. xxvi (1915) p. 308. In this paper the principles underlying the method are briefly described, and full references are given to the original sources of information.

[2] J. Joly, 'The Genesis of Pleochroic Haloes' Phil. Trans. Roy. Soc. ser. A, vol. ccxvii (1917) p. 77.

[3] A. Holmes, Rep. Brit. Assoc. (Manchester, 1915) 1916, p. 432.

then it produced lead at the same rate at the same time in Canada, Scandinavia, India, and in other parts of the world. That is to say, the amount of lead generated by uranium during the time that has elapsed since any given period is—so far as the Earth is concerned—independent of the location of the uranium. Thus, if the ratio of lead to uranium in a uranium-bearing mineral of igneous origin occurring in Mozambique is equal to the Pb/U ratio for igneous minerals occurring in any other part of the world, then these minerals are of the same age, and consequently the rocks in which they occur are also of the same age. The requisite conditions that the minerals used as criteria must be fresh, primary, free from original lead, and free from considerable amounts of thorium, have been fully dealt with in previous papers, and do not here require further discussion.

The chief mineral investigated from Mozambique is zircon, which was obtained in the field during 1911 by crushing considerable quantities of the parent rocks and separating the heavier minerals by panning.

(1) Correlation of the Gneissose Granites.

Zircon was obtained from the gneissose granites of the Ribawe Mountains (Sawa Valley) and Etipoli Hills. The two crops together provided sufficient material for duplicate analyses of lead and uranium. The mean results, which are set forth in Table XI (p. 86), give a lead-ratio of 0·21. A later analysis for thorium was made in Vienna by my friend, Mr. R. W. Lawson, and the amount found (0·0013 per cent.) is so small that the possibility of the lead-ratio being appreciably affected by thorium-lead is completely dispelled.

The only rocks with which an approximate correlation may be made are the Laurentian gneissose granites of Canada. In 1909, zircon and sphene from the Smart Mine, Sebastopol (Ontario), were investigated by Prof. Strutt,[1] and the amount of helium that he obtained from these minerals indicated that they were older than any of the minerals that he examined from other localities. His results therefore serve to confirm the corresponding high value, 0·24, found for the lead-ratio of zircon from the Smart Mine. Very little information is published regarding the geology of the immediate neighbourhood of Sebastopol, but I am indebted to the Geological Survey of Canada for the following information:—

> The minerals mentioned [zircon and sphene] are the same as those associated with orthoclase-pegmatite masses that occur in the phlogopite-apatite bearing pyroxenites of the Templeton and Buckingham districts, Quebec. These pegmatites are regarded by Mr. M. E. Wilson (of the Canadian Geological Survey) as related in origin to the charnockite-like pyroxene-granite of the Buckingham Series,[2] and would therefore be of early Pre-Cambrian age and older than the Villeneuve pegmatite.

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[1] R. J. Strutt, Proc. Roy. Soc. vol. lxxxiii (1909) p. 300 & vol. lxxxiv (1910) p. 195.

[2] M. E. Wilson, South-Eastern Portion of Buckingham Map Area, Quebec: Summary Rep. Geol. Surv. Canada for 1913 (1914) p. 202.

The Buckingham Series belongs to the Laurentian of Logan, and hence we have an approximate correlation between this great formation and that of the Mozambique gneissose granites, for the two ratios are of the same order.[1] I do not wish to insist too far

TABLE XI.

DATA FOR THE CORRELATION OF PRE-CAMBRIAN ROCKS.

Age.	*Mineral.*	*Locality.*	Pb %.	U %.	Pb/U.	*Analyst.*
?	Uraninite	Morogoro, G. E. Africa	6·98*	74·54	0·094	Marckwald.[1]
	,,	,, ,,	6·88	74·72	0·092	,,
MIDDLE PRE-CAMBRIAN.	Bröggerite	Moss, Norway	8·49†	67·0	0·13	Hofmann.[2]
	,,	,, ,,	8·61	67·4	0·13	,,
	Uraninite	Huggenäskilen, Norway	9·0	76·1	0·12	Lorenzen.[3]
	,,	,, ,,	8·8	67·8	0·13	Hillebrand.[4]
	,,	Skraatorp, ,,	8·8	65·2	0·14	,,
	,,	Elvestad, ,,	8·0	57·0	0·14	,,
	,,	,, ,,	9·3	65·8	0·14	,,
	,,	Anneröd, ,,	8·4	66·0	0·13	,,
	,,	,, ,,	7·8	68·4	0·12	Bloomstrand[5]
	Annerödite	,, ,,	2·2	15·0	0·15	,,
	Fergusonite	Ytterby, Sweden	0·18	1·06	0·17	Holmes.
	Gadolinite	,, ,,	0·36	2·41	0·15	,,
	Uraninite	Arendal, Norway §	9·4	56·25	0·17	Lindström.[6]
	,,	,, ,,	9·8	56·0	0·18	Hillebrand.[4]
	,,	,, ,,	10·2	61·2	0·17	,,
	,,	Villeneuve, Canada	10·14	60·0	0·17	,,
	,,	Singar, Gaya, India	8·4	67·6‡	0·12 } ? 0·13 }	Criper.[7]
	,,	,, ,, ,,	8·92	64·3	0·14	Holmes.
	Biotite	Ligonia R., Mozambique	0·014	0·097	0·14	,,
	Zircon	Monapo River ,,	0·026	0·171	0·15	,,
	,,	Nrassi River ,,	0·032	0·193	0·17	,,
LOWER PRE-CAMBRIAN.	Zircon	Mozambique	0·054	0·257	0·21	Holmes.
	,,	Sebastopol, Canada	0·034	0·143	0·24	,,

* Atomic Weight = 206·04, Hönigschmid & St. Horovitz, 1915.
† ,, ,, = 206·06, ,, ,, ,,
‡ Stated as 'oxide of uranium' = 79·55.
§ See footnote 4 on p. 88.

1 Centralblatt für Min. u. Geol. 1906, p. 761.
2 Ber. d. Deutsch. Chem. Gesellsch. vol. xxxiv (1901) p. 914.
3 Nyt Mag. vol. xxviii (1884) p. 249.
4 U. S. Geol. Surv. Bull. 220 (1903) p. 114.
5 Journ. Prakt. Chem. vol. xix (1884) p. 191.
6 Geol. Fören. i Stockholms Förh. vol. lvii (1884) p. 69.
7 Mem. Geol. Surv. India, vol. xxxiv (1902) p. 31.

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1 R. J. Strutt, Proc. Roy. Soc. vol. lxxxiii (1909) p. 300, found 0·0092 per cent. of thorium in the zircons from Sebastopol investigated by him, an amount which is small compared with the uranium present; consequently, if this is a general characteristic, any error in the lead-ratio is more likely to be experimental than due to the presence of lead associated with thorium.

on the exactness of this correlation, for two sets of analyses are but a slender support for so far-reaching a conclusion. The results are placed on record, however, as an example of the method and its application.

(2) Correlation of the Granulitic Granites.

Zircons were collected from the granites of the Nrassi Basin, and from those in the neighbourhood of Mpera, Monapo River. These give lead-ratios of 0·17 and 0·15 respectively. Analysis of a biotite (rich in pleochroic haloes), from a similar granite occurring near Fort Ligonia, Ligonia River (Zambesia), gives a ratio of 0·14.[1] From their structures, mineral composition, and relations to the older rocks, these granites were considered to belong to the same period of intrusion. The radioactive evidence confirms this view as well as could be expected. Considering the minuteness of the quantities analysed, and the possibility of traces of both original and thorium-lead being present, the three ratios seem sufficiently close to warrant a provisional correlation of the parent rocks from which the minerals were obtained.

For comparison, an analysis of a Middle Pre-Cambrian uraninite from the Villeneuve Mine, Ontario, is cited in Table XI (p. 86). I am indebted to the Canadian Geological Survey for permission to quote the following information concerning the geological relationships of the pegmatite in which the uraninite occurs. The details given below are based on the field-work of Mr. M. E. Wilson.

'The Villeneuve pegmatite is an elliptical mass, 200 feet long and 100 feet wide, exposed on the southern margin of a small knob of bedrock protruding through Champlain marine clay.

'With regard to its age, it is known that it intrudes into garnet-gneiss and vitreous quartz-rock (generally called quartzite) belonging to the Grenville Series, and is, in turn, intruded into by later Pre-Cambrian diabase dykes which are approximately of Keweenawan age. This is all that can be determined from the relationship of the mass itself; but, from the relationships of similar masses of pegmatite occurring in the district, it is probable that it has been derived from a hornblende-biotite-granite, which occurs in its vicinity as bosses intruding into both the Grenville and the Buckingham Series.[2] It is, of course, impossible to correlate these rocks with Dr. Lawson's Algoman, which occurs over 1000 miles away. Since, however, it is the youngest member of the basal complex, or Laurentian of Logan, as that part of the Pre-Cambrian is represented in the Ottawa district, it is probably late Archæan.'

We may next turn to some corresponding rocks in the Gaya district of India, which also contain uraninite. Through the courtesy of Messrs. Martin & Co., the Geological Survey of India obtained a good specimen of uraninite from the Singar Mine, Gaya District, which they kindly sent to me for investigation. In addition to expressing my thanks to the Survey for this valuable

[1] Attempts were made to utilize other biotites, but the association with them of autunite completely vitiated the results.

[2] Summary Rep. Geol. Surv. Canada for 1913 (1914) p. 199.

specimen, I wish also to thank Dr. L. L. Fermor for the information that the pegmatites in which the mineral occurs (together with samarskite, columbite, and other radioactive minerals) are regarded as the latest of the Vedic (that is, Archæan) rocks of India. They therefore belong to the post-Dharwar intrusives of Sir Thomas Holland's classification of the Pre-Cambrian rocks of India.[1] The lead-ratio found from the analysis of the Singar uraninite (0·14) is in harmony with this correlation, and indicates that the rocks are of the same age as those of the Moss district of Norway (described below).

In Scandinavia there are three areas of Middle Pre-Cambrian granites and pegmatites in which radioactive minerals are found. These are the districts of Ytterby in Sweden, and of Moss and Arendal in Southern Norway. The Ytterby pegmatites belong to the Ser-Archæan granites of A. G. Högbom,[2] and cannot geologically be distinguished in age from the Moss or Arendal granites. The Moss granites are post-Kalevian, and in their case the lead-ratio is very accurately known, for the atomic weight of bröggerite from Moss has been found by Hönigschmid to be 206·06; the lead-ratio, 0·13, calculated from two analyses of the same mineral by Hofmann, is therefore thoroughly reliable.[3] The Arendal granites probably belong to the same period of intrusion as those of the Moss district, though it is not impossible that they may be of post-Bothnian and pre-Kalevian age. The lead-ratio, 0·17, suggests the latter correlation; but it is not conclusive,[4] for the Ytterby fergusonite also gives a ratio of 0·17, and yet is definitely of Ser-Archæan age.

The ratios may always be too high, if either ordinary lead or thorium-lead happens to be present, and therefore in a series of lead-ratios of minerals of the same geological age, those giving the l o w e s t[5] ratios are most likely to be strictly correct. The only direct method of determining whether the lead present is 'uranium'-lead in its entirety involves a measurement of its atomic weight[6]; and as this is a task which few chemists are capable of undertaking, and for which, moreover, it is particularly difficult to obtain material, it cannot be expected that a complete chain of evidence should always be forthcoming. Such data as are now available are expressed in Tables XI & XII; and it is thought that the

[1] Congrès Géol. Internat. C.R. XIIème Sess. Canada, 1913 (1914) p. 376.

[2] 'Pre-Cambrian Geology of Sweden,' Bull. Geol. Inst. Upsala, vol. x (1910–11) p. 2.

[3] A. Holmes & R. W. Lawson, Phil. Mag. ser. 6, vol. xxix (1915) p. 678.

[4] [More conclusive evidence is provided by an atomic-weight estimation for lead extracted from cleveite, Arendal, carried out by Richards & Wadsworth. Although the Pb/U ratio is nearly 0·19, the atomic weight is not unduly high, being 206·08.—*A. H., March 1919.*]

[5] It should be noticed that in the case of helium-ratios the h i g h e s t values are considerably below the l o w e s t values of the corresponding lead-ratios, this being due to the ease with which helium escapes.

[6] For a list of such determinations, see A. Holmes & R. W. Lawson, *op. cit.* 1915, p. 682; and for a general discussion, see pp. 679 *et seqq.* & pp. 687–88.

results are sufficient to justify a broad correlation of the Pre-Cambrian rocks concerned into Lower and Middle Groups. In

TABLE XII.

Lead-ratios.	*Rocks and Localities.*	*Geological Age.*
0·04	Pegmatites of Appalachians, U.S.A.	Late Carboniferous.
	Uraninite from St. Ives (Cornwall)	Do. do.
0·05	Pegmatites of Langesundfjord (Norway) .	Devonian.
0·06	Balangoda pegmatites, Ceylon	Unknown.
0·07		
0·08		
0·09	Morogoro pegmatites, G.E. Africa.........	Upper Pre-Cambrian (?)
0·10		
0·11		
0·12		
0·13	Pegmatites of Moss District (Norway).	Middle Pre-Cambrian.
0·14	Singar pegmatite, India.	
0·15	Nrassi, Monapo, and Ligonia granites, Mozambique.	
0·16	Ytterby pegmatites, Sweden.	
0·17	Villeneuve pegmatite, Canada.	
	Pegmatites of Arendal district (Norway).	
0·18		
0·19		
0·20		
0·21	Gneissose granite, Mozambique.	Lower Pre-Cambrian.
0·22		
0·23		
0·24	Sebastopol pegmatite, Canada.	

every case where independent geological evidence is on record, it is in complete accordance with the implications of the lead-ratios, as regards both position and sequence. Where geological evidence is lacking, the lead-ratios may, therefore, be used as a general guide to correlation.

XI. Origin of the Inselberg Landscape.

The inselberg type of landscape is a striking characteristic of many parts of Africa. It has been described by W. Bornhardt[1] in German East Africa; by S. Passarge[2] in South-West Africa and Adamaua; by Dr. J. D. Falconer[3] in Northern Nigeria; and most recently by Dr. E. O. Teale & Mr. R. C. Wilson[4] in the Territory of the Companhia de Moçambique. Everywhere it has been developed in areas over which long-continued denudation has exposed the basement-rocks of the African continent; rocks which, as in

[1] 'Die Oberflächengestaltung & Geologie Deutsch-Ost-Afrikas' vol. vii, Berlin, 1910, pp. 34–39.

[2] (*a*) 'Adamaua' 1895; (*b*) 'Die Kalahari' Berlin, 1904; (*c*) 'Ueber Rumpfflächen & Inselberge' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. lvi (1904) Prot. pp. 193–209; (*d*) 'Die Inselberglandschaft in tropischer Afrika' Nat. Wochenschr. n. s. iii (1904) pp. 657–65.

[3] Rep. Brit. Assoc. (Dundee, 1912) 1913, p. 476; see also 'Geology & Geography of Northern Nigeria' London, 1911.

[4] Geogr. Journ. vol. xlv (1915) p. 16; see also A. Holmes & D. A. Wray, *ibid.* vol. xlii (1913) p. 143, and W. M. Davis, 'The Geographical Cycle in an Arid Climate' Journ. Geol. Chicago, vol. xiii (1905) p. 381.

Mozambique, consist of banded and foliated gneisses accompanied by crystalline schists and limestones, and penetrated by later granites and pegmatites.

The formation of the intermont plains has been accounted for in turn by each of the three dominant processes of degradation—wind-scour and dry weathering during desert or arid conditions; marine erosion during an advance of the sea; peneplanation during the course of the 'normal geographical cycle' under conditions of pluvial erosion. As the chief exponent of the desert theory, Passarge has distinguished a number of types. In the Banda type, represented in Western Australia as well as in Africa, the level surface of the plain is ascribed to a general weakening of the winds, whereby overdeepened basins, which tend to form in the absence of rain, have been filled up with sand. The Kordofan type requires the aid of a slight rainfall, just sufficient to stem the undue growth of wind-scoured depressions. In the Adamawa type, the rainfall is now rather more abundant; while in the Rovuma type (German and Portuguese East Africa) the plain of erosion is clearly pre-Cretaceous, and is held to be, at least in form, a relic of desert conditions during the Mesozoic Era. According to Passarge, desert erosion then controlled the topographic evolution of widespread areas, even more extensive than those of the present day. The inselberge themselves are stated to consist of resistant igneous rocks such as granite, or metamorphic rocks such as quartzite. The plains, on the contrary, are formed of less resistant rocks, such as gneiss, schists, or sedimentary deposits.

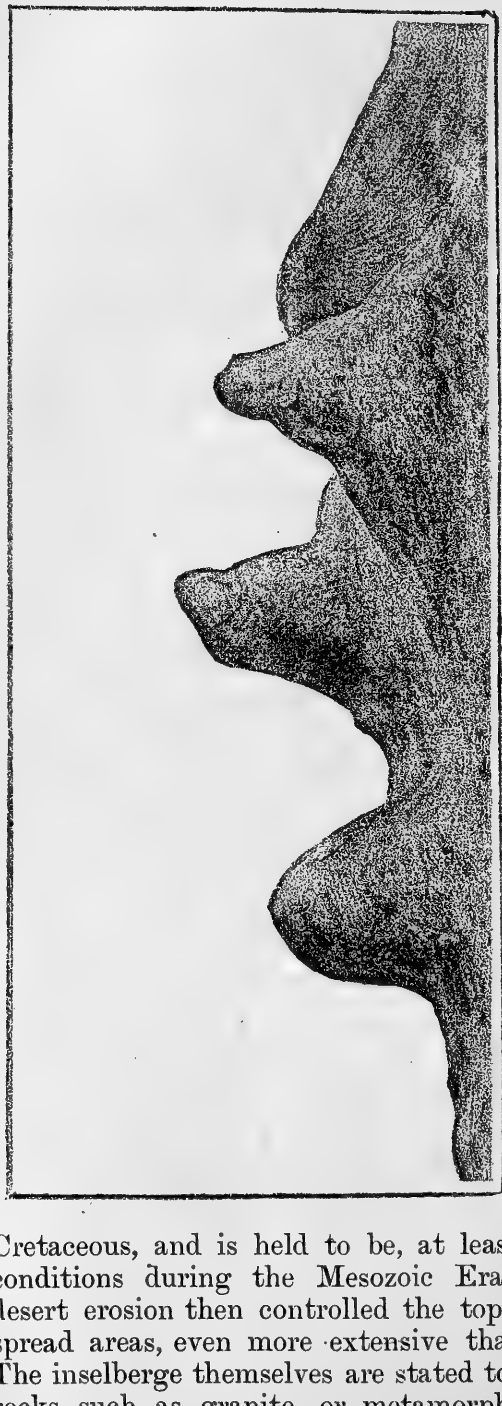

Fig. 12.—*Sketch of the Lebi inselberge, Mbulla Range, by E. J. Wayland.*

The marine erosion theory, which has never found favour, scarcely requires mention, for it was only temporarily suggested by Bornhardt. According to the later views of that writer, the inselberg landscape is regarded as a product of repeated cycles of pluvial erosion. Dr. J. D. Falconer has developed this conception, and in his book on Northern Nigeria (pp. 245–46) he makes the statement that

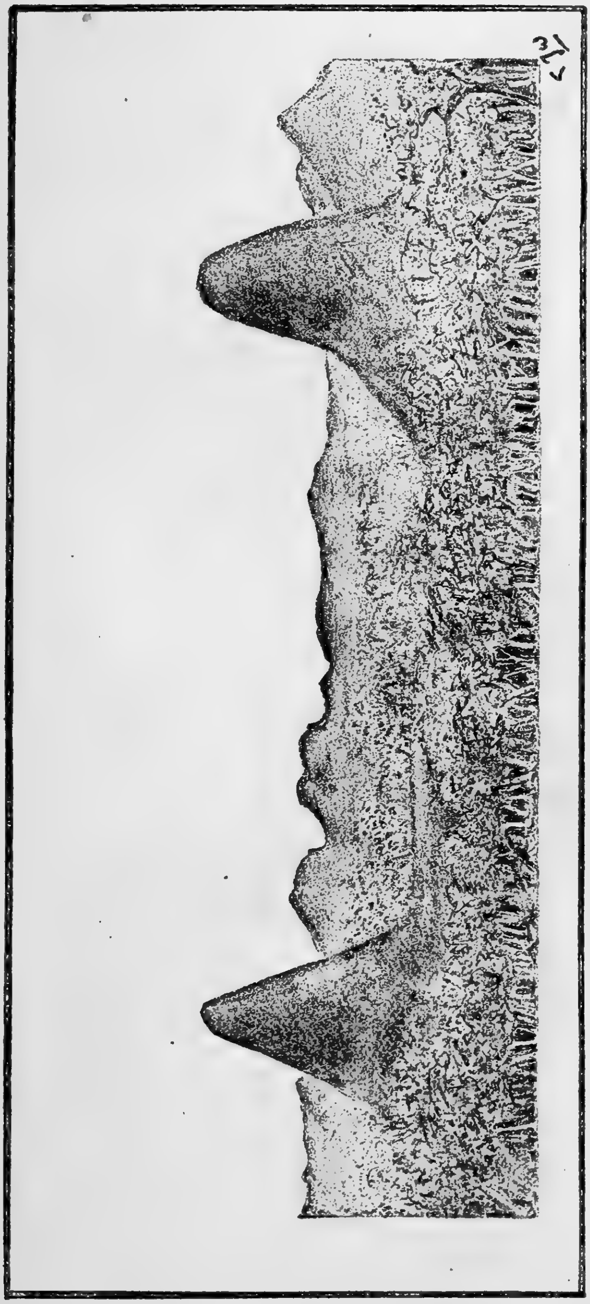

Fig. 13.—*Sketch of the Koldwi inselberge north of the Mtupa Pass, Ribawe, by E. J. Wayland.*

'there is no reason, however, to believe that this peculiar topography cannot arise simply through an alternation of periods of weathering and periods of erosion, brought about either by a gentle oscillation of the crust, or by a repeated base-levelling of the plains and rejuvenation of the drainage system. A plane surface of granite and gneiss subjected to long-continued weathering at base-level would be decomposed to unequal depths, mainly according to the composition and texture of the various rocks. When elevation and erosion ensued, the weathered crust would be removed, and an irregular surface would be produced, from which the more resistant rocks would project.'

This theory might be considered satisfactory if, in addition, it could be shown that there are internal structures and differences of composition in the rocks of the inselberge adequate to explain the superior resistance offered by them as compared with those of the surrounding plain or plateau. In Nigeria such a difference is probably immediately demonstrable, for Falconer ascribes the elliptical outline of the hills to the modification of original phacolithic intrusions (*op. cit.* p. 246). The generalization made by Passarge implies that in Adamawa and in South-West Africa there are similar differences between the rocks of the two land forms. To the Rovuma type, however, this generalization only applies in special circumstances. Throughout German and Portuguese East Africa it is rather the exception to find the inselberg rocks differing markedly from their neighbours of the surrounding plains.

The passage of banded gneisses into granite in certain peaks (as in the Etipoli Hills) and in the gneissic anticlines or elongated domes of others (as, for example, the Mwima and Chica Ranges; see Pl. XI) are clearly cases where the discriminating hand of denudation has picked out slight differences of structure and mineral composition, and has revealed them in the exaggerated form of an inselberg landscape. The whole country abounds with evidence that strongly-foliated or banded rocks lend themselves to attack more readily than granulitic rocks, and that mafic rocks and minerals are removed more rapidly than their felsic associates.

A few isolated peaks and domes, and some of the individual peaks of the mountain-blocks, differ from their surroundings in being built mainly of a grey granulitic or porphyritic granite. Figs. 12 & 13 (pp. 90–91), for which I am indebted to my friend, Mr. E. J. Wayland, illustrate the remarkable appearance of some of these granitic inselberge. This second type is matched in Nigeria, for Falconer (*op. cit.* p. 70), in describing the rocks of Borgu, says:

'The occasional inselberge are composed invariably of grey porphyritic granite.'

A third type of inselberg is also considered to owe its survival to granite intrusion; in this case not to the exposure of ancient stocks or granitic foci, but to the riddling of the gneisses with tongues and apophyses that are probably connected with a more continuous form of intrusion below. Many inselberge and groups of peaks seem to be identical with the surrounding country as regards the composition, structure, and dip of their gneisses, the foliation being independent of the contours of the hills. They differ, however, in being scaffolded and fortified by quartz-felspar veins of extraordinary abundance. The Mhala Hills of Nakavala may be taken as a type of such inselberge.

There are, then, in Mozambique at least three kinds of inselberge that owe their survival to peculiarities of structure or composition:—

(*a*) The gneissic dome or anticline type.
(*b*) The granulitic-granite type.
(*c*) The injection type.

In each case the greater resistance offered to denudation is due to the presence of less foliated (or unfoliated) and more felsic rocks than are found in the adjacent areas. It may be that the inselberge represent relics of those cupola-like portions of upward-moving granitic magmas which locally rose to a higher level in the crust than the parts represented in the intermont plains.

There remains to be considered a fourth type of inselberg. It includes all those peaks which cannot be referred to intrusion processes, since no recognizable differences can be discerned between the structure or composition of their rocks and those of the surrounding district. It is difficult to understand why these inselberge should not have become disintegrated to the same depth as the neighbouring rocks, for the conditions of weathering at the present time are far from favourable to inselberg survival. The effect of insolation is to remove superficial shells from the inselberge (by exfoliation and radial cracking) much more rapidly than the surface of the plateau can be worn down.

At the present time much of the Mozambique plateau is traversed by low ridges which follow the prevailing direction of strike. These ridges must not be confused with the gneissic anticlines of elongated turtlebacks, for they are essentially of the nature of low escarpments.[1] If such escarpments were initiated by pluvial and stream erosion, it seems probable that during subsequent arid conditions the escarpment slopes would be worn back and intensified by localized attack at their base, and that the escarpments themselves would be eaten away laterally, until only isolated remnants remained. Some of the Mozambique inselberge are elongated along the dip, which is always low, and have a steep, often nearly vertical face on one side, which sharply truncates the banding of the gneisses.[2] In several cases, notably Mount Tugwi and a series of peaks north-west of the Mwipi Mountains, the inselberge stand out on low escarpment-like ridges. Mount Tugwi appears to be continued north-eastwards in a series of less prominent inselberge, south-east of which the Monapo River now flows.

Summing up, it would seem that in Mozambique desert conditions, involving the attack of slopes at their bases by arid weathering and the removal of disintegrated material by wind, are more favourable for the development and maintenance of an inselberg landscape than are alternating conditions of deep weathering and rapid erosion.

Faults and Joints.

Although block-faulting cannot be appealed to as a cause for the extraordinary altitude of individual peaks and mountain-blocks, yet in the Ribawe–Nrassi district block-faulting superimposed on the earlier structures seems often to correspond with the lateral limits of the elevated masses. The determination of the faults depends on the assumption that the dip and strike of the gneissic banding and foliation can be used as reliable criteria of the

[1] See A. Holmes, Geol. Mag. dec. 6, vol. i (1914) p. 531, for illustration.

[2] For an admirable illustration (photograph by Mr. D. A. Wray), see Geogr. Journ. vol. xlii (1913), opposite p. 146.

structures. Viewed from various points, the Ribawe Mountains present the appearance of a rectangular block with steep precipitous sides. In the surrounding country on the south and east, the foliation frequently is nearly horizontal and, when otherwise, the prevailing dip is at a low angle towards the west. In the mountains themselves, however, the dip is northwards.[1] This striking divergence suggests that at one time the rocks of the Ribawe block were elevated by an upthrust acting chiefly along the southern edge, a process made possible by two sets of fractures, one nearly due east and west, parallel to the southern front, and the other nearly due north and south, parallel to the eastern walls (see Pl. XI). No exposures of horizontal sections giving direct evidence of faulting have been seen, for around the high peaks such evidences are buried under rock-débris and hidden by thick vegetation. The Bwibwi River gives no help, as in many places vegetation grows abundantly down to the water's edge, and the stream itself has a bed that generally is thickly covered with coarse gravel and transported boulders.

Joints cannot be said to be common in the gneisses, but two systems have been identified parallel to the north-south and east-west fracture-lines. The north-and-south direction is also followed in the Nrassi Basin and elsewhere by a series of pyroxenite-dykes. The same direction is represented by parts of the Mozambique coast, by the small faults in the Cretaceous beds, and by the boundary-fault and basaltic dykes between the Cretaceous and the Pre-Cambrian.[2] On a still larger scale, the north-and-south line of fracture appears to have determined many of the controlling features of this part of the earth's crust. Parallel to it are the faulted eastern coast of Madagascar on the one side, and the Frontier fracture-lines south of the Zambesi on the other,[3] while several sectors of the rift-valleys of Eastern and Central Africa follow the same direction.[4]

XII. Summary.

(*a*) The succession of rocks in eight of the better-known districts of Mozambique is summarized, and it is shown that the general sequence in order of age is—

(5) Dykes of pyroxenite and picrite.
(4) Granites and massive pegmatites.
(3) Granulitic granites and pegmatites.
(2) Biotite-, hornblende-, and garnetiferous gneisses.
(1) Crystalline schists and limestones.

(*b*) The schists are, with few exceptions, the representatives of a differentiated series of detrital deposits including felspathic,

[1] See photograph in Geol. Mag. dec. 6, vol. i (1914) pl. xxxvii.
[2] Q. J. G. S. vol. lxxii (1916–17) pp. 225–26.
[3] E. O. Teale & R. C. Wilson, Geogr. Journ. vol. xlv (1915) p. 16.
[4] E. Suess, 'La Face de la Terre' vol. iii, pt. 3 (1913) fig. 221, p. 971; A. Holmes, Geogr. Journ. vol. xlviii (1916) p. 149.

argillaceous, micaceous, and ferruginous sandstones. Characteristic argillaceous types have not been recognized.

(*c*) Crystalline limestones, occurring as lenticular masses interfoliated with amphibolites and hornblende-gneisses, are described from several localities. Contact-metamorphism by later granitic intrusions has generally resulted in the formation of diopside or actinolite, according to the abundance of silica; while, in some instances, garnet-scapolite rocks have developed. In one case, a magnetite-pegmatite has interacted with a forsterite-marble, giving a contact-rock composed of andradite, augite, sphene, and felspar. It is thought that the crystalline limestones are of exogenetic origin, and that any argillaceous rocks with which they may have been originally associated have been completely assimilated by the granitic magma now represented by the gneisses. Limestones tend to persist—if the pressure be sufficiently high—since they are not easily granitized, like argillaceous rocks, but become enclosed within a blanket of hornblende-gneiss or amphibolite which may preserve an internal core from the attack of igneous exudations.

(*d*) Transitions are described from coarsely-banded biotite-gneiss to gneissose granite poor in biotite and nearly free from foliation; and from coarsely-banded biotite-gneiss through hornblende-gneiss and amphibolite, to garnetiferous rocks and crystalline limestones. It is suggested that the gneisses were produced by the concordant injection of granitic magma (now represented most closely by the gneissose granites of certain inselberge) into a series of pre-existing sediments. Of the latter the argillaceous facies became granitized, and controlled the formation of biotite-gneisses, while the calcareous or dolomitic facies formed with the granite hornblendic and garnetiferous rocks. This suggestion of the composite origin of the gneisses is supported by evidence based on the radioactivity of the rocks.

(*e*) The older rocks are riddled with enormous numbers of small intrusions of granite and pegmatite, of which two series can be recognized, the older being characteristically granulitic in texture, while the younger is typically massive. With the older series is correlated a group of augitic inclusions ranging from granite to quartz-diorite.

(*f*) By means of lead-ratios (Pb/U in zircon), the biotite-gneisses are correlated with the Pre-Huronian Laurentian rocks of Canada; and the granulitic granites belonging to the next period of intrusion are correlated with granitic rocks in the Middle Pre-Cambrian of Norway, Sweden, India, and Canada. The Pre-Cambrian age of a majority of the rocks in the basal complex of Mozambique is thus established.

(*g*) The inselberg landscape of Mozambique is described, and it is shown that, while some of the peaks owe their survival to peculiarities of structure or composition, there are others the constituent rocks of which differ in no recognizable way from those of the surrounding plateau in their immediate neighbourhood. It is considered probable that the landscape may have been developed during the more arid conditions of a former period.

I wish here to repeat the acknowledgments made at the conclusion of my former contribution ('The Tertiary Volcanic Rocks of the District of Mozambique' Q. J. G. S. vol. lxxii, 1916–17, p. 227) to the Portuguese officials in Mozambique, to the Directors of the Memba Minerals Ltd., and to my former colleagues in the field, Mr. E. J. Wayland and Mr. D. A. Wray in particular. The greater part of the laboratory investigation of the rocks was carried out at the Imperial College of Science & Technology during the years 1912–14, the long subsequent delay in completing the paper being due to the pressure of more immediately useful work. I wish to thank Prof. W. W. Watts for placing at my disposal the resources of the Geological Department, for encouragement and critical discussion, and for reading the completed manuscript. Part of the radioactive work was carried out during the years 1912–13 in the laboratory and under the guidance of Prof. the Hon. R. J. Strutt, to whom I owe especial thanks, not only for invaluable instruction and assistance, but also for continuing to lend me his apparatus for determining small quantities of radium in rocks and minerals. The rest of the radioactive work was done with the aid of a Royal Society Grant awarded in 1914, for which I make grateful acknowledgment. Prof. C. G. Cullis, Dr. J. W. Evans, and Mr. H. G. Smith, my colleagues at the Imperial College, have from time to time examined and discussed with me series of rocks and sections, and for their active interest and willing assistance I wish to express my indebtedness. Finally, I owe my thanks to Mr. G. S. Sweeting, who, as on previous occasions, has skilfully prepared the photomicrographs with which the paper is illustrated.

EXPLANATION OF PLATES VIII–XI.

Plate VIII.

Fig. 1. Sediment-gneiss (186), 4 miles north of Mitikiti, in a tributary of the Mitikiti River, Mozambique. Chief minerals: quartz, felspar, and biotite. × 20. (See p. 44.)

2. Quartz-magnetite-granulite (182), found as a pebble in the Monapo gravels between Mitikiti and Murimatigri. Chief minerals: quartz and magnetite. × 20. (See p. 44.)

3. Quartz-mica-schist (172), north of Murimatigri. Chief minerals: quartz, felspar, and biotite. × 20. (See p. 45.)

4. Hornblende-schist (176), Mukumburi Valley, west of Memba. Chief minerals: hornblende, oligoclase, quartz, epidote, and sphene. × 20. (See p. 45.)

5. Forsterite-marble (221), Ampwihi Crossing. Chief minerals: calcite, partly-serpentinized forsterite, and chondrodite. × 20. (See p. 48.)

6. Quartz-garnet-scapolite rock (193), Ampwihi Crossing. Chief minerals: garnet, scapolite, quartz, calcite, sphene, and ilmenite. × 20. (See p. 49.)

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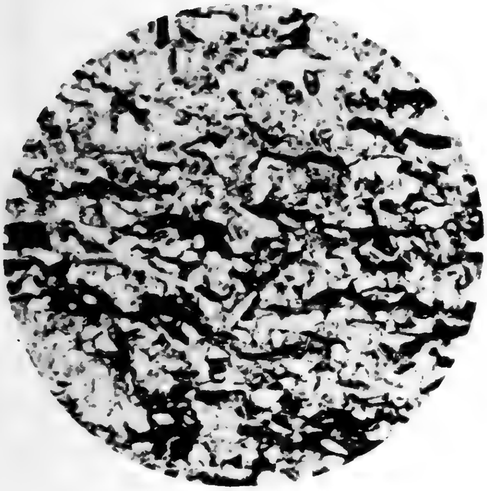

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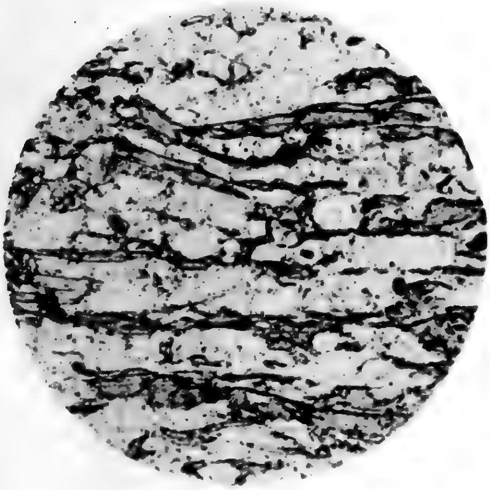

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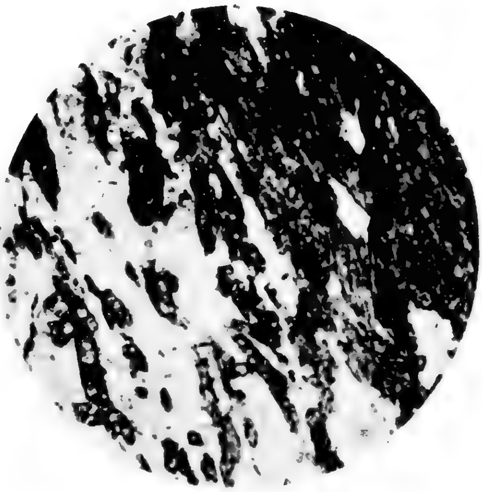

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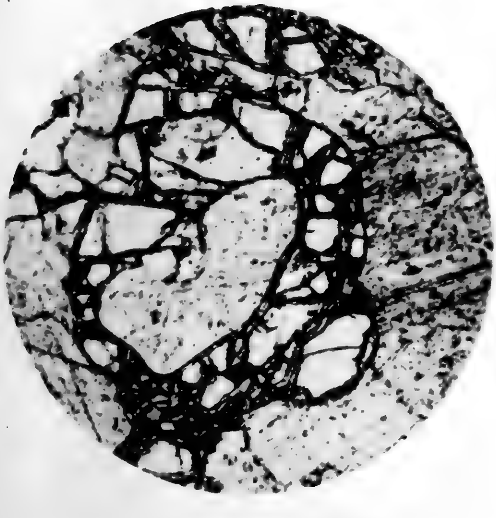

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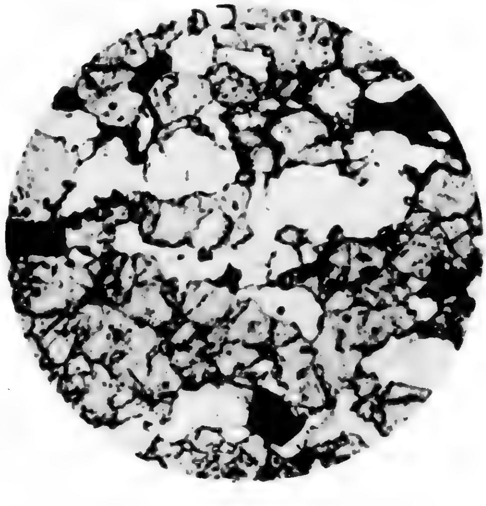

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Bemrose, Collo, Derby.

PRE-CAMBRIAN ROCKS OF MOZAMBIQUE.

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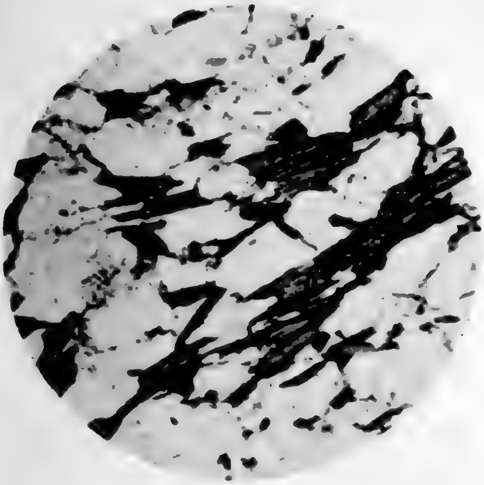

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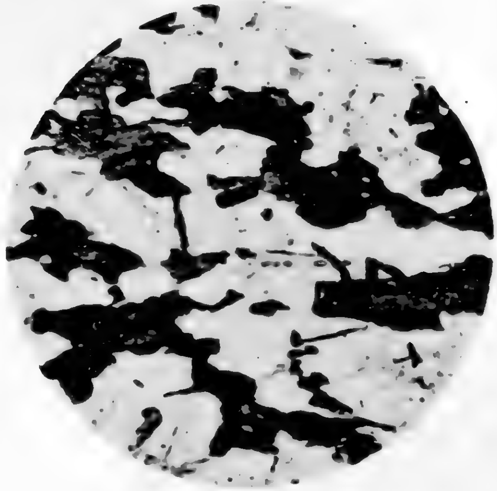

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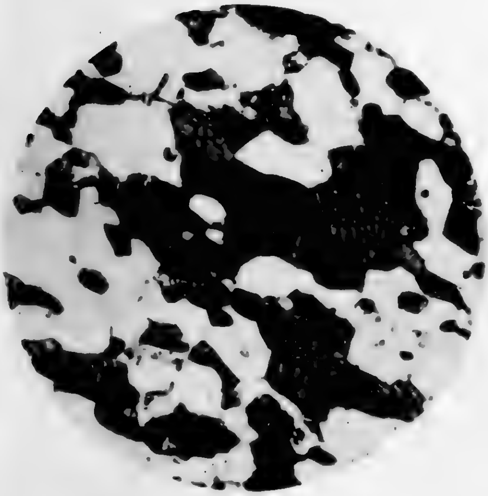

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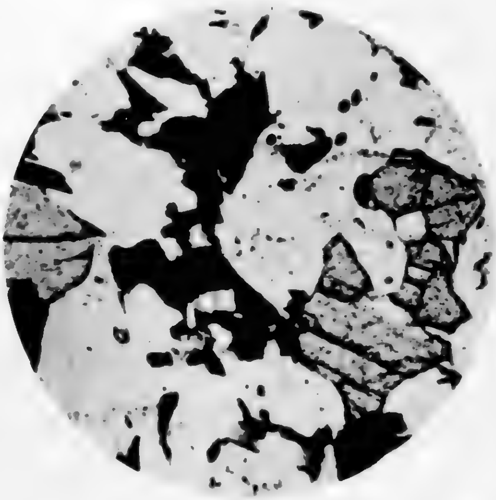

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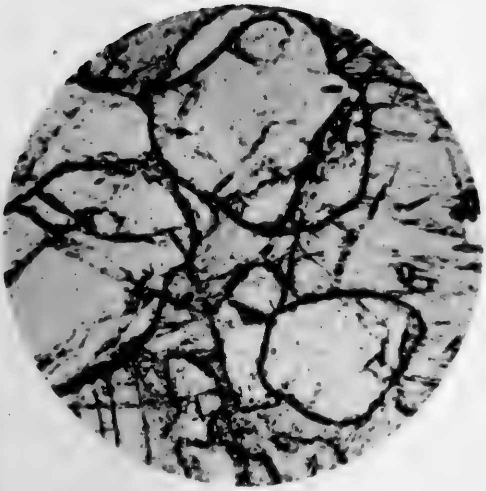

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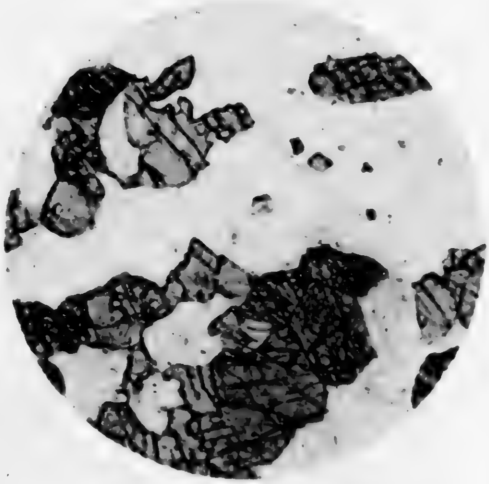

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⎵ = 1 mm.

Bemrose, Collo., Derby.

PRE-CAMBRIAN ROCKS OF MOZAMBIQUE.

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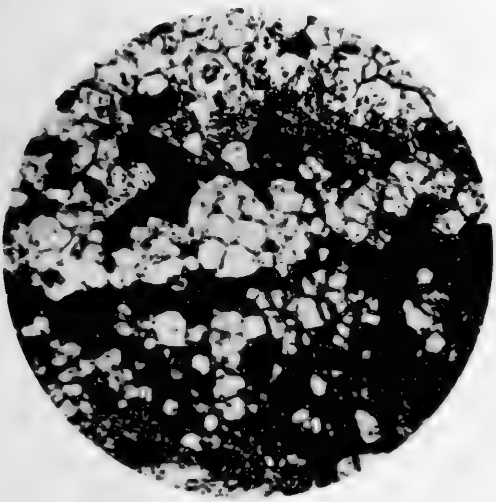

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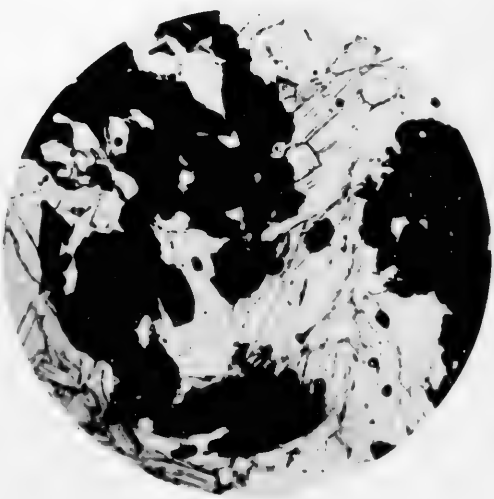

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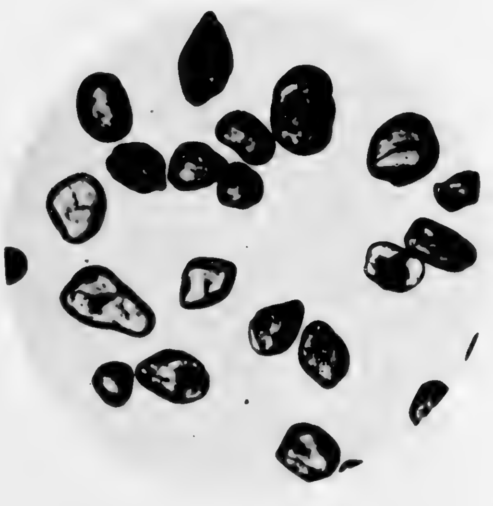

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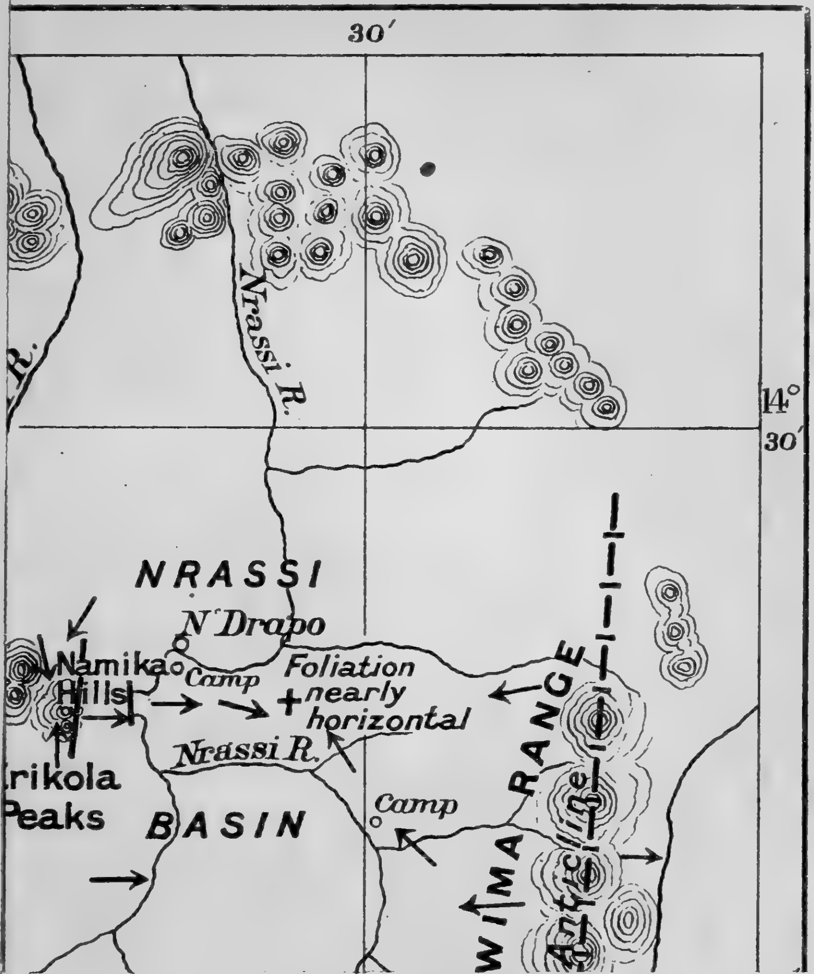
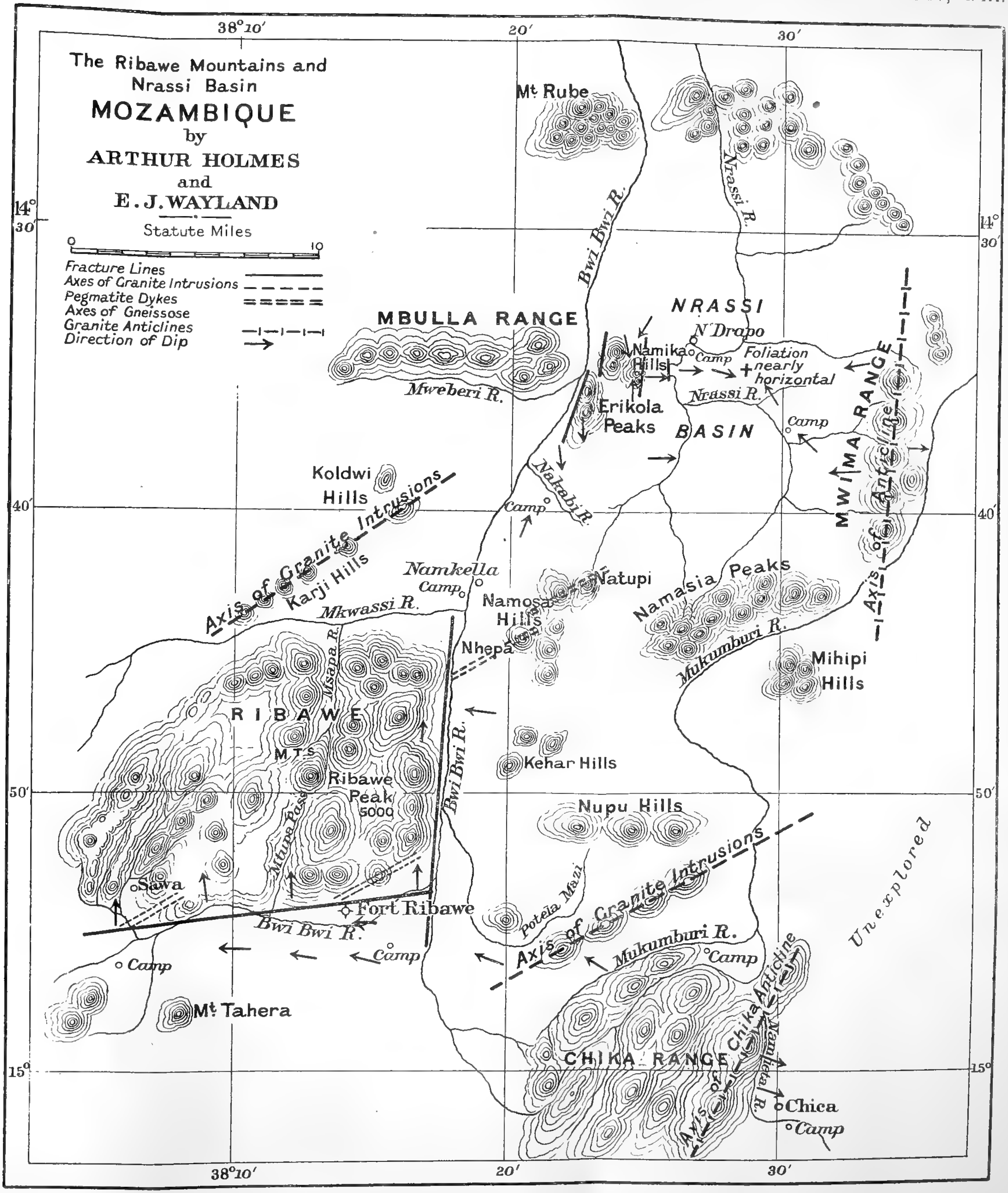
Bemrose, Collo., Derby

PRE-CAMBRIAN ROCKS OF MOZAMBIQUE.


30′
14°
30′
Nrassi R.
R.
NRASSI
N'Drapo
Namika
Hills
Camp
Foliation
nearly
horizontal
Nrassi R.
Irikola
Peaks
BASIN
Camp
WIMA RANGE
Anticline


The Ribawe Mountains and Nrassi Basin
MOZAMBIQUE
by
ARTHUR HOLMES
and
E. J. WAYLAND
Statute Miles
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10
Fracture Lines
Axes of Granite Intrusions
Pegmatite Dykes
Axes of Gneissose Granite Anticlines
Direction of Dip
38°10′
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40′
50′
15°
Mt Rube
Nrassi R.
Bwi Bwi R.
MBULLA RANGE
NRASSI
N'Drapo
Namika Hills
Camp
Foliation nearly horizontal
Mweberi R.
Erikola Peaks
Nrassi R.
BASIN
Camp
MWIMA RANGE
Axis of Anticline
Koldwi Hills
Nakabi R.
Camp
Axis of Granite Intrusions
Karji Hills
Namkella Camp
Natupi
Namasia Peaks
Mkwassi R.
Namosa Hills
Nhepa
Mukumburi R.
Mihipi Hills
RIBAWE
MTS
Msapa R.
Ribawe Peak 5000
Bwi Bwi R.
Kehar Hills
Nupu Hills
Mtupa Pass
Sawa
Fort Ribawe
Bwi Bwi R.
Potela Mani
Axis of Granite Intrusions
Unexplored
Camp
Camp
Mukumburi R.
Camp
Mt Tahera
CHIKA RANGE
Axis of Chika Anticline
Namleda R.
Chica
Camp

Plate IX.

Fig. 1. Biotite-gneiss (49), 3 miles from Ibrahimo, on the road to Mosuril. Chief minerals: quartz, orthoclase, microcline, oligoclase, biotite, and muscovite. × 20. (See p. 54.)

2. Hornblende-gneiss (189), Ampwihi Crossing. Chief minerals: hornblende, andesine-labradorite, perthitic orthoclase, and biotite. × 20. (See p. 58.)
3. Garnetiferous amphibolite (194), Ampwihi Crossing. Chief minerals: hornblende, labradorite, garnet, and titaniferous magnetite. × 20. (See p. 58.)
4. Garnetiferous biotite-gneiss (97), Norray Hills. Chief minerals: quartz, microcline, andesine, biotite, and garnet. × 20. (See p. 62.)
5. Eclogite (77), Norray Hills. Chief minerals: garnet, amphibole, pyroxene, and rutile. × 20. (See p. 62.)
6. Quartz-garnet-pyroxene rock (78), Norray Hills. Chief minerals: garnet, pyroxene, scapolite (meionite), and quartz. × 20. (See p. 62.)

Plate X.

Fig. 1. Augite-granite (27), Sawa Cave, Ribawe Mountains. Chief minerals: quartz, orthoclase, microcline, oligoclase, and pyroxene. × 20. (See p. 73.)

2. Norite rich in sphene (37), floor of the Namieta River, south of Peone Hill. Chief minerals: labradorite, augite, enstatite, and sphene. × 20. (See p. 75.)
3. Rutile-apatite vein in augite-adamellite (21). Chief minerals: apatite, rutile, sphene, and pyrite. × 20. (See p. 73.)
4. Rutile-muscovite rock (74), near Monapo River, east of Mount Tibwe. Chief minerals: muscovite, rutile, and quartz. × 20. (See pp. 73–74.)
5. Pyroxenite (33), half a mile from the foot of Ericola, in a gully draining into the Nrassi River. Chief minerals: diopside, hornblende, and enstatite. × 20. (See p. 81.)
6. Monazite-grains (residue No. 5), separated from the sand of the Bwibwi River above the confluence with the Potela Mazi. × 20. (See p. 83.)

Plate XI.

Map of the Ribawe Mountains and the Nrassi Basin, on the scale of 5 miles to the inch, or 1 : 316,800.

Discussion.

Dr. J. W. Evans spoke of the thorough way in which the Author had worked out his materials and the interest of the conclusions at which he had arrived. The Author had proved his point about the local absorption of the limestone in the granitic magma, but this could not be said with regard to the suggestion that the biotite-gneiss resulted from the absorption of an argillaceous rock by a magma representing a simple binary granite containing only quartz and felspar. An argillaceous rock would not afford the magnesia required, nor did such magmas usually form extensive intrusicns. The discussion in the paper on the mode of production of the inselberg landscape was of especial interest.

Mr. J. F. N. Green said that the paper was of great value to those interested in the Archæan plateau of Africa. He especially welcomed the application of a new method of verifying the Archæan succession. While there was some resemblance to the Haliburton (Canada) rocks, as also to the similar occurrences in India and Finland, the likeness was not well marked, since he understood that oligoclase was not predominant in the biotite-gneisses, which, unlike the Haliburton oligoclase-gneisses intruded into amphibolite and limestone, were unaccompanied by fringes of nepheline- and other alkali-syenites. On the other hand, in West Africa all these phenomena were reproduced, and it seemed that the Archæan of Africa, as of other continents, presented two distinct types of main granitic intrusion. He noted the statement that altered arenaceous sediments only occurred on the coast, and remarked that altered argillaceous sediments seemed to occur chiefly on the outer edges of the plateau, as on the Gold Coast and near Gondokoro, from which latter locality a bit of garnet-kyanite-schist had been given to him. The paper was an important contribution, not only to African, but also to general, geology.

The Author thanked the Fellows for their kind reception of his paper, and expressed his gratitude for the complimentary remarks made.

In reply to Dr. Evans he said that he had been careful not to commit himself to the hypothesis put forward in explanation of the origin of the gneisses and their foliation. In the paper itself an alternative hypothesis—not involving the injection of granite-magma into pre-existing schists—was outlined, but neither view was suggested as being more than a possibility worthy of discussion. Even if the biotite-gneisses were composite, there could be no doubt that they were predominantly of granitic origin. It was necessary, however, to recognize frankly that the problems involved were still far from being completely solved.

Answering Mr. Green, the Author said that, except in the hornblendic rocks, oligoclase was subordinate to orthoclase or microcline in the gneisses. It was of interest to notice that in the banded varieties oligoclase was an abundant mineral in the melanocratic (biotite-rich) bands and streaks, whereas it was no more than an accessory in the leucocratic or felsic portions of the rocks.

[May 6th, 1919.]

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OF

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[The Editor of the Quarterly Journal is directed to make it known to the Publ that the Authors alone are responsible for the facts and opinion contained in their respective Papers.]

*** The Council request that all communications intended for publication by th Society shall be clearly and legibly written on one side of the paper only, w proper references, and in all respects in fit condition for be at once placed in the Printer's hands. Unless this is done, it will b the discretion of the Officers to return the communication to the Author for revis

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Part 2.

THE

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OF THE

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EDITED BY

THE PERMANENT SECRETARY.

[With Five Plates, illustrating Papers by Mr. R. D. Oldham, Mr. J. Morrison, and Mr. L. Richardson.]

July 9th, 1919.

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ORDINARY MEETINGS OF THE GEOLOGICAL SOCIETY TO BE HELD AT BURLINGTON HOUSE.

SESSION 1919–1920.

1919.		
Wednesday,	November	5*—19
„	December	3 —17*
1920.		
Wednesday,	January	7*—21*
„	February (*Anniversary Meeting,* Friday, February 20th)	4*—25*
„	March	10—24*
„	April	21*
„	May	5 —19*
„	June	9 —23*

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

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

3. *A* SEASONAL VARIATION *in the* FREQUENCY *of* EARTHQUAKES. By RICHARD DIXON OLDHAM, F.R.S., F.G.S. (Read February 6th, 1918.)

[PLATE XII.]

WHEN investigating the aftershocks of the great Indian earthquake of 1917, I found that the ratio of shocks occurring during the day half of the twenty-four hours, between 6 A.M. and 6. P.M., to those occurring during the night half, was somewhat greater than the general average during the summer months, when the sun is in north declination, and somewhat less during the winter months, when the sun is south of the equator. As this relation was found not only in the whole record, but also in the natural groups of observations, it seemed probable that the variation was a real one, and not fortuitous; while the fact that the record of the Shillong seismograph, when tabulated by lunar times and seasons, gave a similar variation suggested that the cause was not climatic, but in some way connected with the tidal stresses set up by the attraction of the sun and the moon.[1]

At a later date I made a tabulation (which has not been published until now) of Milne's catalogue of Japanese earthquakes,[2] and again found a similar relation between the ratio of day to night shocks in the two halves of the year; and a similar tabulation of the records from a number of observatories,[3] mostly independent of and covering a later period than Milne's catalogue, again gave the same result.

Recently there has appeared an abstract tabulation of twenty years' records of observations, carried on by the Italian seismological service, which enables the subject to be more completely studied than was possible with the more limited and imperfect records previously available.[4] In this, once more, the relatively greater frequency of earthquakes during the day in summer and the night in winter is shown by a tabulation of the two halves of the year, and the completeness of the record enables a further test to be applied, based on the consideration that, if the observed variation is not accidental but due to some cause, whether climatic or physically dependent on the variation in the position of the sun, it should be greater at the height of each season than the average of the whole of each half-year. The months June and July were, therefore, taken as representing midsummer conditions, and the comparison of day and night frequency showed a divergence from the average of the year in the same direction as that of the season as a whole, but greater in amount. Similarly, the months of

[1] Mem. Geol. Surv. Ind. vol. xxxv, pt. 2 (1903) pp. 117–45.
[2] Seismol. Journ. Japan, vol. iv (1895).
[3] Publ. Earthq. Invest. Committee, No. 8, 1902.
[4] Boll. Soc. Seismol. Ital. vol. xx (1916) pp. 9–31.

December and January, as representing midwinter conditions, showed a larger excess of night shocks than the general average of the winter half-year.

The actual figures and ratios referred to above are set forth in detail in tabular statement No. 1 (p. 101), and in this each group of half-yearly ratios of frequency may be taken as a single event. In any division of the year into two halves the ratio of day to night shocks would very improbably be exactly the same as for the whole: the actual divergence is in no case greater than might reasonably be expected if the variation were purely fortuitous, and the odds are even that the variation would be in either direction. No conclusion can, therefore, be drawn from any one group taken separately; but the probability that the variation would be in the same direction in each of the three groups is only one-eighth. Similarly, the two extremes in the Italian record may be taken as independent events; in each case, if merely accidental, the variation might, with equal probability, be such as to make the ratio either greater or less than the average of the whole of each half-year, but the probability of their being in both cases greater is only one-quarter, reducing the probability of the whole series falling in the order actually found to one thirty-second. In other words, the odds are 31 to 1 that the variations are not accidental but due to some common cause, and, if the lunar tabulation of the Shillong seismograph can be accepted as another event, the odds become 63 to 1.

From these considerations it may safely be laid down as a general principle that earthquakes are rather more frequent during the day in summer and less frequent in winter than the general averages, with an opposite variation in frequency during the night; and that this relation may be expected wherever the record is sufficiently complete, covers a sufficiently long period, and contains not less than about 1000 separate shocks. This last proviso is necessary, for, with so irregular a phenomenon as an earthquake, a good average can only be obtained where a sufficiently large number of separate records is dealt with. Experience has shown that 400 is about the lowest limit which can be safely used, a larger number is better; but the irregularities become so great, when the number in each separate group dealt with falls below 400, that small variations cease to be traceable.

The extent of the Italian record makes it possible to carry the investigation farther, by considering, separately, each of the two-hour periods in which the record is tabulated. This has been done in tabular statement No. 2 (p. 102), from which it will be seen that the relation between day and night shocks which was found in the case of the half-days is also met with in each of the two-hour periods of each half. A similar tabulation of the Japanese catalogue gave results in substantial agreement with the Italian, with irregularities for the periods between 2 and 6 A.M. and 4 to 6 P.M.; the Japan record, however, is much less homogeneous than the Italian, for, of the total number of shocks recorded, more than three-fifths are after-shocks of the Mino-Owari earthquake of October 28th, 1891, and of these three quarters fall in the winter half-year. As a result, the mean number of shocks in the two-hour periods of the summer half-year is only 255, a number much too small to give a good average, with the result that the curve of frequency shows great irregularity. This could be obviated by enlarging the groups by a series of overlapping periods; but the method seems less legitimate than that of simply enlarging the periods to three hours each, by which a series of numbers close to the minimum admissible is obtained. The result of this tabulation is given in statement No. 3 (p. 102), and this and the Italian record are shown graphically in the accompanying diagram (Pl. XII).

An examination of these curves shows that the variation in frequency is distributed symmetrically with regard to the time of meridian passage of the sun, but oppositely in each half-year. In other words, it is represented, for each season, by a curve of 24-hour period, with its maximum and minimum, at the times of meridian passage, superimposed on the general curve of variation in frequency—this superimposed curve being similar in each half-year, but with the maximum of one half coincident in time with the minimum of the other. As the variation in the gravitational stresses set up by the sun follows precisely the same course, it is not unnatural to suppose that the two may be connected as cause and effect, and the suggestion obtains some support from the lunar

I. Day and Night Frequency of Earthquakes.

	Number of Shocks.		*Ratio.*
	Day.	*Night.*	*Day : Night.*
Italy, 1891–1910.			
June-July	791	967	90 : 110
Summer half-year	2057	2615	88 : 112
Whole year	3828	5238	84 : 116
Winter half-year	1771	2623	81 : 119
December–January	583	928	77 : 123
Japan, 1885–1892.			
Summer half-year	1522	1537	98 : 102
Whole year	3872	4456	97 : 103
Winter half-year	2350	2919	93 : 107
Assam Aftershocks.			
Sun's declination over 9° N.	1476	1126	113 : 87
Whole year	3839	3329	107 : 93
Sun's declination over 9° S.	1175	1147	101 : 99
Shillong Seismograph Lunar.			
Moon's declination over 9° N	260	250	102 : 98
Whole record	632	642	99 : 101
Moon's declination over 9° S	194	237	90 : 110

II. DIURNAL DISTRIBUTION OF EARTHQUAKES (ITALY, 1891–1910).

Hours.	Number of Shocks.			Ratio to Mean.		
	Year.	Summer.	Winter.	Year.	Summer.	Winter.
0– 2	1001	500	501	1·32	1·29	1·37
2– 4	1094	556	538	1·45	1·43	1·47
4– 6	903	448	455	1·20	1·15	1·24
6– 8	735	386	349	·97	·99	·95
8–10	582	316	266	·76	·81	·73
10–12	623	329	294	·83	·85	·80
12–14	603	335	268	·80	·86	·73
14–16	666	351	315	·88	·90	·86
16–18	619	340	279	·82	·87	·76
18–20	627	312	315	·83	·80	·86
20–22	755	361	394	1·00	·93	1·08
22– 0	858	438	420	1·14	1·12	1·15
Totals ...	9066	4672	4394	12·00	12·00	12·00

III. DIURNAL DISTRIBUTION OF EARTHQUAKES (JAPAN, 1885–1892).

Hours.	Number of Shocks.			Ratio to Mean.		
	Year.	Summer.	Winter.	Year.	Summer.	Winter.
0– 3	1086	378	708	1·04	·99	1·08
3– 6	1016	365	651	·98	·95	·99
6– 9	975	396	579	·94	1·04	·88
9–12	926	355	571	·89	·93	·87
12–15	1049	425	624	1·01	1·11	·95
15–18	922	346	576	·89	·91	·88
18–21	1079	353	726	1·04	·92	1·10
21– 0	1265	441	824	1·21	1·15	1·25
Totals ...	8318	3059	5259	8·00	8·00	8·00

tabulation of the Shillong seismograph, though the number of shocks dealt with in this case is too small to give it much weight. For the present this must remain a mere suggestion; all that can be asserted is that, whatever may be the actual ratio of day to night shocks in any district and any period, it will be rather greater in summer, and rather less in winter, than the average of the whole year and period.

[In this paper no attempt has been made to apply the method of harmonic analysis because the applicability to earthquake frequency seems doubtful, for reasons which cannot be discussed in detail. As, however, something of the kind seems expected, and as the Italian record, by reason of its completeness and of the fact that the period covered is nearly coincident with the lunar cycle of 19 years, is less unsuited to this method of treatment than the records which had been previously available, it may not be without interest to point out that the observed frequency is closely approximated by the formula

$$N = 755{\cdot}5 + 212 \sin. (t + 61^\circ\, 45') + 122 \sin. (2t + 14^\circ), \quad . \quad . \quad . \quad (1)$$

where N represents the number of shocks occurring in any period of two hours' length, and t the time of the middle of the two hours, reckoned from midnight. This formula may be more conveniently put in the form

$$R = 1{\cdot}0 + {\cdot}28 \sin. (t + 61^\circ\, 45') + {\cdot}13 \sin. (2t + 14^\circ), \quad . \quad . \quad . \quad . \quad (2)$$

where R represents the ratio of the actual to the mean number of shocks in a two-hour period, and from this we get the true harmonic frequency[1] as

$$F = 1{\cdot}0 + {\cdot}28 \sin. (t + 61^\circ\, 45') + {\cdot}14 \sin. (2t + 14^\circ). \quad . \quad . \quad . \quad . \quad (3)$$

In other words, we have a diurnal period with a maximum at 1h. 53m. after midnight and a minimum twelve hours later, combined with a semidiurnal period having maxima at 2h. 32m. after midnight and midday, and minima six hours later. The semidiurnal period may be connected with the gravitational stresses set up by the sun, if the correlation is, as it should be, with the rate of change, not with the actual amount, of the stress. The diurnal period is less easy to explain; there is no apparent connexion with the distribution of the gravitational stresses, nor with the diurnal variation in the height of the barometer; there is some apparent connexion with the diurnal variation in temperature, but it is difficult to see how this could affect the frequency of earthquakes. The last named seems to have a real periodicity, for each of the two decades gives a formula closely corresponding to that of the whole period, and the variation in frequency cannot be attributed, in any appreciable degree, to variation in the perfection of the record, by feeble shocks being recorded at some times of the day, and passing unnoticed at others. This is shown by the separate tabulation of shocks of over V° of the Mercalli scale, that is, shocks of such a degree of violence that they could not pass unnoticed and unrecorded, at whatever hour of the day or night they might occur, in a country where the observation of earthquakes is so well organized as in Italy. This tabulation gives an harmonic frequency of

$$F = 1{\cdot}0 + {\cdot}28 \sin. (t + 61^\circ\, 15') + {\cdot}17 \sin. (2t + 19^\circ), \quad . \quad . \quad . \quad . \quad (4)$$

which does not differ materially from (3).

The seasonal variation in frequency dealt with in the paper involves the introduction of a fourth term which makes the approximate representation of the diurnal periodicity in each half year

$$F = 1{\cdot}0 + {\cdot}28 \sin. (t + 61^\circ\, 45') + {\cdot}14 \sin. (2t + 14^\circ)$$
$$\pm {\cdot}04 \sin. (t + 90^\circ), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

[1] C. Davison, Phil. Trans. Roy. Soc. vol. clxxxiv (1893) p. 1111.

the negative sign of the fourth term being used for the summer, and the positive for the winter, half of the year.

The Japanese record, treated similarly, gives the formula

$$F = 1{\cdot}0 + {\cdot}10 \sin. (t + 107^\circ 15') + {\cdot}04 \sin. (2t + 130^\circ), \quad . \quad . \quad . \quad (6)$$

which, compared with (3), shows amplitudes of about one-third of those in the Italian record, and epochs which precede midnight by 1h. 9m. and 1h. 20m. respectively. The meaning and interpretation of this difference being at present under investigation, further reference to it must be deferred.]

EXPLANATION OF PLATE XII.

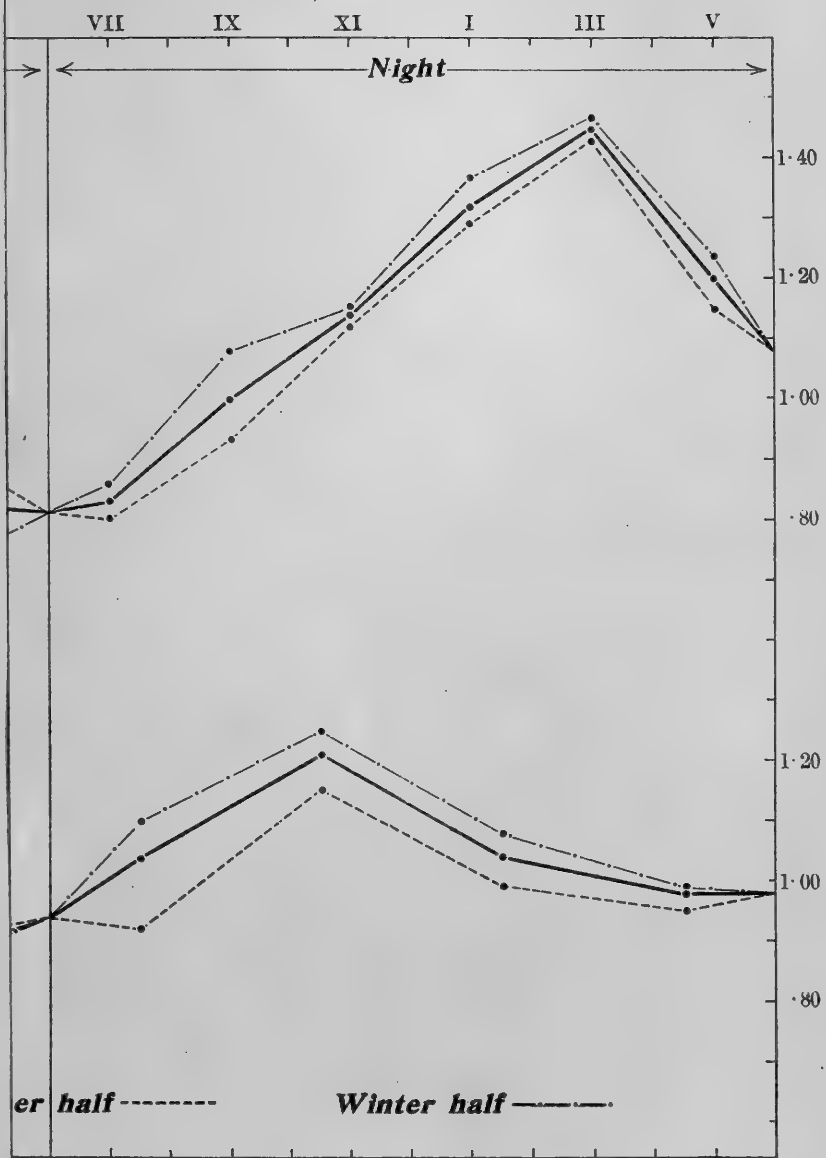
Diagram illustrating the diurnal and seasonal frequency of earthquakes in Italy and Japan.

Discussion.

Dr. J. W. Evans congratulated the Author on the clearness of his exposition of the intricate relations with which his communication dealt. He seemed to have established satisfactorily the reality of the diurnal and seasonal variations in earthquake frequency for which he contended, and their relation to the diurnal inequality of the solar tides in the earth's crust. One naturally compared these results with the pendulum observations by Hecker at Potsdam in a chamber excavated at more than 80 feet below the surface of the ground. These indicated variations in the conformation of the earth's crust, which, like those in the frequency of earthquakes, must be due to stresses of a periodic character. The diurnal variation is, however, attributed to changes of temperature, partly because it is too large in comparison with the semidiurnal and lunar variations to represent the diurnal tidal inequality, and partly because it is greatest in summer and least in winter. It is difficult to understand how the variations in temperature which mainly occur in the outer 6 or 8 inches of the earth's crust and have practically ceased to exist at a depth of 2 feet could have such a result; but there is no other known cause that can be suggested, except the light pressure of the sun's radiation, and that only amounts to 75,000 tons for the whole hemisphere exposed to sunlight. The diurnal variation in earthquake frequency described by the Author cannot be due to the daily changes of temperature, for it is least in summer when these are greatest.

By permission of the President, Dr. Evans then read the following extracts from a letter by Mr. Harold Jeffreys, who had seen the abstract, but was prevented from being present at the discussion:—

The dynamical explanation of these observations is likely to be somewhat difficult. The diurnal effect (period 24 hours) might arise, either from the diurnal bodily tide, or from heating. The former is rather small, depending on the inclination of the Equator to the ecliptic, and should have opposite signs in winter and summer at the same plane, and in the Northern and Southern Hemispheres at the same time. Its amplitude is only about a



NCY OF EARTHQUAKES IN ITALY AND JAPAN.

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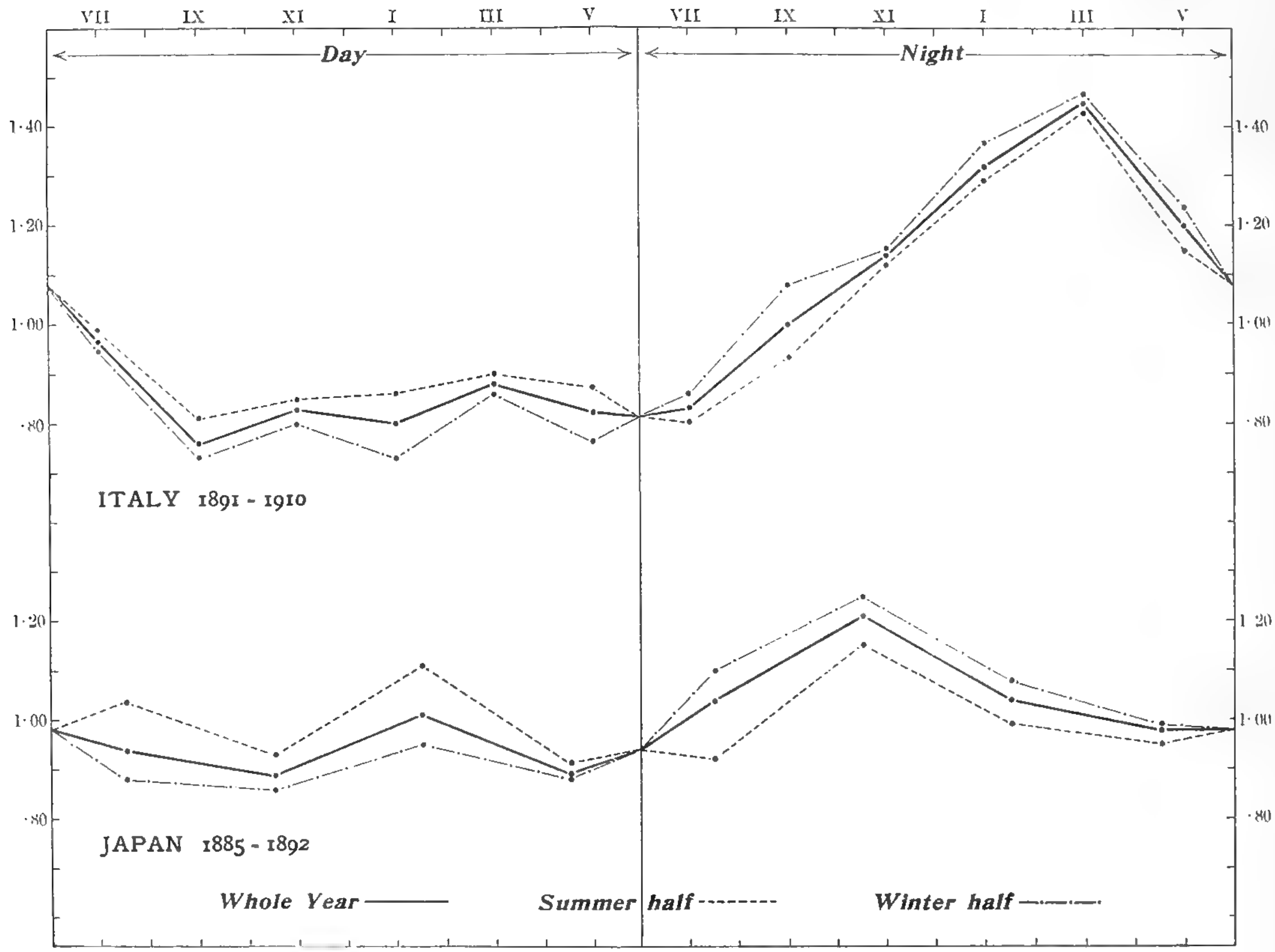


THE DIURNAL AND SEASONAL FREQUENCY OF EARTHQUAKES IN ITALY AND JAPAN.

quarter of that of the solar semidiurnal tide, but this has a node in latitudes $\pm \sin^{-1} \frac{1}{\sqrt{3}}$ — not far from Italy and Japan. From the fact that the difference between day and night persists throughout the year without change of sign, only of amplitude, I should conjecture that the explanation is partly thermal and partly tidal, although I admit that I do not know how heating could produce any effect at such depths, unless it could penetrate in some way down the fault-planes. It is very difficult, for instance, to exclude the direct effect of the surface in finding temperatures in borings.

If the diurnal bodily tide is important in Japan, then the solar semidiurnal tide should produce a far greater effect at the Equator and in high latitudes, and the lunar semidiurnal tide a greater one still; the action of the two together would give a strong fortnightly term. The absence of these would indicate that the effect is mostly thermal.

Mr. W. H. Booth suggested that the Earth's temperature, which increases about 1° Fahr. per 50 feet of depth, was due solely to the friction set up by the work of the sun and moon in bending the Earth's outer surface, and that the temperature probably attains a maximum at a comparatively small depth. This is supported by the high temperatures found in boring the Simplon Tunnel, when boiling water was met with several thousand feet above sea-level. Mountains, of course, standing above the general level, are particularly subject to tidal action. All work is dissipated as heat, and, when the rock-temperatures attain a certain limit, the rocks may be so weakened as to give way: as the Author of the paper suggests, the tendency would be to give way at times of maximum effort of tide-producing agents.

The Author, replying, said that he was by no means satisfied that the variations in frequency were really consequences of the hypothesis on which they had been discussed. All that could be said was that the results were quite concordant and in agreement with the supposition that the tidal stresses set up by the sun were not without effect on the frequency of earthquakes. Some of the results were of interest and value apart from the truth or otherwise of the hypothesis, which was being tested by a discussion of the shocks by lunar as well as solar time.

4. *The* Geology *and* Genesis *of the* Trefriw Pyrites Deposit.

By Robert Lionel Sherlock, D.Sc., A.R.C.Sc., F.G.S.

(Read June 5th, 1918.)

The mass of iron pyrites worked at Cae Côch, Trefriw (Carnarvonshire) appears to be unique in some ways, so far as Great Britain is concerned, consequently its geological characters are of some interest.

In August, 1917, Mr. T. C. Cantrill and myself visited Cae Côch, and as a result of what we saw I spent seven days in the following month in mapping geologically the area around the mine. In this work I received all possible assistance from Mr. E. J. Morris, F.G.S., the Manager of the mine, to whose energy the successful development of the deposit is due. To him I wish to return my thanks, and also to Dr. H. H. Thomas for petrological notes and to Mr. John Pringle for naming the fossils.

The Geological Survey Map (Old Series 78 S.E.) published in 1852, shows a fault, or thrust, at the position of the ore-body, separating Bala Beds above from Contemporaneous Felspathic Trap (engraved F) below. The presence of pyrites is not recorded, nor is it mentioned in the accompanying memoir, probably because it is not seen at the outcrop owing to weathering. At the 4th milestone from Llanrwst the map shows a boundary-line, apparently a fault or thrust, bringing in the same ashes on the north, against Bala Beds on the south. In the memoir by A. C. Ramsay,[1] we read that north of the 4th milestone from Llanrwst volcanic ashes form all the high ground for about a mile in width, as far as Llanbedr. The map, however, shows the southern part of the mass as contemporaneous felspathic trap, as at the mine.

The nearest area of similar rocks that has been mapped in recent years is at Conway, at the mouth of the valley in which Trefriw lies. Miss G. L. Elles[2] has published an account of that region, and, so far as can be inferred from the small area now described, the rocks at Cae Côch may be correlated with the Lower Cadnant Shales and Conway Volcanic Series of the Conway district.

The ore-body is a seam of iron pyrites situated in the steep western slope of the Conway Valley, about a mile north of Trefriw village, where the hill-top rises precipitously to about 860 feet above the river-flat. The ore runs obliquely up the hillside, with an apparent dip of about 27° on the average, rising northwards. The outcrop, however, is not quite straight, owing to some small but sharp folds. Below the large old workings, now called Adit

[1] 'The Geology of North Wales' Mem. Geol. Surv. 2nd ed. (1881) p. 135.

[2] 'The Relation of the Ordovician & Silurian Rocks of Conway (North Wales)' Q. J. G. S. vol. lxv (1909) pp. 169–94 & pl. viii.

No. 2, a scree 450 feet high forms a marked feature in the landscape, and obscures a good deal of the geology.

The ore resembles a bed, usually about 6 feet thick, but varying somewhat, being thicker on the crest of folds and thinner on the limbs. It separates an intrusive igneous mass below from black shales above, which some poorly-preserved graptolites prove to belong to the *arctus* subdivision of the *Dicranograptus* Shales. The intrusion is a thick mass covering the whole hill-slope from half way up the inclined tramway, at 360 feet above sea-level to the alluvial flat below, giving a vertical depth of about 340 feet. Fortunately, an old adit near the bottom of the incline proves that the full thickness of the igneous mass is exposed, for black shale is seen in the adit below the intrusive.

Proceeding northwards, we see that the igneous rock is covered by an overthrust mass of volcanic ash, the thrust having a curved outcrop which is convex southwards and reaching the alluvial flat about 70 yards south of the 4th milestone. The intrusion passes out of sight beneath the ash, but is seen in Adit No. 2, higher up the hill. On the north, the hill-slope is all volcanic ash, until a fault, running approximately east and west, situated about 200 yards north of the 4th milestone, cuts it off and brings in rhyolite.

The top of the hill is a plateau made up of intrusive dolerite, which covers all the other rocks in turn. The same dolerite is also found in crags in the rhyolite area, near the road a little south of the road-metal quarry.

The map shows the outcrops of the various rocks and the section illustrates their relations to one another. The various rocks may now be described in a little more detail.

I. The Clastic Rocks.

The only sedimentary rocks that occur are hard, flaggy, black shales, slightly micaceous and in part somewhat cleaved. At two points numerous poorly-preserved graptolites were found, some of which Mr. John Pringle has been able to determine as *Diplograptus (Amplexograptus) arctus* Elles & Wood, cf. *Diplograptus (Glyptograptus) teretiusculus* (Hisinger), and *Climacograptus* sp. Mr. Pringle adds:

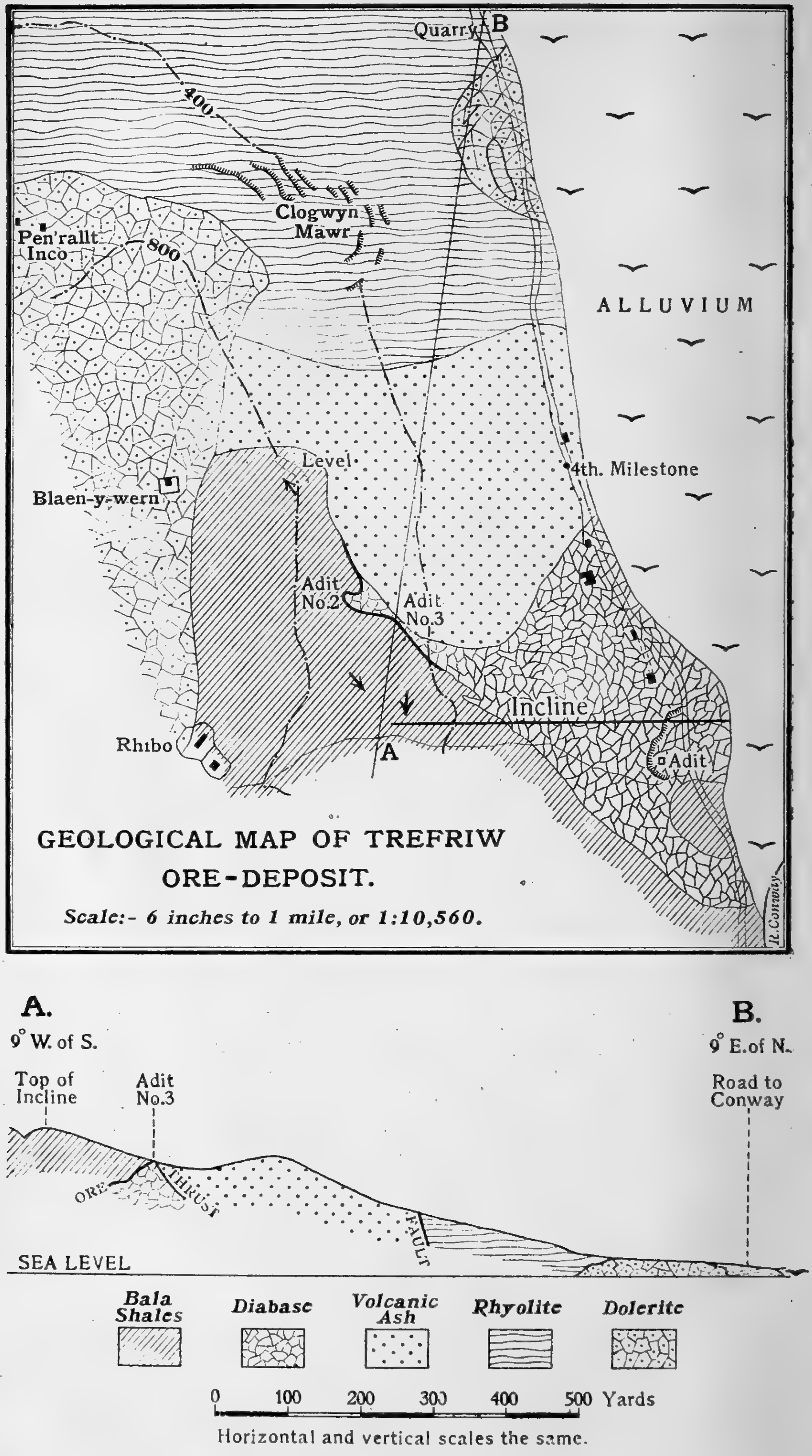
'The forms identified as *Diplograptus (Amplexograptus) arctus* E. & W. occur in some profusion, and they suggest strongly that the shales occupy a corresponding position to that of the Mydrim Limestone of South Wales.'

In Miss Elles's[1] classification these beds belong to the zone of *Nemagraptus gracilis.*

In both localities the fossils were obtained from shale lying only a short distance above the ore. In shale from Adit No. 4, 369 feet above O.D., the graptolites are seen on one side and pyrites on the other, whence it follows that the specimen is from

[1] Q. J. G. S. vol. lxv (1909) p. 172.

Map and section, on identical scales, of the Trefriw pyrites deposit.



immediately above the ore-body. The other locality is the waste material thrown out of the old level on the 800-foot contour, 150 yards east of Blaen-y-wern.

The dip of the shale is southward on the whole, and is approximately parallel to the inclination of the ore-body. As one proceeds along the nearly horizontal pathway from the main (No. 2) adit to the top of the incline, a little below the 600-foot contour, the dip of the shale increases to about 60°. Here, at the head of the incline, we are about 240 feet vertically above the top of the igneous mass. In the slopes above the incline bands of ash are found to occur in the shales at intervals: it is probable, therefore, that these ashy shales are older than the graptolitic beds, and belong to the lowest division of the Lower Cadnant shales: that is, the 'flags and shales with siliceous ashy bands' of Miss Elles's classification. If so, there is a thrust bringing them over the shales with graptolites (*arctus* beds).

II. The Igneous Rocks.

(A) The Intrusive Rock below the Ore-Body.

The upper boundary of the intrusive mass usually is apparently conformable to the shales above, except in a few places where the ore is missing, or where narrow veins of igneous rock jut into the overlying shales. There is also in such places an appearance of contact-alteration of the shales: for some 6 inches to 1 foot of these, next to the igneous mass, have been hardened and have lost their fissile structure, and they also contain crystals and nests of pyrites. Under the microscope no true metamorphic change can be seen, and the contact-alteration is, therefore, confined to the first stages of metamorphism.

The intrusive rock is a diabase containing ophitic augite, serpentine, chlorite, and ilmenite. Near the ore one often sees pyrites in the rock.

Additional evidence that the rock is intrusive is given by its thickness which, as already mentioned, is about 340 feet vertical at the incline.

In the old adit near the road the base of the intrusion is exposed; and black shale seamed with quartz is seen beneath it. The adit contains bad air; but Mr. Morris has penetrated some distance into it, and has brought out a quantity of pyrrhotite from the base of the igneous rock. A specimen is markedly magnetic.

(B) The Volcanic Ash.

Below the main (No. 2) adit there is a great fan of débris covering a large part of the hillside. Through the rubbish emerges an occasional crag of ash. Fortunately, at the entrance to Adit No. 3 (almost beneath No. 2) the ash is visibly thrust over the black shale, while about 10 yards within the adit the ore is reached. The thrust has a steep hade, and the effect is that the ash forms a surface-cap over much of the hill-slope; but, near the bottom of the hill, the intrusive rock emerges from underneath the ash. Upwards, from Adit No. 3, the thrust trends in a north-westerly direction, resting on the shales until it passes beneath the greenstone plateau at the top of the hill.

Proceeding northwards along the hillside, we note that crags of ash become prominent as the débris-fan gives place to wooded slopes, and we then find ash covering the whole hillside from the greenstone plateau to the alluvium at the bottom. Soon, however, as we proceed, the ash is cut off completely by a fault having an approximately east-and-west direction, and bringing in rhyolite. It is possible that the ash may be capable of subdivision into different types, as it varies considerably in appearance in different crags, and, in fact, near the fault the rock is doubtfully pyroclastic and may be a lava. Here it is greatly sheared and is a serpentinized and highly altered diabase showing phenocrysts of albite-oligoclase.

(C) The Rhyolite.

This rock is the cause of the precipices of Clogwyn Mawr. It is a very hard rock, dark grey, of fine texture, resembling a hälleflinta. It extends from the greenstone plateau to the alluvial flat below and is well seen in a road-metal quarry situated by the roadside, 600 yards north of the 4th milestone from Llanrwst. Towards the south it is bounded by the fault referred to above, and northwards it passes beyond the area surveyed. Petrographically it is a silicified soda-rhyolite, containing albite and perthite phenocrysts in a fine-grained felsitic ground-mass, with some indications of banding. Some granular sphene, probably pseudomorphous after ilmenite, is present.

(D) The 'Greenstone.'

Not only does this rock form the plateau at the top of the hill from Rhibo, past Blaen-y-wern and Pen'rallt Inco, but it is exposed in the lower slopes of the hill, near the high road, where it is intrusive in the rhyolite, from 340 to 580 yards north of the 4th milestone. The rock is clearly the newest in the area, covering as it does all the others, which in turn disappear beneath it as they are followed up the hill.

The microscope shows it to be a partly albitized and epidotized, ophitic dolerite, with fresh augites and large plates of decomposed ilmenite.

Dr. A. Harker[1] gives reasons for considering these later greenstones to be probably of post-Carboniferous age. Prof. C. Lapworth & Prof. W. W. Watts[2] show that in the Shelve district the later dolerites alter *Pentamerus* Limestones, and must therefore be post-Llandovery at least.

[1] 'The Bala Volcanic Series of Caernarvonshire & Associated Rocks' Cambridge, 1889, p. 107.

[2] 'The Geology of South Shropshire' Proc. Geol. Assoc. vol. xiii (1894–95) pp. 339–40.

III. The Ore-Body.

This is a finely granular mass of pyrites of considerable purity. The colour is unusually pale for pyrites, but becomes more brassy on exposure. A polished surface examined microscopically shows the pyrites in very minute cubes, aggregated together and separated by interstitial dark areas. Treated with hydrochloric acid small areas effervesce briskly, but most of the polished surface is untouched. This is consistent with the presence of quartz-veins in the ore and also of an efflorescence of gypsum on the floor of the mine, doubtless the result of the action of the oxidized sulphide on calcite in the ore.

The pyrrhotite, mentioned above as found beneath the igneous rock, when polished shows a similar structure to that of the granular ore, with the difference that we have here pyrrhotite instead of pyrites.

The mode of occurrence of the ore-body, between the shale and the intrusion, has been already mentioned. Although it resembles a bed about 6 feet thick, and extends over a considerable distance, it does not seem to be continuous over all the area described. Owing to the fact that the ore has been destroyed by weathering for a distance of several yards from the outcrop, it does not appear at the surface. Its presence, however, seems to be indicated by small thrusts and disturbances in the shales above the igneous rock, as shown at the entrance to the main (No. 2) adit. These disturbances may very possibly be due to the entire destruction of the pyrites by weathering, causing the unsupported shales above to founder. The presence of chalybeate springs is an indication of the presence of pyrites, and the Trefriw Well obtains its water, which is intensely chalybeate, from such a spring. But, in places where the junction of the strata and the intrusive rock is visible there is no obvious disturbance; veins of the intrusion are seen to run upwards into the shales, and there is hardening and silicification of the latter. Here the ore is evidently absent, and indeed never existed.

IV. Origin of the Ore-Body.

The Report of the Royal Ontario Nickel Commission, published in Toronto in 1917, points out (p. 126) that, in the case of many ore-deposits throughout the world that have been closely studied, no agreement has yet been reached regarding the source of the ores, or the manner in which they arrived at their present positions. This statement applies to the chief pyritic deposits, such as those of Rio Tinto or Sudbury, with which one would naturally compare the Trefriw deposits.

F. Berschlag, J. H. L. Vogt, & P. Krusch[1] remark that the

[1] 'The Deposits of the Useful Minerals & Rocks,' transl. by S. J. Truscott, vol. i (1914) & vol. ii (1916) p. 240.

genesis of pyritic deposits presents great difficulty. While formerly they were all classed together, investigation during the last few years has shown that such simplicity does not exist, but that such deposits may be of different origins. The authors conclude that some are magmatic segregations, others are due to contact-metamorphism, others are lodes, and, finally, some are of sedimentary origin.

In the case of Trefriw the theory of magmatic segregation at once breaks down, for pyrites is considerably denser than the diabase and ought, on that hypothesis, to be found below the igneous rock, or at least in hollows in it, instead of forming a sheet of nearly uniform thickness over the top.

Ore-bodies formed by contact-metamorphism,[1] in a large majority of cases accompany acid intrusions, are generally in more or less impure limestones, and are usually associated with many metamorphic minerals, such as garnet, pyroxene, etc. None of these conditions apply at Trefriw. A more important objection to a contact origin is that ores so formed are found within the zone of metamorphism: we have seen that at Trefriw the metamorphic effect is of the slightest, and is confined to a band of shale not more than a foot thick.

There is no 'lode' at Trefriw, in the sense in which the word is used by Berschlag, Vogt, & Krusch (*op. cit.* p. x), that is, as an ore-deposit of tabular shape occurring along a fissure or other line of disturbance.

There remains the possibility of the pyrites being of sedimentary origin. At the horizon of the zone of *Nemagraptus gracilis* occur most, if not all, of the pisolitic iron-ores of Anglesey, Carnarvonshire, and Merioneth.[2] It is at least a remarkable coincidence that the Trefriw pyrites also occurs at this horizon. I think that the origin of the pyrites was as follows. The igneous rock was intruded beneath a bed of pisolitic iron-ore, and the heated waters from the intrusion, although unable to do more than harden shale at the contact, were nevertheless able to transform the iron-ore into pyrites. A certain amount of pyrites would probably be present in the iron-ore, for pyrites is a common constituent of pisolitic iron and not infrequently is abundant enough to render the pisolites valueless for smelting purposes. Moreover, in South Wales, shales of the same age are markedly pyritous, although they contain no pisolitic iron-ore.[3] But the bulk of the sulphur would be provided from the igneous mass in the form of sulphuretted hydrogen. The pisolites, at the outcrop, contain more or less limonite with much silica, etc.; but this is

[1] F. Berschlag, J. H. L. Vogt, & P. Krusch, *op. cit.* p. 349.

[2] T. C. Nicholas, 'The Geology of the St. Tudwal's Peninsula (Carnarvonshire)' Q. J. G. S. vol. lxxi (1915) pp. 125–26. Also E. Greenly, in a memoir on Anglesey, now in the press, and others.

[3] T. C. Cantrill & H. H. Thomas in 'Geology of the South Wales Coalfield. Part X: The Country around Carmarthen' Mem. Geol. Surv. 1909, p. 45.

the result of weathering. Unweathered, they seem to be composed sometimes of magnetite and sometimes of iron silicate. Sulphuretted-hydrogen solutions, aided by heat and pressure, will readily combine with oxides of iron[1] and less easily with iron silicate to form sulphides of iron; whether the outcome is pyrrhotite or pyrites depends on local conditions, and any silica present would crystallize out as quartz. We have seen that quartz-veins occur in the ore at Trefriw, and that the interstitial material visible on a polished surface also appears to be quartz.

C. Van Hise[2] points out that the oxidation of pyrites to magnetite is accompanied by a shrinkage of 37·48 per cent. of the volume. We may expect that the converse change from magnetite to pyrites will be accompanied by a corresponding expansion, and this may help to account for the curious structure locally called 'zebra,' which is found between the ore and the shale, or, in the absence of the ore, may occur next to the intrusive rock. 'Zebra' consists of hardened shale full of ramifying pipe-like masses which present the appearance of worm-burrows. 'Zebra' is clearly a passage-bed from the ore to the shale, and it may be 2 or 3 feet thick. Viewed under the microscope it is seen to consist of dark areas, the mass of the shale containing fairly sharply defined clear areas representing the pipe-like bodies in section. In the clear areas pyrites occurs in well defined though not very numerous cubes; but in the dark areas the sediment seems to have been largely replaced by pyrites. The 'zebra' sometimes shows a pisolitic structure, an important confirmation of the theory that the pyrites is altered pisolitic iron-ore.

The absence of the ore in places is important, and can be explained, if we accept the above theory of its origin, by the local absence of pisolitic iron-ore. The pisolitic bed is known, at various places in North Wales, to have a lenticular character with gaps between the lenticles.

Mr. Morris informs me that, occasionally, the pyrites in the intrusive rock is greatly concentrated near the ore, with the result that the ore-body is at that place thickened by as much as 2 feet.

The age of the pyrites is most probably Bala, for it is clearly formed, on any theory, by the igneous intrusion and the age of this is most probably Bala. Dr. A. Harker[3] says that there is conclusive evidence that all the diabases associated with the Bala strata of Eastern Carnarvonshire, were injected during the Bala period itself. The heat given out by the intrusion was evidently not great, or its metamorphic effects would have been much more marked than is the case: consequently any effects produced by heated waters proceeding from it would date from a time soon

[1] F. W. Clarke, 'Data of Geochemistry' 3rd edit. Bull. U.S. Geol. Surv. No. 616 (1916) p. 333.

[2] 'A Treatise on Metamorphism' Monograph U.S. Geol. Surv. vol. xlvii (1904) p. 406.

[3] 'The Bala Volcanic Series of Caernarvonshire & Associated Rocks' Cambridge, 1889, p. 76.

after the igneous mass was injected, and therefore be of Bala age or very little later. This is of interest, because A. M. Finlayson[1] expressed the opinion that the ore-deposits of this country practically all originated at one of four periods: (1) Pre-Cambrian; (2) Post-Silurian; (3) Post-Carboniferous; and (4) Post-Cretaceous and early Tertiary. Here, however, we have an ore-body which was not formed at any of these periods. Finally, on the above theory, the pisolitic iron-ore was already in existence before the intrusive mass was introduced in late Bala times, a confirmation of the sedimentary origin of the iron-ore, and opposed to the theory that the pisolitic ores are really of the nature of fissure phenomena.[2]

Discussion.

Dr. A. H. Cox remarked on the interest of the paper from the stratigraphical and the economic standpoint. With regard to the suggestion that the pyrites originated from the alteration of a pisolitic iron-ore, it was important to remember that beds with *Nemagraptus gracilis* and *Amplexograptus arctus*, which in South Wales comprised only a small thickness of strata, were represented in North Wales by 2000 to 3000 feet of rock, owing to the incoming of a thick volcanic series. Beds below the volcanic series might well belong to the same, or nearly the same, graptolite-zone, according to the South Wales correlation, as beds above, yet the difference in stratigraphical position was obvious. The Lower Cadnant Shales of Conway, with which the graptolitic shales at Trefriw were correlated by the Author, appeared to represent the *arctus* beds of South Wales, that is beds just above the Mydrim Limestone = zone of *Nemagraptus gracilis*, and they occurred directly above the acidic—Snowdonian—volcanic series. On the other hand, the pisolitic iron-ores of North Wales, while apparently occurring in the zone of *N. gracilis*, were invariably found, so far as he (the speaker) knew, below the acid volcanic rocks. He knew of no occurrence of pisolitic rocks in the Cadnant Shales or in other beds above the volcanic rocks, and he enquired whether such pisolitic iron-ores had actually been discovered at Trefriw or at the corresponding stratigraphical horizon elsewhere in North Wales.

Prof. C. G. Cullis congratulated the Author upon his interesting communication. He also took this opportunity of offering congratulations to the Geological Survey, as a whole, upon the excellent work that they had done in economic geology, both officially and unofficially, since the beginning of the War.

The origin of pyritic deposits was of much interest. Genetically they were of two main types—low-temperature deposits of sedimentary origin, and high-temperature ones of igneous origin. The

[1] 'The Metallogeny of the British Isles' Q. J. G. S. vol. lxvi (1910) pp. 281–98 & pl. xxiii.

[2] W. G. Fearnsides, Rep. Brit. Assoc. (Leicester, 1907) 1908, p. 510; and Geol. Mag. dec. 5, vol. iv (1907) p. 422.

Trefriw deposit would appear to be of the latter type. It was exceptional, however, in that it was connected with diabases, and not with porphyries, as was the case in County Wicklow and in the Rio Tinto region. According to the Author, it had been formed by the contact-metasomatism of a local development of the well-known pisolitic iron-ore of Bala age. There was much to be said for this view, but two other alternative hypotheses might be considered: first, that the deposit represented the more usual replacement of slate along a graptolitic horizon, by waters emanating from an acid intrusion; or, secondly, that it had been formed by the pyritization of the pisolitic iron-ore, by the action of sulphuretted hydrogen of organic origin, immediately after deposition, as had happened to the uppermost layers of the main seam of the Cleveland ironstone of Yorkshire.

The AUTHOR thanked the Fellows for their kind reception of his paper. In reply to Dr. Cox, he said that the beds containing *Amplexograptus arctus* were regarded as part of the *Nemagraptus-gracilis* Zone.

With regard to the points raised by Prof. Cullis, the pyrites seemed to be intimately associated with the diabase, covering its undulating surface in a uniform sheet. Also the upper part of the diabase contained a considerable amount of pyrites, which, although it might be derived from an older pyrites-mass, was more probably formed at the same time, so that the ore-body was later than the diabase and not formed in association with previous acidic intrusions.

Again, it was said that if it be admitted that pisolitic ironstone may have been altered into pyrites, this might have occurred on the sea-floor, in Bala times, almost contemporaneously, and have nothing to do with the diabase. The pyritic ore, however, occurs only in contact with the diabase, although pisolitic iron-ore and black graptolitic shales are found in many places in Anglesey, Carnarvonshire, and Merionethshire, occurrences which again confirm the association of the pyritic ore and the diabase.

5. *The* Shap Minor Intrusions. By James Morrison, B.A., B.Sc. (Read November 21st, 1917. Communicated by Dr. Herbert Lapworth, M.Inst.C.E., Sec.G.S.)

[Plate XIII.]

Contents.

I. Introduction.

An investigation on the minor igneous intrusions of the south-eastern part of the Lake District was commenced by the writer in 1913, the Shap area being first selected for study. The results of the work in that neighbourhood were such as to indicate the desirability of extending the investigation into the adjoining areas on the east and north. The work has not yet been completed, prevalent conditions having considerably interfered with its progress. It is perhaps advisable, therefore, to place on record the results so far obtained, leaving the remainder to be dealt with on some future occasion.

The Shap granite has long been of interest to geologists, its marked porphyritic character and conspicuous basic segregations having quite early attracted attention. Little, however, of any moment concerning it was published before 1868, when H. A. Nicholson's paper 'On the Granite of Shap in Westmorland' appeared.[1] This was followed in 1875 by a series of papers by J. Clifton Ward on the granitic rocks of the Lake District, in one of which[2] their origin was discussed, the work of Sorby being taken as a basis.

It was not, however, until 1891 that the results of a detailed investigation by Dr. Harker & Prof. Marr on the granite and its associated rocks appeared in the Quarterly Journal of this Society—a comprehensive study, both of the granite itself and of the effect produced on the surrounding rocks by its intrusion.

While the plutonic mass has thus received the attention that it

[1] Trans. Edin. Geol. Soc. vol. i (1868) p. 133.
[2] Q. J. G. S. vol. xxxi (1875) p 590.

deserved, no systematic examination of the minor intrusions has yet been made. Various dykes and sills have been mapped by the officers of the Geological Survey from time to time, and their position and character have been recorded in the various Memoirs dealing with the district, while some have been more or less incidentally described by different workers in the area. But no attempt has hitherto been made to view them as a whole, or to trace their bearing on the subsequent igneous history of the district, and thus the phase of minor intrusions as such still requires attention, in order to elucidate and co-ordinate the successive stages of the final episode in connexion with the igneous activity of which the Shap granite was at once the focus and the culmination.

In the present paper an attempt is made to examine the intrusions from the above-mentioned standpoint, and its scope may be briefly indicated. A review of the acid intrusions will be followed by a description of two groups of intermediate composition. Special occurrences will be noted, and the relationship of the various groups will be discussed in connexion with their relation to the plutonic centre. Evidence will be given bearing on the succession of types that were evolved during the phase of minor intrusions.

II. Previous Work.

The dykes mapped by the Geological Survey appear mainly on Quarter-sheets 102 S.W. (New Series 30) and 98 N.E. (New Series 39), with a few additional occurrences on adjacent sheets. In the various Memoirs dealing with this area brief accounts were given of the intrusions mapped. No attempt was made to describe them in detail; but three varieties were noted and a threefold classification adopted :—(1) granitic dykes; (2) micaceous dykes or mica-traps; (3) felsitic dykes. The first-named were stated to be

'found within a distance of 4 miles south-east of the Shap granite from which they are probably spurs. They resemble the Shap granite in lithological character, and contain the same large crystals of pink felspar.' [1]

All the dykes were assigned to one or another of these three groups.

In 1879 Prof. T. G. Bonney, in a paper read before the Geological Society,[2] described a number of lamprophyre dykes occurring in a somewhat irregular line from Windermere to Dent. He distinguished between minettes and kersantites and felsitic varieties of each, which he named minette-felsite and kersantite-porphyrite respectively. Several analyses by F. T. S. Houghton were included.

In 1891 Dr. A. Harker & Prof. J. E. Marr included in their

[1] 'The Geology of the Country round Kendal' Mem. Geol. Surv. 1887, p. 35.

[2] Q. J. G. S. vol. xxxv (1879) pp. 165–79.

account of the Shap granite and its metamorphic aureole a description of some dykes[1] occurring in the Stakeley Valley, which,

'while presenting a considerable range of differences, have at the same time some curious points in common. Further, while they have characters which seem to connect them on the one hand with the Shap-Fell granite, and particularly with its darker patches, they are unmistakably linked on the other hand with the normal type of "mica-traps" found at greater distances from the Shap-Fell intrusion.'

The following year, in a paper on 'The Lamprophyres of the North of England,'[2] Dr. Harker gave reasons for connecting the whole series of lamprophyric dykes—extending from Teesdale to Furness and from Ingleton to Bassenthwaite—with the Shap plutonic mass.

Lastly, two dykes occurring at the head of Long Sleddale Valley were briefly described by Dr. Harker in 'The Naturalist' for 1912, pp. 266–67.

III. General Remarks on the Intrusions.

The intrusions discussed in the present paper occur in an area extending from Shap in the north to Kendal in the south, and from Windermere to Sedbergh in an east-and-west direction. Within this area, forming a triangle with apices at Shap, Windermere, and Sedbergh, are found most of the dykes the direct connexion of which with the plutonic centre can be regarded as definitely established. Every intrusion mapped by the officers of the Geological Survey has been visited, and careful search has been made for intrusions not hitherto recorded; but, in a region such as this, many difficulties await the investigator. The country consists of mountain and rolling heather-covered moorland, interspersed with peat-bogs and intersected by deep river-courses. A glance at the Drift edition of the 1-inch map is sufficient to reveal the large extent of ground which is unavailable for the study of igneous intrusions. All the low-lying land and much of the high is covered with drift or peaty deposits, often of great depth. In places along the hillside small patches of bare rock may appear; but great stretches of country-rock are obscured by a thick mantle of drift, and the highest crags and river-channels alone afford a fair field for investigation. But the drift in the river-valleys is often 50 feet deep, and only where the river has cut down to the floor of the old valley are the rocks revealed; while the denuding action of the stream loosens the boulders, often of great size, which accumulate in such force that all trace of the underlying country-rock is obliterated. In a drift-covered country the time element is important; dykes exposed at one period may be completely buried at a later. This has evidently been the fate of several dykes mapped many years ago by the officers of the Geological Survey, but of which not a trace remains.

[1] Q. J. G. S. vol. xlvii (1891) pp. 287–88.
[2] Geol. Mag. dec. 3, vol. ix (1892) p. 199.

The paucity of dykes exposed, compared with the number that must have been intruded, renders the study of their relationships one of difficulty. When the examples available are determined, not by choice but by chance, there is always the possibility that conclusions formed, though in agreement with existing evidence, may yet be based upon the exception rather than the rule. But the mere recognition of this possibility is in itself sufficient to ensure its due consideration in any attempt to arrive at the correct interpretation of the evidence available.

South of the granite, intrusions occur in greater force, partly due to the gradual westward encroachment of the Carboniferous Limestone outcrop on the north, and partly to the forces operating at the time of injection. The country-rock north of the granite consists of lavas, ashes, and breccias of the Borrowdale Volcanic Series. On the south are the grits, flags, and slates of Silurian age. The general strike of the latter is east-north-east, the direction of the axes of folding. Perpendicular to the folding, and parallel to the faulting accompanying it which has split up the country into somewhat rectangular areas, a narrow belt extending north-north-westwards and south-south-eastwards from the granite forms the principal *locus* of the dykes. The earlier intrusions trend generally in the same direction.

As a rule the exposures are not good, and although occasionally a dyke may be traced for a considerable distance across country, it is generally as a series of small outcrops. When more resistant to weathering, as in the case of the acid dykes, prominent ridges may be formed, flanked by deep depressions. The more basic rocks, on the other hand, are prone to weather more easily than the ground-rock and furrows are formed. Spheroidal weathering is not uncommon. The width may be anything from a foot to several yards; but, while the basic dykes are generally narrow and compact, the acid intrusions are more massive and tend to develop a highly-porphyritic structure. Very rarely can a complete section be found; the junctions are either invisible or obscure, and the portion available for examination is often extremely limited.

Singularly little effect has been produced upon the rocks through which the intrusions have been forced. Contacts are very sharp, and, beyond a slight induration extending for a few inches, rarely more than a foot, from the margin, and the occasional formation of fresh biotite, the rocks are scarcely affected. An apparent exception to this will be mentioned later.

The intrusions usually take the form of dykes, either vertical or highly inclined. There is no general hade, the region having been under the influence of more than one set of movements inducing irregular planes of weakness. The acid rocks form occasionally small irregular bosses, as at Rosgill. Sills are not very common, and occur principally among the intermediate rocks. A sill of quartz-porphyry intruded in the andesitic ashes north of the granite bears some resemblance to the Lake-District intrusions of Ordovician age, but it is probably connected with the granite.

The rocks include a variety of types, ranging from acid felsites to basic lamprophyres—from a granitic facies to a dioritic facies. Porphyritic and non-porphyritic varieties occur sometimes in association, but the latter are frequently microporphyritic. The large orthoclase-phenocrysts which give character to the granite are found also in many of the dykes, and a broad distinction can be made according to their presence or absence. Found in abundance in rocks of varying composition near the granite, they decrease in importance when traced outwards from the centre. Distance from the plutonic centre is not, however, the sole factor determining their abundance or even their presence at all, intrusions in which they are wanting being found in juxtaposition with the most conspicuously porphyritic, even in the neighbourhood of the granite. Dykes containing the large granitic orthoclases, which (to avoid repeated periphrasis) will be designated 'orthoporphyritic,' are most abundant near the granite, rarely exceeding a distance of 4 miles and being confined to the belt already mentioned. Within this somewhat limited area are found rocks ranging from quartz-porphyries to lamprophyres. Associated with them but distributed over a much wider area are rocks of a more usual hypabyssal type. For reasons to be given later these two groups are regarded as belonging to different periods of intrusion, the 'orthoporphyritic' or three-generation rocks being earlier and more intimately associated with the granite than the two-generation rocks. But certain features common to both, and marked similarities in constitution, clearly indicate their origin from a common magma.

The intrusions as a whole may be generally classified as porphyries, porphyrites, and lamprophyres; but it will be more convenient for present purposes to group them as acid intrusives, intermediate intrusives, and lamprophyres.

IV. The Acid Intrusives.

Reference has already been made to the remarkably small number of dykes exposed, compared with the large area affected by the igneous activity which followed the intrusion of the granite. Particularly is this noticeable in the case of the acid intrusives, which are comparatively few in number and generally restricted in direction. That they represent a small proportion only of the actual intrusions is quite evident, especially when the large tracts of drift-covered and peaty moorland in the vicinity of the granite are taken into consideration. The members of this group, apart from the felsites of the adjoining area on the east, are confined to the comparatively narrow belt extending about 8 miles to the south-south-east of the granite and for a somewhat shorter distance in the opposite direction. The rocks vary in colour from pale grey to deep red. All are porphyritic, differing mainly in degree: sometimes the phenocrysts are so numerous as to give to the rock a coarse, almost holocrystalline appearance; or a predominating compact felsitic matrix may be but sparsely studded with the porphyritic element. Alkali-felspars, quartz, and mica are the usual phenocrysts, and the rocks include granite-porphyries, quartz-porphyries, and quartz-felsites.

The specific gravity varies from 2·54 to 2·62, and is always less than that of the granite. A study of the dykes from this point of view yields interesting results. Assuming that the specific gravity bears a definite relation to the basicity of a rock, and can thus be used as a means of comparison, then the acid dykes are always more acid than the granite. The highest density prevails near the granite, three dykes quite close giving 2·620, 2·614, and 2·627 respectively. Considering the intrusions at varying distances to the south, there is a gradual decrease in density, strongly marked at first, but with a diminishing rate in the outer area as the rocks are traced outwards from the granite mass. This is accompanied by a decrease in the porphyritic element, the ground-mass becoming dominant in the outer parts of the area. Where the large orthoclase-phenocrysts are present the rocks are usually of a greyish colour, striated felspars are prominent, and biotite is common, the abundance of phenocrysts of all kinds (including quartz) sometimes being very marked. Where the orthoclase-phenocrysts are absent, the rocks are less porphyritic and more compact, a more or less reddish felsitic ground-mass carrying small phenocrysts of quartz, orthoclase, some oligoclase, and generally less biotite than the preceding. Members of these two groups are sometimes found in association; but, while the former are restricted to the centre of the area, the latter have a wider and more general distribution. The division based on field-evidence is supported by certain differences in microscopic structure. The two groups were intruded at different times, and it is of interest to note that the latter and later group is more acid than the earlier.

In the orthoporphyritic rocks the large orthoclases attain a length of 2 inches; they are commonly twinned and always more or less corroded, but are never so abundant as in the granite. Traced outwards from the centre of the area, they decrease both in size and in relative importance. Abundant and of maximum size 2 miles away, they are only half the size at double the distance, and beyond that no longer form the most conspicuous porphyritic mineral. They are usually pink in colour; but white and almost colourless varieties also occur, some of which exhibit the characters of sanidine.[1] Numerous well-developed oligoclase-crystals are sometimes enclosed, arranged in parallel growth near the margin, together with such early products as apatite, sphene, zircon, and biotite. A marginal intergrowth with quartz occasionally forms a micropegmatitic border.

Among the felspars of the second generation of phenocrysts, orthoclase again appears in varying abundance, seldom exceeding 5 mm. in length, but showing more perfect outlines than the earlier set. In some rocks near the granite it is partly posterior to the

[1] Q. J. G. S. vol. xlvii (1891) p. 288.

quartz, which it frequently encloses. Perthite, or microperthite, is a common phenocryst, sometimes indeed the most important. It builds good crystals with Carlsbad twinning. An acid oligoclase giving low angles of extinction is common; but a more basic variety is met with, the angles occasionally approaching those of andesine. The crystallization periods of oligoclase, orthoclase, and quartz overlap to a considerable extent. Glomeroporphyritic groups consisting of numerous felspar individuals, both microperthite and oligoclase, are found in both the earlier and the later sets of acid rocks.

Quartz plays an important part in all the rocks, and in the extreme types is the only prominent phenocryst. It is frequently moulded and enclosed by later orthoclase (a familiar feature in the granite), more rarely by oligoclase. It is sometimes surrounded by a granular aggregate of quartz and orthoclase which may even be of coarser texture than the remainder of the ground-mass, the boundaries following the outlines of the original crystal rather than of the existing corroded form. The excess of quartz in these bands is probably attributable to the fact that, at the time of intrusion, the relief of pressure enabled the magma to react on the crystal until chemical equilibrium was restored, by which time the viscosity consequent on the fall of temperature was sufficient to prevent complete diffusion of the dissolved silica, the portion remaining in the vicinity being subsequently added in optic continuity. Small patches are occasionally found, in which the quartz exists as a nucleus only. With orthoclase it forms the great bulk of the ground-mass, oligoclase being present as a rule in small quantity only.

Biotite occurs as hexagonal plates and scattered shreds in varying amount. The common change is to chlorite, sometimes giving a dark fibrous appearance under crossed nicols, sometimes the deep colour characteristic of penninite: epidote is usually associated with it, and less frequently calcite, rutile, or muscovite. The last-mentioned mineral also appears in some rocks in the form of plates recognizable macroscopically, but it is not common. Sphene is abundant in some dykes near the granite, both as wedges and as grains, and in others is apparently wanting. It is rare on the whole in the earlier acid set, and, with one or two notable exceptions, almost entirely absent from the later. Apatite is of constant occurrence, especially in association with the biotite, and is sometimes enclosed by sphene.

Iron-ores, though not abundant, are of interest. Secondary pyrite is frequently met with, and rarely ilmenite; but interest centres chiefly in pyrrhotite, which was first recognized macroscopically in a fragment freshly chipped from a dyke near the granite. Further search showed it to be fairly common, and microscopic investigation revealed its presence in small amount in every section. It is common in some dykes, rare in others, and apparently absent from the remainder. In one case it occurs as a constituent of a small basic segregation. Zircon, rutile, anatase, and (in one section) allanite are also found as accessory minerals.

Examples of the earlier or orthoporphyritic dykes occur near the granite and on the moors to the south as far as Borrowdale. The rocks are pale grey in colour, highly porphyritic, and the ground-mass is microgranular. The abundance of phenocrysts frequently gives to them an almost granitic appearance. Apart from the large orthoclase-felspars, numerous smaller phenocrysts of white or yellowish-green striated felspar, abundant quartz, and biotite in varying amount, with an occasional plate of muscovite, make up the bulk of the rock. In thin section, quartz, oligoclase, and microperthite are the usual porphyritic minerals, the relative proportions varying somewhat in different intrusions. The oligoclase may have fairly large extinction-angles, while microperthite more irregular in outline, besides enclosing the former in parallel growth, may either be intergrown with quartz, or fringed by micropegmatite. The large granitic orthoclases are also perthitic in places, most often marginally but sometimes internally, especially round the irregular patches of plagioclase and quartz. The perthite is probably of the secondary type.[1] Apatite, zircon, and pyrrhotite are fairly common accessories; but sphene, on the whole, is rare. Towards the edge of an intrusion the phenocrysts are scarcer, the felspars become prismatic, and biotite increases. Marginal sections show few quartz-phenocrysts, the dominant matrix consisting mainly of small felspar-prisms, indicating an approach both in structure and in composition to the Potter-Fell type of intrusive.

Intrusions of this group are found on Stakeley Fells, Birkbeck Fells, Birkbeck Valley, and the upper part of Stakeley Valley, and one can be traced for 40 yards in a small stream north of the granite. The big dyke on the moor south of Wasdale Beck referred to by Harker & Marr,[2] and the 'sills' marked on the Geological Survey map in Stakeley Beck and its tributary on the south, are similar both in the field and microscopically. The middle intrusion cuts across the bedding, and as all three are in a line with the nearest edge of the granite, it is probable that they are parts of one big dyke running approximately in a north-northwesterly direction.

Three dykes exposed more or less imperfectly on the Birkbeck Fells may also be connected. The northernmost is visible as a few scattered patches rising from an expanse of peaty moorland on Hazel How; the second appears in a rivulet on the south-southwest; and the third forms a small ridge half a mile farther away to the south-east. The trend varies from north-north-east to north-north-west, and all have a high hade. Idiomorphic quartz and perthite are the largest and most prominent phenocrysts, the middle dyke containing also phenocrysts of micropegmatite.

[1] A. Harker, 'Natural History of Igneous Rocks' 1909, p. 258.
[2] Q. J. G. S. vol. xlvii (1891) p. 288.

Intrusions immediately north of the granite bear some resemblance to the plutonic mass itself. One dyke of the orthoporphyritic group contains large pink felspars in a matrix of felspar and quartz with a little biotite; part of the intrusion, however, is finer in texture, even-grained, free from the large orthoclase-felspars, and consists of a granular aggregate of felspar and quartz with less oligoclase and more quartz than the foregoing.

The later dykes are characterized by the absence of the large orthoclase-felspars common to the preceding group; but they are always more or less porphyritic, although the phenocrysts never attain the importance reached in some of the rocks already described. On the whole, they are more acid in composition (judged by their lower density and mineral composition), and are usually of finer texture. In the field a more or less reddish colour is fairly distinctive in the central parts of the area. The ground-mass in section is almost invariably micrographic, ranging from micropegmatitic to true spherulitic. The rocks usually carry porphyritic quartz and felspar measuring up to $\frac{1}{4}$ inch in diameter, in a pale-red, compact, felsitic matrix. Microscopically quartz and perthite are the principal phenocrysts, with subordinate oligoclase and a marked decrease in biotite compared with the earlier rocks. The ground-mass is often spherulitic; but the spherulites polarize in sectors, and rarely show a complete black cross. Most of the phenocrysts are surrounded by spherulitic bands of varying width; but the maximum is reached round the quartz, each grain of which serves as centre for a radiate growth. Small crystals of perthite merge gradually into a similar growth, the fabric of which is entirely felspathic. In some intrusions the matrix tends to be micropegmatitic, instead of microspherulitic; while another variety of matrix consists of an intergrowth of quartz and orthoclase polarizing in irregular but fairly-uniform patches, the extinction of which is determined by the quartz. When best developed, micropœcilitic structure is produced. All the rocks contain a small amount of apatite and zircon; but very little original iron is present, though occasionally pyrrhotite and secondary pyrites are found.

Intrusions of this type occur both north and south of the granite, the extreme variety at a distance of 8 miles. Red Crag owes its name to a similar dyke, intruded along a line of fault affecting the Bannisdale Slates, and forming a ridge along the summit. Numerous exposures occur on the hills to the south, some of which may be connected. Other examples are found in Stakeley Valley, on Greenside Crag, Breast High, and as far south as Docker Fell.

Some felsitic dykes nearer the granite must also be assigned to this group. They differ from the preceding in possessing a micro-granular matrix, although in other respects they are similar. Some of them are associated with more basic rocks, and will be referred to again. The pale-grey porphyritic dyke near Wasdale Head contains abundant pyrrhotite, which also occurs as a constituent of a small basic segregation.

A comparatively narrow dyke in Wasdale Beck, almost hidden from view, presents some unusual features. It is coarsely crystalline in appearance, and its structure granitoid rather than porphyritic. Light grey in colour, the rock is an aggregate of quartz and felspar, with unevenly-distributed flakes of brown biotite. Towards the margin of the intrusion green specks appear, and then become abundant; biotite steadily decreases, and is ultimately replaced by the green mineral. A specimen from a big block in the stream, since disappeared, has a specific gravity of 2·617 (the highest of all the acid rocks), while a specimen from the margin gives 2·658.

Normally the rock is a medium-grained aggregate of light-coloured minerals, reproducing some of the features of the granite and consisting mainly of quartz, oligoclase, and perthite. Occurring sparingly, and intergrown in one instance with biotite, is diopside: this towards the margin becomes increasingly abundant, gradually taking the place of biotite, and occurring both in irregular crystalline form and as granular aggregates. Its presence points to the absorption of calcareous material by the igneous magma, material which had already undergone metamorphism by the granite. Associated with it are irregular grains of reddish-brown sphene and abundant apatite. Further evidence of assimilation is seen in the zoned oligoclase, of which the outer zone is more basic than the core. The plagioclase and diopside are extremely irregular in form, having consolidated at a late stage. An excess of quartz in places has doubtless been obtained from the invaded flags. The dyke was probably intruded before the country-rock had cooled, and thus was capable of incorporating and assimilating the material into which it was injected. This would account for the relatively coarse texture in a dyke of such small dimensions, because, as a rule, even massive dykes of this group have failed to produce any appreciable effect on the ground-rock. An early period must, therefore, be assumed for its intrusion.

The junction-rock is interesting, as showing a higher grade of alteration than the surrounding rocks, metamorphism by the dyke subsequent to that by the granite involving a recrystallization to a mosaic of clear felspar and quartz through which are scattered bright-green granules of diopside.

V. The Intermediate Intrusives.

Rocks differing considerably in character are grouped for convenience under this head. Many of them are porphyrites; but a more general term is used, in order that certain more basic members of one group may be included for discussion along with the porphyrites with which they are closely connected. These intrusions are found in many parts of the area, and exhibit striking points of difference. Some are of more or less restricted occurrence, others cover a wider field. Generally, however, they fall into one of two well-defined groups: (*a*) the Potter-Fell type, (*b*) the Mixed Series, each of which will be considered separately. This division probably connotes a classification by age, a point which will be considered later.

(*a*) The Potter-Fell Type.

The rocks of this group differ from those already described chiefly in the diminished importance of quartz, but they also show a considerable difference in microstructure. They are essentially felspathic in constitution, consisting mainly of felspar with some biotite. In the more acid members quartz may be present in the form of small phenocrysts, generally few in number, as well as in the ground-mass. But it is always subsidiary in importance, and in the more typical representatives is restricted to the matrix, where its role is interstitial. On the whole, therefore, the affinities of these rocks lie between the syenites and the diorites.

The principal felspar is usually an oligoclase or oligoclase-andesine, and the amount of biotite is variable. The gradual decrease in quartz and the increase in biotite mark one line of advance to the more basic derivatives of the magma. Another line of development will be considered later; but the present marks the normal change.

The intrusions are not numerous, yet their distribution may have some significance. Certain well-marked features serve to distinguish them from all others. The rocks, pale to dull red in colour, are generally porphyritic; but the phenocrysts are of a small order, consisting as a rule of little felspar-prisms. Well-jointed parallel to the boundaries, they split readily into roughly-parallel slabs, the irregular sides of which are coated with a greenish aggregate of chlorite and mica. Differential weathering produces a marked longitudinal fluting.

The Potter-Fell intrusion, which is taken as the type, may be traced at intervals across the fell for a mile or so in an east-north-easterly direction, forming a fairly-regular sill intruded into the Kirkby-Moor Flags. Its outcrop on the eastern flank is abruptly shifted to the south-south-east, reappearing some distance away with the same trend as before. A further deviation subsequently occurs. Specimens from different parts are very similar, and all are evidently part of the same intrusion. The rock contains small porphyritic felspars often striated, greenish needles, and a little mica in a dull-red felspathic matrix. Microscopically the ground-mass is composed of small idiomorphic felspars; oligoclase is always very abundant, sometimes in excess, and a variable amount of spherulitic material (mainly orthoclase) occurs interstitially. The principal phenocryst is oligoclase-andesine, often zoned; but andesine appears in some sections, chiefly marginal, while orthoclase is always subordinate. Biotite is abundant, though it is not yet so important as in the lamprophyres. The rock is akin to the porphyrites in many respects, and may be termed a biotite-porphyrite.

Nearer the granite, on the fells of Fawcett Forest, a series of somewhat similar intrusions occur. The rocks are finely crystalline to compact, even-grained rather than porphyritic, the felspars smaller and more uniform in size, and oligoclase preponderates in the ground-mass, which is here definitely micrographic. Rounded quartz-grains with a spherulitic border appear in another dyke of this group, 3 miles south-south-east of the granite. They are associated with phenocrysts of oligoclase-andesine, in a matrix of which the dominant element is a spherulitic intergrowth of orthoclase and quartz. This intrusion is therefore more acid than those described, and its occurrence in the north-north-westerly belt with approximately the same trend is of interest.

As the extreme acid variety of the type now described a dyke may be mentioned, situated within the same belt, but occurring in the outer area, near Lummer Head, about 7 miles from the granite. It is a pale-buff-coloured medium-grained felspathic rock, with a distinct pearly lustre due to the felspar-phenocrysts and to colourless mica. In thin section quartz appears as a phenocryst, in addition to oligoclase and orthoclase. The rock has affinities with the porphyries rather than with the porphyrites.

(*b*) The Mixed Series.

These intrusions are restricted to a somewhat limited area in the immediate neighbourhood of the granite. Their width is often more or less conjectural—some indeed being little more than a series of boulders; but generally they are of smaller dimensions than the acid intrusions, and, though never attaining any degree of prominence in the field, they present some unique features and are of considerable petrological interest.

The rocks are usually dark, micaceous in character, and porphyritic in structure, and represent a fairly wide range of composition. The characteristic feature is the presence of the large orthoclase-felspars of the granitic type which form a striking contrast to the dark groundwork of the rock, inviting almost inevitably comparison with the basic patches of the granite.

The study of these intrusions in the field and under the microscope appears to give the clue to their origin. The large porphyritic orthoclases are prominent in all the rocks in varying degree; but within this limited area their relative abundance does not depend upon the distance of any given intrusion from the granite. Outside the area their occurrence, in other than the acid dykes, is exceptional, the mixed rocks giving place to lamprophyres containing small rounded quartz-grains in unusual association. Traced outwards from the granite, therefore, the felspars abruptly vanish, the quartz that still remains being reduced to small, often microscopic, dimensions. The intimate association of these intrusions with the granite thus indicated is emphasized by the fact that the rocks of the series are entirely confined to the narrow belt previously mentioned.

Porphyritic orthoclase and quartz are found in association in all the rocks, from the acid end to the basic. In some they are large and abundant, in others small and sparsely scattered, but (while always conspicuous) show varying degrees of magmatic corrosion. Occurring throughout the mass of an intrusion right up to the bounding walls parallel to which they are usually orientated, their formation is clearly intratelluric. Relative abundance depends neither on distance from the granite nor on the size of the intrusive mass, near dykes being sometimes less rich than others more remote, and the maximum occurring in the narrowest of the series. Some other factor, therefore, must be sought for the explanation.

The presence of quartz-grains in basic rocks has frequently been recorded, various explanations having been offered to account for this unusual association. J. P. Iddings refers the corroded quartz-grains in certain basalts to the catalytic action of heated water-vapour during an earlier consolidation of the magma, the vapour weakening the affinity between the bases and the silica and permitting them to separate out into more basic silicates and quartz. The consolidation due to pressure is unstable, and, when relief comes, yields to the potential liquidity of the magma. To this period is assigned the partial resorption of the quartz, which is only checked by the second and final consolidation of the magma. The quartz is thus regarded as native to the basic magma.

Dr. A. Harker[1] has suggested that the quartz-grains found in certain lamprophyres originated in a magma of acid composition, and sank into an underlying more basic magma, undergoing corrosion, not necessarily in the original basin, but probably at a later period when the rocks were intruded into their present positions. This is a simple explanation and, moreover, agrees with recorded observation in the field.

In the set of intrusions now described felspar and quartz are found in rocks of a somewhat basic type. Their density being greater than that of the liquid magma from which they usually separate, sinking is a normal consequence, provided that the magma retains a sufficient degree of fluidity, and both minerals will ultimately be found at a level considerably lower than that of origin. Conditions favourable to the development of this process would arise during the cooling of a magma already differentiated into an upper granitic, and a lower more basic, portion. Similar conditions might prevail if differentiation were deferred to a period subsequent to the intrusion of the granite: refusion of the consolidated magma would follow a relief of pressure, local or otherwise; and, if we postulate a state of equilibrium between magma and bounding wall as maintained for a sufficient time to allow gravitational differentiation to take place, cooling of the upper layers would initiate the process. A rise of isotherms alone might even be sufficient to liquefy the matrix, and permit existing phenocrysts to settle into the more liquid layers beneath.

The result of such a process may be briefly considered. By

[1] Geol. Mag. dec. 3, vol. ix (1892) p. 487.

reason of its higher temperature and more basic composition, the underlying magma will possess a higher degree of fluidity. The sinking crystals being in a state of chemical inequilibrium with their new surroundings, reaction between crystal and magma will result in their partial solution. Sinking continues, until either the crystal is entirely dissolved, or a change in physical conditions brings about complete consolidation. The larger individuals may descend a considerable distance before being checked; but many will be completely resorbed, the few ultimately surviving being small and well rounded by the action of the magma—action increasing in intensity as the difference in composition becomes more marked.

Hence on intrusion the upper layers would yield rocks with numerous porphyritic individuals set in a ground-mass probably but slightly more basic than the granite. In a descending sequence the large crystals would show increasing signs of corrosion, the matrix would become enriched in melanocratic constituents at the expense of the quartz, the contrast between the dwindling extraneous element and the increasingly important ground-mass would become more and more marked. From porphyrites the rocks would pass to more basic varieties, the extreme being a more or less basic rock of which the mineralogical constitution would be determined, *inter alia*, by the original chemical composition of the parent magma and the degree of differentiation reached, the extraneous element being reduced to a minimum.

Thus the composition of any particular intrusion would depend upon the portion of the magma from which it was derived, and the result would be the product of two factors opposite in character, but tending to the same end: (*a*) a gradual increase in basicity due to original magmatic differentiation, retarded by (*b*) a decreasing acidification, due to the decreasing relative abundance of phenocrysts from the upper more siliceous layers. These would tend to produce rocks combining features of both acid and basic types, and a series of mixed intrusions would result, consisting essentially of rocks of a more basic magma enclosing xenocrysts of an allied acid magma obtained by settlement under intratelluric conditions.

Compared with the Potter-Fell type these would show a combination of extreme characters, whereas the former exhibit the usual features of intermediate rocks; they would be mixtures of acid xenocrysts and more basic magma, whereas the former follow the law of decreasing basicity in phenocryst and ground-mass; they would be hybrids, the former are transitional varieties. A wide range of composition might be expected overlapping the former in both directions, but especially in the basic. Such is actually the case in the rocks under discussion, and examples occur illustrating the various stages outlined above. The probability of two such strikingly different types of intermediate rock being developed from the same magma might be questioned: it will be sufficient, however, at this stage to point out that they vary, not only in distribution, but also in point of time.

The xenocrysts show characters which accord with the foregoing theory of their origin. In the more acid varieties the felspars attain a maximum size, and form a large part of the rock. Corrosion increases progressively, small well-rounded individuals being the rule in the more basic types. Quartz suffers in a similar manner. The successive stages are best followed under the microscope; hexagonal sections are at first fairly well defined, but the crystals gradually diminish in size, lose all trace of form, and survive as rounded grains. At a certain stage a corrosion-ring appears, increasing in width with the basicity of the rock, and occurring throughout the mass. When flow-structure is present, biotite and pseudomorphs of ferromagnesian minerals are observed tilted against and fractured by collision with the quartz, pointing to its early crystallization; and this, together with the violent corrosion, reaction-rim, and the general basicity of the rock, renders the conception of its crystallization from the surrounding magma scarcely feasible. The orthoclase-xenocrysts are often changed marginally into an aggregate of plagioclase and quartz, the former orientated with respect to the orthoclase, a feature also observed in the basic patches of the granite. The change has sometimes reached an advanced stage—deep gulfs being formed, separated by narrow sinuous bands of the unaltered mineral. In the more basic examples the orthoclase is often microscopic, and secondary growth is not uncommon. Some of the xenocrysts are microperthitic in places, usually round the edges but sometimes internally, especially near the patches of plagioclase and quartz, and very rarely throughout. A number of sections were cut across porphyritic felspars from various basic patches of the granite for comparison, and microperthite was found to occur in somewhat similar fashion.

Of the other constituents of these rocks a variety of plagioclase is the commonest phenocryst, and differs from the foregoing in the possession of perfect contours. The largest crystals in the upper members, apart from the xenocrysts, are oligoclase-felspars of a basic type; while andesine giving symmetrical extinction of 20° is occasionally present. Complex twinning is the rule, and a marked feature is the beautiful zoning exhibited by all the felspars. Oligoclase occurs even in the more basic rocks, but generally as small well-rounded crystals giving low angles of extinction, and frequently bordered by a rim of orthoclase in optical continuity with that of the ground-mass. These may possibly be derived from the upper layers, thus partaking of the nature of xenocrysts, their insolubility in a basic magma disguising to some extent their origin. A secondary growth round a corroded core is of frequent occurrence, the outer zone being either corroded, especially in the more basic rocks, or presenting more or less perfect outlines, as in the upper more acid rocks. Orthoclase is usually restricted to the ground-mass, where it is associated with a decreasing amount of quartz.

Biotite is often fresh, and resembles that of the acid group of intrusions; but at times it is much bent and fractured, has a deep red-brown colour as in the lamprophyres, and breaks down commonly into a mass of chlorite crowded with rutile-needles—a type of alteration very uncommon in the preceding groups, but characteristic of this series. Lenticular calcite and chlorite are fairly frequent alteration-products in some varieties. Lamellar twinning is not unusual. Always abundant, biotite gradually increases in importance, and ultimately becomes the dominant phenocryst.

Absent from the upper rocks, but subsequently becoming associated with the biotite, is a pale amphibole, either colourless or faintly tinged with green, the pleochroism being: X almost colourless, Y yellowish-green, Z faint green. Typical hornblende shapes are never seen, but ragged cross-sections show the usual amphibolic cleavages. The extinction seldom exceeds 18°, polarization is brilliant, and lamellar twinning is quite common. The crystals often consist of aggregates of actinolitic needles, and the appearance is always suggestive of a secondary origin. With the incoming of amphibole the quartz-xenocrysts begin to show a reaction-rim of the same substance, which increases in width as the quartz diminishes in size. Very rarely an augite shape is suggested, though never sharply defined, and it is probable that some of the amphibole may replace that mineral. There are strong grounds, however, for believing that some of it has been derived from biotite.

The abundance of sphene is in marked contrast to its rarity in the acid intrusives, and to its practical absence from the Potter-Fell group. It is constantly present, not only in the form of wedges, but also as irregular grains. Twinning on 110 is common, but lamellar twinning parallel to 221 has also been observed. Alteration leads to a mass of calcite and rutile bordered by packed grains of opaque iron-oxide, and occasionally accompanied by anatase.

Epidote is always present; a more interesting occurrence, however, is allanite, which is found in several of the dykes, though never in abundance. It occurs mainly in small irregular grains, but occasionally forms long narrow crystals about 2·5 mm. in length, elongated along the *b* axis to about eight times the width. Sometimes it is surrounded by epidote in parallel orientation. The colour is somewhat patchy, but the pleochroism gives in order yellowish-green, brownish, brownish-yellow. Transverse zoning is well marked, while apatite and zircon are frequently enclosed. It is interesting to note that allanite is also found in the granite, a section in the Sedgwick Museum Collection containing an elongated crystal similar to those just described.

The remaining accessory minerals include abundant apatite, zircon, pyrrhotite, ilmenite, and some secondary pyrites. Pyrrhotite is fairly common in certain rocks, and, with biotite, forms occasionally small basic aggregates. Carbonates are freely disseminated through the more basic rocks of the series, and accompany quartz in the vesicles. The carbonates which form so prominent a feature of the lamprophyres generally have been referred variously in the past to calcite and to dolomite. To determine their true nature in these rocks micro-chemical methods were adopted. Lemberg's method was used for the contents of the vesicles, and the result in every case proved the carbonate to be calcite and not dolomite. The disseminated carbonates, however, remained unaffected, consequently further treatment was necessary. For these Heger's method was adopted, consisting of treatment with dilute hydrochloric acid and potassium ferrocyanide, which depends for its success on the presence of iron—a condition easily satisfied in these rocks. The carbonates throughout the sections so treated were stained a deep blue, thus proving also to be calcite. Sections of lamprophyres from various parts of the area were likewise tested, but the result never varied. It is clear, therefore, that, although the presence of a certain amount of magnesia is not precluded (microscopic evidence indeed suggesting its presence), the carbonates are predominantly calcic.

The intrusions are found both north and south of the granite, but are more common on the south. Those on the north are richer in xenocrysts frequently of maximum size, a circumstance which, taken in conjunction with the more acid nature of the ground-mass, suggests derivation from the upper levels of the magma: this is a point not devoid of significance. The specific gravity varies from 2·642 to 2·732, indicating a wider range and a greater density than the Potter-Fell rocks, although the presence of the xenocrysts appreciably modifies the true magmatic density.

The orthoclase-xenocrysts reach their maximum abundance in a narrow dyke breaking through the andesitic ashes in the bed of the Lowther, about a mile to the north of the granite. They exceed an inch in length, but are smaller generally than those of the granite, and are associated with quartz-grains, pale-green striated felspars, and plates of mica, the compact grey matrix being quite subordinate. Viewed in thin section, the orthoclases in form and inclusions are comparable with those of the acid rocks; while the quartz-grains are rounded when small, but give indication of hexagonal contours in the larger individuals. Well-developed oligoclase with small angles of extinction is the most important phenocryst, though occasionally an approach to andesine is noticeable, and biotite is subordinate. The ground-mass is a very finely micrographic intergrowth of orthoclase and quartz, with some oligoclase.

A dyke nearer the granite shows a slight advance in basicity, not only in the increased importance of biotite as a phenocryst, but more especially in the appearance of a second generation in the ground-mass. The most interesting feature of the rock, however, is a basic segregation near the margin. It is more or less identical with those of the granite, the chief constituents being biotite, basic oligoclase, and sphene, with very little orthoclase or quartz, and abundant needles of apatite. Associated with the biotite and sometimes isolated is amphibole, appearing here for the first time, clearly secondary, and probably pseudomorphous after augite. The presence of pyroxene in the basic patch and its absence from the enclosing rock raises the question of the origin of the patch. Incorporation of the country-rock is out of the question. The abundance of minerals common to the host, with the addition of pyroxene which is characteristic of a lower portion of the magma, suggests the source. The higher density, greater basicity, and the fact that both were liquid together (shown by the absence of a sharp boundary and the commingling of material) point to the same conclusion. It is a portion of the underlying magma which, becoming involved in the intrusion, gravitated to the lower edge of the dyke, and finally crystallized as a more or less independent mass.

A further stage in the corrosion of the xenocrysts and the gradual increase in basicity of the matrix is seen in a dyke not far off. The xenocrysts are less abundant, the compact matrix is darker and of relatively greater importance, and the rock is generally less porphyritic. Microscopically the principal differences are the greater abundance of mica of both generations, the appearance of amphibole in the body of the rock, and the presence of reaction-rims to the quartz. The rims consist of a confused tangle of flakes, with no definite orientation, and increase in width at the expense of the quartz. Some of the amphibole-aggregates therefore probably indicate the position of former quartz-grains.

In these three dykes, all occurring north of the granite, with specific gravities respectively of 2·642, 2·654, 2·684, successive stages of progressive basicity are exemplified, and the hybrid character becomes increasingly evident. Attempts to classify them on the basis of mineral constituents alone would lead to confusion, as it would be difficult to assign to them a place in any scheme. The difference between the corroded orthoclase and quartz on the one hand, and the idiomorphic plagioclase and biotite on the other, is fundamental, and has to be taken into account. Apart from the xenocrysts the rocks described are biotite-porphyrites, consequently they must be regarded as biotite-porphyrites modified by the inclusion of acid xenocrysts from a more acid but allied magma. In mineral composition and character the third of the series represents an approach to the lamprophyric type.

Intrusions showing a still further advance in basicity, and therefore presumably from a lower part of the magma, occur south of the granite. They are more compact, usually dark grey or reddish brown, and the structure at times is almost panidiomorphic. Considered apart from the xenocrysts, which are smaller than before, though equally if not more conspicuous, many of the rocks are lamprophyres, and frequently biotite is the commonest and only idiomorphic mineral of the larger generation. Hence they are lamprophyres modified by acid xenocrysts.

Microscopically they show certain peculiarities. Amphibole increases in amount, and vies with biotite in importance, but with no claim to be considered of primary origin. It may predominate, giving colour to the rock, or it may be entirely absent. It is probably secondary after augite, though the latter is never present in an unaltered condition.

More interesting, however, is the occurrence of pseudomorphs of which the original mineral has disappeared. Occasionally a shape suggests augite, at other times olivine, though neither mineral is present in a fresh condition. Some of the pseudomorphs, consisting of a mass of fibrous amphibole of the kind already described, may represent augite. Others show a diversity of secondary minerals, and (though often rounded) have at times the outlines and sharp terminations of olivine. Commonly they consist of an aggregate of colourless amphibole-prisms grouped without any definite arrangement, which may either occupy the whole of the pseudomorphs or may be associated with other secondary minerals. They resemble the 'pilite' pseudomorphs after olivine described by F. Becke.[1] The amphibole has the characters of the grammatite of B. Doss.[2] It is colourless and highly birefringent, cross-sections showing the usual amphibolic cleavage. Generally the prisms form a tangled mass; occasionally they lie along the vertical axis of the olivine, or there may be some feeble trace of zoning. Chlorite sometimes fills up the spaces, but pseudomorphs of amphibole alone are frequently crowded with secondary magnetite. Secondary biotite is sometimes present, and is distinguished from the original biotite in the body of the rock (often clinging to the exterior of the pseudomorph) by the absence of the rutile mesh which usually accompanies the decomposition of the latter, and by the greenish-brown colour. A colourless interior is occasionally surrounded by a mixture of amphibole and new biotite similar to that described by Doss; but his suggestion that dynametamorphism has played a part in their production has no application to the present examples. Aggregates of highly-polarizing scales resembling talc are sometimes associated with chlorite and amphibole. Other pseudomorphs consist of calcite and chlorite with a little iron, while in one intrusion they are composed almost entirely of biotite-flakes.

A dyke of the pilitic type occurs on the north side of Stakeley Valley, breaking through and incorporating the Coniston Flags. Centrally the rock is dark grey, marginally it is black and compact. White orthoclase-xenocrysts are conspicuous, but seldom exceed a centimetre in length; quartz is less abundant, and oligoclase is rounded. Biotite now assumes great importance, both as phenocrysts and in the matrix. In section, the bulk is seen to consist of a fine-grained ground-mass of biotite and felspar. Pseudomorphs are abundant: some showing olivine shapes consist of amphibole and chlorite with grains of iron-ore, thus resembling the original 'pilite.' Quartz-grains incorporated from the invaded rock are

[1] 'Eruptivgesteine aus der Gneissformation des Niederösterreichischen Waldviertels' Tscherm. Min. Petr. Mitth. vol. v (1883) p. 163.

[2] 'Die Lamprophyre & Melaphyre des Plauen'schen Grundes bei Dresden' *ibid.* vol. xi (1890) p. 17.

always readily distinguished from the xenocrysts. A section from a joint-plane weathering green contains amphibole almost to the entire exclusion of biotite, although this mineral is absent from the remainder of the rock.

Another type contains amphibole in the ground-mass, in addition to biotite. These rocks are dark, with a greenish tinge due to the amphibole. They contain pink orthoclase- and quartz-xenocrysts, together with biotite, hornblende, and plagioclase. Microscopically the ground-mass has a patchy appearance, suggestive of an imperfect mingling of material. The lighter patches are of felspar and quartz; orthoclase may be most abundant, sheaf-like aggregates being then produced, or the felspar may be wholly plagioclase with interstitial quartz. The dark minerals are similarly bunched together. Hornblende may predominate (as in one example from the upper part of Stakeley Valley), or biotite may be more prevalent; but sections from the same dyke do not show any decided uniformity. The hornblende may be the pale-green fibrous variety resembling that which now forms the corrosion-ring of the quartz, often in tufted aggregates with brilliant polarization; or the colourless variety may be present in the pilitic pseudomorphs. These rocks are allied to the vogesites rather than to the minettes, and are pilitic vogesites or pilitic biotite-vogesites modified by acid xenocrysts.

A variety closely resembling the minettes of the district occurs in various parts of Stakeley Valley and near Gill Farm. Essentially the rocks consist of biotite and felspar, the latter principally orthoclase-prisms grouped in fanlike aggregates. Pseudomorphs of calcite and chlorite are present, together with vesicles, but hornblende is entirely absent. Either augite-minettes or possibly even pilitic minettes may be represented in this group.

These examples illustrate the difficulty attending any attempt to classify hybrids. Judged by the density 2·70 to 2·73, the part played by ferromagnesian minerals, the iron content, and the constituents of the ground-mass, they should be classed as lamprophyres. But the xenocrysts, never entirely absent and often present in great number, are granitic, and it is not always easy to strike a balance between the two. To term them lamprophyres is to ignore the granitic element; to describe them as porphyrites is to ignore on the one hand the lamprophyric groundwork, and on the other, the xenocrysts. The use of the general term of 'quartz-porphyrite' is scarcely warranted, as biotite is the more frequent porphyritic element and is moreover native to the magma; while a consistent application of this mode of nomenclature would lead to such cumbersome forms as 'orthoclase-biotite-hornblende-quartz-porphyrite,' with variations, which obscure the real character of the rocks.

The intrusions of the mixed series are thus the result of a complicated differentiation, and are marked by increasing basicity in an increasingly important ground-mass, retarded by the addition of acid xenocrysts in diminishing amount. The magma yields rocks the characters of which depend on two factors: the abundance of xenocrysts and the composition of the matrix, a decrease in the one and an increased basicity in the other marking the successive stages. The more acid have affinities with the porphyrites, the more basic with the lamprophyres, all being more or less modified in composition by the presence of the xenocrysts, a hybrid series being the result.

From the magma which gave rise to these mixed products came also the basic patches of the granite. They themselves show varying degrees of basicity, and the scarcity of large felspars is accompanied at times by a higher density. The basic patch of the Wet Sleddale dyke is of interest in this connexion. Its density is greater than that of any granitic patch that has been tested, and it probably comes from a lower source. That an intrusion more basic than the granite should be able to tap a lower portion of the reservoir is only to be expected. It may be inferred, therefore, that the granite in its passage involved portions of the underlying magma which consolidated as basic patches, the same magma giving rise to the mixed series of intrusions, some of which in their turn involved portions of a still lower and more basic magma. From the intimate association of the granitic and underlying magmas one might expect a similar close connexion between their products. This is actually the case. The first set of minor intrusions, apart from one or two which may be regarded perhaps as direct apophyses of the granite, consisted of the mixed series. How long a period elapsed prior to their injection is uncertain. Possibly they were intimately connected with the granite in time as they are in space. The upper and more acid were injected north of the granite mass, the lower and more basic on the south, while their restriction to the immediate neighbourhood of the granite is consistent with the above deduction.

The abundance of porphyritic felspars in the granite, together with its basic character, may be regarded as an indication that the exposed mass represents the lower part of the original magma. This proposition is more or less speculative; but it is supported by the presence of the basic patches. Dr. Harker & Prof. Marr[1] state that the amount of metamorphism would suggest the passage of molten material through the channel for a considerable period. It is a reasonable supposition that the differentiation believed to have extended downwards from the mass exposed extended upwards in the mass removed. The latter would be more acid and probably less porphyritic, having lost some of its first-formed elements by sinking. First to be intruded, or extruded, it would be removed by the continued flow, the less acid portion coming last, consolidating in its present position, crowded with felspars, and containing numerous basic patches. This would partly acccount for the greater basicity of the Shap granite, as compared with the Skiddaw granite of probably the same age.

[1] Q. J. G. S. vol. xlvii (1891) p. 292.

A further point may be noted in this connexion. The more acid of the mixed series on the north and the more basic on the south, can be correlated with a similar greater acidity north of the Skiddaw granite. The plutonic masses themselves are similarly related. All appear to be connected with the crustal stresses which produced the present strike of the Lake-District rocks.

The true explanation of the comparative basicity of the Shap granite may lie in a combination of these two factors. Pressure from the south-east affecting first and in full force the Shap area might conceivably produce a considerable flow of material to the existing surface, while the more northern magma, less deeply stirred by a partly-spent force, failed to reach the surface, and consolidated as a laccolite. In each case the continued pressure forced the more acid portions of the magma northwards.

VI. Age and Order of the Intrusions.

Two points require preliminary consideration: (1) the age of the granite; (2) whether all the minor intrusions in the area belong to the same igneous epoch. As regards the former, the age can with certainty be taken as Devonian, the evidence on this point being conclusive. The second is perhaps more difficult to determine, but a genetic connexion is highly probable. All available evidence supports it. Dr. Harker has given reasons for believing that such a genetic connexion exists between the lamprophyres and the granite magma.[1] Similar views have been expressed regarding the dykes and sills of the adjoining area by Sir Aubrey Strahan, who regards them as belonging to the same outburst as the Shap granite.[2]

All the dykes examined agree in certain respects. They are intruded in Silurian or earlier rocks, and are not known to enter Carboniferous rocks. In the central part of the area the general direction of the dykes is north-north-westerly, corresponding approximately to the fractures transverse to the folding, important deviations apart from sills being due, as a rule, to intrusion along lines of fault. A belt in this direction encloses practically all the orthoporphyritic intrusions, together with certain other acid rocks. Outside this belt on the west are the intermediate rocks of the Potter-Fell type, and at a greater angle the most basic of the lamprophyres.

None of these dykes existed, so far as is known, in Ordovician times. They have not suffered from the earth-movements producing the folding, and do not show signs of crush or shearing. Even when rocks intruded in Silurian sediments lack alignment, as in Fawcett Forest, where the sills exposed on the ridges are apparently shifted in succession to the north-west along lines of fault coincident with the intervening valleys, crush-phenomena

[1] Geol. Mag. dec. 3, vol. ix (1892) p. 199.

[2] 'The Geology of the Country around Mallerstang, &c.' Mem. Geol. Surv. 1891, p. 8.

are absent, and the sills appear to have been intruded on planes of weakness rather than disturbed by subsequent movement. Certain dykes in the west present features not common to the lamprophyres generally; but these may confidently be referred to the same magma, as similar features are occasionally reproduced in the mixed series. An acid sill intruded in the volcanic rocks north of the granite shows some resemblance in the field to the Ordovician sills of other parts of the Lake District; but sufficient reasons do not appear for separating it from somewhat similar rocks which undoubtedly belong to the granite. Everything points to the same conclusion, that the whole of the minor intrusions of the area are connected directly or indirectly with the same magma.

The general age having been fixed, it remains to enquire as to the order in which the various intrusions played their part. Conclusive evidence, such as the cutting of one set by another, is unfortunately rare; but sufficient can be gathered from the few instances that occur to enable one to form a fairly definite idea as to the sequence in which the great groups were intruded.

Intersecting dykes are very rare. Far down the Stakeley Valley two dykes are seen close together in the bank of the stream, one belonging to the mixed series, the other an acid intrusion of the ordinary type. They approach each other, but are lost in mid-stream. The marginal portion of the basic dyke ends abruptly against the grit, and appears to be moved aside by the acid dyke, which, however, is so decomposed that it disappears from view before meeting the other. In the adjoining area lamprophyres occasionally cut the felsite sills. The latter, there very abundant, are unlike any of the acid intrusions near the granite, and their exact position in the sequence is perhaps a matter of doubt.

The granite is cut by acid veins of fine aplitic character belonging to a late stage of activity and traversing granite and basic patch indiscriminately; but careful search has failed to reveal its penetration either by basic or even by mixed dykes. This, however, is not conclusive evidence. The reluctance of basic dykes to enter certain formations is well known, and instances need not be quoted.[1] The fact that granite is rarely pierced by basic intrusions has to be taken into account.

Occasionally dykes have been intruded along planes which served as channels for previous magmatic flows. Although rare, these are of importance in determining the true sequence. An intrusion of this kind occurs near Gill Farm. The centre is a quartz-felsite containing large Carlsbad twins of pink orthoclase. The marginal rock is a modified lamprophyre of the mixed series, with the usual orthoclase- and quartz-xenocrysts in a biotite-studded ground-mass of the type previously mentioned as resembling the minettes. The junction of the two rocks is marked by a small belt of mixed material, 12 inches wide, comprising numerous blocks

[1] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 432.

of the dark rock involved in the flow of the acid magma. Less than 12 yards away the sharp junction is absent, and no included blocks are found; but there is apparently a gradual transition from one to the other.

Higher up the same valley is another composite dyke, the study of which yields results of considerable importance. One of the members is a typical quartz-porphyry containing phenocrysts of quartz, microperthite, oligoclase, and occasional mica in a pink ground-mass, compact and felspathic in the hand-specimen, finely microspherulitic in thin section. Biotite is absent from the ground-mass, which consists almost entirely of orthoclase and quartz. This part of the intrusion contains no large granitic orthoclases, and, with its scarcity of biotite and abundance of quartz, is more acid than any of the orthoporphyritic dykes. Alongside comes a dark, more basic rock (evidently of the mixed series) in which pink orthoclase-xenocrysts occur only at the margin. At first sight, the whole appears to form one intrusion; but closer inspection shows that the central portion, which is entirely free from felspar-xenocrysts, is a later product of the magma intruded along the same channel. The junction, when detected, is quite sharp, and the chilled edge is conclusive. A comparison between the two rocks is instructive. The earlier marginal rock is a modified lamprophyre of the mixed series differing in no way essentially from that of the composite dyke at Gill. The central intrusion, however, is distinguished by the absence of felspar-xenocrysts, though rounded quartz is present. It is a dark-grey porphyritic rock; but the phenocrysts are of a small order, yellowish-green oligoclase being the most common, while biotite is perhaps not quite so abundant as in the marginal intrusion. In thin section biotite and felspar are again the chief constituents; but the texture is almost trachytic, the ground-mass consisting largely of laths of striated felspar and prisms of orthoclase, with some quartz, sphene, apatite, and pyrrhotite. The rock appears to be a transitional variety resembling in some respects a lamprophyre, in others a porphyrite. The abundance of oligoclase-phenocrysts and the diminution in biotite determine its classification as a biotite-porphyrite. On the whole, therefore, it is less basic than the earlier marginal rock, and this is borne out by its specific gravity: 2·680 as compared with 2·713. The effect on the earlier rock has been remarkably small, the only change recognizable in section being the production of biotite in the pseudomorphs.

Consideration of this central member raises the question of its magmatic source. If it belongs to the same period as the mixed series of intrusions and is derived from the same magma, then the absence of the orthoclase-xenocrysts would indicate a lower horizon than those that furnished material for any known member of the series, and consequently one would expect to find a further increase in basicity. The reverse being the case, it is evidently not a product of the mixed magma; and it must be assigned to a still later period, when, differentiation on a large scale having produced more and less basic derivatives of a magma practically free from ready-made felspars, a period of renewed activity set in over a wider area resulting in a set of intrusions which, while sometimes availing themselves of former lines of weakness (forming thereby composite dykes), overlapped in every direction the former scene of activity and gave rise to the numerous lamprophyres and felsites of the outer parts of the area. As the earlier set of intrusions coincide generally in direction with the series of north-north-west faults, so many of the later set coincide in direction with the series of faults ranging from north-east to north, fracturing the country east of the Lune. The two distinct types of intrusion thus appear to be related to the two main types of fracture of the district, and it is of interest to note the order in which the two were intruded.

Some dykes in Long Sleddale Valley throw light on the closing stages of activity. Two were described by Dr. A. Harker[1] in 1912, and the incorporation of acid rock by basic was especially noted. Two features of interest arise from their study. The upper dyke is a lamprophyre of the minette-kersantite type, consisting essentially of felspar and biotite with some hornblende and magnetite. Enclosed are portions of a felsitic rock, mainly of orthoclase and quartz with much secondary material; but the quartz is often anterior to the felspar, and sphene is present, two features linking it with the granite. The lower dyke contains similar enclosures, presumably from the same source; but the dyke itself is more basic. Plagioclase and hornblende are the essential constituents, the remaining minerals including biotite, apatite, magnetite, and irregular pseudomorphs of calcite and chlorite. The rock is thus allied to the spessartites. A somewhat similar dyke in contact with the upper lamprophyre presents a chilled edge to it. The specific gravity of the spessartite is 2·729, and that of the earlier intrusion 2·665.

Whether the acid inclusions were brought up in a fluid state, or were picked up by the lamprophyres during intrusion, cannot be definitely stated; but the fact that the smaller patches sometimes show flow-structure with the linear arrangement parallel to the walls of the dyke, shows that the enclosed rock was sufficiently plastic to be moulded, and as analogous features are present in some of the dark patches of the granite, the two may be comparable in this respect. This would indicate that the two magmas co-existed in a fluid state, the result of differentiation on a wide scale, of which the central portion of the composite dyke in Stakeley may be a product. At what stage the advanced differentiation occurred it is impossible to state; but its manifestation was considerably later than the intrusion of the mixed series, and was probably connected with the movements which caused a swinging of the later products of the deep-seated magma from a south-easterly to a south-westerly direction. In the adjoining area

[1] 'The Naturalist' 1912, pp. 266–67.

lamprophyres cut the felsites, which are there very abundant forming thick sills, and this (together with their position) may indicate their intrusion at an early stage. Further work in this district is necessary, in order that one may form a correct conclusion.

The lamprophyres of the west represent two stages of intrusion. These agree with the order so commonly found in the concluding phase of activity—increasing basicity. Both co-existed with felsite; but, while the enclosures of the earlier lamprophyres contain medium to basic oligoclase, the felspar in the spessartite enclosure is usually monoclinic. Whether this is fundamental or a mere coincidence cannot be stated definitely from the few sections examined; but it is interesting to observe that they follow the lines which one would expect, on the assumption that they represent complementary derivatives from the same magma—an increasing divergence in the later members towards the basic and acid ends.

The most acid intrusions are the quartz-orthoclase veins traversing the granite, which are comparable with the acid enclosures just described. It is probable that the spessartites and the veins are the extreme complementary products of the magma.

VII. Summary.

Differentiation under the influence of gravity produced an upper acid and a lower more basic magma.

Cooling under plutonic conditions caused the separation of acid phenocrysts which, owing to their density, sank to lower and more basic levels, resulting in a concentration at a lower horizon.

At the commencement of igneous activity the upper layers of the acid magma were removed by more or less prolonged intrusion or extrusion, the lower and consequently more basic portion of this magma finally consolidating in the channel of flow as the Shap granite, rich in felspars and involving portions of the underlying magma as basic patches.

The sinking of acid phenocrysts into the underlying magma produced a series of rocks characterized by the presence of acid xenocrysts in a ground-mass of varying chemical composition, the normal increase in basicity due to gravity being offset by the xenocrysts in diminishing amount. The resultant hybrid series includes rocks ranging from biotite-porphyrites to pilitic lamprophyres, all more or less modified by the addition of xenocrysts from a more acid but allied magma.

The mixed magma gave rise to the first important group which, with the accompanying acid group, forms the earlier set of intrusions. These are local in distribution, being restricted to the immediate neighbourhood of the granite, and are distinguished by the presence of large orthoclase-felspars of the granitic type.

Further differentiation on a regional scale produced after a considerable interval a later set of intrusions, ranging from acid felsites to basic lamprophyres, covering a wider area and overlapping the former in every direction. They are characterized by the absence of porphyritic orthoclase, although quartz-grains are commonly found even in some of the basic members. Last to be intruded were the most basic lamprophyres, incorporating portions of a felsitic magma. These show an increasing basicity, apparently indicating an increasing divergence to more basic and more acid poles.

Two lines of variation are found: (1) horizontal, extreme acid and basic types occurring in the outer parts of the area; (2) directional, the earlier set coinciding in direction with the north-north-west fractures transverse to the strike of the country-rock, the later set with a general trend more or less at right angles to the former, and corresponding approximately to the lines of fracture to the east.

The intrusions thus belong to two distinct periods, and appear to be related to the two main series of crust-movements which determine the geological structure of the area.

In conclusion, I wish to record my thanks to the late Prof. T. McKenny Hughes for granting facilities for the work at the Sedgwick Museum, and for unrestricted access to the collection of rocks and sections; also to all who have so kindly and willingly rendered help in various ways.

EXPLANATION OF PLATE XIII.

Figs. 1 & 2 illustrate two stages of the mixed series, the rocks showing a progressive increase in basicity.

Fig. 1. Biotite-porphyrite. Hornblende (probably after augite) now appears, and also forms a corrosion-rim round the quartz as seen on the left. The dark mineral is mainly biotite, but a little hornblende also is present. Sp. gr. = 2·684. × about 30 diameters. (See p. 133.) T.

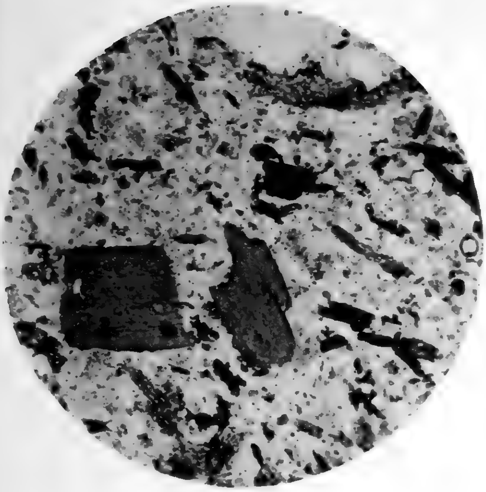
2. Pilitic biotite-vogesite. On the upper margin is a rounded oligoclase-crystal, in the centre a pseudomorph mainly consisting of colourless amphibole with some magnetite; pale-green hornblende is seen on the left associated with pyrrhotite and scattered throughout; a plate of biotite appears on the right. The felspar is principally orthoclase. × about 25 diameters. (See p. 135.) M.

3. Basic segregation in biotite-porphyrite. The minerals shown are sphene of irregular form, biotite uniformly dark, hornblende with interior breaking away, and pyrrhotite; the colourless mineral is felspar, mainly plagioclase. × about 25 diameters. (See p. 132.) M.

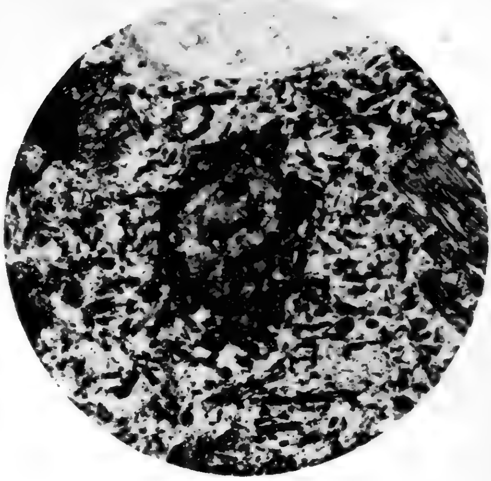
4. Intermediate rock of the Potter-Fell type. Crossed nicols. Consists essentially of felspar (much of it plagioclase) and biotite; between is microspherulitic orthoclase with a little quartz. × about 25 diameters. (See p. 126.) M.

5. Spessartite. The rock is a plexus of laths of plagioclase-felspar and idiomorphic hornblende, with abundant magnetite, occasional calcite, and some interstitial quartz. The two larger individuals are labradorite. × about 25 diameters. (See p. 140.) M.

1.



2.



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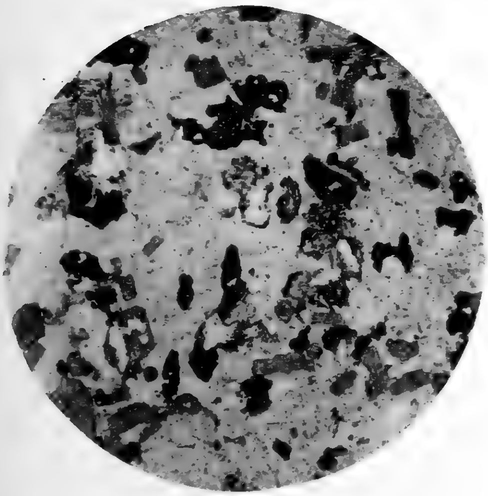

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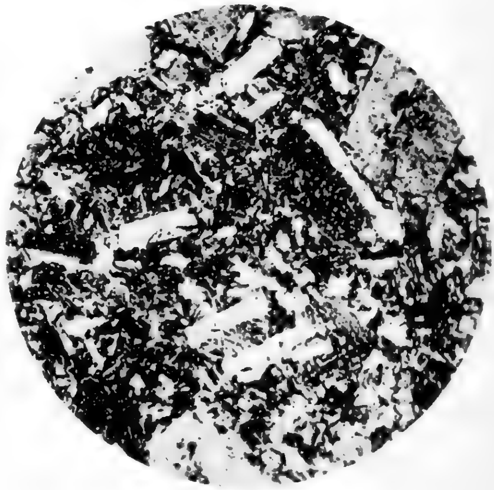

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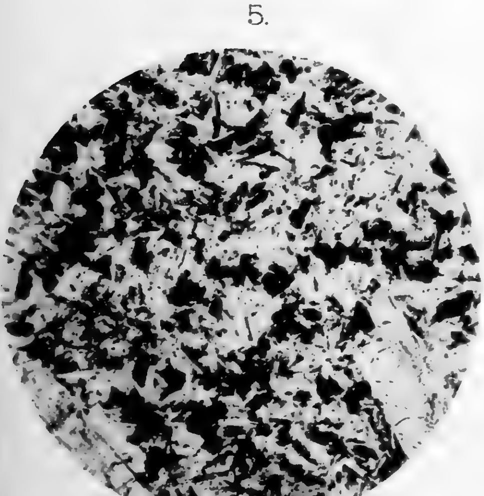
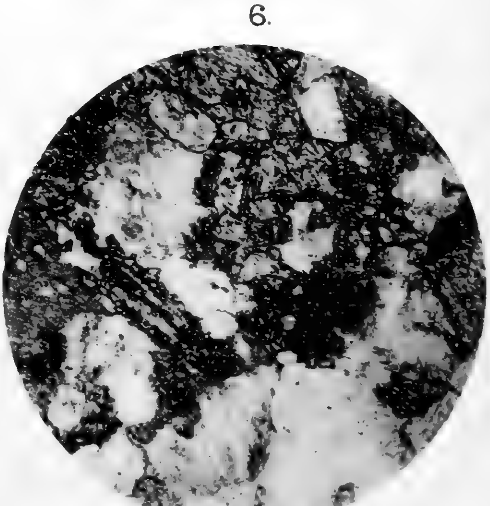


6.



J. M. & T. T., Photomicro.

Bemrose, Collo., Derby.

INTRUSIVE ROCKS FROM THE SHAP DISTRICT.

Fig. 6. An acid dyke near the granite, probably an apophysis showing assimilation of country-rock. Quartz is colourless, felspar (both plagioclase and orthoclase) less clear owing to sericite. The other mineral is diopside moulding apatite and sphene. × about 30 diameters. (See p. 125.) T.

[The microphotographs marked M. were taken by the Author, those marked T. by Mr. Tams, Cambridge.]

Discussion.

The President (Dr. A. Harker) congratulated the Author upon a contribution which presented numerous points of interest. While confirming generally the results formerly reached by Prof. Marr and the speaker, this paper seemed to make a decided advance in the interpretation of the mutual relations of this group of intrusions. The roughly-radiate disposition of the dykes about the granite as centre was resolved into two groups, approximately parallel to dip and strike respectively and intruded at distinct epochs. It was in harmony with the received conception of differentiation that the extreme types, both acid and basic, should not only be found in the outlying members of the system, but should also represent the latest injections. Another point of interest was the asymmetric arrangement implied in the situation of the more acid minor intrusions on the northern side of the granite. This connects itself with the unilateral character of the Caledonian crustal stresses, and finds a parallel in the horizontal differentiation exhibited by the granite-masses of Skiddaw, Eskdale, and Foxdale.

Dr. J. W. Evans thought that the facts brought forward by the Author afforded valuable evidence for the solution of the problems of the mechanism of igneous intrusion. He inquired whether there was evidence of flow-structure indicating the direction of the flow in particular cases. The change of the strike of the intrusions, from one direction in the earlier intrusions to another nearly at right angles to it, indicated an important change in the nature of the forces affecting the district.

Dr. J. V. Elsden asked the Author to how great an extent evidences of assimilation could be recognized where intrusions had invaded limestone strata. He thought that the Author had somewhat extended the definition of the term 'xenocryst' in applying it to crystals which had merely changed their position within the magma. This term was more often used to denote undigested inclusions of extraneous matter. It was also questionable whether rocks formed from mixed magmas, differentiated from the same parent, should strictly be called 'hybrid'—a term which he would prefer to use where no genetic relationship of the mixed types was concerned. Rosenbusch's petrographic term 'spessartite,' also, appeared to be unfortunate, the same word being in current use in a definite mineralogical sense. These small points of criticism were, however, quite insignificant in view of the importance and value of the Author's communication.

The AUTHOR, in reply, thanked the Fellows for their reception of his paper. With reference to the remarks made by the President on the influence of distance and the width of channel on the flow of the large felspars, he mentioned the interesting fact that the narrowest dyke of the mixed series was the richest in felspar xenocrysts. Evidence on the point raised by Dr. Evans regarding the direction of flow of material had been sought for in the field, but the exposures were seldom sufficiently complete to make a general statement possible. Where the fluxion-structure, however, was most marked, the movement appeared to be vertical rather than horizontal. In answer to Dr. Elsden, the Author pointed out that the term 'xenocryst' was generally applied to a crystal found in a magma other than that from which it had separated out; and the term 'hybrid' to a rock which was the product, not of a homogeneous magma, but of a mixture of magmas of different chemical composition, even if more or less allied, as was the case in Skye. In that sense the terms were used in the paper under discussion. Spessartites were originally named after the locality from which they were first described, and as the name was now in general use for lamprophyres of that type associated with magmas of a similar nature, it was applicable to the rocks now described.

6. *The* Inferior Oolite *and* Contiguous Deposits *of the* Crewkerne District (Somerset). By Linsdall Richardson, F.R.S.E., F.G.S. (Read June 20th, 1917.)

[Plates XIV–XVI.]

Contents.

I. Introduction.

In this paper I propose to give a detailed description of the Inferior Oolite and contiguous deposits of the Crewkerne district. The extent of this district, for the purpose of the present communication, will be observed from the map (fig. 1, p. 146).

(i) Geographical extent of the Inferior Oolite.—Reference to the Geological Survey Map, Sheet XVIII (Old Series) will show (1) that the most extensive tract where the Inferior Oolite limestones occur, free from overlying rocks, is in the immediate neighbourhood of Crewkerne; (2) that there are numerous masses well separated from the principal tract; and (3) that the beds are affected by numerous faults.

(ii) Previous literature.—Comparatively little information has been published concerning the Inferior Oolite and immediate sub- and superjacent deposits of this district, with the exception of Ham Hill. This locality, famous for its warm-coloured building-stone, attracted considerable attention on the part of Charles Moore,[1] James Buckman,[2] and H. B. Woodward.[3]

The second author was correct in his local correlations of the Ham-Hill Stone—a conclusion also arrived at by H. B. Woodward—but was incorrect in his correlation with the Cotteswolds; although his recognition of the Cephalopoda-Bed below the Sands at Midford (near Bath) and around Yeovil, but above the Sands of the Cotteswolds, came nearer to the truth than was imagined. The actual solution arrived at by Mr. S. S. Buckman—published with a descriptive section in 1889[4]—that the Ham-Hill Building-

[1] Proc. Somerset Arch. & Nat. Hist. Soc. vol. xiii (1867) p. 126.

[2] *Ibid.* vol. xx (1875—pt. for 1874) p. 151; Q. J. G. S. vol. xxxiii (1877) pp. 4–6; Proc. Dorset Nat. Hist. & Ant. F. C. vol. i (1877) p. 68.

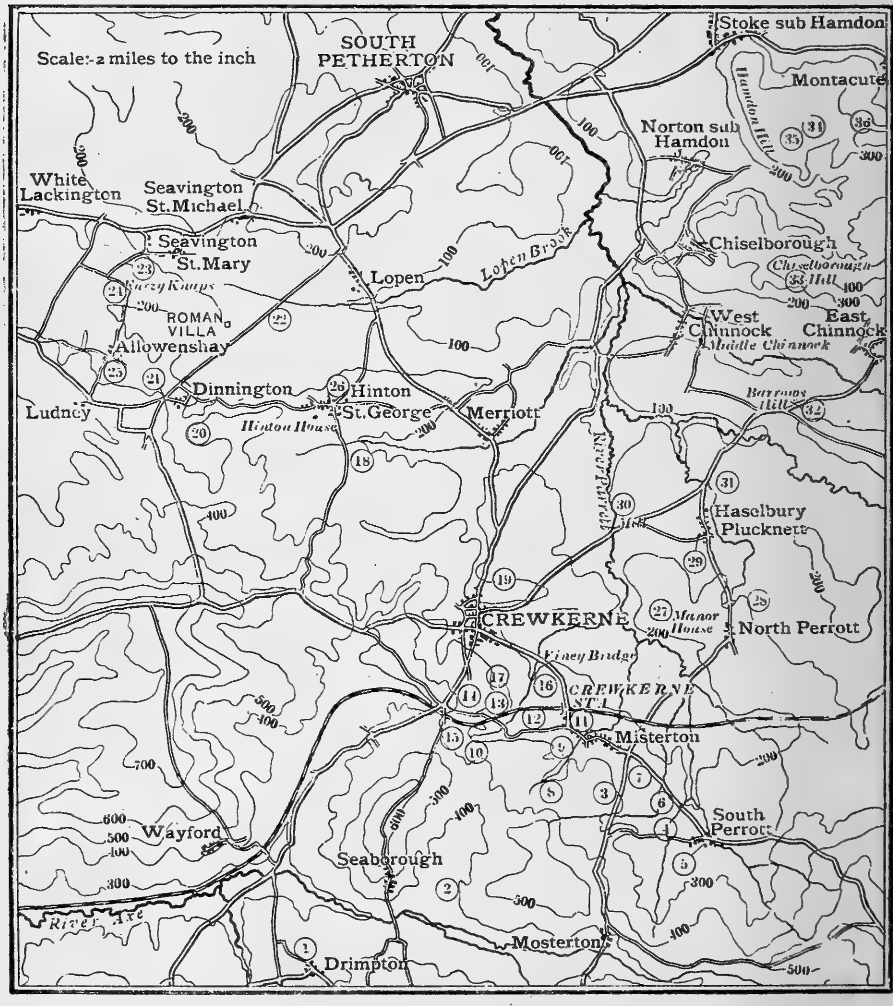
[3] Proc. Bath Nat. Hist. & Ant. F. C. vol. vi (1887) p. 184.

[4] Q. J. G. S. vol. xlv (1889) pp. 448–49.

Stone and its subjacent sands were a thick development of only a small middle portion of the Gloucestershire Cephalopoda-Bed was something quite unexpected. His dates—the Building-Stone as of *moorei* hemera and the subjacent sands as of *dumortieriæ* hemera—have been fully accepted.

As regards the rest of the district, in the seventies a considerable collection of fossils from the Crewkerne district was made by

Fig. 1.—*Map of the Crewkerne district, showing the localities where exposures of Inferior Oolite are observed.*



James Buckman and especially by his then pupil, Mr. Darell Stephens (now Mr. D. S. Darell), F.G.S.—the railway-sidings at Crewkerne Station, which were then under construction, yielding as quarrying proceeded a large number of specimens. Brachiopods so obtained, together with those procured by J. F. Walker, who had also collected in this district,[1] were sent to Davidson, and several

[1] Geol. Mag. dec. 2, vol. v (1878) p. 555.

local species were described in his communications first to the Dorset Field Club[1] and then to the Palæontographical Society.[2]

In the early eighties Mr. S. S. Buckman explored the rocks of the district, particularly around Crewkerne and Haselbury Plucknett. The brachiopods were dealt with by Mr. Buckman in 1882, and as the species were allocated to their zones and localities, the first indication of the zones of the district is thus obtained.[3] Other brachiopods were dealt with by him in 1910[4] and certain ammonites in his Monograph.[5]

W. H. Hudleston, in his well-known monograph, gives some particulars concerning the section at 'Drympton' (Drimpton), and a fairly-detailed account—accompanied by a 'profile'—of one at Haselbury (see p. 165 of the present paper).[6]

In 1891 a party of the Somerset Archæological & Natural History Society visited Crewkerne, and the late H. B. Woodward contributed some 'Notes on the Geology of Crewkerne.'[7] The information that he gave concerning the rocks under consideration appeared again in 1894—amplified and accompanied by a 'List of Fossils from the Inferior Oolite Series near Crewkerne.'[8]

In 1914 some members of the Geologists' Association of London visited the district, and saw the quarries at the Misterton Lime-works and Manor House (North Perrott), and Slade's Quarry—also at North Perrott.[9]

(iii) The lower and upper limits of the Inferior Oolite Series.—The division-line between the Lias and Oolite is now generally drawn between the deposits of *moorei* (Lias) and *aalensis* (Oolite) hemeræ. As the deposits of both these hemeræ are sand in this district, and as sandy matter continued to be deposited until the close of the *Ancolioceras* hemera, the line of demarcation between Lias and Oolite—as in the case of the Burton-Bradstock–Broadwindsor District—is not well marked.

The bulk of the Yeovil Sands is of *dumortieriæ-moorei* hemeræ.

The base of the Yeovil Sands has been observed by Mr. S. S. Buckman at White Lackington Park, near Ilminster, where it rests on an 'arenaceous marl-bed'[10] of *dispansi* hemera.

Above the Inferior Oolite comes the Fuller's Earth.

In the district extending from Burton Bradstock, near Bridport,

[1] Proc. Dorset Nat. Hist. & Ant. F. C. vol. i (1877) pp. 73–88 & pls. i–iv.

[2] 'British Fossil Brachiopoda' Monogr. Palæont. Soc. Suppl. vol. iv, pt. 2, no. 2 (1878); & Suppl. vol. v, pt. 3 [Conclusion], 1884.

[3] Proc. Dorset Nat. Hist. & Ant. F. C. vol. iv (1882) pp. 1–52.

[4] Q. J. G. S. vol. lxvi (1910) pp. 99 *et seqq.*

[5] 'Ammonites of the Inferior Oolite Series' Monogr. Palæont. Soc. Suppl. (1905) pp. lxvii, lxix, lxx.

[6] 'The Inferior Oolite Gasteropoda' Monogr. Palæont. Soc. pt. i (1887) pp. 39–41.

[7] Proc. Somerset Arch. & Nat. Hist. Soc. vol. xxxvii (1892) pp. 60–69.

[8] 'The Jurassic Rocks of Britain, vol. iv—The Lower Oolitic Rocks of England (Yorkshire excepted)' Mem. Geol. Surv. 1894, pp. 69–71.

[9] Proc. Geol. Assoc. vol. xxvi (1915) pp. 74–76.

[10] Q. J. G. S. vol. xlv (1889) p. 450.

to Broadwindsor, the highest limestone of the Inferior Oolite is a thin bed with a bluish centre, often rubbly, and readily recognized. It is the '*Zigzag* Bed,' and—as its name implies—is of *zigzag* hemera. The bed extends into the Crewkerne district, and has been observed in its typical condition as far north as Haselbury-Mill Quarry (30),[1] Haselbury Plucknett.[2]

The *Zigzag* Bed is succeeded by 'The Scroff,' which has been dated as *fuscæ* hemera. The Scroff contains the little brachiopod *Aulacothyris cucullata* S. Buckman,[3] and—like the *Zigzag* Bed—extends into the Crewkerne district. J. F. Walker appears to have discovered the characteristic little brachiopod (*Aulacothyris cucullata*) in the quarry (9), near Misterton Church, for he has written—

'in a quarry near the Church at Misterton, near Crewkerne, I found a band of clay [The Scroff] lying on the top of the Inferior Oolite stone, containing numerous specimens of a variety of *Waldheimia meriana* associated with *T. decipiens*.' (Proc. Dorset Nat. Hist. & Ant. F. C. vol. iii, 1879, p. 46.)

Fuller's Earth is to be observed in an opening near Slade's Quarry at North Perrott (28), and at the Haselbury-Mill Quarry (30). Higher deposits have been dug for brick-making near the tunnel about a mile west of Crewkerne Station; at Lye's brickyard south-east of the brewery at Crewkerne (19)[4]; and at East-Cross Hill (32)[5] between Haselbury and East Chinnock.

II. Subdivisions recognizable in the Inferior Oolite of the Crewkerne District.

The subdivisions recognizable in the Inferior Oolite of this district will be seen on reference to the folding table (facing p. 170), from which also an idea will be obtained of their geographical distribution and thicknesses.

(xxvii) *Aalensis* Beds.—The *Aalensis* Beds are well developed (29 feet 8 inches) and very satisfactorily exposed at Chideock-Quarry Hill, near Bridport (Dorset).[6]

In the Crewkerne district there is an exposure of a portion of the *Aalensis* Beds in the bank by the roadside (23) at Furzy Knaps, near Seavington St. Mary—a village 4 miles north-west of Crewkerne. The deposits here are very fossiliferous, and have yielded to me ?[7] *Canavarina venustula* S. Buckman, *Pleydellia*

[1] The numbers in parentheses refer to the corresponding numbers on the map (fig. 1, p. 146).

[2] On the old Ordnance Survey map the name is given as 'Haselbury' only

[3] Q. J. G. S. vol. lxvi (1910) p. 102 & pl. xii, figs. 1–2.

[4] H. B. Woodward, 'The Jurassic Rocks of Britain, vol. iv—The Lower Oolitic Rocks of England (Yorkshire excepted)' Mem. Geol. Surv. 1894, p. 67.

[5] *Ibid.* p. 235. Woodward gives the name of the hill as High Cross Hill, but it is called East Cross Hill on the current 6-inch map.

[6] S. S. Buckman, Q. J. G. S. vol. lxvi (1910) p. 64.

[7] In this paper the note of interrogation is placed before the name of the genus, species, subdivision, or hemera that it queries.

leura (S. Buckman), and *Cotteswoldia subcandida* S. Buckman; while Mr. Charles Upton has obtained a specimen of *? Terebratulina deslongchampsi* Davidson.[1]

East of Crewkerne the *Aalensis* Beds 'attenuate,' and fail somewhere between North Perrott and Yeovil Junction, for they have not been detected in the Sherborne district.[2] A mile-and-a-half east of Crewkerne, at the Manor-House Quarry, North Perrott, the evidence for *Aalensis* Beds consists in the occurrence of the zonal ammonite in a deposit having a decidedly remanié aspect, which rests on the Perrott Stone.

(xxvi) *Opaliniforme* Beds.—At Chideock-Quarry Hill the *Opaliniforme* Beds consist of [3]—

	Thickness in feet	inches.
'(6 *a*) Brown ironshot marly stone with Opalinoid Ammonites, cf. *Canavarella*	1	0
(*b*) Sandstone with Opalinoid Ammonites, cf. *Walkeria* [*Walkericeras* [4]] *subglabra*, *Rhynchonella stephensi* (*cynocephala*)	1	8
(*c*) Sands and sandburrs. *Rhynchonella* of *cynocephala*-pattern; Opalinoid Ammonites	3	8'

and the equivalents of these, together with the bottom stratum (1 foot thick) of the *Scissum* Beds, constitute the Brachiopod Beds at Whaddon Hill.

These *Opaliniforme* Beds extend into the Crewkerne district, and are well exposed in a roadside section in Cat-Hole Lane south of Crewkerne (p. 160), where the deposits (a^1) and (a^2) represent bed (6 *a*) of Chideock-Quarry Hill. Deposits (a^1) and (a^2) of Cat-Hole Lane are represented at the Manor-House Quarry, North Perrott, by the greater portion of the sandy clay (Bed 3) above the Perrott Stone (p. 163), and at Barrows'-Hill Quarry (32) by a very similar deposit (p. 169).

(xxv) *Scissum* Beds.—These are well exposed at the Conegar-Hill Section, Broadwindsor, where they consist of irregular sandstone and sand-rock with intervening deposits of sand. The harder portions are replete with fossils, among which the most noticeable are—*Gryphæa cygnoides* Whidborne, *Pholadomya fidicula* J. de C. Sowerby, *Lima inoceramoides* Whidborne, and *Volsella sowerbyana* (A. d'Orbigny).

Similar beds extend into the Crewkerne district, and are to be seen in the sections—opposite Hill Farm, South Perrott (5); near Lecker Bridge (4); and near Well-Spring Farm, near Misterton (7).

Farther north, however, at the Manor-House Quarry, North Perrott (27), and Barrows'-Hill Quarry (32), softer beds, consisting mainly of sand, are seen. They are rich in specimens of *Aulacothyris blakei* (Walker), *Rhynchonella cynocephala* auctt., and

[1] See p. 162.
[2] S. S. Buckman, Q. J. G. S. vol. lxvi (1910) table iii, facing p. 78.
[3] *Ibid.* p. 63.
[4] S. S. Buckman, 'Yorkshire Type Ammonites' vol. ii, pt. ix (1913) p. iii.

Terebratulæ, and I am inclined to regard them as a thicker and softer development of the bottom-stratum of the *Scissum* Beds as developed at Whaddon Hill,[1] or—expressed in another way—as on the horizon of the top-stratum (early *scissi*) of the Brachiopod Beds of that locality and of the Conegar-Hill Section, Broadwindsor.

The *Scissum* Beds are absent from the neighbourhood of Bradford Abbas in the Sherborne district, and therefore—like the *Aalensis*- and *Opaliniforme*-Beds—fail somewhere between Haselbury and Yeovil Junction.

(xxiv) *Ancolioceras* Beds.—These beds[2] are not always easy to separate, on the one hand from the *Scissum* Beds below, and on the other hand from the *Murchisonæ* Beds above. They are very fossiliferous, containing many species common to the *Scissum*-Beds, and are characterized by ammonites of the genus *Geyerina*[3] and Lytoceratids of the style of *Pachylytoceras aalenianum* S. Buckman.

At the Conegar-Hill Section, Broadwindsor, the *Ancolioceras*-Beds comprise two strata, each 1 foot thick. Similar strata extend into the Crewkerne district, and are to be seen at the Misterton Limeworks (3) and Slade's Quarry, North Perrott (28). It may be that the upper portion of the lowest rock-mass visible (in 1916) at Haselbury-Mill Quarry (30) is of this date, but I have not obtained any evidence from ammonites here.

(xxiii–xxii) *Murchisonæ* Beds.—The true *Murchisonæ* Beds in the neighbourhood of Beaminster are very rich in specimens of *Zeilleria anglica* (Oppel). Beds replete with specimens of the same species have been observed by Hudleston at Drimpton (1)—a village 3 miles south-south-west of Crewkerne, and at Haselbury Plucknett (29)—2 miles east-north-east of Crewkerne. In the intervening tract—in which are situated Misterton and North and South Perrott—specimens of *Zeilleria anglica* (Oppel) are rarely met with, and the beds are not always easy to separate from the *Ancolioceras* Beds below.

(xxi–vii) *Bradfordensis–Niortense* Beds.—The only rock that I have seen *in situ* in the Crewkerne district that is referable to some hemera between *murchisonæ* and *garantianæ* hemeræ is ironshot rock (0 to 4 inches thick) in places attached to, or filling fissures in, that of *murchisonæ* hemera.

Such rock is seen at the Misterton Limeworks (3), the quarry near Misterton Church (9), and at the Ten-Acres-Field Quarry (6). Where the surface of the underlying *Murchisonæ* Beds could be examined it was found to be waterworn and iron-stained. In 1914 I remarked that this ironshot rock was either of *bradfordensis* or of

[1] L. Richardson, Proc. Geol. Assoc. vol. xxvi (1915) p. 73.

[2] S. S. Buckman, Q. J. G. S. vol. lxvi (1910) p. 79. See also L. Richardson, *ibid.* vol. lxxi (1915–16) pp. 479–80.

[3] Emended from *Geyeria*—S. S. Buckman, 'Yorkshire Type Ammonites' vol. ii, pt. ix (1913) p. iv.

discitæ hemera.[1] Since 1914 I have collected two Rhynchonellids, probably of unnamed species, which render it fairly evident that it is of *bradfordensis* hemera.[2]

Evidence of the occurrence in this district of rock belonging to one or more hemeræ between *murchisonæ* and *garantianæ* is to be had from two sources. Hudleston makes mention of a massive shell-bed with large conchifera and keeled ammonites, 2 feet 4 inches thick, at Haselbury (29) above the *Zeilleria-anglica* Horizon (*murchisonæ*).[3] Mr. S. S. Buckman informs me (*in litt.*) that 'one would expect *bradfordensis*, but I cannot confirm this.'

In the Moore Collection at Bath are a number of ammonites and other fossils, attached to tablets labelled by Moore, recorded as having come from Dinnington, a village 3 miles from Crewkerne in a north-westerly direction. Through the kindness of the Rev. H. H. Winwood, F.G.S., I was enabled to send a selection of the ammonites to Mr. Buckman. When returning the specimens he wrote:

'Two of them are obviously from Dundry [Hill, near Bristol] and invalidate Moore's evidence. The others

[*Brasilina crinalis* S. Buckman, *bradfordensis* hemera; *Brausina* cf. *contorta* (S. Buckman), *discitæ* hemera; *Erycites* aff. *tulcus* (Gregorio), *bradfordensis* hemera; *Graphoceras decorum* S. Buckman, *discitæ* hemera; *Hammatoceras* cf. *lorteti* Vacek (*non* Dumortier sp.), *murchisonæ* or *bradfordensis* hemera; *H.* cf. *sieboldi* Vacek (*non* Oppel sp.), about *bradfordensis-concavi* hemera]

are from a matrix unfamiliar to me, but the matrix—and, in some cases, the test—shows much likeness to the Stoke-Knap conditions: by this I mean that they indicate an area more linked up with Stoke Knap than with Bradford Abbas.

'Dinnington may be the locality for J. Sowerby's type of *Ammonites concavus* [which Sowerby states came from] "the neighbourhood of Ilminster,"[4] and Davidson figures "*Terebratula perovalis*"—a *Concava*-Bed fossil from "Dunnington"[5] (Dinnington).'

I have not discovered any section in the neighbourhood of Dinnington that displays the sequence from the *Murchisonæ* to the Top Beds.[6] There is no reason, however, why *Bradfordensis*-, *Concava*-, and *Discites*-Beds should not occur in the district: indeed the matrix of the specimens of *Brasilina crinalis* and *Graphoceras decorum* mentioned above reminds one of the ironshot rock attached to the top of the *Murchisonæ* Beds at the Misterton Limeworks and neighbouring sections.

The surface of the ironshot rock seen at the Misterton Lime-

[1] Proc. Geol. Assoc. vol. xxvi (1915) p. 75.

[2] See records of sections at Ten-Acres Field Quarry (p. 158) and the Limeworks, Misterton (p. 154).

[3] 'The Inferior Oolite Gasteropoda' Monogr. Palæont. Soc. pt. i (1887) p. 41.

[4] 'Mineral Conchology' vol. i (1815) p. 214 & pl. xciv.

[5] 'British Fossil Brachiopoda' Monogr. Palæont. Soc. vol. i, pt. iii (1852) p. 51 & pl. x, fig. 4.

[6] By the term 'Top Beds' is meant the rock of *garantianæ–zigzag* hemeræ (inclusive).

works, the quarry near the Church (9), and Ten-Acres-Field Quarry is waterworn and ferruginous.[1]

(vi, v) *Garantiana* Beds.—No rock of *garantianæ* hemera occurs in the neighbourhood of Broadwindsor, as is shown by the section at Conegar Hill (p. 153), where limestone of probably *schlœnbachi* date rests directly on the *Murchisonæ* Beds. At Misterton Limeworks, the Lecker-Bridge section (South Perrott), and Ten-Acres-Field Quarry, however, occurs rock very barren of fossils, but similar to that of *garantianæ* hemera at Green-Hill Quarry, near Innsacre Farm, Shipton Gorge (Dorset)—that is, somewhat soft limestone with numerous brownish oolite-granules. At the Lecker-Bridge section there is below the main layer rubbly limestone (0 to 4 inches thick); but at the Hill-Farm section, South Perrott (5) there is no rock at all of *garantianæ* hemera.

At Slade's Quarry, North Perrott, the *Garantiana* Beds have 'expanded,' are very fossiliferous, and in addition to the quantity of rich yellowish-brown ochreous matter associated with the lowest layer (*c*) (see p. 164), their top marly layer is rich reddish-brown, owing to the presence of oxidized iron-pyrites such as one is accustomed to meet with at this horizon in the Burton-Bradstock–Beaminster district. At the Haselbury-Mill Quarry a similar ferruginous marly layer overlies a 6-inch bed of limestone, the lithic structure of which calls to mind the Marl-Bed and subjacent limestone of the neighbourhood of Bradford Abbas.

North-west of Crewkerne, at the quarry in Hinton Park (20) the rock of *garantianæ* hemera consists of some ? 4 feet 6 inches of massive rich brown, ferruginous limestone, overlying a hard somewhat conglomeratic limestone (? 18 inches thick) full of fossils, including *Patoceras annulatum* (A. d'Orbigny)—the whole recalling the Hadspen Stone of the Castle-Cary district.[2]

Top Limestones.[3]—Top Limestones, similar to those of the neighbourhood of Beaminster and Broadwindsor, extend into the Crewkerne district, and maintain their similarity throughout it with the exception of the neighbourhood of Haselbury Mill. In this direction the Top Limestones have 'attenuated,' their constituent beds are better separated one from the other, and, at the Haselbury-Mill Quarry, include a very interesting Sponge-Bed, very similar in appearance to the well-known one at Shipton Gorge (Dorset).[4]

Indications of the *Zigzag* Bed, similar to its equivalent at Broadwindsor and elsewhere in the Burton-Bradstock–Broadwindsor district, have been found in an opening near Slade's Quarry,

[1] I have seen a specimen of *Pleurotomaria*, stated to have come from Dinnington, in a matrix which at once called to mind that of the Irony Bed of Louse Hill, near Sherborne (Dorset). It may be that rock of *blagdeni* date occurs sporadically in 'pockets' in this neighbourhood, as is also probably the case at Dundry Hill, near Bristol.

[2] L. Richardson, Q. J. G. S. vol. lxxi (1915–16) pp. 486, 504, 505.

[3] This term embraces the beds dating from *truellei* to *zigzag* inclusive.

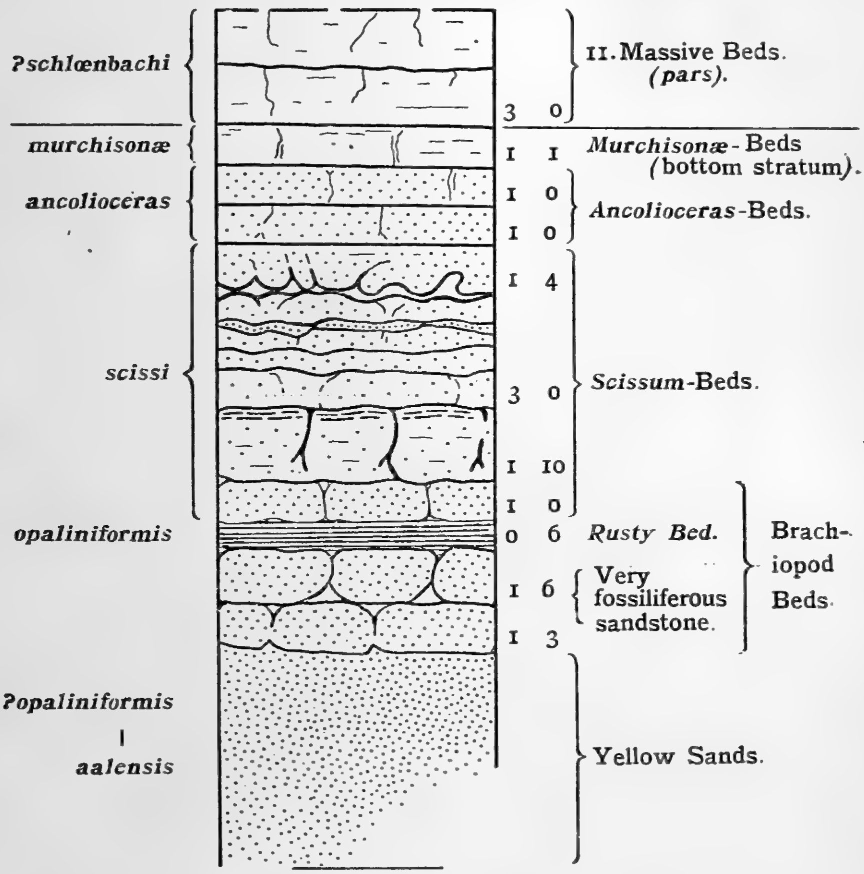
[4] Proc. Geol. Assoc. vol. xxvi (1915) pp. 60–61.

North Perrott, and a more fossiliferous development of it—rich in specimens of species of *Parkinsonia* and *Morphoceras*—at Haselbury-Mill Quarry.

III. Local Details.

Conegar-Hill section, Broadwindsor (Dorset).—The last and northernmost section in the Burton-Bradstock–Broadwindsor district is that in the road-cutting at Conegar Hill. Here the sequence is as follows:

Fig. 2.—*Sequence of Inferior-Oolite deposits at Conegar Hill, Broadwindsor (Dorset).*[1]



Drimpton (Dorset).—Some 2 miles north-west of the above section, at Drimpton, is a small but now disused quarry (1) in which—as Hudleston has remarked[2]—*Murchisonæ* Beds, rich in specimens of *Zeilleria anglica* (Oppel), are exposed.

Hudleston has also remarked that the place is noteworthy for 'very pretty species of *Trochus* or *Delphinula*.'[3] I have

[1] The upper 3 or 4 feet of the Yellow Sands may be of *opaliniformis* hemera.
[2] 'The Inferior Oolite Gasteropoda' Monogr. Palæont. Soc. pt. i (1887) pp. 39–40.
[3] *Ibid.* p. 40.

collected here[1] *Trochus sybilla* Hudleston, *Cucullæa oblonga* J. Sowerby,[2] *Terebratula etheridgei* Davidson (rare), and *Montlivaltia lens* Edwards & Haime. R. F. Tomes has recorded from here *Montlivaltia delabechei* Edwards & Haime,[3] and Mr. S. S. Buckman *Rhynchonella* aff. *weigandi* Haas & Petri—also

'from Netherton [near Beaminster] in Dorset, from the base of what is known as "Inferior Oolite limestone," that is, beds deposited before the *Murchisonæ* hemera strictly so-called.'[4]

Little Windsor.—The quarry here is now (1916) overgrown.

Seaborough.—Portions of the Top Limestones—from which I obtained *Rhynchonella* cf. *parvula* Deslongchamps and *Holectypus hemisphæricus* (Agassiz)—are to be seen in an old quarry (2) near this village.

Limeworks, Misterton (Somerset).—In the quarry at this locality, the following beds are exposed:

3. LIMEWORKS, MISTERTON.

		Thickness in feet	inches.
Schlœnbachi ..	Microzoa-Beds. 4. Limestones and some marl; *Terebratula sphæroidalis* auctt.: seen..	2	0
	5. Marl with yellow 'ochreous bodies'[5]	0	2
	Massive Beds. 6. Limestone: *Belemnopsis bessina* (A. d'Orbigny), *Ostrea* sp., *Acanthothyris panacanthina* Buckman & Walker, *Rhynchonella subtetrahedra* auctt.,[6] etc.	1	6
	7. Marl: 0 to 1 inch	0	1
	8. Limestone, similar to 6	2	0
?truellei	?9. *?Truellei* Bed. Limestone: *Rhynchonella subtetrahedra* auctt., isocrinoid-ossicles, echinoid-radioles, etc.	1	4
	to the base of which is attached		
Garantianæ ...	Equivalent of the *Astarte-obliqua* Bed. Limestone, 2 to 4 inches: usually.........	0	4
∿∿∿∿∿∿∿∿	Non-sequence. Deposits of *niortensis-concavi* hemeræ (inclusive) wanting.		
Bradfordensis.	Limestone, hard, bluish-grey, ironshot; belemnites, *Rhynchonella* of the *Rh.-ringens* series: 0 to 4 inches: average	0	2
	attached to the		
Murchisonæ ...	Blue Bed. (*a*) Limestone, hard, bluish-grey; bone (piece of), *Variamussium pumilum*		

[1] Mr. Charles Upton informs me that a schoolmaster at Drimpton collected and distributed many fossils from this quarry.

[2] The type-specimen of *Cucullæa oblonga* J. Sowerby was found 'at Dundry in the Inferior Oolite, holding grains of iron-ore' (Min. Conch. vol. iii, pl. ccvi, fig. 1, 1818, p. 7)—that is, it came from the *Sauzei* Bed of that locality. The specimens recorded as '*Cucullæa oblonga* J. Sowerby' in the present paper are similar to those from the *Sauzei* Bed of Dundry Hill, although they come from much lower down.

[3] Geol. Mag. dec. 3, vol. iii (1886) p. 388.

[4] Q. J. G. S. vol. li (1895) pp. 453, 462.

[5] Throughout this paper the 'ochreous' matter referred to is due to the oxidization and hydration of iron-pyrites.

[6] Mr. Buckman informs me that it is very doubtful whether this is the true Dundry-Hill form.

		Thickness in feet	inches.
	(Lamarck),[1] *Pseudoglossothyris simplex* (J. Buckman): 3 to 7 inches	0	5
	(*b*) Limestone, similar to (*a*); *Variamussium pumilum* (Lamarck), and *Lima inoceramoides* Whidborne	0	7
Ancolioceras...	Red Bed. Limestone, hard, grey, with a pinkish tinge; *Geyerina* cf. *evertens* S. Buckman, *Eopecten velatus* (Goldfuss), *Terebratula conglobata* Deslongchamps, *Galeropygus agariciformis* (Wright): 6 to 8 inches	0	8
	Grey or Cockle Bed. Limestone, hard, grey, sandy to the touch; ammonite of the *Hyattina-brasili* S. Buckman aspect, *Cœlastarte* spp., *Camptonectes* sp., *Ctenostreon* sp., *Ceromya concentrica* (J. de C. Sowerby), *Cucullæa oblonga* J. Sowerby, *Gresslya abducta* (Phillips), *Gryphæa cygnoides* Whidborne, *Lima inoceramoides* Whidborne, *Pholadomya oblita* Lycett, *Protocardia* sp., *Trigonia ? sculpta* Lycett, *Eopecten velatus* (Goldfuss), *Pseudoglossothyris leesi* S. Buckman, *Terebratula* spp., *Berenicea* sp. (usually on the specimens of *Lima*), etc.	1	1
Scissi	Sand-rock. Surface exposed.		

Mr. Charles Upton has examined for me a sample of the marl from Bed 5, and reports having found the following fossils:

Two small fish-teeth—one smooth, the other fluted.

OSTRACODA.
Bairdia hilda Jones.
Cytheropteron sp.
Polycope sp.

FORAMINIFERA.
Cristellaria acutauricularis Fichtel & Moll.
—— *rotulata* (Lamarck).
—— *tricarinata* Reuss.
Cornuspira cretacea Reuss.
Flabellina pulchra A. d'Orbigny.
Nodosaria affinis Terquem.
—— *communis* (A. d'Orbigny). One specimen.
—— *raphanus* (Linné).
Planularia crepidula Fichtel & Moll.
—— *harpula* (A. d'Orbigny).
—— *pauperata* Jones & Walker.
Polymorphina lactea Walker & Jacob.
Textularia trochus A. d'Orbigny.
Vaginulina sp.

The representative of the *Astarte-obliqua* Bed rests on a level, waterworn, and iron-stained surface of the underlying bed. This bed is of *murchisonæ-Ancolioceras* hemeræ—the greater portion of the bed being of the earlier date. Writing of the *Ancolioceras* Beds here Mr. Buckman observes:

'At Misterton, which is near Crewkerne, the strata hitherto regarded as early *murchisonæ* yield Lytoceratoids of the style of *Pachylytoceras aalenianum*.'[2]

The Blue Bed is probably of early *murchisonæ* hemera and correlative with what remains of the *Murchisonæ* Beds at the Conegar-Hill Section, Broadwindsor. The upper portion—that

[1] E. T. Paris & L. Richardson, Q. J. G. S. vol. lxxi (1915–16) p. 529.
[2] Q. J. G. S. vol. lxvi (1910) p. 79.

characterized by an abundance of specimens of *Zeilleria anglica* (Oppel), as seen at Drimpton—is not represented.

Prof. S. H. Reynolds has very kindly examined microscopically for me pieces of the Blue, Red, and Grey Beds. Concerning the Blue Bed he states—

'It is composed of a mass of finely-divided calcareous organisms with frequent subangular quartz-grains. Crinoid ossicles are by far the most plentiful; but foraminifera are not infrequent. A good deal of the staining is due to ferric oxide.'

The Red and Grey Beds are dated as *Ancolioceras* on the evidence of the ammonites.

'The Red Bed is a non-oolitic rock of fine and uniform grain. It is composed of crinoidal fragments, foraminifera, and many pieces of small molluscs—gastropods and lamellibranchs—embedded in a calcite matrix, which is sometimes structureless and sometimes finely crystalline. Some of the fragments, particularly of crinoids, are partly replaced or stained with ferric oxide. Many small quartz-grains occur.' [S. H. R.]

The Grey Bed is also known to the quarrymen as the 'Cockle Bed,' on account of the large number of fossils that it contains. It is

'a fine-grained gritty limestone. Crinoidal fragments form the bulk of the rock. Small angular quartz-grains are very plentiful, but are irregularly distributed.' [S. H. R.]

As in the case of the equivalent bed in the Conegar-Hill section, the nether surface of the Grey Bed here is very irregular, and fits into an equally irregular surface of the immediately subjacent sand-rock of the *Scissum* Beds.

Concerning this section H. B. Woodward wrote [1] that it shows

'a few beds of the pale [Top] limestones belonging to the zone of *A. Parkinsoni*; lower down there were brown oolitic and ironshot limestones (2 ft. 2 in.); and, at the base, hard, grey, shelly and oolitic limestones, yielding fine specimens of *Ceromya concentrica* and also *Gryphæa sublobata*—the latter recalling the Gryphite Grit of the Cotteswold Hills.

'The same *Gryphæa* occurs also abundantly at Haselbury: and in both of these Dorset* localities it is associated with *Ammonites Murchisonæ*. It occurs in higher beds near Bruton.' †

* The Misterton Limeworks and Haselbury are in Somerset.

† I have recorded *Gryphæa sublobata* (Deslongchamps) from the rock of *shirbuirniæ* hemera at Sunny Hill, Cole, near Bruton. See Q. J. G. S. vol. lxxi (1915–16) p. 498.

The *Gryphæa* mentioned by H. B. Woodward as occurring at Misterton and Haselbury is doubtless the form called '*Gryphæa cygnoides*' by Whidborne.[2]

Lecker-Bridge section.—Near Lecker Bridge (4), South Perrott (Dorset), rock of *garantianæ* hemera—similar to its equivalent at the Misterton Limeworks—is seen resting on sandstones, the date of the highest portion of which I have been unable to ascertain; but it is either *Ancolioceras* or *scissi*.

[1] 'The Jurassic Rocks of Britain, vol. iv—The Lower Oolitic Rocks of England (Yorkshire excepted)' Mem. Geol. Surv. 1894, pp. 68–69.

[2] Q. J. G. S. vol. xxxix (1883) p. 494 & pl. xv, figs. 8–8 *a*.

4. LECKER-BRIDGE SECTION.

		Thickness in feet	inches.
? Schlœnbachi.	Massive Beds. Limestone, greyish-white and sparry: seen	2	0
Garantianæ...	(*a*) Limestone similar to its equivalent at the Misterton Limeworks	0	3
	(*b*) Limestone, similar to (*a*) but more rubbly; 0 to 4 inches	0	2
~~	Non-sequence. Deposits of *niortensis–Murchisonæ* and *? Ancolioceras* hemeræ wanting.		
Ancolioceras	Sandstone, grey, fine-grained	0	10
or	Sandstone, in irregular layers, with which is		
Scissi.	associated sandy marl	0	10
Scissi	Sandstone	0	10
	Sandburrs and sand; *Ceromya concentrica* (J. de C. Sowerby), *Gervillia whidbornei* Paris, *Gryphæa cygnoides* Whidborne, *Goniomya* sp., *Pholadomya fidicula* J. de C. Sowerby, *Volsella sowerbyana* (A. d'Orbigny): seen	3	0

At a slightly-lower level in the bank north of the preceding section are seen

irregular layers of sandy rock with partings of a noticeable pale-yellow sandy 'marl' containing *Variamussium læviradiatum* (Waagen), *Terebratula whaddonensis* S. Buckman, and *Serpula tricarinata* auctt.—beds calling to mind the Brachiopod Beds (*scissi-opaliniformis*) of Whaddon Hill.

Hill-Farm section, South Perrott (Dorset).—By the roadside opposite this farm (5) is a face of rock.

5. HILL-FARM SECTION, SOUTH PERROTT.[1]

		Thickness in feet	inches.
? Schlœnbachi.	Massive Beds. Limestones: seen	4	0
~~	Non-sequence. Deposits of *? truellei–Murchisonæ* and *? Ancolioceras* hemeræ wanting.		
Ancolioceras or *Scissi.*	Sandstones, grey, calcareous, fairly massive; *Nautilus* sp., *Gervillia whidbornei* Paris, *Trigonia ? sculpta* Lycett, *Pholadomya fidicula* J. de C. Sowerby: about	1	8
Scissi	Sandstones, in thinner layers with sandy partings; *Cucullæa oblonga* J. Sowerby, *Entolium demissum* (Phillips), *Volsella sowerbyana* (A. d'Orbigny)	4	0
	Sandstone, softer: seen	2	0

The upper portion of this section is difficult to reach, but no rock of *garantianæ* hemera was detected.

Ten-Acres-Field Quarry, near South Perrott.—At (6) is a quarry 'in work,' in which the sequence of beds is similar to that at the Misterton Limeworks.

[1] The holotype of *Lima inoceramoides* Whidborne (Q. J. G. S. vol. xxxix, 1883, p. 507 & pl. xvii, fig. 5) came from the Inferior Oolite 'south of Perrott.' This species is very characteristic of the *Ancolioceras*- and *Scissum*-Beds of this neighbourhood, and possibly by 'south of Perrott' South Perrott is meant.

6. Ten-Acres-Field Quarry, near South Perrott.

		Thickness in feet	inches.
Schlœnbachi...	Microzoa-Beds. 6. Limestone: seen	2	0
	7. Marl and rubble	0	2
	Massive Beds. 8. Limestone, rather sparry; *Ctenostreon* sp.	2	0
? *Truellei*	? *Truellei* Bed. 9. Limestone; *Belemnopsis bessina* (A. d'Orbigny), *Rhynchonella* aff. *parvula* Deslongchamps, *Rh. subtetrahedra* auctt., isocrinoid-ossicles, etc.	1	2
	to the base of which is attached		
Garantianæ...	Limestone, similar to its equivalent—(*a*) at the Misterton Lime-Works	0	4
~~	Non-sequence. Deposits of *niortensis–concavi* hemeræ (inclusive) wanting.		
Bradfordensis.	Limestone, hard, bluish-grey and yellowish-brown, well ironshot, with an ironstained surface (to which oysters are attached); *Rhynchonella* sp.[1]; usually............................	0	4
	joined on to the surface of the bed below		
Murchisonæ — *Ancolioceras*.	Limestone; *Nautilus* sp., *Pseudomelania heterocycla* (Deslongchamps), *Cœlastarte* sp., *Entolium demissum* (Phillips), *Gryphæa cygnoides* Whidborne, *Lima inoceramoides* Whidborne, *Pholadomya fidicula* J. de C. Sowerby, *Variamussium pumilum* (Lamarck), *Rhynchonella* aff. *weigandi* Haas & Petri, *Pseudoglossothyris simplex* (J. Buckman), *Terebratula* sp., *Zeilleria anglica* (Oppel) (rare near the top), *Galeropygus agariciformis* (Wright), *Berenicea* sp. (usually on the *Limæ*) etc.	2	8
Scissi	Sand-rock, with a very irregular surface.		

Well-Spring-Farm Quarry, Misterton (Somerset).—In the field at (7) is an old quarry on the line of fault shown on the Geological Survey map (Old Series, Sheet XVIII). In the quarry are seen Top Limestones of the usual type, let down against grey sandy *Scissum* Beds on the south side of the fault.

The Top Limestones are seen in an old quarry at (8).

Quarry near Misterton Church.—In the old quarry (9) south of Misterton Church the Top Limestones are seen resting on rock of *garantianæ* hemera (similar to its equivalent at the Misterton Limeworks), and this in turn on the ironstained surface of the *Murchisonæ–Ancolioceras* Beds, to which is attached, here and there, ironshot rock also similar to the corresponding deposit at the Limeworks. No doubt this is the quarry where J. F. Walker found evidence in the form of 'a variety of *Waldheimia meriana* [probably *Aulacothyris cucullata* S. Buckman], associated with *T. decipiens*,'[2] of the Scroff (*fuscæ* hemera).

[1] Mr. S. S. Buckman, to whom I submitted this specimen for examination, informs me that he has 'this peculiar broad triangular form, but larger and with one plait, from the [*Rhynchonella*-] *ringens* Beds of Sherborne [Dorset].'

[2] Proc. Dorset Nat. Hist. & Ant. F. C. vol. iii (1879) p. 46.

The Top Limestones are at present (1916) being worked in a quarry near Henley Farm (10).

Crewkerne Station.—This is the locality [1] from which the numerous specimens labelled 'Crewkerne Station' were collected in the past—especially by Mr. Darell. As the quarrying operations proceeded the sidings were extended, but now such operations have ceased. The beds exposed were 'the upper limestones' of Mr. S. S. Buckman [2]—a portion of the Top Limestones. In 1891 he referred them to the *Zigzag* Zone,[3] for he informs me that his 'Broad Windsor district' [4] included Crewkerne Station. Before the more detailed separation of the Top Limestones was effected the term '*Zigzag* Zone,' he also informs me, sometimes included deposits of *schlœnbachi* date, and at other places they would be reckoned *truellei*. Thus the holotype of *Terebratula stibara* S. Buckman is stated to have come from the '"Top Beds" of Crewkerne Station (Somerset) . . . circa *schlœnbachi* zone.'[5] *Zeilleria bicornis* S. Buckman is recorded from the same beds and locality.[6]

Railway-cutting, Crewkerne.—I have not had the opportunity of examining what remains unobscured of this section (12). According to H. B. Woodward [7] the beds exposed here were:

		Thickness in feet	inches.
'[*Schlœnbachi*–*? truellei.*]	7. Pale rubbly oolitic limestones (zone of *Ammonites Parkinsoni*)	6	0
[*Bradfordensis*	6. Brown shelly and ironshot oolite	2	0
| *Ancolioceras.*]	5. Hard brown limestone passing into compact grey oolitic limestone	1	5
[*Scissi*]	4. Pale sandy and shelly limestones	3	0
[*Opaliniformis.*]	3. Brown sandy marl with *Terebratula infra-oolitica*	1	0
[*Opaliniformis*].	2. Indurated marl and sandy limestone with *Ammonites*, *Belemnites*, *Pecten læviradiatus*, and *Rhynchonella*	1	3
	1. Sands with irregular bands and nodules of calcareous sandstone: *Pecten*, *Rhynchonella cynocephala*, *Serpula*	6	0'

Before justifying the dates here suggested for the beds noted by Woodward, it will be best to describe a section in Cat-Hole Lane.

[1] Proc. Somerset Arch. & Nat. Hist. Soc. vol. xxxvii (1892) p. 65.

[2] Proc. Cotteswold Nat. F. C. vol. xiii, pt. 4 (1901) p. 268; and 'Ammonites of the Inferior Oolite Series' Monogr. Palæont. Soc. Suppl. (1905) p. ccvi.

[3] Rep. Brit. Assoc. (Cardiff) 1891, p. 656; and Geol. Mag. dec. 3, vol. viii (1891) pp. 502–503.

[4] *Ibid.*

[5] Q. J. G. S. vol. lxvi (1910) pp. 100 & 108, pl. xii, figs. 5–6.

[6] Proc. Cotteswold Nat. F. C. vol. xiii, pt. 4 (1901) p. 253.

[7] 'The Jurassic Rocks of Britain, vol. iv—The Lower Oolitic Rocks of England (Yorkshire excepted)' Mem. Geol. Surv. 1894, p. 68.

13. Cat-Hole-Lane Section, Crewkerne.

		Thickness in feet	inches.
Scissi	Sandstone in loose pieces.		
Opaliniformis.	(a^1) Brown and purplish-grey-streaked sandy marl; belemnites, *Gryphæa* sp. (some of the less gryphoid form of an *Ostræa-knorri* Voltz aspect), *Variamussium læviradiatum* (Waagen), *Aulacothyris blakei* (Walker), *Rhynchonella cynocephala* auctt., *Terebratula* of the *T.-haresfieldensis*-Group, *T. whaddonensis* S. Buckman: seen	1	0
	(a^2) Brown marly sandstone with an occasional ill-preserved opalinoid ammonite; belemnites, *Pleuromya* sp., *Rhynchonella cynocephala* auctt.—all rare	0	8
Opaliniformis.	(b) Ammonite Bed. Sandstone, very fossiliferous; cf. *Canavarella toma* S. Buckman (periphery not acute enough and radial line hardly sufficiently curved), *Cypholioceras* sp. nov. (a morphic equivalent to species prior to *Lioceras uncinatum* S. Buckman), *Walkericeras subglabrum* S. Buckman (Monogr. Amm. Inf. Ool. Series, pt. ii, 1888, pl. xiii, fig. 9), belemnites, *Pleuromya* sp., *Variamussium læviradiatum* (Waagen) (common)	1	0
	(c) Sands and sandburrs; *Goniomya* sp., *Pleuromya* sp., *Pteria (Oxytoma)* sp., *Variamussium læviradiatum* (Waagen), *Serpula tricarinata* auctt. (common): seen	1	6

Beds (a^1) and (a^2) would seem to be the equivalent of the Rusty Bed of the Conegar-Hill Section, Broadwindsor, and of Whaddon Hill, near Beaminster;[1] while the Ammonite Bed is comparable with the very fossiliferous sandstone bed, bed 6 *b*, at Chideock-Quarry Hill,[2] and the similar bed immediately below the Rusty Bed at Whaddon Hill.[3]

Referring now to Woodward's section in the railway-cutting, one can have little doubt that bed (c) at Cat-Hole Lane is equivalent to the top portion of his Bed 1: the Ammonite Bed to his Bed 2: and beds (a^2) and (a^1) probably to his Bed 3. His Bed 4 is probably of *scissi* date: Beds 5 and 6 probably of *murchisonæ-Ancolioceras* hemeræ, with ironshot rock (as at the Misterton Limeworks) attached to the top: while his Bed 7 embraces the Top Limestones.

Upon-Lang Quarry, Crewkerne.—The best section of the Top Limestones in the neighbourhood of Crewkerne is at this quarry.

[1] Proc. Geol. Assoc. vol. xxvi (1915) p. 73.
[2] S. S. Buckman, Q. J. G. S. vol. lxvi (1910) p. 63.
[3] L. Richardson, Proc. Geol. Assoc. vol. xxvi (1915) p. 73.

14. Upon-Lang Quarry, Crewkerne.

		Thickness in feet	inches.
	Soil, purplish in places.		
Schlœnbachi...	Microzoa-Beds. Limestone, rubbly in places and iron-stained, with some yellowish marl; *Belemnopsis bessina* (A. d'Orbigny) (often with *Berenicea* attached), *Ctenostreon* sp., *Lima œpybolus* Whidborne, *Aulacothyris carinata* (Lamarck), *Holectypus hemisphæricus* (Agassiz), etc.	2	0
	Marl, yellowish	0	3
	Limestone, with 'ochreous bodies' in places ...	2	0
	Marl: 0 to 3 inches	0	1
	Limestones, more thinly-bedded than the strata below, with two layers of marl—showing 'ochreous bodies'—in the lower portion	2	3
	Massive Beds. Limestones: seen	3	0

Top Limestones, similar to those seen at Upon-Lang Quarry, are being worked in a quarry (16) near Viney-Bridge Mills, Crewkerne, and again at a quarry (18) near Hinton St. George. Formerly similar beds were worked at Kithill-Lane Quarry (17), while the highest beds of the Inferior Oolite and some overlying Fuller's Earth were observed by H. B. Woodward at the now abandoned Lye's Brickworks 'south-east of the Brewery at Crewkerne'[1] (19).

Hinton-Park Quarry, Hinton St. George.—Near the Keeper's Lodge in Hinton Park is a quarry (20) in which Top Limestones—very similar to those seen in the quarry at (18)—are displayed above massive, rich brown, ferruginous limestones of *garantianæ* date that call to mind the Hadspen Stone of the Castle-Cary district. When I first visited the quarry in 1913, the lowest stratum of these *Garantiana* Beds seen was a hard, ironshot, conglomeratic limestone that yielded the fossils recorded below; but in 1916 the quarry was not 'in work' and this bed was not exposed.

20. Hinton-Park Quarry.

		Thickness in feet	inches.
Schlœnbachi...	Limestone, with which is associated yellowish marl: seen	2	4
	Limestones, with thin layers of marl	6	2
	Marl and rich-brown ochreous matter (oxidized iron-pyrites)	0	1
? *Truellei*	Limestone; *Belemnopsis bessina* (A. d'Orbigny), *Entolium demissum* (Phillips), etc.	1	6
Garantianæ...	Limestone, massive, rich brown, ferruginous ...	?4	6
	Limestone, hard, ironshot, and conglomeratic; *Patoceras annulatum* (A. d'Orbigny), *Belemnopsis bessina* (A. d'Orbigny), *Pleurotomaria palæmon* A. d'Orbigny, *Trochus ?biarmatus* Münster, *Astarte manseli* S. Buckman, *Entolium demissum* (Phillips), *Protocardia* sp., *Grammatodon* sp., *Trichites* sp., *Trigonia costata* J. Sowerby, *Cidaris ?bouchardi* Wright, *Pygorhytis ringens* (Agassiz), *Holectypus hemisphæricus* (Agassiz), etc.	?1	6

[1] 'The Jurassic Rocks of Britain, vol. iv—The Lower Oolitic Rocks of England (Yorkshire excepted)' Mem. Geol. Surv. 1894, pp. 67–69.

The Top Limestones are worked in a quarry by the side of the Foss Way (22) between Dinnington and Lopen.

Lopen.—At Lopen there is a small outlier of Inferior Oolite and Fuller's Earth, but I could not find any sections. Moore's species, '*Rhynchonella? lopensis*,' came 'from a bed of blue Oolitic Marl, occurring in the neighbourhood of Lopen, near Ilminster.'[1]

Furzy Knaps, Seavington St. Mary.—This section—which must not be confused with that at Furzey Knaps, near Yeovil,[2]—is in the bank by the roadside at (23).

23. Section at Furzy Knaps.

		Thickness in feet	inches.
? *Aalensis*......	1. Sandstone, hard, yellowish-grey; ? *Cotteswoldia* sp., *Thracia* sp., *Rhynchonella cynocephala* auctt.: seen	2	0
	2. Yellowish sandy marl: 2 to 4 inches	0	3
Aalensis	3. Sandstones, two irregular beds, with an intervening deposit of marl; *Thracia* sp., *Pleuromya* sp., *Serpula tricarinata* auctt.	0	10
	4. Greyish-brown impure sandstone crowded with ammonites — ? *Canavarina venustula* S. Buckman, cf. *Cotteswoldia crinita* S. Buckman (one of the *Aalensis* Group), *Walkericeras delicatum* S. Buckman, *Megateuthis voltzi* (Phillips), *Pleurotomaria* sp., *Pholadomya* cf. *acuta* Agassiz, etc.	0	4
	5. Greyish-brown and yellowish-brown-streaked indurated, somewhat clayey, sand with sand-burrs; *Cotteswoldia subcandida* S. Buckman, ? *C. crinita* S. Buckman, *Pleydellia leura* S. Buckman, *Pleuromya* sp., *Rhynchonella cynocephala* auctt., ? *Terebratulina deslongchampsi* Davidson, *Zeilleria* aff. *whaddonensis* S. Buckman, etc.: seen	5	0

The specimen of ? *Terebratulina deslongchampsi* Davidson was collected by Mr. Charles Upton, and this appears to be the first satisfactory record of its occurrence in this country.[3]

[1] '*Rhynchonella ? lopensis*' was first described as '*Rhynchonella ? triangularis* Moore' by Davidson in 1854 ('British Fossil Brachiopoda' Monogr. Palæont. Soc. vol. i, pt. iii—Appendix, p. 30); but, as the specific name was occupied, Moore changed it to '*lopensis*' in 1855 (Proc. Somerset Arch. & Nat. Hist. Soc. vol. v, 1855, p. 114 & pl. i, figs. 9–10). As '*Rhynchonella ? lopensis* Moore,' Davidson deals with and figures the species in his Monograph in 1878 ('British Fossil Brachiopoda' Monogr. Palæont. Soc. vol. iv, pt. ii, no. 2, p. 217 & pl. xvii, figs. 8–9). Mr. Buckman informs me (*in litt.*) that he has found 'the same and allied species of this very peculiar and distinctive Rhynchonellid in the Marl Bed (*Garantiana* Beds) of Bradford Abbas: this proves the date of some Lopen deposit.' I have not met with any deposit in the Inferior Oolite of this neighbourhood answering to Moore's description, and it is well to bear in mind that Moore regarded the Yeovil Sands as belonging to the Inferior Oolite Series (Proc. Somerset Arch. & Nat. Hist. Soc. vol. xiii, 1867, pp. 141–43). They contain beds of 'blue marl' in places near their top.

[2] 'Ammonites of the Inferior Oolite Series' Monogr. Palæont. Soc. Suppl. pt. xiii (1905) pp. clxxii & clxxiv.

[3] The specimens on which Davidson founded the species came from France (Ann. & Mag. Nat. Hist. ser. 2, vol. v, 1850, p. 450 & pl. xv, figs. 6–6 *a*). Charles Moore recorded the species from the Middle Lias of Whatley, near

In the lane (24) near Allowenshay yellow sands and sandburrs, full of *Serpula tricarinata* auctt., are exposed. From a hard bed at the top I obtained a number of specimens of a small form of *Rhynchonella cynocephala* auctt., and from one of the sandburrs *Dumortieria arenaria* S. Buckman indicating *moorei* hemera.

There are excellent sections in the Sands in the lanes at Dinnington (21) and Hinton St. George (26).

Manor-House Quarry, North Perrott.—This quarry is the one mentioned by H. B. Woodward as situated 'by New Hall, west of North Perrott Church.' [1]

Concerning the quarry, Woodward wrote that it shows

'about 18 feet of false-bedded shell-limestones, interbedded with buff sands and sandy limestones, that . . . occur locally in the upper part of the Midford Sand in this district, and are well represented at Ham Hill. The shell fragments are mostly indeterminable as to species, consisting of *Ostrea*, *Pecten*, and *Avicula*; but Mr. Rhodes obtained *Pecten demissus* and *Belemnites voltzi* (?).' (*Loc. cit.*)

A photograph of this section is reproduced in Pl. XIV.

Quarry at North Perrott Manor House.

		Thickness in feet	inches.
Scissi	1. Bluish-grey and pale-yellow, very fine-grained, micaceous, sandy clay; *Belemnites* sp., *Aulacothyris blakei* (Walker), *Rhynchonella cynocephala* auctt., *Terebratula* cf. *T.-haresfieldensis* Group: about	4	0
? Scissi	2. Limestone, fairly-regular band of whitish-looking sandy limestone, *Ostrea* sp.	0	6
Opaliniformis | *Aalensis.*	3. Yellow, micaceous, sandy clay, weathering to a pale grey, with rubbly limestone and rolled and often phosphatized fossils in the lower portion; *Pleydellia aalensis* (Zieten) at the very base; *Belemnites irregularis* Schlotheim (rolled), *Ostrea* sp. (some are of an *Ostrea-knorri* Voltz aspect, others more gryphoid), *Aulacothyris blakei* (Walker), *Zeilleria whaddonensis* S. Buckman, *Rhynchonella cynocephala* auctt., *Rh. pentaptycta* S. Buckman: about	1	0
'Perrott Stone' (probably *moorei*).	4. Limestone, brown, practically made up of shell-fragments, shaly in places, very hard, blue-centred and crystalline in others, irregularly bedded; *Lytoceras* sp. (large and not infrequent): about	18	0
	5. Sand-rock, often soft and very sandy: seen...	2	0

The 'Perrott Stone' has been used considerably in the village for building-purposes, and has a very pleasing warm-brown colour.

Frome, Somerset (Proc. Somerset Arch. & Nat. Hist. Soc. vol. xiii, 1867, p. 157); but Davidson states that he was unable to check Moore's identification, because the specimens (Moore's) had been mislaid ('British Fossil Brachiopoda' Monogr. Palæont. Soc. vol. iv, pt. ii, no. 1, pp. 117–18).

[1] 'The Jurassic Rocks of Britain, vol. iv—The Lower Oolitic Rocks of England (Yorkshire excepted)' Mem. Geol. Surv. 1894, p. 71. This section was visited by some members of the Geologists' Association on April 14th, 1914 (Proc. Geol. Assoc. vol. xxvi, 1915, pp. 74–76). It is now within the gardens of the Manor House, which were extended in 1914.

The sandy clay of Bed 3 corresponds to Beds (a^1) and (a^2) of the Cat-Hole Lane section; while the rubbly limestone and rolled and often phosphatized fossils in its lower portion represent the worn remains of probably an attenuated development of the greater portion of the *Opaliniforme* Beds, and the *Aalensis* Beds.

Slade's Quarry, North Perrott.—In two adjacent fields on the south side of Trindlewell Lane are two openings—one, a quarry (Slade's—(28)) 'in work'; the other, an old working under the hedge some 150 yards to the west.

SECTION IN THE OLD WORKING.

		Thickness in feet	inches.
Fuscæ	Fuller's Earth. Clay; *Belemnopsis* sp.: seen	2	6
	The Scroff. Yellowish-grey indurated marl: about	0	3
Zigzag	*Zigzag* Bed. Limestone, rubbly, bluish-grey; *Œcotraustes* sp.	0	6
Schlœnbachi...	Limestones; *Terebratula sphæroidalis* auctt., *Collyrites ovalis* (Leske): seen	1	0

28. SLADE'S QUARRY.[1]

		feet	inches
? Truellei	Limestones, 'sparry,' largely composed of fragments of isocrinoid-ossicles; *Belemnopsis bessina* (A. d'Orbigny): seen	2	0
Garantianæ...	Reddish-brown, ferruginous, clayey deposit: average	0	1
	(*a*) Limestone whitish, with occasional large grains, very fossiliferous; *Parkinsonia* sp., *Belemnopsis bessina* (A. d'Orbigny), *Ataphrus acmon* (A. d'Orbigny) and varieties, *Delphinula* sp., *Pleurotomaria elongata* (J. Sowerby), *P. granulata* (J. Sowerby) var. *cœlata* Deslongchamps, *Arca* sp., *Ctenostreon pectiniforme* (Schlotheim), *Trigonia costata* J. Sowerby, *Rhynchonella parvula* Deslongchamps, *Rh. ?plicatella* (J. de C. Sowerby), isocrinoid-ossicles, *Cidaris bouchardi* Wright, *Collyrites ovalis* (Leske), *Holectypus hemisphæricus* (Agassiz), *Corynella cribrata* Hinde, and *Holcospongia sulcata* Hinde	1	5
	(*b*) Limestone, whitish; *Belemnopsis bessina* (A. d'Orbigny), *Astarte manseli* S. Buckman, *Cidaris* sp., isocrinoid-ossicles	0	7½
	(*c*) Limestone, similar to (*b*), with a greater quantity of ochreous matter associated	0	4½
^^^^^^^^^^^^^^	Non-sequence. Deposit of *niortensis-bradfordensis* hemeræ (inclusive) wanting.		
Murchisonæ | *Ancolioceras.*	Limestone; *Geyerina* sp. (1 foot 11 inches from the top of the bed), *Cœlastarte* sp., *Cucullæa oblonga* J. Sowerby, *Entolium demissum* (Phillips), *Variamussium læviradiatum* (Waagen), *Gervillia whidbornei* Paris, *Gresslya abducta* (Phillips), *Isocardia cordata* (J. Buckman), *Lima inoceramoides* Whidborne (often with *Berenicea* attached), *Opis trigonalis* (J. de C. Sowerby), *Trigonia ?sculpta* Lycett, *Terebratula* sp.: seen	2	8

[1] This quarry was also visited by the Geologists' Association on April 14th 1914 (Proc. Geol. Assoc. vol. xxvi, 1915, p. 75).

In the old working the beds mentioned may be seen after a little excavating has been done.

The rock of *garantianæ* hemera is very interesting, on account of its highly fossiliferous nature.

The limestone dated *murchisonæ-Ancolioceras* is separable into three layers—the upper two (equivalent to the Blue and Red Beds of Misterton), 22 inches thick; the lowest (equivalent to the Grey or Cockle Bed), 10 inches thick.

The *Scissum* Beds are not exposed; but the quarryman said that the quarry was not worked deeper, because only soft sandy rock would be encountered.

Haselbury Plucknett.—In times past there was a quarry of considerable extent situated to the south of the church (29). It is now filled in, and serves as a small common for the village. Doubtless this was the quarry visited by Hudleston, concerning which he wrote[1]:

'This is a place of considerable importance as a quarry, but it is more remarkable for *Echini* and conchifera than for gasteropoda. *Isocardia cordatá* is a noteworthy fossil here, since its occurrence in Dorset has not often come under my notice.*

'It must be allowed that Profile No. 3 [that is, of this Haselbury section] is very inferior in interest ... to the two preceding [Burton-Bradstock Cliff and Vitney or Vinney Cross], since but few gasteropoda are noted from this quarry. I have introduced it mainly to show the preponderating importance of the Lower Division, and especially of the *Murchisonæ* zone in this area. The massive shell-bed with keeled ammonites certainly represents nothing higher than the *concavus (Sowerbyi)* zone, whilst all the rest must be in the *Murchisonæ* zone or lower. The gasteropoda are probably on the same line as at Drympton, which I conceive to be towards the base of the *Murchisonæ* zone.'

* Specimens of this fossil are not uncommon in the beds of (1) *Murchisonæ* and (2) *Ancolioceras-scissi* hemeræ at the Marston-Road Quarry, near Sherborne.

The information given with Hudleston's 'Profile' (*op. cit.* p. 41) is:

			Thickness in feet	inches.
'[*schlœnbachi*]	[1].	Top Bed. No fossils noted	1	0
	[2].	Brash	0	3
[*? bradfordensis*]	[3].	Massive shell-bed with large conchifera. Keeled ammonites	2	4
[*Murchisonæ*]	[4].	Massive creamy limestones, with some shells: *Ammonites murchisonæ*, *Lima etheridgei*, and *Waldheimia anglica*: common	2	0
[*? Ancolioceras*]	[5].	Calcareous rock	0	11
	[6].	Shelly towards the top, with a few gasteropoda	1	6
[*? Scissi*]	[7].	Base-bed	1	4'

Mr. S. S. Buckman considers Bed 7 to be of *scissi* hemera,

[1] 'The Inferior Oolite Gasteropoda' Monogr. Palæont. Soc. pt. i (1887) p. 40.

and Beds 5 & 6 probably *Ancolioceras*.[1] From 'the white limestone of the "lower beds" [that is, 4–6],' of '*Murchisonæ* hemera,' he records *Paqueria angulata* S. Buckman[2]; 'probably from Haselbury, Somerset, and certainly from the horizon of *Zeilleria anglica*, for there is a specimen thereof in the matrix,' *Ludwigia tuberculata* S. Buckman[3]; and 'from the lower beds [that is, 4–6],' *Ludwigia gradata* S. Buckman.[4] Bed 3, Mr. Buckman suggests to me (*in litt.*), may be *bradfordensis*, but he does not recollect any *bradfordensis* specimens from Haselbury; also he informs me that he does not remember having seen any specimens indicating *garantianæ* hemera from this locality. This is the quarry from which the greater number of the fossils labelled 'Haselbury' came in the seventies and eighties, and is the one referred to as 'Haselbury' in Mr. Buckman's paper on 'The Brachiopoda from the Inferior Oolite of Dorset & a Portion of Somerset.'[5]

The paratype of *Lytoceras sigaloen* S. Buckman, a specimen 16 inches in diameter, came 'from Yeovil Sands, Haselbury, Somerset,'[6] but Mr. Buckman informs me that its 'more exact horizon is unknown, as the specimen was purchased from a working collector.'

Haselbury-Mill Quarry, Haselbury Plucknett.—The section displayed in this quarry is of very considerable interest, but has not been noticed by any previous author.

30. Haselbury-Mill Quarry.

		Thickness in feet	inches.
	Chocolate-coloured clayey soil, with numerous flints.		
	Fuller's Earth. 1 *a*. Brownish-yellow clay, with darker layers. 'Snuff-boxes' occur in the lowest portion; *Belemnopsis* sp.: about...	3	0
Fuscæ	?Equivalent to the Scroff. 1 *b*. Chocolate-coloured clayey marl, with large specimens of *Terebratula sphæroidalis* auctt.: average......	0	2
Zigzag	2. *Zigzag* Bed. Limestone, rubbly, bluish-centred, but weathering whitish, and having a layer of chocolate-coloured clayey marl below; *Morphoceras* aff. *inflatum* (Quenstedt), *M. polymorphum* (A. d'Orbigny), *M.* aff. *polymorphum* (A. d'Orbigny), *M. pseudo-anceps* (Ebray), cf. *Parkinsonia planulata* (Wetzel, ?*non* Quenstedt), *Procerites procerus* (Seebach), *Amberleya* sp., *Opis lunulatus* (J. Sowerby), *Acanthothyris spinosa* (Linné), *Terebratula sphæroidalis* auctt., etc.: average...............	0	4

[1] Q. J. G. S. vol. lxvi (1910) p. 79.

[2] 'Ammonites of the Inferior Oolite Series' Monogr. Palæont. Soc. Suppl. (1905) p. lxvii.

[3] *Ibid.* p. lxix.

[4] *Ibid.* p. lxxi.

[5] Proc. Dorset Nat. Hist. & Ant. F. C. vol. iv (1882) pp. 5, 20, 23, 26, 29, 36, 43.

[6] Geol. Mag. dec. 3, vol. ix (1892) p. 260.

		Thickness in feet	inches.
Schlœnbachi...	3. Limestone, very shelly, weathering into three irregular layers; *Oppelia subradiata* (A. d'Orbigny *non* Sowerby), cf. *Procerites evolutoides* Siemiradzki, belemnites, *Ataphrus* sp., *Natica* sp., *Pleurotomaria* sp., *Trochus* sp., *Trigonia costata* J. Sowerby, *Trochocyathus* sp.	0	9
	4. Limestone, fairly massive-looking, with an irregular nether surface. Numerous lamellibranchs in places. *Belemnopsis bessina* (A. d'Orbigny), *Ataphrus* sp., *Pleurotomaria* sp., *Acanthothyris panacanthina* Buckman & Walker, *Rhynchonella* sp., *Trochocyathus magnevillianus* (Michelin), *Serpula* sp., isocrinoid-ossicles, etc.	1	3
	5. Sponge-Bed—a greyish-white deposit of marl and rubble with numerous examples of the sponges *Craticularia foliata* (Quenstedt), *Holcospongia liasica* (Quenstedt), and *Tremadictyon sparsum* Hinde; *Serpulæ* and microfossils (see list below). *Alectryonia* cf. *costata* (J. de C. Sowerby), *Chlamys* cf. *ambigua* (Münster),[1] *Dimyodon sollasi* (Whidborne),[2] *Aulacothyris crewkerniensis* S. Buckman, *Rhynchonella* sp., *Zeilleria waltoni* (Davidson), etc.: average	1	0
? Truellei	6 *a*. Limestone, with innumerable isocrinoid-ossicles showing on the weathered surface. Oxidized iron-pyrites	0	8
	6 *b*. Limestone, similar to *a*	0	6
Garantianæ...	7. Rich yellowish-brown marl and ochreous matter: 0 to 3 inches	0	2
	8. Limestone, grey, with large granules. Oxidized iron-pyrites. *Terebratula sphæroidalis* auctt.	0	6
....	Non-sequence. Deposits of *niortensis-murchisonæ* hemeræ (inclusive) wanting.		
Ancolioceras ! *Scissi*.	9. Limestone, hard, grey, sandy, passing down into more sandy and softer rock weathering brownish. Has some rich reddish-brown ochreous matter in cavities. Belemnites, *Entolium demissum* (Phillips), *Variamussium læviradiatum* (Waagen), *Ceromya concentrica* (J. de C. Sowerby), *Isocardia cordata* (J. Buckman), *Trigonia ? sculpta* Lycett: seen	1	8

The lowest bed (9) seen in this quarry is dated as *Ancolioceras-scissi* on the basis of comparison, because I did not obtain any evidence from ammonites.

I did not obtain here a single specimen of *Zeilleria anglica* (Oppel)—the characteristic brachiopod of the *Murchisonæ* Beds of the neighbourhood of Beaminster.

The lithic characters of the rock dated as *garantianæ* call to

[1] This form is similar to those, noticed as being closely allied to *Chlamys ambigua* (Münster), from the *Truellei*- and *Schlœnbachi*-Beds of Burton Bradstock: E. T. Paris & L. Richardson, Q. J. G. S. vol. lxxi (1915–16) p. 526.

[2] G. F. Whidborne, Q. J. G. S. vol. xxxix (1883) p. 515 & pl. xv, figs. 21–22.

mind those of the Marl Bed and subjacent limestone of the neighbourhood of Bradford Abbas; and those of Bed 6, the rock queried as *truellei* at Slade's Quarry, North Perrott.

The most interesting deposit in this section is the Sponge-Bed. It is similar in appearance to the well-known spongiferous beds at Shipton Gorge (Dorset).[1] The sponges here at Haselbury, however, are represented by few species.

Mr. Upton has examined for me a sample of the marl from the Sponge-Bed, and reports the occurrence of the following fossils:

BRACHIOPODA.[2]
Crania canalis Moore.
?*Spiriferina minima* Moore.
?—— *oolitica* Moore.
Thecidella granulosa (Moore).
—— *serrata* (Moore).
—— sp.
Zellania davidsoni Moore.

POLYZOA.
Fragments of several forms.

OSTRACODA.
Bairdia fullonica Jones & Sherborn. Common.
Cytheridea sp. Similar to a specimen found in Bed 2 (?*fuscæ*) of King's Pit, Bradford Abbas.[3]
Cythereis sp.
Polycope sp.
Several undetermined forms.

ANNELIDA.
Serpula sp.
Spirorbis midfordensis Richardson.[4]

HOLOTHUROIDEA.
Chirodota convexa Whidborne.[5] Two specimens were obtained from the Sponge-Beds at Peas-Hill Quarry, Shipton Gorge.

SPONGIDÆ.
Reniera sp. Spicule.

FORAMINIFERA.
Biloculina sp.
Cornuspira cretacea Reuss.
Cristellaria acutauricularis Fichtel & Moll.
—— *cultrata* Montfort.
—— *exilis* Reuss.
—— *gladius* (Phillips).
—— *italica* Defrance.
—— *rotulata* (Lamarck).
—— *tricarinata* Reuss.
Flabellina pulchra A. d'Orbigny.
Frondicularia oolitica Terquem.
Glandulina humilis Römer.
Lagena elongata Ehrenberg.
—— *lævis* Montfort.
Lingulina semiornata Reuss.
Marginulina bullata Reuss.
—— *contracta* Terquem.
—— *inæquistriata* Terquem.
Nodosaria brevis (A. d'Orbigny).
—— *communis* (A. d'Orbigny). Very common.
—— *nitida* A. d'Orbigny.
—— *radicula* (Linné).
—— *raphanistrum* (Linné).
—— *raphanus* (Linné).
Planularia bronni (Römer).
—— *crepidula* Fichtel & Moll.
—— *harpula* (A. d'Orbigny).
—— *pauperata* Jones & Parker.
—— *recta* A. d'Orbigny.
—— *rœmeri* (Reuss).
Polymorphina fusiformis Römer.
—— *lactea* Walker & Jacob.
Rhabdogonium cf. *hærengense* (Gümbel).
Textularia trochus A. d'Orbigny.
Vaginulina cf. *heteropleura* Terquem.
—— *striata* A. d'Orbigny.

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[1] L. Richardson, Proc. Geol. Assoc. vol. xxvi (1915) pp. 60–61. See also E. A. Walford, Q. J. G. S. vol. xlv (1889) pp. 561–74 & pls. xvii–xix; and *ibid.* vol. l (1894) pp. 72–78 & pls. ii–iv.

[2] Mr. Upton remarks that all these species of brachiopods occur also in the Upper Coral-Bed of Dundry Hill, near Bristol.

[3] Proc. Geol. Assoc. vol. xxii (1911) p. 262.

[4] L. Richardson, Q. J. G. S. vol. lxiii (1907) p. 435.

[5] See C. Upton, Proc. Cotteswold Nat. F. C. vol. xix (1917) p. 116.

From the occurrence of the Thecidellæ and specimens of *Spiriferina oolitica* Moore, Mr. Upton is inclined to regard the deposit as being of *truellei* hemera: that is, of the date of the Upper Coral-Bed of Dundry Hill (near Bristol), Midford (near Bath), and the Cotteswolds. I have regarded it as *schlœnbachi*, because of the apparent absence of corals (*Isastræa*), the occurrence of *Tremadictyon sparsum* Hinde, its similarity to the Sponge-Beds—definitely of *schlœnbachi* hemera—of Shipton Gorge and Burton Bradstock; and because of its stratigraphical relations to beds above and below.

Barrows-Hill Quarry, East Chinnock, near Haselbury.[1]—In this quarry (32) is seen—in ascending order—the top-portion of the equivalent to the 'Perrott Stone'; yellow and grey sandy clay (10 inches) similar to that of Bed 3 at the Manor-House Quarry, North Perrott; and sandy clays, with subordinate bands of greyish-white limestone (8 feet seen), which contain in abundance specimens of *Aulacothyris blakei* (Walker), *Rhynchonella cynocephala* auctt., *Terebratula whaddonensis* S. Buckman, and *Terebratula* sp.

Chiselborough Hill.—The 'Roadstone,' which is worked in a quarry (33)[2] on this hill, is very similar to the Perrott Stone and comparable with the 'Riddings' of Ham Hill. It is most likely of *moorei* date.

Ham Hill.—At Ham Hill (see p. 145 of this paper) the portion of the Yeovil Sands of *dumortieriæ* date consists of yellow micaceous sands, with irregular bands of sand-rock and sand-burrs, about 90 feet thick. They are excellently exposed in a deeply-sunken lane (36) south-west of Montacute. The portion of *moorei* date is exposed in the big quarry on the hill (35) and the main mass of it is a 'freestone'—the celebrated Ham-Hill Building-Stone.

In the big quarry the sequence is as follows:[3]

		Thickness in feet.
1. Sand: seen about		10
2. 'Riddings'		30
3. Ham-Hill Stone	'Yellow Beds'	33
	'Grey Beds'	15
4. 'Bottom-Bed'—hard sandstone		$1\frac{1}{2}$

[1] This is the 'near Haselbury' of Mr. Buckman's paper of 1882 (Proc. Dorset Nat. Hist. & Ant. F. C. vol. iv, pp. 16, 33, & 43); 'Middle Chinnock' of his paper of 1895 (Q. J. G. S. vol. li, p. 453); and 'Little Silver' of his 1910 paper (Q. J. G. S. vol. lxvi, p. 101).

[2] 'The Jurassic Rocks of Britain, vol. iv—The Lower Oolitic Rocks of England (Yorkshire excepted)' Mem. Geol. Surv. 1894, p. 71.

[3] S. S. Buckman, Q. J. G. S. vol. xlv (1889) p. 449.

In the Rock Quarry (34)[1] the Sand (1 above) is seen overlying some 20 feet of 'Riddings.'

IV. Conclusion.

In this communication a detailed description has been given of the Inferior Oolite and immediately sub- and superjacent deposits of the Crewkerne district.

Roughly speaking, the Upper Liassic Sands of *dumortieriæ-moorei* hemeræ south-west of a line joining South Petherton, Crewkerne, and South Perrott, are very similar to their equivalents in the Burton-Bradstock–Beaminster-Broadwindsor District. North-west of that line, however, limestones—largely composed of shell-débris—replace a considerable portion of the yellow sand of *moorei* hemera, 'thickening' from about 18 feet at North Perrott ('Perrott Stone') to 78 feet at Ham Hill ('Riddings and Ham-Hill Building-Stone').

In the extreme south-western portion of the district, around (say) Drimpton, the *Aalensis* Beds are probably also very similar to their equivalents in the Burton-Bradstock–Beaminster-Broadwindsor district, and at Furzy Knaps, near Seavington St. Mary (4 miles north-west of Crewkerne), what is seen of them is highly fossiliferous. East of Crewkerne, however, these beds 'attenuate,' and fail altogether between North Perrott and Yeovil Junction.

At Broadwindsor, Whaddon Hill (near Beaminster), and Chiddock Quarry Hill (near Bridport), the *Opaliniforme* Beds comprise, in descending order—

(*a*) Rusty Bed,
(*b*) Very fossiliferous sandstone, and
(*c*) Sands and sandburrs.

The equivalent of Bed *b* is readily recognized at the Cat-Hole-Lane Section, Crewkerne, where it is very rich in ammonites. Above are deposits 20 inches thick, with little doubt equivalent to the Rusty Bed of more southern localities. East of Crewkerne, the *Opaliniforme* Beds — like the *Aalensis* Beds — 'attenuate,' the lower beds apparently disappearing first. Also, like the *Aalensis* Beds, they fail somewhere between Crewkerne and Yeovil Junction: to be more exact, between East Chinnock and the Junction.

The *Scissum* Beds are 6 feet 2 inches thick at Broadwindsor and rich in specimens of *Gryphæa cygnoides* Whidborne, *Lima inoceramoides* Whidborne, *Volsella sowerbyana* (A. d'Orbigny), etc. They retain the characters exhibited at Broadwindsor in the area south of the L. & S.W. Railway; but at North Perrott—on the

[1] Not the 'Rocks' Quarry, as it has been previously denominated in Proc. Geol. Assoc. vol. xxii (1911) p. 259 and Proc. Cotteswold Nat. F. C. vol. xvii (1914) p. 113.

5. ...ARM SECTION, ...TH PERROTT, DORSET.	4... LECKER... SECTIO... SOUTH P...	...H PERROTT. 28. ...'S QUARRY. 27. ...OUSE QUARRY.	30. HASELBURY-MILL QUARRY, HASELBURY PLUCKNETT.	32. BARROWS' HILL QUARRY, EAST CHINNOCK.
		...) WORKING. ...r's Earth, 2 ft. 6 ins. ...f, about 3 ins.	Fuller's Earth, seen: 3 ft. ? The Scroff, average: 2 ins.	
		6 ins.	4 ins.	
...imestones (...*chlœnbachi*), ...een: 2 ft.	Lime... (*? schlœ...* seen: ...	...*bachi* Beds, ...n: 1 ft.	*Schlœnbachi* Beds—Limestones; 2 ft. Sponge-Bed, 1 ft.	
? wanting.]	[? wa...	...S QUARRY. ...Bed, seen: 2 ft.	*? Truellei* Bed, 1 ft. 2 ins.	
—	3 to ...	...t. 6 ins.	8 ins.	
—	—	—	—	
—	—	—	—	
—	—	—	—	
—	—	—	—	
—	—	—	—	
—	—	—	—	
—	—	—	—	
—		—	—	
—	—	... strata—*Zeil-* ...*nglica* Beds ...g.] 2 ft. 8 ins.	[Upper strata—*Zeilleria-anglica* Beds apparently wanting. Probably the lower strata also.]	
Ancolioceras ...*scissi*.—1 ft 8 ins. seen: 6 ft.	*Anco...* or *scissi...* seen: 3...	...USE QUARRY. ...y, seen: 4 ft. (*? scissi*), 6 ins.	seen: 1 ft. 8 ins.	Sandy clays with subordinate bands of limestone, seen: 8 ft.
		...ndy clay (cor- ... to a^1 and a^2 ...t-Hole Lane ...th rubbly lime- ...lled and often ...d fossils at the		Sandy clays corresponding to Bed 3 at Manor-House Quarry, North Perrott.
				[Apparently not represented.]
		...tt Stone ...ly *moorei*)		Top of 'Perrott Stone' seen

ANALYSIS OF THE PRINCIPAL SECTIONS IN THE CREWKERNE DISTRICT.

Hemeræ.	Conegar-Hill Section, Broadwindsor, Dorset.	1. Drimpton, Dorset.	5. Hill-Farm Section. South Perrott, Dorset.	4. Lecker-Bridge Section, near South Perrott.	Misterton, Somerset. 9. Quarry near the Church. 3. Lime-Works.	14. Upon-Lang Quarry. 13. Cat-Hole-Lane Section.	20. Hinton-Park Quarry. 23. Furzy Knaps, Seavington St. Mary.	North Perrott. 28. Slade's Quarry. 27. Manor-House Quarry.	30. Haselbury-Mill Quarry, Haselbury Plucknett.	32. Barrows' Hill Quarry, East Chinnock.
fuscæ.					Quarry near the Church. The Scroff.			In old working. Fuller's Earth, seen : 2 ft. 6 ins. The Scroff, about 3 ins.	Fuller's Earth, seen : 3 ft. ? The Scroff, average : 2 ins.	
i A. *zigzag.*					[Probably represented.]			6 ins.	4 ins.	
ii, i. *schlœnbachi.*	Limestones (*? schlœnbachi*), seen : 3 ft.		Limestones (*? schlœnbachi*), seen : 2 ft.	Limestones (*? schlœnbachi*), seen : 2 ft.	Lime-Works. Microzoa-Beds, seen : 2 ft. 2 ins. Massive Beds, 3 ft. 7 ins.	Upon-Lang Quarry. Microzoa-Beds, seen : 6 ft. 7 ins. Massive Beds, seen : 3 ft.	Hinton-Park Quarry. *Schlœnbachi* Beds, seen : 8 ft. 7 ins.	*Schlœnbachi* Beds, seen : 1 ft.	*Schlœnbachi* Beds—Limestones ; 2 ft. Sponge-Bed, 1 ft.	
iv, iii. *truellei.*	[? wanting.]		[? wanting.]	[? wanting.]	*? Truellei* Bed, 1 ft. 4 ins.	[?]	*? Truellei* Bed, 1 ft. 6 ins.	Slade's Quarry. *? Truellei* Bed, seen : 2 ft.	*? Truellei* Bed, 1 ft. 2 ins.	
vi, v. *garantianæ.*	—		—	3 to 7 ins.	2 to 4 ins.	[Probably represented.]	Limestone (*cf.* Hadspen Stone), about 4 ft. 6 ins. Limestone, conglomeratic ; about 1 ft. 6 ins.	2 ft. 6 ins.	8 ins.	
vii. *niortensis.*	—		—	—	—	—	—	—	—	
viii. *blagdeni.*	—		—	—	—	—	(See footnote, p. 152.)	—	—	
ix. *sauzei.*	—		—	—	—	—	—	—	—	
xi, x. *witchelliæ.*	—		—	—	—	—	—	—	—	
xii. *shirbuirniæ.*	—		—	—	—	—	—	—	—	
xiv, xiii. *discitæ.*	—		—	—	—		(For remarks on the possible occurrence in this neighbourhood of deposits of these hemeræ, see p. 151.)	—	—	
xix, xv. *concavi.*	—		—	—	—			—	—	
xxi, xx. *bradfordensis*	—		—	—	*Rh.-ringens* Beds horizon : 0 to 4 ins. [*P.-brebissoni* Bed not represented.]	[Probably deposits similar to those at the Lime-Works, Misterton, are present.]		—	—	
xxiii, xxii. *Murchisonæ.*	[Upper strata wanting.] Bottom stratum—1 ft. 1 in.	Upper strata—*Zeilleria-anglica* Beds. [Lower strata probably represented.]	—	—	Blue Bed, 1 ft.		[Probably represented.]	[Upper strata—*Zeilleria-anglica* Beds wanting.] seen : 2 ft. 8 ins.	[Upper strata—*Zeilleria-anglica* Beds apparently wanting. Probably the lower strata also.]	
xxiv. *Ancolioceras.*	2 ft.	[Probably represented.]	*Ancolioceras* or *scissi.*—1 ft 8 ins.	*Ancolioceras* or *scissi*—1 ft. 8 ins.	Red Bed, 8 ins. Grey Bed, 1 ft. 1 in.		[Probably represented.]		seen : 1 ft. 8 ins.	
xxv. *scissi.*	7 ft. 2 ins.	[Probably represented.]	seen : 6 ft.	seen : 3 ft. 10 ins.	Surface seen.	Cat-Hole Lane. Sandstone in loose pieces.	[Probably represented.]	Manor-House Quarry. Sandy clay, seen : 4 ft. Limestone (*? scissi*), 6 ins.		Sandy clays with subordinate bands of limestone, seen : 8 ft.
xxvi. *opaliniformis.*	(*a*) Rusty Bed, 6 ins. (*b*) Very fossiliferous sandstone, 1 ft. 6 ins. (*c*) Sand-rock and sands, ? 4 ft. 3 ins. to 5 ft. 3 ins.					a^1, a^2. Marl and marly sandstone, 1 ft. 8 ins. *b.* Ammonite Bed, 1 ft. *c.* Sands and sandburrs, seen : 1 ft. 6 ins.	[Probably represented.]	(Bed 3.) Sandy clay (corresponding to a^1 and a^2 at the Cat-Hole Lane Section), with rubbly limestone and rolled and often phosphatized fossils at the base.		Sandy clays corresponding to Bed 3 at Manor-House Quarry, North Perrott.
xxvii. *aalensis.*	Yellow Sands.						Furzy Knaps. *? aalensis*-sandstone and marl, 2 ft. 3 ins. *aalensis*-sandstones, clayey sand, sandburrs and sand, seen : 6 ft. 2 ins.			[Apparently not represented.]
moorei.								Perrott Stone (probably *moorei*).		Top of 'Perrott Stone' seen.

north—what appears to be equivalent to their lowest portion is softer and thicker. The *Scissum* Beds also fail between East Chinnock and the Junction.

The *Scissum* Beds are succeeded by the *Ancolioceras* Beds—at the Conegar-Hill section, Broadwindsor, two strata, each 1 foot thick. The *Ancolioceras* Beds extend into the Crewkerne district. They are well exposed at the Misterton Limeworks and at other sections in the neighbourhood, and apparently were proved in the now filled-up quarry in Haselbury-Plucknett village. Probably the *Ancolioceras* Beds persist throughout the Crewkerne district.

The upper portion of the *Murchisonæ* Beds is the main horizon for *Zeilleria anglica* (Oppel). In the neighbourhood of Beaminster specimens of this brachiopod are very abundant. The true *Zeilleria-anglica* Beds are absent from the Conegar-Hill section, but occur at Drimpton in the extreme south of the district under consideration. They have apparently been met with in the now filled-up quarry in Haselbury Plucknett; but I have not detected them elsewhere in the district.

Attached in places to the top of the *Murchisonæ-Ancolioceras*-Beds is ironshot rock, probably of *bradfordensis* hemera: perhaps of late *bradfordensis* date—the date of the *Rhynchonella-ringens* Beds of the Sherborne District. A thicker deposit of *bradfordensis* hemera may be present in the neighbourhoods of Dinnington and Haselbury Plucknett, for fossils have been found by previous workers which suggest that this is the case; but I personally have not obtained any evidence. Ammonites in the Moore Collection at Bath point to the occurrence of deposits of *concavi* and *discitæ* hemeræ in the neighbourhood of Dinnington; but I have not detected any deposit in the district that belonged to a hemera between those of *bradfordensis* and *garantianæ*. Traces of rock of *blagdeni* hemera may occur, however, in the neighbourhood of Dinnington.

There is thus a great hiatus in the Inferior Oolite Series of the Crewkerne district, there being—except possibly in the neighbourhood of Dinnington—no rock present assignable to any hemera between those of *bradfordensis* and *garantianæ*—the latter the date of the wide-spreading Upper *Trigonia* Grit of the Cotteswolds.

The rock of *garantianæ* hemera varies a good deal in lithic characters, thickness, and the number of fossils that it contains in the Crewkerne district. Thus, at the Misterton Limeworks it is from 2 to 4 inches thick and practically unfossiliferous; it is wanting at South Perrott; is very fossiliferous at North Perrott; contains few fossils at the Haselbury-Mill Quarry; but at Hinton St. George is probably 6 feet thick, and very similar in appearance to the Hadspen Stone of the Castle-Cary district.

It has not been possible to identify definitely the *Truellei* Bed in the district. Not more than the lowest 2 feet of the Top Limestones may be of this hemera: the main part of those limestones is of *schlœnbachi* date. The *Schlœnbachi* Beds 'attenuate' east of Crewkerne; but at Haselbury-Mill Quarry, in what I regard as their lower portion, is a very interesting Sponge-Bed, similar in appearance to that exposed in the Peas-Hill Quarry, Shipton Gorge (Dorset). The Sponge-Bed is rich in microzoa, and Mr. Charles Upton—on the evidence that they supply—would correlate the deposit with the Upper Coral-Bed (early *truellei*) of Dundry Hill, Midford, and the Cotteswolds.

The *Zigzag* Bed has been observed at North Perrott and Haselbury Mill.

The Scroff—tbe horizon of *Aulacothyris cucullata* S. Buckman—was apparently observed by J. F. Walker in a quarry near Misterton Church.

Fuller's-Earth clay succeeds the Scroff.

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[July 9th, 1919.]

L. R. photo.

QUARRY IN 'PERROTT STONE,' AT NORTH PERROTT MANOR HOUSE, NEAR CREWKERNE (SOMERSET).

L. R. photo.

VIEW OF A PORTION OF THE QUARRY AT THE MISTERTON LIME-WORKS, NEAR CREWKERNE (SOMERSET).

Fig. 1. View of a Portion of the big Quarry on Ham Hill, near Yeovil (Somerset).

T. W. Reader photo.

Fig. 2. View of another Portion of the same Quarry, showing the Ham-Hill Building-Stone.

T. W. Reader photo.

[1=Sand; 2='Riddings'; 3=Ham-Hill Building-Stone.]

CONTENTS.

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PART 3.

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1919.		
Wednesday,	November	5*—19
„	December	3 —17*
1920.		
Wednesday,	January	7*—21*
„	February (*Anniversary Meeting*, Friday, February 20th)	4*—25*
„	March	10—24*
„	April	21*
„	May	5 —19*
„	June	9 —23*

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

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

EXPLANATION OF PLATES XIV–XVI.

Plate XIV.

Quarry in 'Perrott Stone,' at North Perrott Manor House, near Crewkerne (Somerset). (See p. 163.)

Plate XV.

View of a portion of a quarry at the Misterton Limeworks, near Crewkerne (Somerset). (See p. 154.)

Plate XVI.

Fig. 1. View of a portion of the big quarry on Ham Hill, near Yeovil (Somerset). (See p. 169.)

Fig. 2. View of another portion of the same quarry, showing the Ham-Hill Building-Stone. 1=Sand; 2='Riddings'; 3=Ham-Hill Building-Stone.

7. *The* Chellaston Gypsum Breccia *in its* Relation *to the* Gypsum-Anhydrite Deposits *of* Britain. By Bernard Smith, M.A., F.G.S. (Read December 19th, 1917.)

[Plates XVII & XVIII.]

Contents.

I. Introduction.

It is now generally accepted that the extensive beds of gypsum that occur in this country are the deposits of salt lakes or inland seas, and the opinion has been steadily growing that the sediments with which they are usually associated are the products of weathering of an arid region.

In recent years the geographical conditions of the periods when gypsum was deposited have been discussed by numerous writers, including Beasley, Bosworth, Burns, Geikie, Goodchild, Hewitt, Jukes-Browne, Lomas, Metcalfe, Wade, and Watts.

The object of this communication is not so much to discuss the geography of these periods, as to throw some light upon the actual mode of accumulation of gypsum, chiefly from the standpoint of the field-observer.

In any question dealing with gypsum, however, it is almost impossible to avoid dealing also with the anhydrous form of calcium sulphate, since the two minerals occur so frequently in intricate and puzzling association. The main point at issue is whether gypsum is to be regarded as an original deposit, or as a secondary formation.

We may dismiss the isolated occurrences of gypsum which result from the decomposition of sulphides in rocks containing lime, as being a minor point well understood, and confine ourselves to the more extensive deposits occurring as beds and smaller masses, or as a matrix to the rocks in which the thicker deposits are found.

Various suggestions have been advanced to explain the origin of these deposits :—

(i) Some may be due to evaporation by concentration of river-water charged with salts, flowing into inland basins without outlet.

(ii) Others may be formed when an arm of the sea is isolated and exposed to evaporation.

(iii) Certain deposits have been claimed to be the results of the action of sulphureous emanations from volcanic vents upon limestone or other calcareous rocks.

(iv) Under certain conditions gypsum may be formed from anhydrite ; but, if so, we still have to determine how the anhydrite was deposited.

The early part of this paper deals chiefly with the stratigraphical aspects of the question. I propose, so far as possible, to postpone to a later stage (pp. 195, 198) any theories upon the possible chemical changes and balances (which have been discussed by many authors[1]) necessary to produce precipitation either of gypsum or of anhydrite, and my final endeavour will be to show that many of the gypsum-anhydrite deposits in this country must have been formed *ab initio* in stratiform manner, and are not the result of subsequent changes, additions, or replacements of any importance.

Deposition in Inland Basins.

The majority of the British deposits were apparently formed as chemical precipitates on the floors of inland basins cut off from the open sea, but fed by rivers (in the case of the Permian and Trias, at least) bearing sediment derived from a country of low average rainfall and high average temperature. The deposits may be classed as those of salt lakes, as distinct from bitter lakes.

In some cases the salt lakes may have been portions of the ocean, isolated and fed by rivers; while in other cases they may have been inland lakes formed solely by river-waters, which may, however, have dissolved—from the rocks within their drainage-areas—oceanic salts that were deposited in earlier geological ages.

If to these conditions we add change in temperature, also earth-movements which would at times cause one basin to open into another or cause diversion in river-drainage, and alteration in climatic conditions, we have all the circumstances necessary for the precipitation of mineral salts contemporaneously with the peculiar sediments of such areas. We should not expect to find an unbroken sequence of saline deposits, such as would result from the steady and uninterrupted evaporation of a given amount of

[1] Sir Archibald Geikie, 'Text-Book of Geology' 4th ed. vol. i (1903) pp. 525–31 ; F. W. Clarke, 'Data of Geochemistry' 3rd ed. Bull. U.S. Geol. Surv. No. 616 (1916) pp. 226–28 ; J. L. A. Roth, 'Allgemeine & Chemische Geologie' vol. i (1879) pp. 463 *et seqq.*

Fig. 1.—*Topographical map of the neighbourhood of Chellaston, showing the localities where alabaster, etc. has been worked.*

[Scale: 6 inches = 1 mile, or 1 : 10,560.]

sea-water, or of a given body of fresh water. We should rather anticipate a varying set of conditions upon which changes might be rung.

All this was in general admitted by J. G. Goodchild, but he was doubtful whether the exact balance between the influx of water into closed basins and the subsequent evaporation of that water could have been maintained for a sufficiently long period to admit of the uninterrupted precipitation of such masses of sulphate of lime as occur in our red rocks. He says[1] that

'All the facts brought to light by a study of the closed basins of the present day testify to the view that such forms of deposition are very exceptional. Instances are, in fact, unknown . . . . Variations in salinity have been the rule, and not the exception. In all of them the prevailing mode of occurrence of the chemical precipitates is that of thin sheets—varying from a few inches in thickness to mere films of disconnected spangles—which are interleaved with a succession of sedimentary deposits brought in by freshets.'

Without going farther into the matter for the moment, we may recall that thick masses of the Magnesian Limestone of Nottinghamshire and Yorkshire appear to have been formed exclusively of chemically-precipitated rhombs of dolomite, accumulated as a dolomite-sand in which false bedding is developed on a large scale.[2]

In the spring of 1915, Dr. R. L. Sherlock and I examined practically all the important worked deposits of gypsum in this country, and it was my fortune to come across a breccia of an interesting type, which will now be described.

II. The Chellaston Breccia and Associated Sediments.

The rock is exposed in the Chellaston Alabaster Quarries (the sole representative, in this Derbyshire village, of a long series of excavations that furnished the material for some of the finest monumental work in the country[3]) worked by Messrs. H. Forman & Son, to whom thanks are due for offering both time and information so liberally (see map, fig. 1, p. 176).

The gypsum occurs as a series of 'pillars,' sometimes almost or quite in contact, but usually separated by 'coarsestone' and 'foulstone,' the former consisting of more gypsum than marl, the latter of more marl than gypsum.

These pillars are nearly circular in plan, except when they abut one against the other, when they may be roughly polygonal. They

[1] 'Some Observations upon the Natural History of Gypsum' Proc. Geol. Assoc. vol. x (1887–88) p. 442.

[2] 'Geology of the Country around Ollerton' Mem. Geol. Surv. 1911, pp. 12–13.

[3] See 'Special Reports on the Mineral Resources of Great Britain: vol. iii—Gypsum & Anhydrite' Mem. Geol. Surv. 1915, p. 17. In this volume also accounts will be found of most of the mines and quarries mentioned in the present communication. See also A. T. Metcalfe, 'The Gypsum Deposits of Nottinghamshire & Derbyshire' Trans. Inst. Min. Eng. vol. xii (1896–97) pp. 107–14.

are usually shaped like basins below, and are sometimes slightly concave above, but more frequently the surface is gently domed and uneven. A large pillar measures about 12 feet in diameter, and from 8 to 9 feet thick. The foulstone occurs chiefly between the more widely separated pillars: when shaly it is seen to be horizontally bedded, and is riddled throughout with minute veins of fibrous gypsum, as well as larger ones which occasionally attain a thickness of 2 inches. It sometimes includes large rounded lumps ('hard-horses') of pale loamy marl measuring up to 2 feet in length.

Each pillar passes at its sides and bottom into coarsestone or foulstone. The coarsestone is chiefly red gypsiferous marl and gypsum, bound together by plates of selenite and riddled with satin-spar. In places a mass of coarsestone will form by itself a kind of irregular pillar, embedded in foulstone (fig. 2).

Fig. 2.—*Mode of occurrence of alabaster pillars at Chellaston. (Length of section=90 feet.)*

[White=alabaster; cross-hatching=coarsestone; horizontal shading =foulstone; black=swallowholes.]

At or near the junction of two or more pillars frequently occur swallowholes that have been leached out along lines of weakness at the sides of the pillars, and carry down surface-waters to a level some 20 feet below the floor of the quarry.

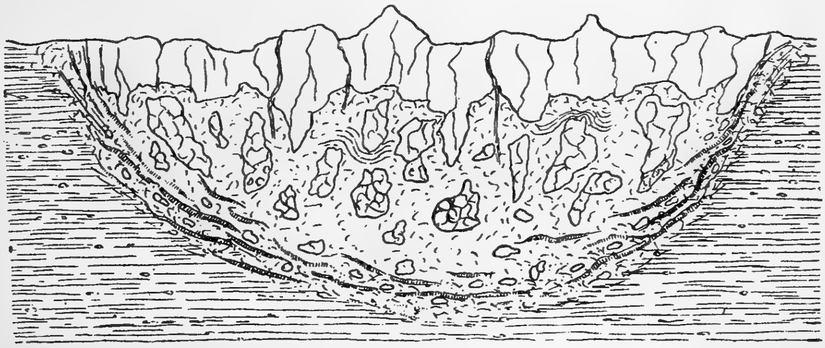
From an examination of numerous sections (some of which may illustrate only a few of the points set out below) a typical pillar may be described as follows:—

The upper part is formed of pure white alabaster, veined in an up-and-down direction by irregular pale-green bands. The upper surface is rough and pinnacled (fig. 3, p. 179), while evidences of solution are frequent. In plan the green colour-bands form a reticulate network, in which no regular arrangement can be made out like that in the vertical section. The lower surface of this upper white layer is also irregular and overlies a breccia, thickest in the centre of the pillar, which consists, in general, of irregular masses of white gypsum embedded in red gypsum. The masses of white gypsum are sometimes stained with pink patches, but are more often veined with green, and they vary in shape from sharply angular to subangular or rounded, the roundest masses being usually small and occupying the lowest position in the bed. The red gypsum is fairly pure, and will take a high polish, like the white alabaster; in places, however, it encloses a little marl which unfits it for this purpose, and when it is still more impure it verges on coarsestone. It occasionally shows signs of stratification.

The lower bowl-shaped portion of the pillar is usually composed of coarsestone enclosing numerous ovoid or rounded lumps of white gypsum, and veins of satin-spar arranged more or less horizontally or in conformity with the curved outline of the pillar. The deepest red colour occurs in this outer and lower layer, owing to the amount of included Keuper marl.

At this locality there are only a few relics of original cover or 'cap' left, for, as a rule, Glacial drift overlies the gypsum and fills up parts of the swallowholes between the pillars; but at one or two spots traces of about 2 feet of green and red marl were found resting rather unevenly upon the white alabaster. At Woodlands,

Fig. 3.—*Diagram of a typical pillar at Chellaston, showing white alabaster overlying lumps of the same set in red alabaster. (Height of section = 9 feet.)*



[Fibrous gypsum in coarsestone is shown by narrow vertically shaded bands.]

a quarter of a mile towards the south-east, the 'cap' is exposed as a bed, from 2 to 3 feet thick, of green sandy marl and green gypsiferous marl resting upon a little red marl overlying the main bed of gypsum.

Sequence of Events before the Formation of the Breccia.

We may now attempt to follow the sequence of events that led up to, and finally resulted in, the formation of the breccia.

The gypsum was apparently laid down irregularly, and conjointly with the deposition of the horizontally-stratified marl, in the form of basin-shaped masses, which were probably due to crystallization being set up at numerous isolated points, each of which is now situated on the central axis of a pillar. The lowest mass of gypsum in each case was mixed with red marl, and now forms the coarsestone of the pillar; the next mass contained relatively little marl, but was stained by the colouring-matter—this is the red gypsum; the upper mass was pure white gypsum, and, in all probability, had a smooth upper surface, but its lower boundary may have been irregular.

Each isolated mass of gypsum grew from the base upwards, concurrently with the deposition of ordinary sediment around it, and each thin deposit of crystals overlapped the one below; thus the pillar was built up of successive layers of increased diameter. A certain amount of thickening probably occurred about the centre, so as to give to the upper surface a slightly domed contour, but this is by no means certain. During crystallization impurities may have been expelled to the margin of each layer.

The final result was a pillar of gypsum filling a 'pot' in the horizontally-bedded marls.

Formation of the Breccia.

After the deposition of a certain amount of green and red marly cap on the white gypsum, it appears that the weight of the cap, which is of higher specific gravity than gypsum, caused the underlying semi-consolidated white gypsum to break up into irregular masses, some of which foundered and slid down beneath their fellows into the lower layer of red gypsum. The upper masses were thrown into confusion and packed together, or half turned over, erecting their broken corners as irregular pinnacles and bosses, which probably remain as such to this day, for some of the pinnacles are extremely sharp. Solution, however, has taken effect at their bases.

The green colouring matter of the cap has crept downwards along the cracks between the lumps in the upper layer and formed the nearly vertical colour stains, while in places thin columns or bands of pale buff-coloured dolomitic mud or marl descended quite 2 feet into, and even through, the upper white gypsum. Some of the red marl, associated with or overlying the green cap, has also penetrated downwards a short distance.

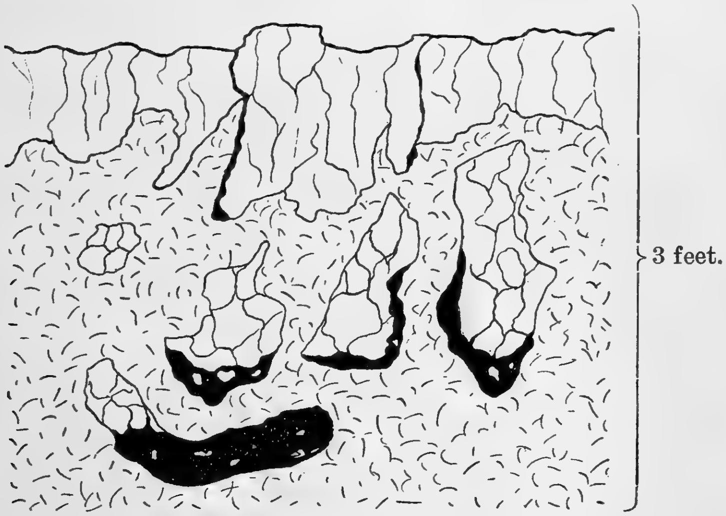
The break-up of the white gypsum accounts for the irregularity of the under-surface of the upper layer, and the turning on their sides of broken fragments would close up the gaps left by the foundered masses.

In the next layer—the red and white breccia—the different degrees of angularity, or of rounding, of the lumps of white gypsum presented a difficulty until it became noticeable that the roundest fragments are usually the lowest and have obviously suffered most during their descent. The foundered white masses are penetrated irregularly by veins of the green colouring-matter, and call to mind crystals of olivine undergoing serpentinization. The veins occur along incipient cracks, which in many cases have become actual fractures during descent.

It is interesting to note that the green coloration is more closely related to the white fragments than to their red setting, and in one pillar at least this connexion was so evident that the whole process of brecciation was clearly revealed. In this instance a quantity of pale-green calcareous (or possibly dolomitic) mud was attached to each fragment of white gypsum, and it was obvious that in nearly every case it had endeavoured to find its way by gravitation to the bottom of the 'pot,' and in so doing had caused the white fragments to revolve to such an extent that their original upper surfaces are now underneath (fig. 4). The green marly slime appears to have crept downwards along the curved walls of the pots also.

In the red gypsum, again, as above stated, there is sometimes more than a suggestion of bedding, especially if a little marl is present. At one point there was a series of small folds and faults, apparently caused by descent of the white lumps and the upthrust of red gypsum to take their place.

Fig. 4.—*Masses of white alabaster with adherent green 'cap' (black) in red alabaster, Chellaston.*



In the lower layers of coarsestone the rounded lumps of white gypsum are probably original secretions, similar to the rounded lumps found in all gypsiferous beds (see below); a few of them, however, may be the ultimate result of the revolution of broken fragments. Similar little segregations occur in parts of the green and grey marly 'cap' that have slid down into the red gypsum.

Location of the Breccia.

The brecciation is peculiar, local in occurrence, and seems to be entirely due to the formation of the gypsum in more or less isolated spots. The green-stained alabaster is an unusual type, rarely found in other mines or quarries. A little occurs at Woodlands, and there is said to be some in the Duddle workings of the Aston-Glebe Mine, about half a mile away. It has also been recorded from Kingston-on-Soar and Castle Hayes, between Tutbury and Fauld (see p. 183).

In the direction of Woodlands and Aston Glebe the pillars occur closer and closer together, and increase in size and irregularity, until they form with the coarsestone a fairly continuous seam with a nearly unbroken 'cap.' The greater continuity of the gypsum in the seam seems to have permitted of a consistent support to the cover, which therefore held firm.

The breccia furnishes the following points of interest:—

(*a*) The gypsum was formed *in situ*, as such, and accumulated chiefly in stratiform manner at isolated points in pillars, separated by horizontally-bedded marls.

(*b*) These pillars may unite and form, in conjunction with a certain amount of coarsestone, a continuous bed, as at Aston Glebe.

(*c*) The green coloration of both marl and gypsum must be original, a fact that should be borne in mind when the subject of colour in variegated strata is under consideration.

(*d*) The gypsum appears to have remained in a soft condition while a certain thickness of cover was being deposited.

(*e*) If the cover collapsed in the manner suggested, the upper white gypsum must have been slightly more rigid than the lower red gypsum.

III. Gypsum Deposits of other Districts.

If we now review some of the gypsum deposits of other districts it becomes possible to interpret certain puzzling features in the light of the Chellaston Breccia.

That which is true in the case of these nearly isolated pillars on the fringe of the more continuous beds of gypsum must be true also for the beds themselves. We may, therefore, conclude that the extensive seam of gypsum worked at Aston Glebe, Chellaston, and the similar seams occurring at about the same horizon [1] at Fauld, Sudbury, Gotham, and Kingston-upon-Soar (where the pillars are termed 'bullets' and the coarsestone is described as 'fault') must have been deposited in their present arrangement on the floor of an enclosed basin. From floor to cap the beds are original deposits, sometimes pure, at other times mixed with sediment.

Aston Glebe.—At Aston Glebe the seam is fairly continuous, and varies from 4 to 10 feet in thickness, the gypsum often occurring in irregular beds or posts, from 6 inches to 2 or 3 feet thick, sometimes separated by 1 or 2 inches of stratified marl. There are no balls or pillars of uniform size; but the larger masses of white rock are chiefly found near the top of the seam, the coarser and redder rock occurring below—an arrangement comparable with that in the Chellaston 'pots.' Some of the masses of white gypsum weigh hundreds of tons.

[1] About 140 feet below the base of the Tea-green Marls. This is the lower belt of workable gypsum, belt B. The higher belt (A) of the Newark district comprises about 60 feet of strata immediately below the Tea-green Marls. See 'Special Reports on the Mineral Resources of Great Britain: vol. iii—Gypsum & Anhydrite' Mem. Geol. Surv. 1915, p. 9.

There is little red and streaky rock, but certain parts are similar to the 'bird's-eye' of Cumberland: that is, rounded clots or patches of white gypsum set in a matrix of red gypsum (see p. 185). The roof consists of a definite belt of marl, sandy loam, and 'skerry' similar to that at Woodlands. In places the seam is thin, owing to the inclusion of masses of horizontally-bedded foulstone connected with that of the floor. In the Duddle workings a rock with pale-green stain is found in outlying parts where the seam appears to be less continuous and full of foulstone. The green portions usually underlie the white rock.

Fauld and Draycott.—At Fauld and Draycott-in-the-Clay the seam appears to be very similar. Mr. T. Trafford Wynne refers to extremely white and soft gypsum found in detached bodies near the edges of the main deposits near Tutbury, and locally termed 'self-pillars.' He states[1] that

> 'on the small hills in the vicinity of Castle Hayes, between Tutbury and Fauld, may still be seen the remains of shallow excavations from which the blocks of alabaster were extracted in the past. These blocks do not appear to have been portions of any regular seam, but were detached lumps of varying size.'

Dr. R. Plot observes[2] that

> 'in some of it [alabaster] there are veins of a dirty red colour, which yet are not very unsightly; but they have a sort which is harder and stronger than the rest, bearing a better polish, and finely water'd with a blewish colour, much esteemed by Artists, it making as good work almost as Marble . . .'

The roof of the main deposit is composed of hard marl containing still harder blue marl, 'bullets' and 'balls' (see p. 187) of gypsum, weighing several tons.

Here, therefore, the conditions are similar in many respects to those at Chellaston. (The main seam, however, contains anhydrite, and in places the top of the seam swells upwards into domes, each of which contains a core of anhydrite.)

Newark-on-Trent.—In this district the seams occupy a higher horizon in the Keuper Marl,[3] and consist of a series of thin beds of white gypsum with rows of lenticular nodular masses, or of balls, in the marls between and above them. Identical beds can be matched in quarries several miles apart, and each is separated from its fellows by only a few feet of marl in parallel stratification. Occasionally the three separate beds, known as Top White Rock, Middle White Rock, and The Riders, combine to form one thicker seam. Mr. A. T. Metcalfe notes[4] that in thick (relatively only to

[1] 'Gypsum, & its Occurrence in the Dove Valley' Trans. Inst. Min. Eng. vol. xxxii (1906–1907) p. 172.

[2] 'The Natural History of Staffordshire' 1686, p. 174.

[3] See footnote, p. 182.

[4] 'The Gypsum Deposits of Nottinghamshire & Derbyshire' Trans. Inst. Min. Eng. vol. xii (1896–1897) p. 110.

the thinner Newark seams) beds the upper portion is usually the purest; the bottom is commonly coarsestone or foulstone.

Carlisle District.—In the Vale of Eden, so well known to Goodchild, the deposits of Cocklakes, Acrehead, and Cotehill occur in the gypsiferous shales beneath the St. Bees Sandstone. The seam is as much as 24 feet thick, and is split up usually into three layers, the central being anhydrite. With this exception the seam, as a whole, is very similar to those of the Derbyshire and Staffordshire districts. It is, however, a more continuous deposit and a less stained variety of rock. The lower seam of gypsum is split into two by a bed, or post, of coarse stone of variable thickness. From a purely stratigraphical standpoint all the evidence suggests original stratiform deposition. The boundaries (resembling bedding-planes) are as regular as those, for example, in a series of bedded sandstones and shales. The beds forming the floor are parallel to the deposits, and, apart from local disturbance due to solution of the top of the seam, the overlying marls and shales are also regular and undisturbed. The question as to whether there has been any conversion from anhydrite to gypsum, or *vice versa*, will be discussed later.

Penrith District.—Farther south deposits of gypsum occur at Kirkby Thore and Temple Sowerby, in the Plant-Bed Series at the top of the Permian deposits.

At Kirkby Thore Quarry (situated about 1 mile north-east of Kirkby Thore Railway-Station) the gypsum forms a massive bed, from 18 to 20 feet thick, which is overlain by a gypsiferous 'cap' and underlain by a gypsiferous 'black post.' The seam shows clear evidence of its formation as a stratified deposit.

The rock is greenish grey to faintly pink, and of close-grained saccharoidal texture; but in some cases it consists of selenite-crystals, set in a ground-mass of the finer-textured rock stained by grey colour-bands and splashes which probably owe their character to organic impurity. The bands are narrowly spaced ($\frac{1}{2}$ to $\frac{3}{4}$ inch apart), and the seam can be divided into four separate horizons showing different arrangements in descending order (fig. 5, p. 185):

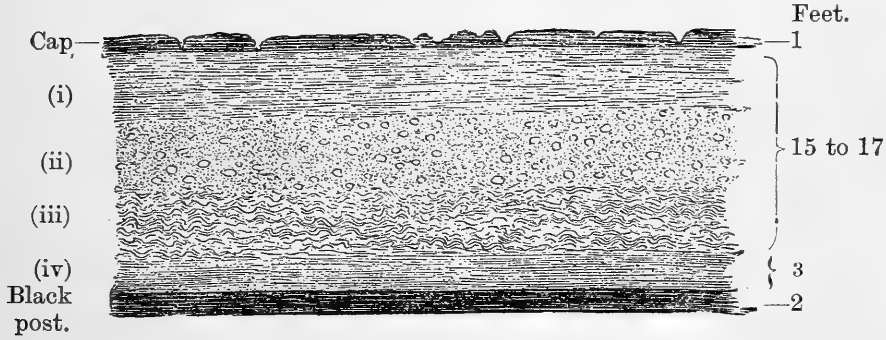
(i) Bands nearly horizontal and parallel.
(ii) Nests of white gypsum set in a dark-grey matrix ['bird's-eye'].
(iii) Bands folded and sometimes contorted.
(iv) Bands horizontal.

Each band of colour is apparently the accompaniment of successive thin sheets of gypsum, similar to some of those in the cap and black post, laid down one upon the other, the contained impurities having been thrust to the surface (or bottom) of each layer during the process of crystallization. They recall the traces of horizontal bedding occasionally visible in the Chellaston pillars.

In the third horizon the contortions are similar to those which occur in certain other stratified rocks, such as fine sandstones, and were probably due to lateral creep on a gently-sloping floor under the action of gravity.[1] In this connexion it may be recalled that in my estimation the gypsum of the Chellaston pots retained a soft and sticky consistency for a long time. The folds in the contorted layers are about 1 foot long and from 6 to 8 inches in amplitude.

The 'bird's-eye' may be due to segregation of white gypsum set up at many different spots in a soft grey gypsum that had been deposited in unbroken sequence with no definite laminar or stratiform arrangement (compare, for instance, clay with shale). The absence of any sign of angularity in the white portions, or of broken cover, is against the theory that 'bird's-eye' is due to brecciation. The white fragments may be compared with the rounded lumps at the bottom of the Chellaston pillars, and in the coarsestone. Bird's-eye occurs sometimes in the pink and white rock of other areas: for example, Cocklakes and Aston Glebe.

Fig. 5.—*Diagrammatic section showing the structure of the gypsum at Kirkby Thore Quarry.*



[(i) & (iv)=horizontal bands; (ii)='bird's-eye'; (iii)=folded bands.]

The 'cap' and the 'black post' are similar one to the other: that is, mixed, stratified sediment and gypsum, the latter often in stellate clusters arranged along the bedding-planes. The cap is undisturbed, and any signs of disturbance in the overlying marls can be fully explained by collapse of these beds into the solution-channels and potholes formed by subsoil water in the cap. In Derbyshire such disturbances in the overlying beds have probably been accentuated by the differential shrinkage of the more irregular seam during consolidation.

At Thistle Plaster Quarry, a short distance to the west, the same seam is 16 feet thick. There is little or no 'bird's-eye' here, and most of the colour-bands are horizontal. This is consistent with the theory that the bed was laid down in successive thin sheets, for one part might suffer contortions under the action of gravity, or even disturbance by current action, while another, a little farther off, might be unaffected. Disturbances in the marls and drift overlying the seam are again obviously due to the action of

[1] B. Smith, 'Ball or Pillowform Structures in Sandstones' Geol. Mag. dec. 6, vol. iii (1916) pp. 146–56.

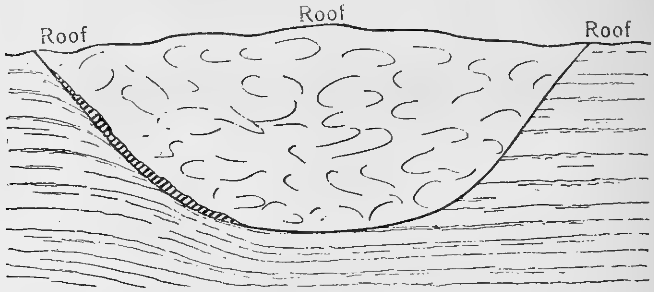
subsoil-water in the formation of channels and pot-holes in the seam, and lend no support to Goodchild's theory of 'downward percolation' (p. 188).

At Acorn Bank Mine, about three-quarters of a mile north-east of Temple Sowerby, the gypsum overlies a bed of anhydrite of fairly regular distribution, but wanting at intervals. The complex seam rests upon shales, etc., overlying a lower bed of gypsum, no longer worked. The whole of this mass is probably the equivalent of the seam at Thistle Plaster Quarry.

The Weald.—In the Weald of Kent the evidence is in favour of the gypsum of the Purbeck Beds having been formed *in situ*, much in its present condition.

The roof and floor of the seam at the Subwealden Mine, Robertsbridge, consist of alternations of stratified shales, silts and limestones with gypsum, like the 'cap' of Kirkby Thore, the limestone being a new component. The obvious stratification and lamination of the sediment points to deposition in shallow water, in which considerable agitation is indicated by ripple-marks and current-bedding. The gypsum in these beds occurs either in little thin layers of brownish tint, or as a cement, or sometimes in fibrous veins.

Fig. 6.—*A pillar of white gypsum in the Subwealden Mine. On the left is a slickensided surface with fibrous gypsum.*



[Scale: 1 inch=3 feet.]

The main seam of gypsum averages 4 feet in thickness, but is rather irregular, although its central plane maintains a fairly constant horizon. Where the bed is thickest it is purest, where thinnest it is more mixed with coarsestone: the bed, in fact, is a complex of gypsiferous shales and limestones with irregularly scattered lenticles and masses of white gypsum. The latter seem to represent 'pillars' like those of Chellaston or Aston Glebe. It must be noted that the white masses are often basin-shaped below, and very frequently the horizontally-bedded shales in the coarsestone abut against their curved surfaces, like the marls against the Chellaston pillars (fig. 3, p. 179). Subsequent movements of all the Purbeck strata have caused a certain amount of internal readjustment in the seam, and occasionally the solid masses of gypsum have been driven through the more yielding calcareous shales and thin limestones that underlie or abut against them. Thus, as in the case figured (fig. 6, p. 186), slickensides may be developed at the contact. The purest gypsum is said to be found behind the masses of limestone that appear to swell up from the floor or descend from the roof. In such cases it is obvious that the miners have broken through foulstone into a 'pot.'

In the floor the shales contain nodules of gypsum varying in size from that of a pea upwards. These may be compared with the rounded nodules at the bottom of the Chellaston pots.

It is clear that in the process of solidification the enclosing shales and limestones pinched the seam together chiefly between the pillars, and after solidification earth-movements have affected all the beds, for they are bent into the form of a shallow anticline. There has consequently not only been readjustment in the seam itself, but the seam as a whole has undergone differential movement relative to the enclosing beds, resulting in the creation of planes of weakness at the top and bottom of the seam. These are now filled with fibrous gypsum, which, according to the miners, occurs as a continuous sheet both above and below the seam; but, where the seam is thickest and purest, the fibrous gypsum is thinnest, and *vice versa*. This is what might have been expected.

IV. Suggested Nomenclature: 'Pillars,' 'Balls,' and 'Domes.'

In the foregoing account I have used the term 'pillar' only in reference to those isolated masses of gypsum that are shaped more or less like bowls, and it seems well that it should be thus restricted. There are other isolated masses of different shape that have been variously denominated bullets, balls, etc., which should be distinguished from pillars when possible.

The rounded, ellipsoidal or bi-convex masses might be called 'nodular masses' or 'balls,' while those which are the inverse of pillars and are shaped like inverted bowls or plano-convex lenses resting on their flat faces, might be termed 'domes.' The term 'ball' could be used in all cases where both shape and origin are indefinite.

There is no difficulty in understanding how the nodular masses of different sizes may have been formed in series or as isolated units, when we recall the formation of isolated pillars. In Nottinghamshire I have noticed 'domes' occurring in isolation above the main gypsiferous horizon.[1] The surrounding marls appear both to abut against their convex backs, and to arch partly over them.

It seems probable that the 'pillar' habit is due to segregation of pure gypsum in successive layers of sediment during a period of increasing mineral deposition; while the plano-convex 'dome' habit is due to segregation of pure gypsum during a period of decreasing mineral deposition.

[1] 'Geology of the Melton Mowbray District' Mem. Geol. Surv. 1909, p. 15.

Mr. A. T. Metcalfe states that, in the portions of the strata immediately surrounding a large 'ball' in the Newark district, gypsum

> 'sometimes appears to be altogether absent, as though it had been drawn away to form the "ball" by a concretionary process.'[1]

Goodchild claims to have seen many cases in Cumberland, as well as in Staffordshire and Westmorland, where the original bedding of the marls can be distinctly traced through nodules of gypsum, and he deduces that the nodules have grown by secretion *in situ*, and have displaced the marls.[2]

While we may admit that a limited amount of secondary secretory action may have taken place at times, it seems more likely that the segregatory action was original; especially when we remember that traces of bedding are visible in the original red gypsum of the Chellaston pots (pp. 179, 181).

V. 'Downward Percolation' Theory.

Goodchild, as mentioned above (p. 177), states that the prevailing mode of occurrence of gypsum, at the present day, is that of thin sheets interleaved with a succession of sedimentary deposits; and, after many years of experience and on mature deliberation (*op. supra cit.* p. 442), he expressed the opinion that most, if not all, of our British deposits of gypsum

> 'seem to represent numerous episodes of higher salinity in the history of the old inland lakes—the normal periods, or those of lower salinity, being represented by the ordinary form of sediment present in those rocks.'

Up to this point we are in agreement. He goes on to say, however, that the sulphate of lime diffused throughout the sedimentary strata was to some extent dissolved by subsequent infiltration and transported to lower levels, where it has been concentrated in more or less nodular, or even as stratiform, masses, there being at the same time a gradual displacement of the beds around. The deposit grows by further additions, extruding a corresponding quantity of the matrix as it does so.

Exception must be taken to this explanation of the formation and growth of the beds of gypsum, for there is little field evidence to uphold the theory, which has already been challenged by the late D. Burns.[3]

At Chellaston there is no sign whatever of addition to the seam from above at a date subsequent to deposition; for, to take only one point, the horizontally-bedded and practically undisturbed foul-

[1] 'The Gypsum Deposits of Nottinghamshire & Derbyshire' Trans. Inst. Min. Eng. vol. xii (1896–97) p. 109.

[2] 'Some Observations upon the Natural History of Gypsum' Proc. Geol. Assoc. vol. x (1887–88) p. 435.

[3] 'The Gypsum of the Eden Valley' Trans. Inst. Min. Eng. vol. xxv (1902–1903) p. 414.

stone between the pillars occurs right up to the top of the latter: that is, to the roof of the deposit as developed at Woodlands and Aston Glebe. Nor is there any sign of a similar action in the Newark district; and it appears to me inconceivable that beds of such regular thickness and such large area could be produced by this means. The extrusion of a corresponding quantity of Keuper Marl would necessitate the regular vertical uplift of several feet of strata, in each case over many square miles. Again, the intervening beds of marl are often still gypsiferous. Also two or three beds may be quite close one to the other, whereas at other times a thin bed may be overlain by a fairly thick mass of still highly gypsiferous marl.

The theory might be seriously entertained if the layers of gypsum were frequently oblique to the stratification of the marls, or if the extrusion of the matrix had been highly irregular.

Other objections might easily be raised; but, since these beds rarely exceed a foot in thickness, Goodchild might have allowed that they are original. If so, we might enquire why they have not been thickened by downward percolation, seeing that the gypsiferous marls bear a strong similarity to those of the Eden Valley. The deposits have been described by Mr. A. T. Metcalfe, who considers them to be the deposits of a saline inland sea.[1]

In the Carlisle district Goodchild's theory can be applied only to the top bed of gypsum, for he does not suggest that the downward-moving gypsum can be converted into anhydrite in the process. This will leave the lower 14 feet of the seam to have been formed by original deposition, or in some other way. As above stated, the lower bed of gypsum is split into two by the inclusion of a central rib of coarsestone, which should be deprived of its gypsum if the lowest part of the seam were due to downward percolation. On the contrary, however, there is evidence that the gypsum, in either coarsestone or foulstone, both in this and in other districts, is partly secondary and derived from the pure seams.

The occurrences at Kirkby Thore and Temple Sowerby give no support to the percolation theory, which Burns condemns as being quite untenable upon dynamical grounds alone.[2] Goodchild refers to the disturbed nature of the beds immediately above the seams in the Eden Valley as evidence in favour of his theory. The disturbance, however, appears to be due to solution of the top of the gypsum by subsoil waters in recent times (p. 185).

In the Purbeck deposit of the Weald there is not the slightest evidence of secondary additions. The seam is one of original deposition, the gypsum having been laid down continuously with the ordinary sediments in alternating layers, as a rule; although in places a 'pot' of gypsum occurs from which sediment was excluded at the time of deposition, but not pushed aside by a subsequent segregatory process.

[1] 'The Gypsum Deposits of Nottinghamshire & Derbyshire' Trans. Notts Nat. Soc. 1894; and Trans. Inst. Min. Eng. vol. xii (1896-97) pp. 107-14.

[2] 'The Gypsum of the Eden Valley' Trans. Inst. Min. Eng. vol. xxv (1902-1903) p. 414.

VI. 'Volcanic' Theory.

Another theory has been advanced by various writers, namely, that the beds were originally limestones which have been converted into gypsum by sulphureous waters, either directly on the sea-bed or under a certain amount of cover. This explanation was offered by Burns to account for the deposits of the Eden Valley in particular,[1] assuming that the beds were covered by little or no sediment at the time of alteration.

The sulphureous waters are usually assumed to be due to volcanic (solfataric) action; yet among the British Mesozoic rocks there is no evidence of such action, and there is very little in the rocks associated with the gypsiferous deposits of the Permian Era.

If altered, the limestones must have been fairly pure to begin with, but few of the known Permian and Triassic limestones ever are pure, while those associated with the Sussex gypsum are impure. In the latter case it is hard to imagine, from the character of the seam, how a pure limestone could be converted into gypsum in so irregular a manner. At Kirkby Thore the structure of the gypsum precludes this suggested mode of origin.

Gypsum and anhydrite certainly occur in association with the Magnesian Limestone; but sliced specimens (p. 196) seem to show that the whole deposit was original.

If any limestones had been altered under cover, at a date long subsequent to their deposition, there would surely have been found intermediate stages of the process.

Dr. A. Wade describes how shells, or raised coral-reefs, become converted into gypsum in the Eastern Desert of Egypt,[2] but considers it due partly to capillary action, and partly to a metasomatic replacement of the calcium carbonate, in which the shells are destroyed. In such cases intermediate stages are found, and volcanic action is not suggested.

It would appear that, if I have rightly interpreted the origin of the Chellaston Breccia, most of the important deposits of calcium sulphate in this country must be regarded as original and formed contemporaneously with the sediments in which they now occur. An explanation is still required for the irregularity of some of the seams and the segregation of the purer masses in pots, balls, or domes. Yet, whatever the cause, which is a problem that more immediately concerns the chemist, the facts of deposition hold good. There seems to be a general tendency for mineral salts to collect in lenticular masses, either bi-convex or plano-convex, when the convexity may be above or below.

[1] 'The Gypsum of the Eden Valley' Trans. Inst. Min. Eng. vol. xxv (1902–1903) pp. 410–34.

[2] 'Some Observations on the Eastern Desert of Egypt' Q. J. G. S. vol. lxvii (1911) p. 253.

VII. Anhydrite in its Relation to Gypsum.

(a) Field Evidence.

In cases where anhydrite is associated with gypsum it is interesting to determine, if possible, whether the present association is original, or whether conversions from the one to the other have taken place since the time of deposition. The subject is difficult and full of pitfalls; but I venture to discuss it because it seems to be inseparable from the subject of this paper, and also in the hope that it may lead to further light being thrown upon the subject.

We may consider the following possible changes, which might have taken place in different cases:—

(1) The whole deposit was originally gypsum, which was first converted into anhydrite, and then partly reconverted into gypsum.
(2) The whole deposit was originally anhydrite.
(3) The deposit originally was partly anhydrite and partly gypsum.

(1) An example under this head occurs at Ludwig Mine, Lyon County (Nevada), where the change from gypsum to anhydrite is thought (by J. Claude Jones[1]) to have been due to an igneous intrusion, and the subsequent reconversion to gypsum to vadose waters operating near the surface of the ground.

Another example is the gypsum-anhydrite association in New Brunswick and Nova Scotia described by H. E. Kramm,[2] who assumes that the minerals were deposited from sea-water as gypsum, and converted into anhydrite by being warmed to $63\frac{1}{2}^{\circ}$ C., or more, under a thick cover of sediment. With removal of the load rehydration began, and is still going on.

According to Prof. R. C. Wallace, who has recently discussed the genetic relationship of gypsum to anhydrite in North America,[3] direct geological evidence has yet to be adduced before any theory can be accepted that transformation of gypsum to anhydrite at great depths below the surface takes place to such an extent as to be of geological importance.

No one, so far as I am aware, has suggested that the gypsum-deposits of Britain have suffered so many vicissitudes, therefore we may pass on to a consideration of the next possibility.

(2) This is a simple case to state, but one quite as difficult to prove. Burns puts it as follows[4]:—

> 'The prevailing idea is that the whole bed was at one time anhydrous and has gradually, through geological ages, been converted into gypsum, a process which is still going on.'

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[1] In a letter ('Economic Geology' vol. vii, 1912, pp. 400–402) discussing a paper by Dr. A. F. Rogers (*ibid.* pp. 185–89), who considers that the anhydrite is original.

[2] Summ. Rep. Geol. Surv. Canada for 1911 (1912) pp. 322–27.

[3] 'Gypsum & Anhydrite in Genetic Relationship' Geol. Mag. dec. 6, vol. i (1914) pp. 271–76.

[4] 'The Gypsum of the Eden Valley' Trans. Inst. Min. Eng. vol. xxv (1902–1903) pp. 417–18.

Cases in which transformation processes may have taken place, and undoubtedly did take place, at or near the surface, contemporaneously with the deposition of the beds and while they were in a soft and wet condition, must be ruled out. In these circumstances expansion due to hydration would have no effect upon the underlying sediments, or upon those subsequently deposited.

Prof. Wallace states[1] that the conditions under which natural anhydrite could be transformed into gypsum are as follows:—

(*a*) at 30° C. in presence of a saturated solution of sodium chloride.
(*b*) at 66° C. in presence of water.

The figures given by Van't Hoff are 32° C. and 63½° C. respectively.

With regard to conversion during past ages:—

(*α*) In the Keuper of Cumberland, Nottinghamshire, Staffordshire, and Durham there is no convincing field evidence[2] to support the theory that conversion has taken place under a thick blanket of sediment. Even if the temperature were suitable and a saturated solution of common salt available, it might be expected to operate on beds of anhydrite in the same area in the same way; we should not expect to find, for example, one seam of anhydrite converted into gypsum at both top and bottom, as at Cocklakes, and another only altered at the top, as at Acorn Bank. In the first case the expansion on conversion would be liable to shatter the enclosed rib of anhydrite in all directions and separate it into isolated fragments, instead of which we find a practically solid bed. Again, the more irregular seams and isolated occurrences, where the anhydrite occurs sporadically, would be easily penetrated in all directions by invading solutions. In such cases we should expect practically no anhydrite to be left unchanged, if any of the gypsum was formed by this process.

(*β*) These arguments would apply also in the case of water at the higher temperature.

The conclusion that hydration is still going on (in the Eden Valley) is founded on the following observations[3]:—

'(i) Near the outcrop, where the circulation of water has been freer, the anhydrite entirely disappears, as it does also at the edges of the bed where it comes up against the clay; (ii) following a deposit into the hill ... as the cover increases, so usually does the proportion of anhydrite; and (iii) wherever a feeder of water has been found to traverse the bed, the rock has been found hydrated in that neighbourhood.'

From these observations Burns draws other conclusions, which, in my opinion, are nearer the truth, namely, that the masses of

[1] 'Gypsum & Anhydrite in Genetic Relationship' Geol. Mag. dec. 6, vol. i (1914) p. 272.

[2] For certain details of these occurrences see Special Reports, vol. iii, 'Gypsum & Anhydrite' Mem. Geol. Surv. 1915; 2nd ed. 1918.

[3] D. Burns, 'The Gypsum of the Eden Valley' Trans. Inst. Min. Eng. vol. xxv (1902–1903) p. 418.

pure gypsum are most easily attacked by water and denuded, so that the gypsum surrounding the anhydrite areas is on the edges of the areas of pure gypsum that have been removed. He also points out that it is difficult to see how a ball of anhydrite, in the midst of gypsum, could be converted into gypsum without bursting the surrounding rock. He finally concludes that the central parts, where they are now anhydrite, have always been anhydrite.

On the north-western boundary of Cocklakes Mine the seam is faulted parallel to a line along which the anhydrite thins out, and the upper and lower beds of gypsum coalesce. The writer interpreted this as implying that the fault occurred along a line of weakness where the strengthening rib of anhydrite was absent.

With regard to the action of subsoil water, we may observe that at Acorn Bank, where there is no underlying gypsum, the anhydrite has been as freely exposed at the bottom as at the top to the action of percolating water for countless years. Again, at Cocklakes the open joints, or 'backs,' in the anhydrite are merely faced by 1 or 2 inches of gypsum, which occurs in thin layers like stalagmite, the anhydrite being apparently unaffected. The conversion of the upper and lower layers of a bed of anhydrite into gypsum would give rise to the shattering of the remainder of the anhydrite, but this has not happened.

At Fauld, also, the anhydrite is apparently unaffected, and it is found where quantities of water are met with.

Lumps of anhydrite left in the open doubtless become covered with a film of gypsum in a few years, but this is probably due to actual solution and redeposition rather than replacement.

Although we have no records of the conversion having taken place in this country, cases have been met with and reported on elsewhere.[1] At least one case is known in Europe, in which a tunnel was driven through a deposit of anhydrite and thrown out of alignment by the swelling of the material when changed into gypsum, the alteration being brought about by trickling water.[2]

(3) Prof. Wallace concludes that, while secondary transformations are possible at considerable depths, and also at the surface, the character of the gypsum-anhydrite deposits of North America may be accounted for most directly, and with least difficulty, as due to original deposition.[3] British occurrences seem to call for a similar generalization.

Since, in the first place, there are no indications that the gypsum of the Chellaston pots, or the gypsum of the Kirkby-Thore quarry, was ever anhydrite, we might argue that there is no reason why the gypsum associated with anhydrite in the equivalent seams should ever have been in the anhydrous state.

[1] Sir Archibald Geikie, 'Text-Book of Geology' 4th ed. vol. i (1903) pp. 400 & 453.

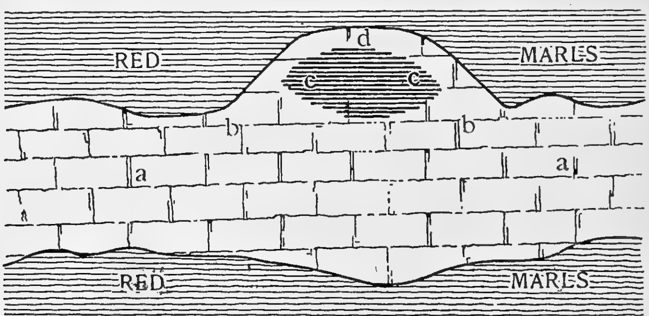
[2] H. Ries & T. L. Watson, 'Engineering Geology' 2nd ed. (1916) p. 114.

[3] 'Gypsum & Anhydrite in Genetic Relationship' Geol. Mag. dec. 6, vol. i 1914) p. 276.

The regularity of the beds of anhydrite at Cocklakes, Cotehill, and Acorn Bank, and their fairly sharp line of demarcation from the gypsum suggest original deposition. In specimens in my possession the change in the upward direction from anhydrite to gypsum occurs in $\frac{3}{4}$ inch, and in the downward direction in $1\frac{1}{2}$ inches.

At Fauld the conditions are somewhat different. The anhydrite, or, as it is locally termed, 'hard stone,' is met with in varying quantities, and is found sometimes in one and sometimes in another part of the seam, although never immediately in contact with the roof or floor of the mine, and it appears and disappears without any apparent reason. There seems to be no dividing line and no clear cleavage between gypsum and anhydrite, the latter being often intimately mixed with the best gypsum-stone. Near the surface it is rare, and it appears to increase with the thickness of cover—all of which might be taken as arguments in favour of the conversion of anhydrite into gypsum.

Fig. 7.—*Section showing the occurrence of 'hard stone' (anhydrite) at Fauld. (After T. Trafford Wynne.)*



[Scale: 1 inch = 32 feet.]

a = seam of normal thickness; b = thickening of seam; c = anhydrite; d = fine white gypsum.

Where the seam is thickest (over 20 feet), however, a bed of anhydrite is often found at points rising above the average height of the gypsum, with a further thickness of best-quality gypsum above it (fig. 7). Had the gypsum been derived from original anhydrite one would have expected the unaltered cores to be situated lower down and nearer the centre of the seam, not in masses rising above the average level.

These thickenings at the top of the seam are said to be usually from 15 to 40 feet in diameter, more or less circular in form,[1] and the anhydrite in them varies from 2 inches to 3 feet in thickness. They are, like the 'domes' of Nottinghamshire and other districts (p. 187), welded on to the main seam; and, since these masses of anhydrite are apparently not relics of what was previously a thick

[1] T. Trafford Wynne, 'Gypsum, & its Occurrence in the Dove Valley' Trans. Inst. Min. Eng. vol. xxxii (1906–1907) p. 180.

bed of anhydrous calcium sulphate, it is reasonable to suppose that the gypsum surrounding the masses is original, unless indeed some of it suffered conversion at the time of deposition of the remainder.

Since anhydrite, according to Van't Hoff, can be precipitated in the presence of a strong solution of common salt at 36° C., but may be converted into gypsum at 32° C. under the same conditions, and since anhydrite is often found inside gypsum masses, and unmixed with ordinary sediment (dolomite when precipitated chemically is an exception), there is a reasonable probability that many of the anhydrite masses were formed during periods when the waters were hotter and the land suffering under more intense conditions of drought than when the gypsum was deposited. With fall of temperature—sometimes due to influx of land water—and change in strength of the solutions, gypsum would be deposited again, and part of the anhydrite might, or might not, be hydrated before being buried too deeply to be affected. When drought was greatest, ordinary sedimentation was least, hence large beds of anhydrite are more frequently found in contact with gypsum rather than with sediment.

In those cases where anhydrite is mixed confusedly with gypsum and muddy sediment, or occurs in the centre of isolated balls, the deposition not only of the anhydrite, but of the gypsum and the attendant sediments as well was also irregular. Constant changes in the strength of the various mineral solutions were taking place with the inrushes of water that brought the sediment into the inland basins. Transformation processes at, or near, the surface (often at fairly high temperatures) would thus play a greater part than in those cases where crystallization was more regular.

Thus the field evidence, on the whole, appears to be in favour of the formation of the greater part of both the anhydrite and gypsum of England as original deposits that have undergone little subsequent alteration since they were buried by later deposits.

(*b*) Microscopic Evidence.

We may now discuss the evidence furnished by the microscope:—

(i) In a specimen of the anhydrite from Cocklakes, the mineral occurs in long crystals, less sheaf-like than those of the Gotham and Fauld rock that will be described presently. Plates of gypsum occasionally enclose crystals of anhydrite in ophitic fashion, and with these are minute rhombs of dolomite (measuring $\frac{1}{60}$ mm.), smaller than those of the Magnesian Limestone of Nottinghamshire and Yorkshire, referred to below, where the rhombs measure about $\frac{1}{20}$ mm. These rhombs are aggregated in lines and clusters separating variously oriented bundles of anhydrite-crystals (measuring $\frac{2}{3}$ mm. $\times$ $\frac{1}{12}$ mm. average size; bundles are 2 to 3 mm. across): they give to a hand-specimen of the rock a pseudo-crystalline appearance which is coarser than the true crystalline structure. The ophitic plates of gypsum imitate a porphyritic structure.

The plates of gypsum evidently crystallized later than the anhydrite, and these have obviously not been derived from it by hydration, but crystallized out from the mother liquor. The dolomite probably came out simultaneously with the anhydrite.

(ii) This association of dolomite, anhydrite, and gypsum occurs frequently in the Permian rocks east of the Pennines. Thin slices of Lower Magnesian Limestone from a deep boring in Lincolnshire show granular dolomite with plates and patches of anhydrite, in a ground-mass of gypsum, and with occasional parallel intergrowths of anhydrite and gypsum. The whole is suggestive of chemical precipitation and assemblage of the dolomite rhombs as a sediment, with nearly contemporaneous crystallization of the anhydrite and gypsum.

With regard to this dolomite-anhydrite, or dolomite-anhydrite-gypsum phase, we may refer to Dr. A. Wade's conclusions[1] as to the conditions of deposition of a similar series in the Eastern Desert of Egypt, namely, that it is an original deposit, occurring on the edge of an enclosed basin, in the centre of which rock-salt is the most important deposit.

(iii) A specimen of the contact collected by Dr. R. L. Sherlock, from a loose block at Gotham, consisted of bundles of crystals of anhydrite set in a matrix of gypsum, but passed rapidly into a rock in which anhydrite was predominant, the anhydrite being merely veined by gypsum. It is evident that the gypsum is of later formation than the anhydrite, while the latter is bounded by sharp outlines determined by cleavage-planes, and furnishes little evidence of alteration, although gypsum forms an infilling.

(iv) A slice of the anhydrite from Fauld, proved to be similar to that from Gotham, and the cracks formed in course of preparation of the slide are similar, as regards their boundaries, to the gypsum veins in the Gotham anhydrite.

(v) Examination of the gypsum-anhydrite contact at Cocklakes, however, discloses clear evidence of a conversion having occurred. The anhydrite occurs here between two beds of gypsum.

A. At the contact between the top of the anhydrite and the overlying seam of gypsum a change is seen, as at Gotham (iii), from gypsum at one extremity to anhydrite at the other, with an intermediate zone consisting partly of the one mineral and partly of the other (Pl. XVIII, fig. 1). The anhydrite contains gypsum-filled veins, which are arranged more or less parallel to the upper surface of the bed, become gradually smaller as they occur deeper in the body of the anhydrite, and finally taper off in thin threads. On the other hand, the isolated fragments of anhydrite, set in the gypsum mosaic, become progressively smaller as their distance from the main body of anhydrite increases.

The bulk of the gypsum is a mosaic of crystals averaging $1\frac{1}{3}$ mm.

[1] 'Some Observations on the Eastern Desert of Egypt' Q. J. G. S. vol. lxvii (1911) p. 257. See also Sir Archibald Geikie, 'Text-Book of Geology' 4th ed. vol. i (1903) p. 530.

in longest diameter, with well-defined outlines, somewhat rounded or subangular. Some much larger crystals are occasionally twinned.

The anhydrite occurs in sheaves or fascines of elongated crystals (averaging $\frac{1}{2}$ mm. in length, and from $\frac{1}{30}$ to $\frac{1}{20}$ mm. in breadth) with good rectangular cleavage and brilliant interference-tints in sections of normal thickness. The anhydrite bundles having different orientation, in some cases appear in cross-section. Cracks in the anhydrite have often been initiated in the anhydrite mass parallel to the long axis of the crystals of one of the bundles, and have then cut across the differently oriented crystals of an adjacent bundle. These cracks have probably been caused by the expansion consequent upon the conversion of anhydrite into gypsum: for, in certain cases, it is clear that there has been replacement of the anhydrite on each side of the original crack, giving rise to a vein of gypsum in which the crystals of this mineral filling the gap have taken on the habit of the contiguous crystals of anhydrite where they lie parallel to the direction of the vein (Pl. XVIII, fig. 2), and have formed well-shaped pseudomorphs—quite different from the habit of the gypsum of the mosaic.

Where the anhydrite-crystals lie transversely to the vein the gypsum occurs as an irregular mosaic, and the anhydrite frequently shows a moth-eaten appearance as if it were being destroyed in an irregular manner.

In more than one case, again, crystals of anhydrite, in optical continuity, appear on both sides of a vein of gypsum, and the vein may enclose a fragment of anhydrite, also in optical continuity with the two walls of the vein.

The isolated patches of anhydrite exhibit similar features. They appear to be in process of being 'eaten up' piecemeal, and the resultant gypsum often shows a sheaf-like arrangement in imitation of the sheaves of anhydrite, but this effect cannot be distinguished in the gypsum $\frac{1}{4}$ inch away from the average line of the junction. In the main mosaic of the gypsum these pseudomorphs have undulose extinction, similar to those of a strained quartz-crystal in an igneous rock.

B. At the contact between the bottom of the anhydrite and the lower bed of gypsum at Cocklakes (Pl. XVIII, fig. 3), there is clear evidence, as in the previous case, of the destruction of isolated remnants of anhydrite, which have a brown-stained margin and surroundings in which the original structure of the anhydrite can still be made out. The ends of the long anhydrite-crystals are often pseudomorphously replaced by brown-stained gypsum. Other anhydrite-crystals show moth-eaten boundaries, and have been replaced by gypsum with a minutely fibrous structure. The matrix consists of gypsum of the same type, with larger crystals of clear selenite in places.

Where anhydrite is predominant it is often finely granular and occasionally sheaf-like, as in the last slice, but sometimes occurs in bigger and broader crystals. Pseudomorphs of gypsum occur most naturally where the attack of solutions has been broadside to the anhydrite-crystals. Ophitic plates of gypsum occur sporadically enclosing little fragments of anhydrite, and are somewhat similar to those occurring in the body of the anhydrite away from the junction, as described above.

In both of the above cases there are also numerous rhombs of dolomite, scattered through both gypsum and anhydrite, which appear to have settled out at an early stage in the process of crystallization of the sulphate of lime. Their average size is $\frac{1}{60}$ mm. in diameter, and the larger ones are from $\frac{1}{40}$ to $\frac{1}{30}$ mm. in diameter.

Thus we are compelled to accept the conclusion that some of the anhydrite has been converted into gypsum [1] near the present line of contact at least.

In attempting to estimate the amount of the change, and the time of the change, we must remember that :—

(1) No sign of pseudomorphs can be detected a very short distance from the contact, and that the larger crystals of gypsum occur most frequently away from the zone of contact.

(2) Ophitic plates of gypsum, which must be regarded as original, occur in the anhydrite both near the bottom, and also well away from the zone of contact.

From the latter we infer that gypsum settled out at a late stage from the mother liquor from which the anhydrite was formed. There must therefore have been rather delicate chemical balances capable of being easily upset by changes in temperature or concentration.

The sequence of events seems to have been somewhat as follows [2] :—

(1) Concentration of solutions, due chiefly to evaporation through rise in temperature.
(2) Deposition of lower gypsum with larger crystals of selenite, up to a temperature of about 36° C.
(3) At about 36° C. anhydrite begins to crystallize out. Perhaps a little solution of topmost gypsum due to temporarily lessened concentration of calcium sulphate.
(4) At over 36° C. anhydrite deposited in sheaves of crystals, with mother-liquor in the interstices.

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[1] Stages in the conversion revealed by the microscope have been described by F. Hammerschmidt ('Beiträge zur Kenntniss des Gyps- & Anhydrit-Gesteines' Tscherm. Min. Petr. Mitth. vol. v, 1883, pp. 275–79), whose conclusions in the main must be accepted. In one case isolated fragments of anhydrite have regular contours, and are each surrounded by a retinue of tiny fragments separated by gypsum from the margin of the central anhydrite (pl. ii, fig. 6). They become smaller outwards until they merge into the gypsum. Some well-separated fragments have the same optical reaction, and others are now pseudomorphs after anhydrite. Conversion of anhydrite to gypsum in the United States has also been proved on microscopic examination by American geologists.

[2] For further evidence of seasonal changes in Keuper times, see my paper on 'The Upper Keuper Sandstones of East Nottinghamshire' Geol. Mag. dec. 5, vol. vii (1910) pp. 310–11.

(5) With falling temperature the deposition of anhydrite ceases at 36° C., and gypsum is again deposited in a solution with temporarily increased concentration. Plates of gypsum ophitically enclosing anhydrite begin to be formed.
(6) At about 32° C. a little of the anhydrite at both the upper and the lower contact is converted into gypsum, the contact favouring the change, which, however, for various reasons (as, for example, fall in temperature or absence of much mother-liquor near the contact) might not be extensive.

Thus the microscopic evidence, so far as I have studied it, seems to support the conclusion arrived at from a consideration of the field relationship, that most of the gypsum-anhydrite deposits of this country are original, and that conversions from anhydrite into gypsum are mainly confined to the zone of contact, and usually took place at the time of deposition.

In discussing the upper gypsum of Gypsumville, Prof. R. C. Wallace mentions that there has unquestionably been a certain amount of transformation into gypsum of the top beds of the underlying anhydrite since Tertiary times. Analyses of the upper anhydrite-beds show a continuously increasing water-value from the middle of each bed to the margin, which he takes as evidence that a gradual change is taking place. He believes, however, that only the lowest beds of the upper gypsum have thus originated, the higher beds having been precipitated as such.[1]

Microscopic instead of chemical analysis might show an increasing proportion of gypsum towards the upper and lower surfaces of these upper anhydrite-beds, due to disturbance of the chemical balance at the time of deposition, in the manner discussed above.

VIII. Fibrous Gypsum.

A few words may, perhaps, be added with regard to the occurrence of fibrous gypsum.

Most of the fibrous gypsum that I have seen appears to be of secondary origin, formed by solution and redeposition of the normally-deposited gypsum; a little may have been formed in the beginning. It has been forming from the time of deposition of the seams of massive gypsum down to the present day.

Whenever cracks appeared—in the freshly deposited and scarcely hardened gypsum; in the marls themselves, or in the seams and balls long after consolidation; and at times when later earth-movements bent, squeezed, and cracked the rocks—fibrous gypsum seems to have healed the scar. We find it as part of the translucent alabaster of the irregular deposits at Aston Glebe and Chellaston, but it rarely occurs in the more regular seams at Kirkby Thore. It forms part of the coarsestone, and riddles the foulstone through and through in tiny veinlets. It occurs where

[1] 'Gypsum & Anhydrite in Genetic Relationship' Geol. Mag. dec. 6, vol. i (1914) p. 275.

there are obvious signs of movement, especially along the boundaries of the cores of purer gypsum in the pots, and it interlaces the rocks where they have been disturbed owing to the solution of part of the thicker masses of gypsum.

Wherever a gap appeared, either horizontal, vertical, or oblique, the fibre-like crystals sprang from one or other, but usually from both walls, until the scar was healed. The fibres generally grew at right angles to the faces of the cracks, and in most cases we can trace the central joining-line where they met from opposite sides, somewhat like the irregular central junction of the prismatic columns of a basic igneous dyke.

It is being formed at the present day. In the Subwealden Mine long silky fibres spring from the pit-props and the fallen blocks of stone, where water has been drawn up by capillary action and has evaporated at the surface. In the Acorn-Bank Mine it is also growing from the roof and on the pack-walls.

Fairly-thick horizontal veins of fibrous gypsum or satin-spar are common in parts of the Keuper Marl, and at first it seems difficult to understand how the rock could be held apart, while tender fibres (like those of the Subwealden Mine) build a solid rampart across the gap. These horizontal beds, however, are most common where calcareous and dolomitic beds ('skerries') occur in the marl. During the slow desiccation of the marls, shrinkage would occur vertically as well as horizontally, and gaps might be formed and held open by the overlying girder or plate-like skerries, which might sustain a considerable weight of marl without collapsing.

Again, a slight differential movement in a horizontal direction between an irregular bed of gypsum and its enclosing sediments, caused by anticlinal or synclinal bending of the rocks—as in the Weald—would be expected to open cracks at the top and bottom of the seam. Percolating waters would do the rest.

I venture to throw out the suggestion that fibrous gypsum probably forms most easily in the presence of carbonate of lime. In the Subwealden Mine, where fibrous gypsum is growing now, the water must be strongly impregnated with the carbonate, and in the Acorn-Bank Mine there are calcareous beds in the roof. The Keuper Marls are highly charged with carbonates, and secondary fibrous gypsum occurs perhaps most freely in and near the calcareous and dolomitic skerry-belts where the gypsum was originally deposited in selenitic plates binding the marl together.

IX. Conclusions.

1. The Chellaston Breccia furnishes a concrete case, affording proof that the gypsum of which it is composed was laid down in its present position as such, and has suffered no appreciable alteration or addition since the time of its original deposition and brecciation. There is no evidence that the rock was ever anhydrous.

2. The brecciation was due to the instability of the cover over-

lying isolated, or nearly isolated, masses of soft gypsum filling depressions or 'pots' in the Keuper Marl.

3. By comparison with this deposit, and also by independent evidence, it seems probable that the greater number, if not all, of the important beds of gypsum in this country were deposited as gypsum and have never been in the anhydrous condition. They have behaved throughout as stratiform deposits, and have suffered internal movements, nearly contemporaneous with their formation, similar to those that have occurred elsewhere in semi-consolidated laminated silts and sandstones of various geological ages.

4. When anhydrite is present, the balance of evidence favours the view that it is original, and was deposited in a stratiform manner, in sequence with gypsum, the deciding factors being chiefly temperature and concentration of solutions. When it occurs in the middle of balls of gypsum, both minerals are, in part, segregations.

5. Microscopic evidence furnishes proof that there has been in some cases an alteration of anhydrite into gypsum. This alteration, however, is considered to have occurred at the time of deposition, and to be confined to the existing plane of contact between the two minerals.

6. In this country no case has been made out for the conversion of a bed of limestone into gypsum.

7. Fibrous gypsum is nearly always of secondary origin, and has been formed, whenever the opportunity offered, from the date of deposition of the gypsiferous beds down to the present day.

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EXPLANATION OF PLATES XVII & XVIII.

PLATE XVII.

A pillar of gypsum, Chellaston Alabaster Quarries. This shows the upper, fairly-continuous, white alabaster, overlying pink or red alabaster with included masses of white—forming the 'Breccia.' The nearly horizontal markings are wire-saw cuts. (See p. 178.)

PLATE XVIII.

Fig. 1. Section showing the contact between the top of the anhydrite and the overlying seam of gypsum at Cocklakes Mine, Cumberland. On the left of the slide is anhydrite with veins of gypsum; on the right of the slide is gypsum enclosing isolated patches of anhydrite. The section shows, at the top, pseudomorphs of gypsum after anhydrite. The small black rhombs are dolomite. Ordinary light. Magnification × 16. (See p. 196.)

2. The same as above, between crossed nicols. The points marked A in the two sections are identical. Magnification × 16. (See p. 196.)

3. Section showing the contact between the bottom of the anhydrite and the underlying seam of gypsum at Cocklakes Mine, Cumberland. On the left of the slide is anhydrite; on the right of the slide gypsum. The irregular ('moth-eaten') boundary of the anhydrite is seen, where the crystals lie transversely to the average line of contact with the gypsum. Isolated patches of anhydrite are partly replaced by brown-stained gypsum. The small black rhombs are dolomite. Ordinary light. Magnification × 25. (See p. 197,)

DISCUSSION.

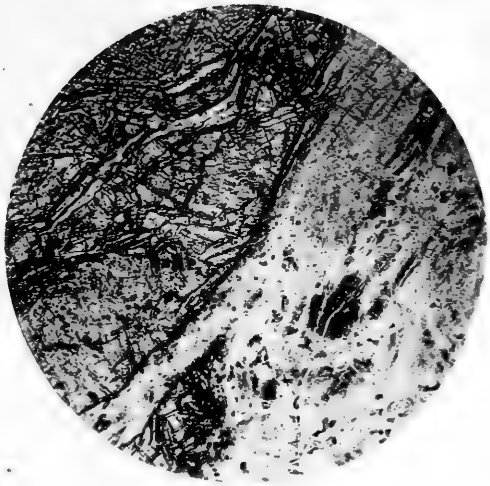
The PRESIDENT (Dr. A. HARKER) expressed his appreciation of the value and interest of the paper, and remarked that each occurrence of gypsum and anhydrite offered its own problems.

Dr. J. W. EVANS thought that the Author had brought forward a number of interesting new observations with regard to the structure and relations of the deposits described. He enquired whether these were not mostly of Triassic age. The mineral precipitates of the Permian were apparently the result of the desiccation of an isolated marine area at a temperature, as a rule, sufficiently high to determine the formation of anhydrite, which has since been converted into gypsum. This has been shown to be the case in Germany, and the course of events was doubtless the same in the

R. O., Photo.

Bemrose, Collo., Derby.

PILLAR OF GYPSUM, CHELLASTON ALABASTER QUARRIES.



1. ×16

2. ×16

3. ×25

H.H.T., Photomicro.

Bemrose, Collo., Derby.

ANHYDRITE AND GYPSUM FROM COCKLAKES MINE (CUMBERLAND).

closely similar deposits of the North-East of England. Those of the Trias, on the other hand, would seem to be due to the desiccation at a lower temperature of inland lakes, which very probably owed the materials they held in solution to wind transport across the desert, in the manner demonstrated by Sir Thomas Holland in the case of the Sambhar Lake.

Mr. J. F. N. GREEN asked whether there was any evidence that the 'pillars' had formed as actual pillars on the lake-floor, like those found now in certain salt-lakes—as, for example, those of Mono Lake (California), where the structure was developed in concentric layers, sediment afterwards filling up the gaps. Or was chemical and sedimentary deposition simultaneous on a level floor?

Prof. W. J. SOLLAS thought that this excellent piece of petrological work might prove to have an important bearing on other branches of geological study. The alternations of rock-salt and anhydrite at Stassfurth had already suggested seasonal changes from summer to winter, and these could be counted, so that it was possible to determine the rate of deposition. In the alternations of anhydrite and gypsum an even more definite record of changes in temperature and other conditions might, perhaps, be discovered.

Sir HENRY HOWORTH and Mr. W. WHITAKER also spoke.

The AUTHOR, in reply to Dr. Evans, pointed out that some of the seams that provided the strongest evidence of original deposition occurred in the Permian rocks of the Vale of Eden. He was aware that conversion of anhydrite into gypsum had occurred in Germany, but evidence was not always forthcoming that the whole of each bed of gypsum was formed in this way.

The carvings made from Derbyshire and Staffordshire alabaster were, as Sir Henry Howorth stated, justly famous, and of exceeding beauty. Dr. Plot records that in the first half of the 17th Century, a pure white alabaster, watered with a bluish colour, was highly prized by sculptors. This rock was similar to the blue-veined alabaster quarried by Mr. Forman. The best white rock used in the past probably came from isolated pillars.

An interesting point was raised by Prof. Sollas. The Author had indicated recently how the 'skerry' bands or belts of the Keuper, or the laminated silts and shales of the Ordovician and Silurian, might one day furnish time-scales by which the duration of these respective periods might be measured.

Replying to Mr. Green, he did not think that the pillars stood out above the surrounding sediments during formation; their upper surfaces, however, might have been slightly convex. There was little difference between the gypsum at the surface and that under cover.

In conclusion, his thanks were due to Dr. H. H. Thomas and Dr. F. L. Kitchin for their kind help during the preparation of the paper.

8. *The* Kelestominæ: *a* Subfamily *of* Cretaceous Cribrimorph Polyzoa. By William Dickson Lang, Sc.D., F.G.S. (Read June 5th, 1918.)

I. Introduction.

In 1906, under the name *Cribrilina jukes-brownei*, Mr. Brydone [1] described a Cretaceous cribrimorph Polyzoan of remarkable structure. There is little beyond its cribrimorph intraterminal front-wall to connect it with *Cribrilina*; [2] indeed, at the time of the establishment of *C. jukes-brownei* its affinities were unknown for lack of correct interpretation of certain of its more specialized features; and, were it not for the subsequent discovery of an allied species, *Morphasmopora brydonei*,[3] connecting the highly-specialized *M.* [*Cribrilina*] *jukes-brownei* with a less-specialized form from Rügen described by Marsson under the name of *Kelestoma elongatum*,[4] the extraordinary modifications of *Morphasmopora jukes-brownei* might still be unexplained.

Kelestoma and *Morphasmopora* are quite separate, though allied, genera of Pelmatoporidæ, isolated from the rest of the family and constituting the subfamily Kelestominæ. The Pelmatoporidæ are a very large assemblage of Cretaceous cribrimorph Polyzoa, that is, of Cheilostome Polyzoa whose intraterminal front-wall is built of more or less fused terminal spines. The family consists of those whose fused spines (costæ) are produced as hollow outgrowths upwards beyond their fusions; the broken ends of these form rows of pelmata (when of small diameter, pelmatidia) on the surface of the intraterminal front-wall. The complete family was dealt with in summary detail in 1916,[5] and its largest section, the subfamily Pelmatoporinæ, in a more expanded manner in [1919].[6] Its various subfamilies may be derived from a hypothetical ancestral Pelmatoporid, and, in order to explain the structure and evolution of the Kelestominæ, it is convenient first to examine this hypothetical Pelmatoporid ancestor.

II. The Primitive Pelmatoporid (fig. 1).

To arrive at such an ancestral form it is necessary to strip from the various Pelmatoporid subfamilies all that is specialized in them and all that is exclusively diagnostic of them, thus discovering

[1] R. M. Brydone, Geol. Mag. dec. 5, vol. iii (1906) p. 297 & fig. 9 on p. 298.

[2] The inaptness of applying Recent generic names to Cretaceous Polyzoa was realized by Brydone (see *op. cit.* p. 292).

[3] W. D. Lang, Ann. & Mag. Nat. Hist. ser. 8, vol. xviii (1916) p. 85.

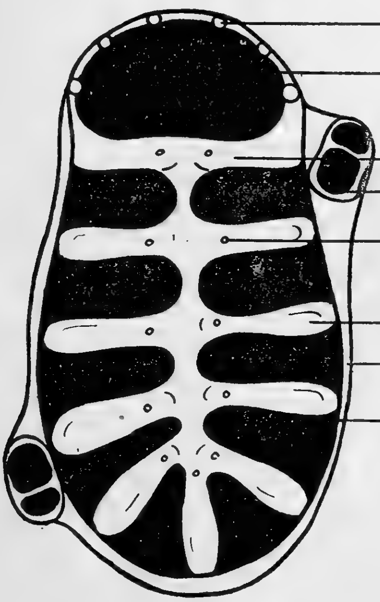
[4] Th. Marsson, 'Palæontologische Abhandlungen' vol. iv (1887) p. 99.

[5] W. D. Lang, *op. cit.* pp. 83–112.

[6] W. D. Lang, Phil. Trans. Roy. Soc. ser. B [vol. ccix]. The paper, read in November 1917, is in the press.

the underlying primitive characters which compose the common ancestor. To do so presupposes a general knowledge of the various subfamilies, and it is not proposed to enter into a description of these, but to take the knowledge for granted, and to describe this supposed ancestral form. The hypothetical ancestral Pelmatoporid (fig. 1), as I conceive it, was a multiserial, incrusting, unilaminar cribrimorph Polyzoan. The œcia were dimorphic, that is, consisted of normal œcia and avicularia; the former of moderate size (about ·4 mm. long), and generally elliptical in shape. The extraterminal front-wall was comparatively small. There was no secondary interœcial tissue. The intraterminal front-wall consisted of about

Fig. 1.—*Diagram of a hypothetical Primitive Pelmatoporid. × about 150 diameters.*



ten rather slender and very widely-separated costæ with no lateral costal fusions, but firmly united in a thin median line of fusion. Close to this line of fusion were the upturned, hollow prolongations of the costæ, which were of small diameter, so that their broken ends form a row of pelmatidia on each side of the mid-line. Each half of the apertural bar resembled the other costæ. The aperture was semicircular or super-semicircular in shape. There were six small apertural spines. The avicularia were comparatively numerous, sporadically distributed in the interœcial valleys, indifferently orientated, monomorphic, small and with blunt, short apertures divided by a bar into a smaller, more or less semicircular, proximal, and a larger, distal, or mandibular portion. Such a form is diagrammatically represented in fig. 1, and it is necessary to grasp its essential characters in order to understand the following description of their modifications.

It has been claimed[1] that the Cheilostome Polyzoa, in evolving from primitive to specialized forms, continually pass from a less to a more calcareous condition, and that, consequently, their skeletons contain more and more calcium carbonate as any one line of evolution proceeds. Further, it was claimed that this secretion of calcium carbonate (whether originating as a by-product of metabolism, or as the final result of an explicit excretory act), though at first, possibly, of use to the organism for rendering its skeleton more protective, very soon got out of control, probably through the inefficiency of inhibiting factors; and it became a pressing problem in the organism's bionomy where to dispose of its increasing superfluity of calcium carbonate so as least to interfere with its normal functions. There is no evidence that the Polyzoa ever gained control over this derangement of metabolism, or that they ever learned to counter it by resorption; but a good deal to show that these calcareous lineages are doomed to ultimate extinction under their masses of superabundant skeletal tissue.

III. The Kelestominæ.

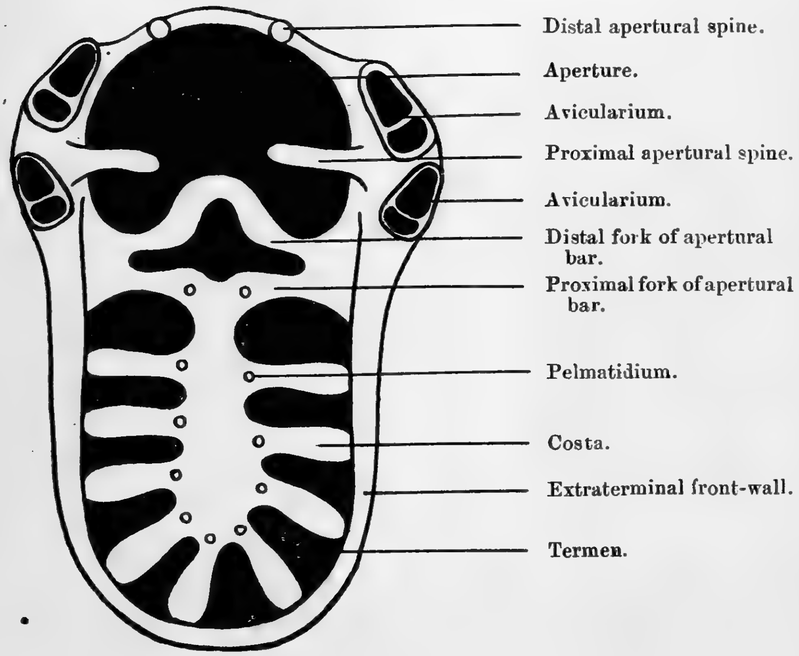
It is to be expected, then, that the dominant feature in the development of the Kelestominæ from the Primitive Pelmatoporid will be the greater calcification of the skeleton. It has been shown[1] that this is brought about in the cribrimorphs mainly by a general solidification of the intraterminal front-wall, and a deposition of secondary calcium carbonate on the middle portion of that structure; by laying down secondary calcium carbonate in the interœcial valleys; and by building up secondary structures in the neighbourhood of the aperture. All three methods are used in the Kelestominæ, but the last two are the most prominent. Besides these three general methods of depositing secondary calcium carbonate, the following structural modifications occur in the Pelmatoporidæ generally, many of them ministering to one or other of the general methods, or affording by themselves the opportunity of increased deposition of calcium carbonate. (Catagenesis, however, often implying a smaller deposit of calcium carbonate in the structure concerned, may come about in certain cases.) The asty tends to become erect and bilaminar or cylindrical; the œcium tends to increase in size, to become shorter compared with its length, and more parallel-sided; the number of costæ increases, but may again diminish by catagenesis; the apertural spines are reduced from six to four, but are often greatly enlarged and otherwise modified in connexion with a secondary aperture; the avicularia become fewer, definitely distributed, definitely orientated, dimorphic or polymorphic, larger, and with more pointed apertures.

[1] W. D. Lang, Geol. Mag. dec. 6, vol. iii (1916) pp. 74–76, and Ann. & Mag. Nat. Hist. ser. 8, vol. xviii (1916) p. 82.

Generally the Kelestominæ conform to these common rules. It is in the emphasis that they lay on particular applications of some of these rules that they are peculiar. The structures mainly affected in the Kelestomine evolution are (1) the apertural bar; (2) the apertural spines; (3) the interœcial secondary tissue; and (4) the number of costæ. The first two are correlated and are most important, concerning, as they do, both genera fundamentally; the third also concerns both genera; and the last behaves somewhat differently in *Kelestoma* and in *Morphasmopora*.

It is, therefore, possible to reconstruct a hypothetical Primitive Kelestomine from which both *Kelestoma* and *Morphasmopora* may be derived. Such a form, diagrammatically represented in fig. 2, is considered to have the following characters:—the

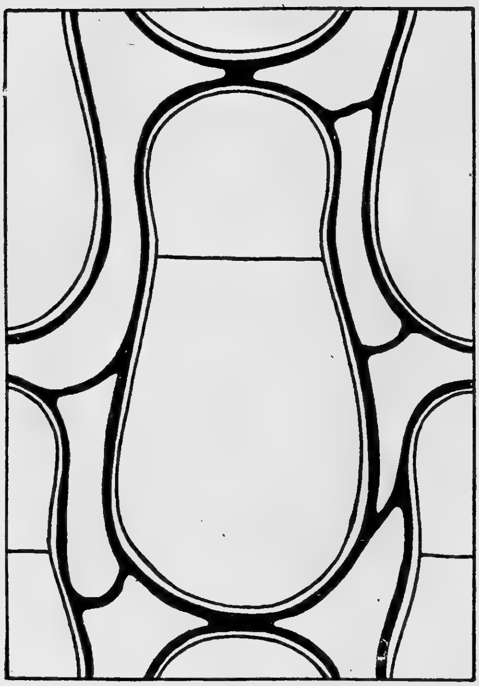
Fig. 2.—*Diagram of a hypothetical Primitive Kelestomine.* × *about 133 diameters.*



asty is incrusting and unilaminar; the œcia are dimorphic; the normal œcia are about ·5 mm. long, about ·3 mm. wide, and elliptical in shape; there is a fair amount of secondary interœcial tissue; the costæ are about ten in number; each half of the apertural bar is bifid in a more or less vertical plane, and the upper prongs of each half fuse one with the other, as do those of the lower half; the number of the apertural spines is reduced to four, and the proximal pair are considerably enlarged; their distal ends approach or even unite with the fusion of the upper prongs of the apertural bar; the aperture is normal in shape; the avicularia are definitely arranged in one or more pairs on each side of the aperture of every normal œcium.

On comparing, now, the Primitive Kelestomine with the Primitive Pelmatoporid, the former will be seen to have advanced upon the latter in the following particulars:—the œcium is larger; there is present some secondary interœcial tissue; the apertural bar is complicated; the apertural spines are reduced in number, and the proximal pair are differentiated in connexion with the apertural bar; the aperture is more advanced in shape; and the avicularia are definite in numbers and position. The diagnostic Kelestomine character is the bifid apertural bar. The other modifications, even the enlargement (though in a less degree) and fusion with the apertural bar of the proximal pair of apertural spines, are common developments, or occasionally seen in other Pelmatoporid subfamilies. Nevertheless, the development of secondary interœcial tissue and the behaviour of the avicularia must also be further examined, if the complexities of *Morphasmopora jukes-brownei* are to be fully understood.

Fig. 3.—*Diagram of an œcium and portions of six others, very much enlarged, to show how secondary tissue arises as contour-like ridges and buttress-like spurs in the interœcial valleys. (Secondary tissue is the thick black line.)*



The development of secondary interœcial tissue may be considered first. In the Pelmatoporidæ generally, secondary interœcial tissue first appears as a contour-like ridge running round the front-wall in the neighbourhood of the termen (fig. 3) and occasionally sending out buttress-like spurs that run across the interœcial valleys and meet the ridge of secondary interœcial tissue of the opposite œcium. As these contour-like ridges and buttress-like spurs are reinforced by more calcareous tissue, it appears as if the interœcial valleys were filled up to the levels of the termina with interœcial secondary tissue, but that this tissue had median lacunæ (elongate between two œcia, but triangular where three œcia meet) at the bottom of which the extraterminal front-wall can still be seen (fig. 4). Next, these lacunæ become smaller, their floors become covered with secondary tissue, and, finally, they become obliterated, while the interœcial valleys become so full of secondary tissue that this tends to overflow the intraterminal front-wall (fig. 5). The last condition is never attained by the Kelestominæ; but both *Kelestoma* and *Morphasmopora* have abundant interœcial secondary tissue with elongate lacunæ, and, in *Morphasmopora jukes-brownei*, these elongate lacunæ, whether in the form of long slots or very much lengthened triangles, take on a curved or wavy shape, and often simulate the apertures of avicularia.

Fig. 4.—*Diagram representing a further development of the condition represented in fig. 3. The secondary tissue (black) has increased in amount.*

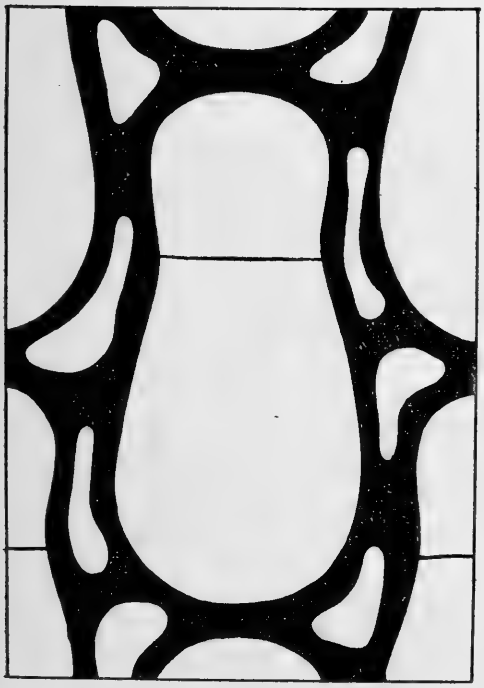
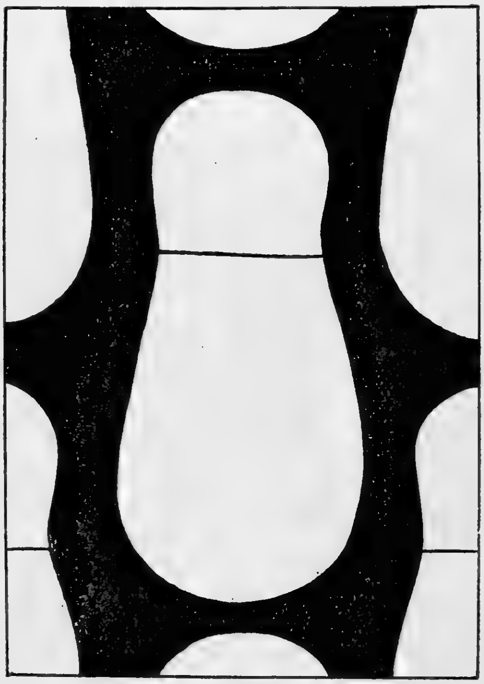


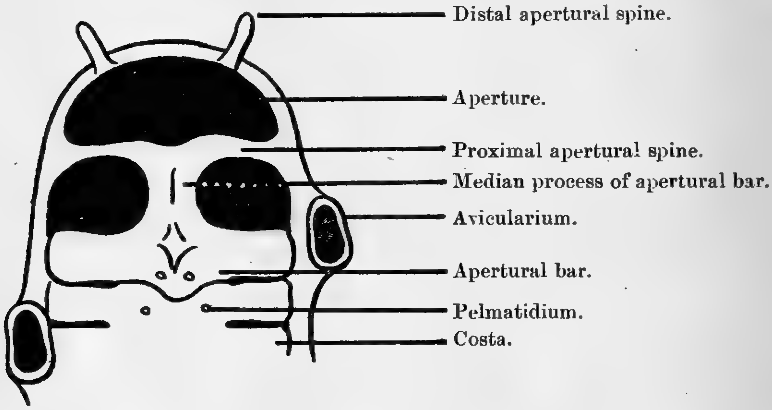
Fig. 5.—*Diagram showing a still further development of secondary tissue (black) which now completely fills the interœcial valleys, and has no median lacunæ.*



The behaviour of the Kelestomine avicularia also is noteworthy. We have seen that the sporadically-distributed, indifferently-orientated, blunt-apertured avicularia of the Primitive Pelmatoporid became the definitely-placed and definitely-orientated, somewhat acute-apertured avicularia of the Primitive Kelestomine. The numbers are fixed at four, in two pairs, in connexion with the aperture of every normal œcium; and, of these pairs, the more proximal is placed in the interœcial tissue just beside the proximal pair of apertural spines, and the distal pair just distal to them. During evolution, the proximal pair are sooner or later discarded, and the distal pair become raised on long pillar-like pedestals that keep at about the same height as the fusion of the proximal apertural spines with the fused distal forks of the apertural bar, and form with them the proximal shield of the secondary aperture. There is always, however, a deep cleft between these pedestalled avicularia and the proximal apertural spines, that may, nevertheless, be imperfectly filled with secondary tissue—imperfectly because of the median lacuna in the secondary tissue. The avicularia are always more or less distally directed.

It is difficult to account for the bifid splitting of the apertural bar. Only the proximal fork of each side bears a pelmatidium, showing that each half is not formed of two adjacent costæ fused proximally and diverging distally. The Kelestomine apertural bar is to some extent comparable with that type, occurring independently in more than one family of cribrimorphs, which has a median spine that (like the fused distal forks of the Kelestomine apertural bar) fuses with the proximal pair of apertural spines to form the proximal shield of a secondary aperture. In such cases (fig. 6)

Fig. 6.—*Diagram of the distal end of the œcium of a Pelmatoporid having a median process of the apertural bar fused to the proximal pair of apertural spines. Very much enlarged.*



it is often obvious that the median spine is double: that is, formed of two fused processes, one from each half of the bar; and often, in the Pelmatoporidæ, the pelmatidium- or pelma-bearing end of each half of the bar is turned somewhat towards the proximal end of the œcium: that is, in a direction opposite to that in which the median process is turned. This gives a tendency to the formation of a diamond-shaped depression in the middle of the apertural bar. Now the Kelestomine apertural bar has a similarly diamond-shaped opening between its two pairs of fused forks, formed, apparently, in a similar way. Thus it may be regarded as a further development of the apertural bar with a median spine; or the bar with a median spine a further fusion of the Kelestomine bifid bar. The former is the more probable; since the spined structure occurs several times in different families and genera of cribrimorphs and in most cases can be derived from a simple apertural bar.

One other character of the Primitive Kelestomine must be noticed. The apertural spines are reduced to four in number from the six of the Primitive Pelmatoporid. It is obvious that, if this were all, the amount of calcium carbonate deposited in apertural spines would be less in the Primitive Kelestomine than in the Primitive Pelmatoporid from which it is derived; and this is contrary to the fundamental principle postulated for cribrimorph evolution. But the proximal pair of apertural spines is very much thickened in the Kelestominæ, and the loss of a pair is much more than counterbalanced in this enlargement of the proximal pair. It is difficult to see any positive reason why the spines should be reduced in number; but such a reduction is almost universal in the Pelmatoporidæ (the Castanoporinæ provide exceptions), and is shown by the ancestrœcia of many four-spined forms having six apertural spines. In fact, the ancestrœcium of *Morphasmopora jukes-brownei* (fig. 12, p. 217) has six, and the proximal pair is already considerably enlarged. It seems, then, that the reduction in the number of Pelmatoporid apertural spines is a true catagenesis, and that the increased superfluity of calcium carbonate released thereby must be laid down in other parts of the skeleton. Because of parallel instances in other subfamilies of Pelmatoporidæ, the possession in *Morphasmopora brydonei* of six apertural spines is regarded as a Primitive Pelmatoporid rather than a Primitive Kelestomine character.

To sum up: the Kelestominæ are Pelmatoporidæ in which each half of the apertural bar is bifid in a more or less oblique plane, and each fork fuses with the corresponding fork of the other half; moreover, the fused distal forks fuse with the proximal pair of apertural spines, which are very much enlarged. Other characteristic, though not diagnostic features, are an abundant interœcial secondary tissue with narrow, elongate lacunæ, which tends to spread into and fill up interstices in the rim of the secondary aperture; and one or two pairs of avicularia accompanying the aperture of every normal œcium.

IV. Kelestoma Marsson (fig. 8, p. 214).

And here *Kelestoma* and *Morphasmopora* part company. They take opposite directions with regard to two correlated characters: namely, comparative œcial length, and the number of costæ. *Morphasmopora* also carries to extremes certain modifications of structure which *Kelestoma* does no more than initiate. In *Kelestoma*, then, the œcial length greatly increases compared with its width, from being less than twice as long as wide in the Primitive Kelestomine to nearly three times as long as wide in *Kelestoma*. The costæ also increase from less than ten in the Primitive Kelestomine to over twenty in *Kelestoma*; and the pelmatidia have retreated somewhat from the mid-line, leaving a broad median area of fusion. There is a considerable amount of secondary interœcial tissue with elongate and fairly straight median lacunæ.

The proximal shield of the secondary aperture is formed by the fusion of the proximal pair of apertural spines with the fused distal prongs of the bifid apertural bar. The distal prong and the proximal spine of each side lie nearly parallel and separated by a deep slot. The avicularia are reduced to a single pair placed one on each side of the aperture immediately distal to the proximal pair of apertural spines, directed obliquely towards the mid-line of the aperture which they accompany, and carried up on a pedestal to a level with the proximal rim of the secondary aperture. The avicularia lie close alongside the apertural spines, are parallel with them, and are separated from them only by a deep groove. There are thus three structures lying alongside each other and parallel with each other: namely, the distal forks of the apertural bar, the proximal apertural spines, and the avicularia; also the first two are separated by a slot-like hollow, and the last two by a deep groove. The distal shield is lower than the proximal shield, and merely

Fig. 7.—*Diagram of the distal end of an œcium of a hypothetical Primitive* Kelestoma. *Very much enlarged.*

consists of a rim of secondary tissue continuous with the secondary interœcial tissue lying between the aperture and the œcium distal to it and containing large median lacunæ. This distal shield overtops and obliterates the distal pair of apertural spines. Thus the secondary apertural ring consists distally of a rim of secondary tissue, proximally (somewhat laterally) of the circum-apertural avicularia, then of the broken ends of the proximal pair of apertural spines, and, finally, of the fusions of the proximal apertural spines and the fused distal forks of the bifid apertural bar. Moreover, a patch of secondary tissue with a more or less circular median lacuna fills a gap in the ring between the apertures of the circum-apertural avicularia and the broken ends of the proximal apertural spines. The complete secondary aperture is diagrammatically shown in fig. 8 (p. 214), and an intermediate stage between this and the aperture of the Primitive Kelestomine and occurring in a hypothetical Primitive *Kelestoma* is shown in the accompanying figure (7).

Evolution within *Kelestoma* appears to have affected colonial habit, œcial size, costal number, and avicularian shape. The asty progresses from incrusting, through erect and bilaminar to erect and cylindrical; the œcia increase somewhat in size; the costæ undergo a slight catagenetic decrease in number; and the avicularia tend to become more pointed. These characteristics may be summarized in the following tabular diagnosis of the three species:—

1. *Kelestoma elongatum* Marsson. Incrusting; œcia about ·75 mm. long; costæ, 27 to 30.
2. *Kelestoma gradatum*, sp. nov. Erect, bilaminar; œcia about ·9 mm. long; costæ about 27.
3. *Kelestoma scalare* Lang. Erect, cylindrical; œcia about ·9 mm. long; costæ about 24.

All these species occur in the Senonian, zone of *Belemnitella mucronata*, on the island of Rügen.

KELESTOMA GRADATUM, sp. nov. (fig. 8, p. 214).

Diagnosis.—*Kelestoma* with an erect, bilaminar asty; œcia about ·9 mm. long; costæ about 27.

Distribution.—Senonian, Campanian, zone of *Belemnitella mucronata*; Rügen.

Type specimen.—British Museum, D 15065. Agnes Laur Collection. Since *Kelestoma gradatum* has not yet undergone published description, it is necessary to give it formal descriptive treatment.

V. MORPHASMOPORA Lang (figs. 10–12, pp. 215–17).

Kelestoma diverged from the Primitive Kelestomine by greatly lengthening the œcia and greatly increasing the number of costæ. The Primitive *Morphasmopora* may be imagined as remaining comparatively squat in œcial shape, and but slightly increasing the number of costæ of the Primitive Kelestomine; though carrying the differentiation of apertural spines to far greater lengths than does *Kelestoma*. Besides, the avicularia of *Morphasmopora* are primitively four in number (being two only in the Primitive *Kelestoma*) accompanying the aperture of each normal œcium—a lowly, more proximal pair and a distal pair that during evolution becomes carried high up on a pedestal to the level of the secondary apertural rim; moreover, their apertures in *Morphasmopora brydonei* are distally and obliquely directed away from the mid-line of the aperture that they accompany, instead of towards it as in *Kelestoma*, but proximally and obliquely towards the mid-line in *Morphasmopora jukes-brownei*. Fig. 9 (p. 214) is a diagram of the aperture of a hypothetical Primitive *Morphasmopora* showing these characters. In *Morphasmopora jukes-brownei* (fig. 11, p. 216) one pair of avicularia has been lost, and the single proximally-directed pair is not so highly raised on the apertural rim. This species is also catagenetic in the number of costæ, possessing ten only, whereas in *M. brydonei* they had increased to twelve from the original ten of the Primitive Kelestomine.

Fig. 8.—*Diagram of* Kelestoma gradatum, *sp. nov.* × *about 133 diameters.*

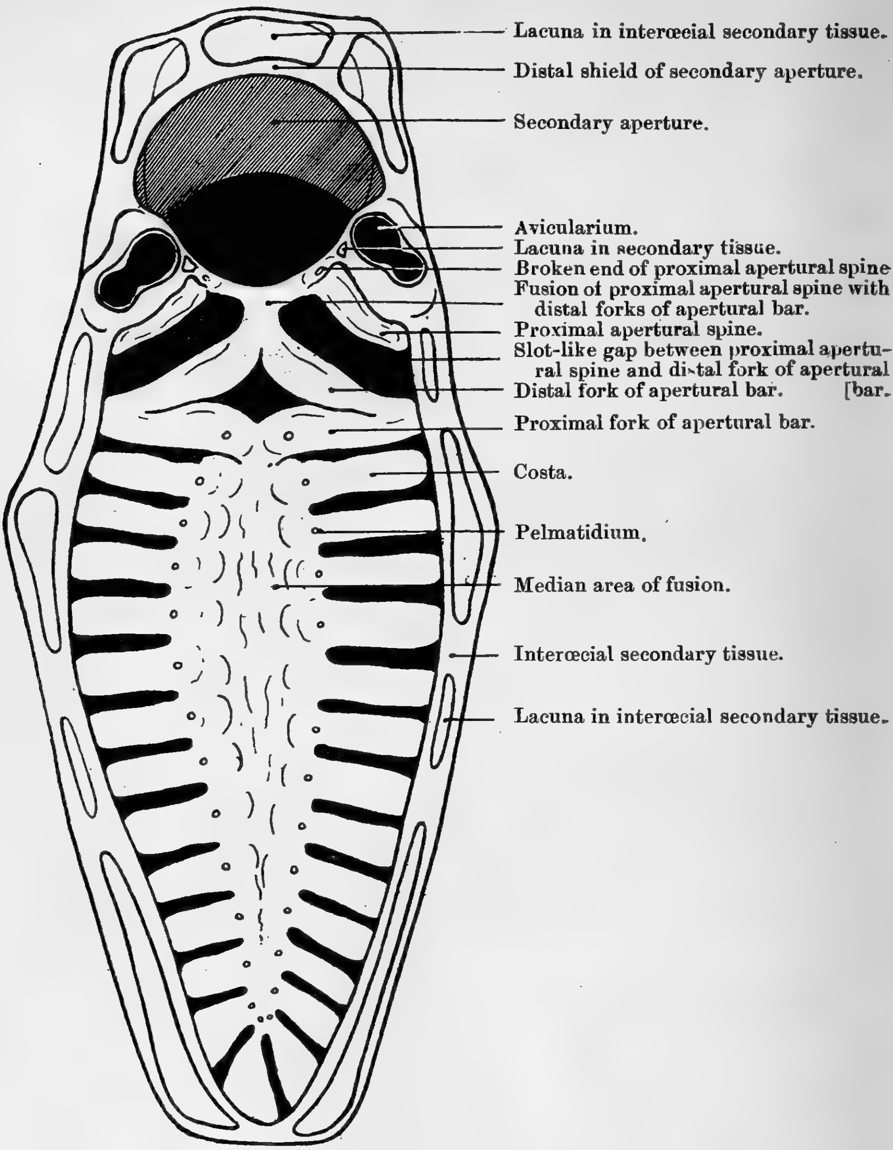
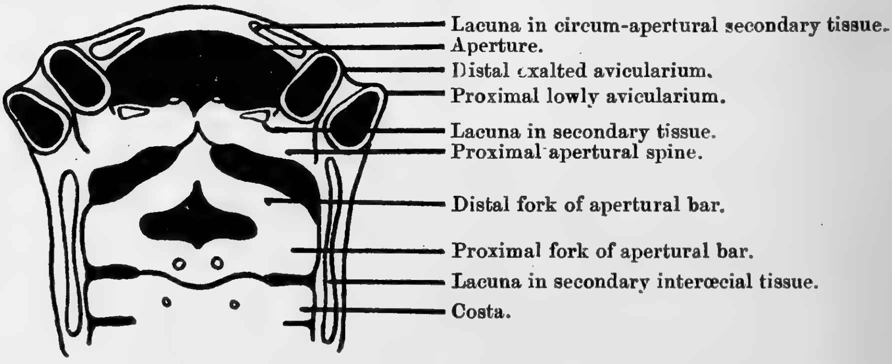


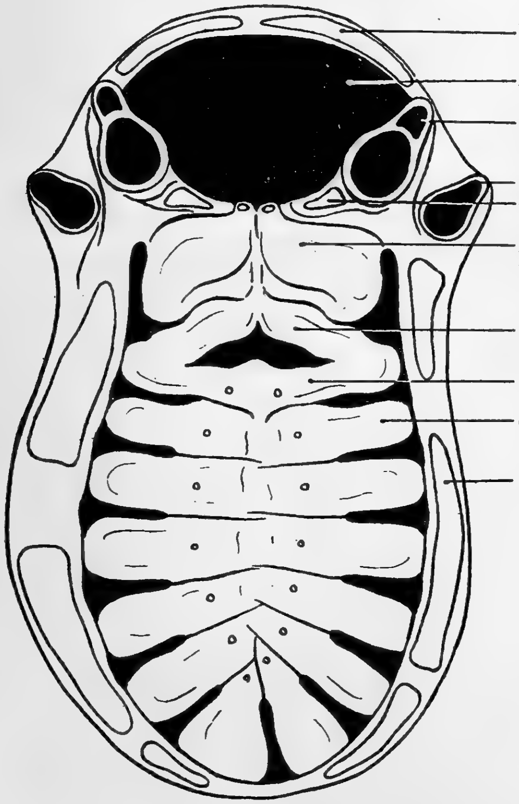
Fig. 9.—*Diagram of the distal end of the œcium of a hypothetical Primitive* Morphasmopora. *Very much enlarged.*



VI. Morphasmopora brydonei Lang (fig. 10).

The secondary aperture of *Kelestoma* is peculiar in appearance; that of *Morphasmopora* is almost grotesque; that of the Primitive *Morphasmopora* may well have had an intermediate appearance, as suggested in fig. 9. From such a condition, the extraordinary aperture of *M. brydonei* may have been evolved by the enormous enlargement of the proximal apertural spines which impinge against

Fig. 10.—*Diagram of an œcium of* Morphasmopora brydonei. × *about 133 diameters.*

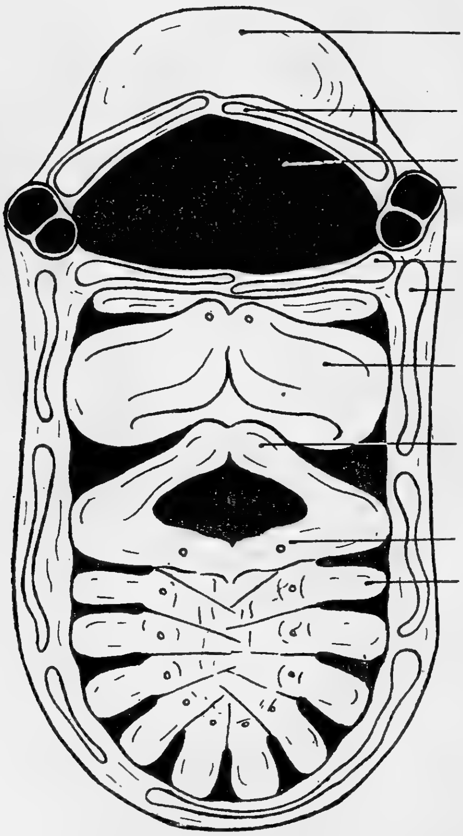


the distal forks of the apertural bar, but form fusions with them only distally. On the proximal rim of the aperture, the apertural spines remain separated from the pedestalled avicularia by a patch of secondary tissue with a median lacuna. The distal apertural rim is amalgamated with the secondary interœcial tissue surrounding the aperture, and this has long slot-shaped lacunæ; thus a long and a short pair of lacunæ occur respectively on the distal and proximal parts of the apertural ring.

VII. Morphasmopora jukes-brownei (Brydone) (figs. 11 & 12, pp. 216–17).

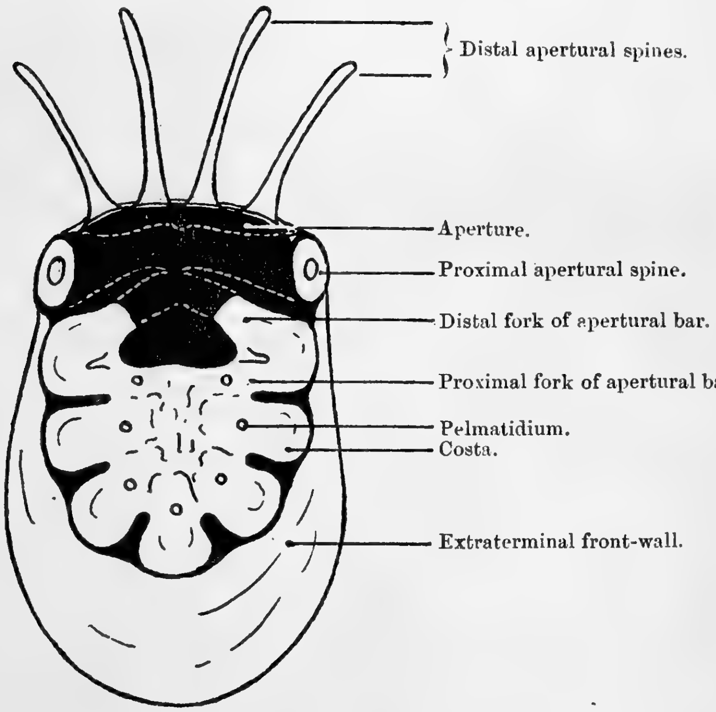
An evolution has been followed from hypothetical primitive forms through the comparatively simple *Kelestoma* and the more complex *Morphasmopora brydonei.* And in its light the extremely modified structures of *M. jukes-brownei* may now be interpreted. The intraterminal front-wall occupies only about the proximal half of the œcium, and that part of it which is formed by the apertural bar is nearly as big as the more proximal part formed of normal costæ. The costæ are about ten in number, rather widely spaced;

Fig. 11.—*Diagram of an œcium of* Morphasmopora jukes-brownei. × *about 133 diameters.*



but their pelmatidia have retreated from the distal ends nearly to half-way to the proximal ends, and the median area of fusion occupies all the space between the pelmatidia—thus the intraterminal front-wall is considerably consolidated. The apertural bar is greatly enlarged, each fork being wider than a normal costa. There is a large, more or less diamond-shaped median space between the fused forks on each side. The proximal pair of apertural spines is even larger than in *M. brydonei,* and occupies as much room as the apertural bar with its bifurcations. The fused distal forks of the apertural bar fuse with the apertural spines; but proximally there is a deep cleft between the apertural spines and the apertural bar. The circum-apertural avicularia are not so highly raised as in *M. brydonei*, are blunter in shape, more widely separated, and directed proximally and towards the mid-line of the aperture which they accompany; and the patch of interœcial tissue that was intercalated in *M. brydonei* between the avicularium and the proximal apertural spine on each side is extended to meet its fellow patch across the distal ends of the apertural spines, so that the proximal edge of the secondary aperture is formed of this strip of secondary tissue with its long, tongue-shaped, median lacunæ. Distal to the

Fig. 12.—*Diagram of ancestrœcium of* Morphasmopora jukes-brownei. × *about 175 diameters.*



avicularia the distal edge of the secondary aperture is bounded, as in *M. brydonei*, by two strips of secondary tissue meeting in the mid-line, each containing a long, somewhat triangular lacuna, so that each bears some resemblance to a much-elongated avicularium. The interœcial secondary tissue has long, sinuous lacunæ.

A comparison of fig. 11 (p. 216), representing the ephebastic *Morphasmopora jukes-brownei*, with fig. 2 (p. 207), representing the hypothetical Primitive Kelestomine, shows the extent to which modification is carried in the former.

VIII. The Ancestrœcium of Morphasmopora jukes-brownei (fig. 12, p. 217).

It is fortunate that the ancestrœcium of *Morphasmopora jukes-brownei* should have been preserved in one of the specimens of this species in the British Museum collection (D 8005). It is to be expected that its characters will fall into three categories: (1) primitive characters expressing remote ancestral influence; (2) youthful characters exhibited in simplicity of structure due to tender age; and (3) advanced characters indicating high specialization. To the first cause is due the great number of the apertural spines, the large size of the extraterminal front-wall, and, perhaps, partly, the small œcial size and the small number of the costæ; to the second, mainly, the small œcial size and, partly, the small number of costæ; also the absence of secondary tissue; while the greatly enlarged proximal pair of apertural spines, their (presumed) fusion with the apertural bar, and the bifid character of the last-named structure are characters that fall under the third category. It is interesting, in this connexion, to note that the ancestrœcium of *M. jukes-brownei* not only does not show any peculiar specific characters, but does not even proclaim the genus *Morphasmopora*. The utmost systematic characters that it exhibits are those of the subfamily Kelestominæ.

The ancestrœcium may be described as follows:—The œcia are about ·3 mm. long, about ·2 mm. wide, and oval in shape. The extraterminal front-wall is very large, at least proximally. The costæ are five in number. The apertural bar is bifid and very large, but not so large, comparatively, as in the ephebastic œcia. The proximal apertural spines are greatly enlarged, but they are thinner than the costæ; while the ephebastic apertural spines are about four times as thick as the costæ. Distal to the enlarged proximal apertural spines are two pairs of long, thin, distal apertural spines. There is no secondary tissue.

IX. Summary.

The Kelestominæ are a subfamily of Pelmatoporidæ, characterized by a bifid apertural bar. By stripping the diagnostic characters from the various Pelmatoporid subfamilies, a hypothetical Primitive Pelmatoporid is obtained, from which the Kelestominæ (as well as the other subfamilies) can be derived. Similarly, a hypothetical Primitive Kelestomine may be reconstructed, from which the two Kelestomine genera (*Kelestoma* and *Morphasmopora*) can be independently derived. *Kelestoma* is chiefly characterized by its great œcial length and the large number of its costæ; and evolution within the genus is mainly concerned with an anabasis of colonial characters and œcial length, and a catabasis of costal number; and is expressed in the single lineage *K. elongatum*—*K. gradatum*—*K. scalare*.

Morphasmopora has two species, *M. brydonei*, with four avicularia accompanying each normal œcium, and a less specialized (though extraordinarily complex) secondary aperture; and *M. jukes-brownei*, with a pair of avicularia to each normal œcium, and a secondary aperture formed of structures so specialized that, were it not for comparison with *Kelestoma* and *Morphasmopora brydonei*, they would be almost impossible to interpret. The ancestrœcium of *M. brydonei* shows characters that fall into three categories: namely, primitive, youthful, and special.

All the material described is from the Senonian, zone of *Belemnitella mucronata*, of Rügen, except a metatype specimen of *Morphasmopora jukes-brownei*, from the same zone at Trimingham, Norfolk, in the British Museum Collection (D 8005).

Discussion.

Dr. S. F. Harmer did not feel able to estimate the value of the Author's results, as these are at present represented only by preliminary accounts. He believed, however, that the Author is engaged on a very valuable line of investigation, and that the gratitude of zoologists is due to him for his efforts to trace the lines of evolution of the forms to which he is devoting his attention.

The study of Recent Cheilostomata is full of difficulties, and the Author's work should help to remove some of them. The family Cribrilinidæ, as represented in the recent fauna, corresponds in the main with the Author's 'Cribrimorph Polyzoa.' It is, perhaps, doubtful whether the large number of families and subfamilies recognized by the Author are really required; and a question was asked with regard to the effect of these subdivisions on the arrangement of the Recent forms. It might be anticipated that the divergence which already existed in Cretaceous times would have continued to take place, in which case it might prove necessary to place most of the genera, and even many of the species, of existing 'Cribrilinidæ' in separate families. The hope was expressed that the Author would define his position with regard to this question.

The necessity for the introduction of certain terms used by the Author was questioned; and the word 'œcium' was especially mentioned. The Author had informed him that this term had been introduced in place of 'zoœcium' for fossil skeletons, on the ground that 'zoœcium' implies the presence of soft parts and because 'œcium' is convenient in forming compound words. No objection was made to the use of 'œcium' in compounds, but it was contended that it is not required on other grounds. In its modern sense the term 'zoœcium' was introduced by Smitt (as 'zooœcium') in 1865, although a variant ('Zoœcies') had been employed by Lamouroux, in a somewhat different sense, as early as 1816. In both cases the idea underlying the use of the term was that the zoœcium is the house of the polype or polypide; and although it is now recognized that it is merely the body-wall, frequently calcified, of an individual of the colony, its use is universally admitted to be convenient. But an ordinary house does not cease to be a house, even when its windows have been destroyed and its external paint has been lost. In the same way, the term 'zoœcium' seems to be still applicable, even though the soft tissues have disappeared during fossilization. A common procedure, in the study of recent forms, is to remove the soft parts of the zoœcia by means of 'eau de Javelle.' Units thus treated are strictly comparable with the so-called 'œcia' of fossils, and it was suggested that it would be very inconvenient to be precluded from describing them as 'zoœcia.'

The Author, in reply to Dr. Harmer's question concerning the correlation of Cretaceous with Recent cribrimorph Polyzoa, expressed his opinion that there was no direct genetic connexion between them. Any Cretaceous cribrimorph lineage that could be followed to a considerable length, ended in forms so differentiated and so hampered with secondary calcium carbonate that further evolution was inconceivable. Recent cribrimorphs, or 'Cribrilinidæ,' probably arose from one or more stocks of membranimorphs, or 'Membraniporidæ,' and were related to Cretaceous forms only by means of ancestors with chitinous skeletons. Even the different Cretaceous cribrimorph families have arisen independently from different membranimorph stocks.

As to the term 'œcium,' the Author had originally introduced it for the 'shell' of a Polyzoan, as contrasted with the 'zoœcium,' which included the shell and the soft tissues in connexion with it. The word, therefore, was established in order to prevent confusion of thought and to provide a term comparable with 'conch' among molluscs, 'tegulum' among brachiopods, and 'theca' among corals—convenient in such compounds as 'protoconch,' 'protegulum,' etc.; indeed, 'protœcium' has already been used by Cumings for the embryonic shell of Polyzoa, and 'ancestrœcium' by the Author for the shell of the ancestrula or earliest individual (it involves the protœcium as well as the shell of the first colonial individual) in Cheilostome Polyzoa.

9. *The* HIGHEST SILURIAN ROCKS *of the* CLUN-FOREST DISTRICT (SHROPSHIRE).

By LAURENCE DUDLEY STAMP, B.Sc. (London), A.K.C.L., F.G.S. (Read January 9th, 1918.)

[PLATES XIX & XX.]

CONTENTS.

I. INTRODUCTION.

IN the counties of Radnorshire, Montgomeryshire, Shropshire, and Herefordshire, rocks of Ludlow age have been indicated over considerable areas on the Geological Survey maps.[1] There are also several large outliers of Old Red Sandstone strata in this region, and both sets of rocks are crossed from Church Stretton on the north to beyond Presteign on the south by the great Church-Stretton Fault (see fig. 1, p. 222). This fault marks approximately the boundary between the shelly calcareous type of Silurian sediment in Shropshire and the argillaceous type in Wales. The Shropshire succession of Ludlow rocks has been studied in detail (most recently by Miss G. L. Elles & Miss I. L. Slater[2]), and the ground has been well known to geologists since the original work of Murchison.[3] On the other hand, the country immediately to the west of the great fault is little known, and no detailed account of the uppermost Silurian and Old Red Sandstone rocks has been published. Scattered references certainly exist, but they deal with the general characters of the district rather than with special features and definite localities.

It was, therefore, suggested by Dr. A. H. Cox that I should undertake an examination of the area, with the view of determining the sequence and distribution of the uppermost Silurian strata. These rocks are here of especial interest, since the district occupies an intermediate position between the Shropshire (Ludlow) district with its calcareous type of sediment, on the one side, and the Welsh area, where the corresponding rocks are of an argillaceous character, on the other.

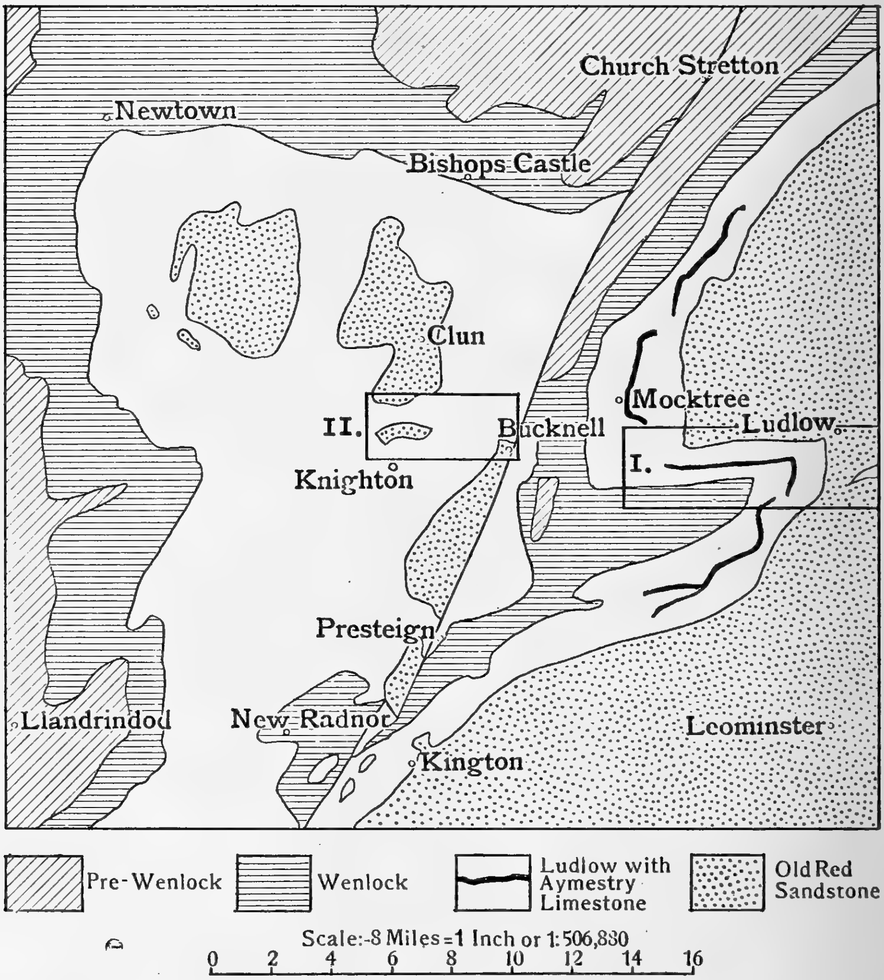
[1] One-inch (Old Series) Sheet 56; also Sheets 60, 61, & 55.

[2] Q. J. G. S. vol. lxii (1906) p. 195.

[3] 'Silurian System' vol. i (1839) pp. 195 *et seqq.*; 'Siluria' 4th ed. (1867) pp. 123 *et seqq.*

This paper is concerned, then, with a small portion of the large area of highest Silurian rocks of the Welsh Borderland, and the district was selected as near as possible to the typical Ludlow area, consistent with being on the western side of the great fault. The district, indicated on the sketch-map (fig. 1), comprising the

Fig. 1.—*Geological sketch-map of the Welsh Borderland.*



[I=Ludlow district, investigated by Miss G. L. Elles & Miss I. L. Slater. II=Bucknell district.]

greater part of the basin of the River Redlake (a tributary of the Teme), has been mapped on the 6-inch scale. The ground is shown on the 6-inch Ordnance Survey maps, quarter-sheets Shropshire 69 S.W., 69 S.E., 76 N.W., 76 N.E., 76 S.W., 76 S.E., 77 N.W., and 77 S.W.

Previous Work.

The country was mapped on the 1-inch scale by the Geological Survey in 1849,[1] and a horizontal section[2] is taken almost along the line of the Redlake Valley. No descriptions were published, and Jukes-Browne,[3] writing in 1912, sums up the information concerning the district in these words:

> 'In the country round Kington, Clun, and Radnor Forest these graptolitic shales [Lower Ludlow] are succeeded by a great thickness of brownish sandy shale with beds of brown flagstone and sandstone, which are shown in the sections of the Geological Survey to be from 1700 to 2000 feet thick.'

Murchison[4] mentions the absence of the Ludlow Bone-Bed in the Clun Forest, and gives reasons for including the 'Tilestones' in the Silurian rather than in the Old Red Sandstone sequence. He also mentions the occurrence of carbonized plant-remains in the Tilestones of Clun Forest, and emphasizes[5] the 'gradual mineral transition' from Upper Silurian to Old Red Sandstone rocks. He adds, however, that the area occupied by the latter formation is well shown by the reddish colour of the soil, though in some places soil of similar colour is also formed by the highest beds of the Upper Ludlow Series.

The Ludlow Bone-Bed certainly occurs in the extreme north of the area near Bishop's Castle,[6] and also in a modified form in the south-east near Kington[7]; but all efforts to trace it over the greater part of the Welsh Border district have failed, and the absence of this important band has doubtless hindered the correlation of the Transition Beds.

II. Topography and Surface-Geology.

The scenery, although presenting no remarkable features, affords a good example of a landscape controlled by geological structure. The district comprises a series of hills ranging in height from 1200 to 1500 feet, separated by valleys often nearly 1000 feet deep. The hills have generally a steep, thickly-wooded scarp-slope and a gentle dip-slope, which is sooner or later truncated as it comes within the erosive province of the stream in the valley. This structure has a curious effect on local agriculture, the fertile soil of the dip-slopes being cultivated to the fullest extent right up to the hill-summit. It is certainly striking, after climbing some 800 or 900 feet of rough woodland or wild moorland, to come suddenly upon a

[1] One-inch (Old Series) Sheet 56 N.E.
[2] Horizontal Section No. 30 (1853).
[3] 'Stratigraphical Geology' 2nd ed. p. 174.
[4] 'Siluria' 4th ed. (1867) p. 134. [5] *Ibid.* p. 243.
[6] Discovered by Garnett-Botfield: see C. Lapworth & W. W. Watts, Proc. Geol. Assoc. vol. xiii (1894) p. 328.
[7] R. W. Banks, Q. J. G. S. vol. xii (1856) p. 93.

succession of cornfields at the top of the hill at an altitude of 1500 feet O.D. Where the dip of the strata is considerable (as, for example, near the great fault), the hills have a more conical form with steep sides. Bucknell Hill may be mentioned as a good example of this latter form.

The hard, evenly-bedded flags of the Upper *Chonetes* Beds cap many of the hills (for instance, Caer Caradoc [1] and Hodrey Hill); but, where the crests are formed of Temeside Shales, the hills are lower, more rounded, and characterized by a red soil which is said to be particularly suitable for wheat-growing.

Several of the larger valleys seem to be determined by fault-lines. The deep valley near Selley Hall, which has been taken as the western boundary of the area considered, is a typical rift-valley. Part of the Redlake Valley itself, east of Chapel Lawn, is probably determined by a fault-line.

The valleys are remarkable for their content of 'drift,' a fact that is noted on the original 1-inch map of the Geological Survey. This 'drift' consists almost entirely of material of local origin, and includes big angular blocks fallen from the neighbouring hills, and smaller waterworn pebbles. In certain places the latter predominate, and a true alluvium is formed: as, for example, in the large area of recent deposits near Purlogue, covering at least one square mile at a level of 750 feet O.D. An extensive lake seems to have occupied the site at one time, and from the red colour of its shores (cut in Temeside Shales) the River Redlake possibly derives its name: although here, as in many districts, the suffix 'lake' may mean simply 'stream.'

All the larger streams in the district are re-cutting their courses in the recent deposits, and have rarely cut down to the bed-rock. At Chapel Lawn the alluvium exceeds 20 feet in thickness, and Saxon remains have been found at a depth of 14 feet. In one part of its course, however, the Redlake flows through a narrow gorge about 60 feet deep. It is very significant that this gorge is immediately below the large area of alluvium mentioned above, and it was doubtless formed when the old lake burst through its lower boundary.

It is only in the little wooded gorges which mark the upper courses of the smaller streams (in many cases including the springs at their source) that continuous sections of solid rock are visible, and such sections are usually very short.

In passing, it may be of interest to note the distribution of glacial erratics. Big, and usually smoothed, blocks of pale conglomerate and grit occur very frequently on the hills to the north of Chapel Lawn, but not on the hills to the south. At several localities these boulders have been collected to form stone-circles. Glacial drift obscures the exposures on many of the hills to the north.

[1] Not to be confused with the better-known hill of the same name near Church Stretton.

III. Classification and Description of the Strata.

The stratigraphical succession is as follows :—

		Thickness in feet.
Old Red Sandstone (?)[1]		—
Temeside Shales		350
Downton-Castle Sandstone Group		110
Chonetes Beds	Upper	50
	Lower	300
Rhynchonella Beds		300
Dayia Shales		? 300
Lower Ludlow Shales		—
		1410

It will be noticed that the grouping is similar to that adopted in the Ludlow district[2] except that the Aymestry Limestone is absent from the Clun-Forest area, and that the *Chonetes* Beds are subdivided into an upper and a lower group. It will be shown later that the upper division of the *Chonetes* Beds is to some extent comparable with the *Spirifera-elevata* Shales of Ludlow.

The thicknesses stated above are only approximate, but they are interesting as a basis for comparison with other districts.

At Mocktree Hill (see map, fig. 1, p. 222) the total thickness, including the Aymestry Limestone (250 feet), is 850 feet; around Ludlow[3] the total thickness is only about 550 feet, including the 100 feet belonging to the Aymestry Limestone; farther northeastwards the beds are still thinner, totalling about 180 feet in South Staffordshire, as described by Mr. W. W. King & Mr. W. J. Lewis.[4]

Although each of the above divisions may be described as having its own characteristic lithology, there is a notable tendency to a repetition of characters which is often very confusing. Moreover there is, with perhaps one exception (namely, above the Downton-Castle Sandstone), a complete lithological transition from one set of beds to the next. Hence it is difficult to determine satisfactory divisional lines for use in mapping. This difficulty is accentuated in the case of the *Rhynchonella* Beds, the identification of which depends largely on negative evidence, namely, the absence of *Chonetes*.

[1] See note, p. 242.
[2] G. L. Elles & I. L. Slater, Q. J. G. S. vol. lxii (1906) p. 198.
[3] *Ibid.* pp. 199 *et seqq.*
[4] Geol. Mag. dec. 5, vol. ix (1912) pp. 437 *et seqq*

Group	Division	Subdivision	Bed	Lithology
Old Red Sandstone (?).[1]				Purplish-red sandstone.
Temeside Group.	F. Temeside Shales.		*f.*	Fragment-Bed and associated shales.
			c–e.	Olive-green shales.
			a–b.	Rubbly olive-green shales, with bands of micaceous green grit.
	E. Downton-Castle Sandstone Series.		*d–e.*	Yellow tilestones and slightly greenish bedded sandstones.
			c.	Massive yellow sandstones.
			a–b.	Grey shales with bands of sandstone and *Platyschisma* Limestone. (= *Platyschisma* Shales.)
Upper Ludlow Group.	D. *Chonetes* Beds.	Upper.	*b–c.*	Greenish laminated flags. Yellow or blue evenly-bedded flagstones, with narrow bands of soft shale.
		Lower.	*a.*	Irregularly-bedded calcareous flagstones, with a few thin bands of soft grey shale.
	C. *Rhynchonella* Beds.			Grey calcareous flags, with bands of hard, massive, blue flagstones, especially at the upper and lower limits of the beds.
Aymestry Group.	A–B. *Dayia* Shales.			Striped laminated shales and dark mudstones with irregular fracture.
Lower Ludlow (?).				Dark-grey shales and indurated mudstones.

(1) The Lower Ludlow Shales.

The lowest beds exposed in the district are seen along the north side of the Teme Valley west of the hamlet of Weston. They are indurated mudstones, and greatly resemble the Wenlock and Lower Ludlow Shales of Builth.[2] A diligent search has revealed no graptolites, but the occurrence of numerous small lamellibranchs and species of *Orthoceras* distinct from those in higher beds seems to indicate a Lower Ludlow horizon. In the old quarry about half-a-mile west of Weston these beds dip steeply at 24° north-north-westwards, while in the railway-cutting less than 100 yards away to the east they are apparently horizontal, and, judging from the inclination of the succeeding beds, the high dip displayed in the quarry-section is due to purely local folding.

(2) The Aymestry Group.

The Aymestry Limestone is absent from this district.

The indurated mudstones just mentioned pass up gradually into a great thickness of shales, which, towards the base, tend to be dark-grey and massive, with an irregular fracture and no very marked bedding. Such rocks are seen in the lower part of the road from Chapel Lawn to Pentre Hodrey and again at Obley. In the

[1] See note, p. 242.

[2] G. L. Elles, Q. J. G. S. vol. lvi (1900) p. 370; E. M. R. Wood, *ibid.* p. 415.

upper part the shales have a very characteristic feature: in hand-specimens they are well laminated with alternate light and dark laminæ, which thus impart a striped appearance to the whole. They contain few fossils, but *Dayia navicula* occurs in several places. Along with this form *Cardiola interrupta*, *Orthoceras tracheale*, and a small trilobite have been obtained. These beds are distinct, both as regards lithology and fossil-content, from the succeeding strata, and correspond to the *Dayia* Shales of the Ludlow district.

The junction between the *Dayia* Shales and the *Rhynchonella* Beds is not well marked, but some bands of massive, hard, blue flagstone usually occur about this horizon.

A few remarks on the apparently anomalous variation in thickness of the Aymestry Limestone may not be out of place here. The Limestone, which is about 100 feet thick at Ludlow, thickens westwards to 250 feet at Mocktree Hill—only 6 or 7 miles east of Bucknell—and, while known to occur at Pedwardine[1] (immediately east of the Church-Stretton Fault near Bucknell), it has absolutely disappeared in the area here mapped.

Determinations of Calcium Carbonate in Ludlow Rocks.

	I.	II.	III.	IV.	V.	VI.
Calcium carbonate	30%	85%	22%	25%	22%	15%
Insoluble residue	70%	15%	78%	75%	78%	85%

I. Aymestry Limestone, Mocktree Hill.
Block in fresh condition, with characteristic fauna of *Conchidium knightii* and *Atrypa reticularis*.

II. Aymestry Limestone, Pedwardine.
A band of nodular limestone with abundant corals (*Halysites*, *Favosites*, etc.). One of the persistent bands of true limestone.

III. *Dayia* Beds, road from Chapel Lawn to Pentre Hodrey.
Massive dark shale.

IV. *Rhynchonella* Beds, near Chapel Lawn.
Hard, blue, massive flagstone at the base of the beds.

V. *Rhynchonella* Beds, Selley Cross.
Typical specimen from the upper part.

VI. *Chonetes* Beds, Hodrey Hill.
Typical specimen.

The above determinations of the amount of calcium carbonate present in the various Ludlow rocks have revealed the following interesting facts:—

(1) The bulk of the Aymestry Limestone with its typical fauna at Mocktree Hill is only slightly more calcareous than the *Rhynchonella* or *Chonetes* Flags of Clun Forest.

(2) The Aymestry Limestone at Mocktree Hill is really a calcareous flagstone, with certain bands richer in lime and forming true limestone. Some of these bands persist on the west, one being exposed in the faulted inlier of Pedwardine, and another being recorded from near Bishop's Castle.[2]

[1] A. H. Cox, Q. J. G. S. vol. lxviii (1912) p. 371.
[2] Caradoc Club, 'Record of Bare Facts' 1892, p. 23.

It thus appears that the Aymestry Limestone does not thin and die out to the west of Mocktree, but that there is a true lateral transition into calcareous shales. The characteristic fauna of brachiopods and corals certainly does die out somewhat abruptly towards the west, and it was most probably of the nature of a littoral fauna thriving round the island of Central England in Silurian times.

(3) The Upper Ludlow Group.

The Upper Ludlow Group in this district admits of the same broad divisions as in the Ludlow district:—

D. *Chonetes* Beds—zone of *Chonetes striatella*.

C. *Rhynchonella* Flags—zone of *Rhynchonella nucula*.

C. The *Rhynchonella* Flags.—The series has an ill-defined lower limit, since the striped *Dayia* Shales pass up gradually into less conspicuously-laminated shales containing *Orthoceras striatum*, *O. ibex*, and numerous small lamellibranchs. These are in turn succeeded by hard, massive, calcareous beds containing few fossils, followed by calcareous flagstones, 150 to 200 feet thick, which become more fossiliferous in the upper part. The flagstones break up in rough slabs, fairly distinct from the more nodular and irregular weathered masses of the *Chonetes* Beds above. Certain bands in the flagstones, generally of a blue colour, are harder and more massive than the normal, and are much used in local buildings.

Fossils are not very abundant in the *Rhynchonella* Beds. The commonest are casts of a few chambers of an *Orthoceras*. These examples are generally about an inch across, and might easily be mistaken for inorganic concretions, except for the presence in most of an indication of the siphuncle almost in the centre of the chamber. Several specimens of these in the Geological Department, British Museum (Natural History), are labelled 'cast of septal surface of *Orthoceras marloense*? J. Phillips.' Though occurring also in the *Chonetes* Beds, these casts are very typical of the *Rhynchonella* Beds, especially when associated with *Serpulites longissimus*, *Orthonota amygdalina*, and with large specimens of *Rhynchonella nucula*.

The upper limit of the *Rhynchonella* Beds is generally marked by several harder blue bands, and by the appearance of *Chonetes*.

D. The *Chonetes* Beds.—The *Chonetes* Beds fall naturally into an upper and a lower division.

(*a*) The Lower *Chonetes* Beds are irregularly-bedded calcareous flagstones of blue-grey colour. They weather into thick slabs of a nodular character, due to the somewhat concretionary nature of the beds, and thus differ from the *Rhynchonella* Flags.

In this connexion Murchison[1] notes that

> 'Like other Silurian sediments of higher antiquity, this mudstone has a tendency to run into large spheroids, and occasionally contains small concretions of sandy clay, which, being more destructible than the pure argillaceous matrix, weather out. . . .'

It is noticeable that the weathering varies according to the location of the rock. Where exposed on hillsides, it remains blue-grey on freshly-broken surfaces; but, when protected by a layer of soil or subsoil, it weathers to that pale yellow-brown which is so well seen in the sections at Norton Camp near Craven Arms.[2] In the latter case the fossils are preserved as iron-stained casts. Similar differences in weathering may be noted in the *Rhynchonella* Flags, but they are not quite so marked.

The brownish weathered rock somewhat resembles in appearance a soft sandstone, and this resemblance seems to account for the fact that several writers have referred to 'brownish sandy shale' and 'brown flagstones and sandstones' succeeding the Lower Ludlow Shales in Clun Forest. It is difficult to find a suitable name for the beds which have here been termed 'calcareous flags' and 'shales.' Murchison[3] refers to 'grey calcareo-argillaceous masses . . . . which, from their incoherent nature, easily decompose into mud'; he notes that 'the chief . . . . portion of the Upper Ludlow contains more calcareous matter and sand than the beds immediately beneath,' and compares the rock with the Tertiary 'macigno' of Italy. A microscopical investigation of specimens from the *Dayia* Shales, the *Rhynchonella* Beds, and the *Chonetes* Beds has shown that the rocks consist largely of fine quartzose silt; sand-grains are few or absent, flakes of mica fairly abundant, and the matrix consists of calcareous and argillaceous matter.

Throughout the *Chonetes* Beds occur bands of soft grey shale from 3 to 12 inches thick. Two such bands are exposed in the gorge of the Redlake above Llynaven Farm.

Fossils are far more numerous in the Lower *Chonetes* Beds than in the *Rhynchonella* Beds, and these increase in numbers towards the top of the series. The most characteristic forms are *Chonetes striatella*, *Discina rugata*, *Rhynchonella nucula*, and *Orthis lunata*. The chamber-casts of *Orthoceras* mentioned in the account of the *Rhynchonella* Beds also occur, but are less common. Numerous species of lamellibranchs occur, but *Orthonota amygdalina* of lower beds is less conspicuous. *Serpulites longissimus*, too, is less common in the *Chonetes* Beds than in the *Rhynchonella* Beds.

In the upper part of the Lower *Chonetes* Beds crinoid-stems and impressions of ossicles are frequently abundant, and often associated with casts of bryozoa. The zone-fossil, *Chonetes striatella*, varies considerably in its specific characters. In the fossil lists

[1] 'Siluria' 4th ed. (1867) p. 131.

[2] G. L. Elles & I. L. Slater, Q. J. G. S. vol. lxii (1906) pp. 214–18.

[3] *Op. supra cit.* p. 131.

there is recorded as *Chonetes striatella* var., an interesting form the valves of which are more convex and elongated than in the normal type, and a pustulated ornamentation may almost obliterate the radial striations. The pustules probably mark the point of attachment of spines, and thus the form may be analogous to the well-known spinous modifications of such genera as *Productus* and *Acanthothyris*. This variety of *Chonetes* has been noticed in typical *Rhynchonella* Beds, below the horizons in which the type form, *Ch. striatella*, appears, and it ranges through the Lower *Chonetes* Beds but has not been seen in the Upper *Chonetes* Beds.

(*b*) The Upper *Chonetes* Beds present a lithological change from the lower group, which is more or less marked in different sections. The strata of this division are for the greater part well-bedded slightly-arenaceous flagstones, which are more resistant to weathering than the lower beds: consequently they form the 'capping' of many hills, and control the gentle dip-slopes. On the more barren hills, such as Caer Caradoc and Hodrey Hill, large slabs of these rocks may be seen. They are 2 or 3 inches thick, but often many feet in length and breadth. The surface of these masses undulates gently, and this may be due to tidal or wave action, but is certainly not 'ripple-marking' in the ordinary sense of the term, as the rounded crests of the gentle undulations are at least a foot apart. On the surface of these slabs most of the fossils characteristic of the Lower *Chonetes* Beds may be seen; but the fossils, whether isolated or grouped together, are confined to the division-planes, and are not distributed through the mass of the rock. When freshly broken the flags are blue-grey, but they weather to a yellow-brown. These hard flagstone-bands have been much in demand locally for building purposes.

The sediments overlying the flags generally show a return to a type of lithology very similar to that of the Lower *Chonetes* Beds. They differ in retaining, however, a certain amount of lamination which is typically absent in the lower beds. They have, moreover, a greenish tint approaching in appearance the colour of the Temeside Shales.

These Upper *Chonetes* Beds correspond approximately to the '*Spirifera-elevata* Shales' of the Ludlow area. The latter fossil is, however, neither very common nor widely distributed in the district examined. Yet, at certain localities (as, for example, south-east of Five Turnings) there occur thin bands crowded with fossils, among which *Spirifera elevata*, *Chonetes striatella*, and *Orthis lunata* are particularly abundant. Although these bands are certainly not 'bone-beds,' they doubtless result from causes similar to those favouring the formation of 'bone-beds': namely, the initiation of unfavourable conditions killing off large numbers of organisms of all kinds; rather than the temporary existence of favourable conditions causing a rapid multiplication of individuals. The significance of fossil-bands of small individuals was emphasized by Prof. Garwood[1] in his researches on the Carboniferous Limestone of the Lake District. This general conclusion is borne out by the character of the fossils themselves, as the individuals are all of small size. The only species that seem to retain their normal dimensions are *Chonetes striatella* and *Beyrichia* sp., and, in the case of the former, about equal numbers of very small and normal individuals occur associated together. *Spirifera elevata* is of moderate dimensions; but the Orthids are without exception small, and in many cases the specimens of *Orthis lunata* seem to have a shorter hinge-line than in the normal individuals, and thus they resemble *O. elegantula* or *O. orbicularis*. The change is still more marked in *Rhynchonella nucula*, a very small form of which is the only Rhynchonellid present in the bands. This form is quite unlike the typical *Rh. nucula* of lower beds, but resembles the specimen figured in 'Siluria' pl. xx, fig. 2. Mr. S. S. Buckman[2] has expressed his doubts concerning the authenticity of records of Silurian brachiopods, and contrasts the reputed long range of many species with the short range of Mesozoic types. He instances in particular *Orthis elegantula*—a typical Wenlock form—which is recorded from the Ordovician to the Upper Ludlow. It may be that varieties such as occur in these transitional beds have been mistaken for species described from other horizons. There is need of much detailed palæontological work in connexion with these Upper Ludlow brachiopods; but the investigation is hampered by the fact that the fossils occur almost exclusively as casts.

(4) The Temeside Group.

F. Temeside Shales.
E. Downton-Castle Sandstone.

E. Downton-Castle Sandstone.—In the Ludlow district, notably at Downton Castle, the summit of the Upper Ludlow Series is well defined by the presence of the Ludlow Bone-Bed: accordingly there is no difficulty in determining the lower limit of the Temeside Group. The lower of the two divisions of the Temeside Group has been called the Downton-Castle Sandstone.[3] At Ludlow, in the Ludford-Lane section, the strata immediately succeeding the Ludlow Bone-Bed are 'mottled sandstones and shales'[4] about 3 feet thick, with a *Beyrichia* Band at the top and followed by an argillaceous *Platyschisma* Bed. Farther west, at the Downton-Castle inlier, the same beds are noted as 'mottled sandstone,'[5] still about 3 feet thick, and succeeded by the *Platyschisma* Band. Similar beds occur at Downton-Castle Bridge, and there they take on a character which is of particular

[1] Q. J. G. S. vol. lxviii (1912) p. 455.
[2] Proc. Geol. Assoc. vol. xviii (1904) p. 454.
[3] G. L. Elles & I. L. Slater, Q. J. G. S. vol. lxii (1906) p. 199.
[4] *Ibid.* p. 203.
[5] *Ibid.* p. 210.

interest in a consideration of the Bucknell district. In the section (*op. cit.* p. 208) illustrating the sequence at Downton-Castle Bridge the beds are described as 'Ea, unfossiliferous sandy shales.' When visiting this locality I noticed that these beds are quite unlike any others to be found in the neighbourhood; they are thinly-bedded, brittle, dark-grey shales tending to have a wavy surface, and readily splitting into very thin laminæ. A silvery sheen is imparted to the surfaces of these laminæ by the presence of fine-grained micaceous material. These silvery shales are succeeded by the *Platyschisma* Band which is here, in addition, a bone-bed (the Downton Bone-Bed). The *Platyschisma* Band in all the above-mentioned sections is overlain in turn by massive Downton-Castle Sandstone.

These shales, comparatively insignificant in the Ludlow area, become of considerable importance in the Bucknell district. In the east of the area mapped, one fairly-continuous section of the transition-beds from the Upper Ludlow rocks to the Temeside Shales is exposed. This section will be described in detail later. There is no trace of the Ludlow Bone-Bed here, and the greenish Upper *Chonetes* Beds pass up gradually into the silvery *Platyschisma* Shales. These in turn pass into micaceous tilestones (yellow thinly-bedded Downton-Castle Sandstone), which become more massive and finally assume a greenish tint in the upper part of the group. The sandstones are followed, somewhat abruptly, by greenish rubbly marls belonging to the Temeside Shales.

Farther west are three outliers of 'Old Red Sandstone' marked on the Geological Survey maps ($\frac{1}{4}$-inch index-map, Sheet 14). See sketch-map, fig. 1, p. 222. One of these outliers, which may (for convenience) be termed the Five Turnings Outlier, is small—about a mile long and half-a-mile broad—and is situated about a mile north-east of Knighton. A second, the Clun Outlier, is of greater extent, and stretches northwards from the Redlake Valley, north-west of the little village of Chapel Lawn, to beyond Clun. The third—the Bettws-y-crwn Outlier—is seen on the north-west. An examination of the Five Turnings Outlier and the south-eastern margin of the Clun Outlier has disclosed the following succession:—

Old Red Sandstone (?).[1]	Purplish-red sandstone.
Temeside Shales.	'Fragment-Bed' and shales. Olive-green rubbly shales. Micaceous green sandstone.
Downton-Castle Sandstone.	Yellow tilestones. Yellow sandstone. *Platyschisma* Shales.
Chonetes Beds.	Greenish mudstones.

The Downton-Castle Sandstone Series is here of particular interest, and presents a notable development from the corresponding beds in

[1] See note, p. 242.

the neighbourhood of Bucknell itself. The greenish Upper *Chonetes* Beds again pass gradually into dark, brittle, thinly-laminated shales. At various horizons, and in some places throughout their entire thickness, these shales have a very curious structure. When broken into slabs they present a puckered appearance, like ripple-marking on a small scale, with the crests of the 'ripples' about half an inch apart and much broken up. These beds are more resistant to weathering than lower beds, and hence are often seen as relict blocks in the fields. The fossil-content of these shales varies greatly both horizontally and vertically. In the lower part, where the bedding is more regular, *Lingula minima* frequently occurs. *Platyschisma helicites* is found throughout the shales, and is often so abundant as to form bands of hard compact limestone weathering to a soft brownish rock. *Modiolopsis complanata* is frequently associated with *Platyschisma*. In the upper part of the shales, where the puckered structure is usually well developed, fossils are comparatively rare and are always distorted. The distortion is principally in a vertical direction, and the fossils are so pressed down into the matrix that they present very indistinct outlines. *Platyschisma helicites* and a species of *Holopella* are the types that most frequently show this crushing.

Some species from the *Chonetes* Beds survive into these shales, and *Rhynchonella nucula*, *Chonetes striatella*, and *Orthis lunata* are occasionally found associated with the typical fossil *Platyschisma helicites.*

The occurrence of *Platyschisma* and *Holopella* throughout these beds is a point of great interest, since, in the Ludlow district, the former fossil is limited to one thin band.

Bands of sandstone make their appearance in the upper part of the shales (typical sections will be described in detail later), and the latter are succeeded finally by a hard bedded sandstone of a greenish colour, which, after 12 or 18 inches, becomes yellow and massive and similar to the typical Downton Sandstone of the Ludlow area. The yellow sandstone is about 5 or 6 feet thick, and passes upwards into yellow, thinly-bedded, micaceous tilestones. The tilestones are about a foot thick, and are succeeded by more rudely-bedded green micaceous sandstones, followed by green marl with one or two hard grit-bands of a similar colour. It is evident that the limit of the Downton Sandstone is formed by the yellow tilestones.

The smaller outlier (Five Turnings Outlier) is marked 'tilestones' on the Geological Survey map,[1] and the beds were therefore included by the Surveyors in the Old Red Sandstone Series. Similar beds in the larger outlier (Clun Outlier) are not indicated, but the base of the so-called Old Red Sandstone is designated 'Green Marl.' The shales, which underlie the tilestones and have been shown to belong to the Downton-Castle Sandstone Series, were classed as the highest beds of the Upper Ludlow Series.

[1] One-inch, Old Series, 53 N.E.

The Downton Sandstone itself is not very fossiliferous; but in its lower part certain whitish bands occur, the colour of which is due to fragments of the delicate valves of *Lingula minima*. Complete specimens are rare, and, when complete, the specimen is seen to be a small and stunted form.

In a few localities the lower part of the sandstone also includes narrow bands full of the casts of *Bellerophon trilobatus*. *Platyschisma* and *Holopella* occur sparingly through the whole mass of the sandstone. These are sufficient to demonstrate the Silurian age of the rocks.

Some doubt seems to exist as to the identity of the species of *Holopella* from this horizon. Murchison[1] figures *H. conica*, *H. gregaria*, and *H. obsoleta* from the 'Upper Ludlow—Tilestone Beds.' The specimens that I have obtained are too crushed to allow of detailed examination; but they compare best with *H. gregaria* or *H. conica*, since *H. obsoleta* is a larger species with tumid whorls. Miss G. L. Elles & Miss I. L. Slater[2] record *H. gregaria* from this horizon; but Prof. T. T. Groom[3] in the Malvern district records only *H. obsoleta* from the Upper Ludlow and *H. gregaria* from the May-Hill Sandstone.

Several factors necessitate the linking of the grey *Platyschisma* Shales with the sandstone of the Downton-Castle Sandstone Series or zone of *Lingula minima*. There is, first, palæontological evidence in the occurrence of *Platyschisma* and *Lingula minima* throughout; secondly, there is the gradual lithological transition; and, finally, the evidence of the corresponding beds at Downton itself.

F. Temeside Shales.—The Temeside Shales are the most clearly-differentiated group of rocks in the district, and their lower limit is almost the only sharply-marked division-plane in the whole succession. Throughout their thickness, the prevalent colour of these rocks is olive-green, and they weather to form a very characteristic brick-red soil.

In the east of the area the lowest beds are rubbly green shales (designated 'marls' on the Geological Survey map) which rest upon the Downton-Castle Sandstone. The junction is seen in a small quarry along the Bucknell and Weston Road: only a few feet of Temeside Shales are exposed; but higher beds, consisting of green micaceous sandstone and hard compact green rock, are exposed in the river-cliff close by the railway-bridge on the same road. Similar beds are seen in the lane from Bucknell Village to Bucknell Hill.

In the west at Five Turnings, Downton-Castle tilestones are succeeded by micaceous greenish grit, somewhat irregularly bedded, and about 2 feet thick. This grit seems to be extremely variable

[1] 'Siluria' 4th ed. (1867) pl. xxxiv.
[2] Q. J. G. S. vol. lxii (1906) p. 219.
[3] 'Geology in the Field' Jubilee vol. Geol. Assoc. (1910) pp. 713–14.

and often absent along the margin of the Clun Outlier. It is followed by olive-green shales of considerable thickness—at least 350 feet. Towards the base these tend to be very rubbly. They pass gradually upwards into concretionary green marl; the concretionary structure is most typically developed about 50 feet above the base of the shales. At this level the whole rock is built up of large spheroidal masses, from $1\frac{1}{2}$ to $2\frac{1}{2}$ feet in diameter, with concentric layers, which remind one of the well-known spheroidal weathering of dolerite (see fig. 2). About this horizon the Temeside Shales contain bands of 'cornstones.' The cornstones have either been formed *in situ*, or were produced by the contemporaneous erosion of thin nodular limestones. They are sometimes

Fig. 2.—*Temeside Shales in the old quarry 300 yards north-north-west of New Invention, showing spheroidal structure.*

L. D. S. photo.

[The disc is a florin, whence the scale may be inferred.]

regarded as of algal origin, although no trace of algal structure has been seen in sections cut from the nodules. The cornstones are small, rarely exceeding 1 inch in diameter. Some of them certainly appear to consist of fragments of other limestones, and the bands would be more properly designated 'cornstone conglomerates.' One such band occurs in a quarry north-west of New Invention, and a limestone-pebble containing *Favosites* sp. was obtained from it. In three separate instances large pebbles of Aymestry Limestone with *Conchidium knightii* and *Atrypa reticularis* have been found loose on quarry-floors at this horizon; but considerable search has not revealed similar large pebbles *in situ*, wherefore their presence may be merely a coincidence and due to glacial or other agents: as, for instance, recent carting of limestone for agricultural purposes.

The rubbly shales are abundantly fossiliferous in places, but the fossils are mostly fragmentary casts of small lamellibranchs. Other remains include fragments of *Lingula cornea*; one or two portions of Eurypterids; *Beyrichia* often abundant, and small oval bodies about an eighth of an inch long, which may be ostracods (*Leperditia*).

The Temeside Shales retain their rubbly or concretionary character in a vertical direction for about 250 feet, interrupted at intervals by thin bands of greenish grit and micaceous sandstone, but in the upper part they become more distinctly laminated and pass into pale olive-green shales. No fossils have been obtained from these upper shales, and the beds are seen only on Clun Hill in the area mapped. In an old quarry on the southern slope of that hill the shales, which are slightly micaceous, are well exposed. In the upper part of the quarry there is a thin band of yellow sandstone crowded with carbonized plant-fragments and Eurypterid remains. Although a few feet of the olive-green shales succeed this sandstone-band and the highest beds are not exposed, the top of the series cannot be more than a few feet above the topmost beds in the quarry, as fields a little higher up the hill are strewn with large fragments of pale purplish-red sandstone, here designated the lowest beds of the Old Red Sandstone (?).[1] Thus the band of sandstone in the quarry corresponds very closely in nature and position with the 'Fragment-Bed,' which has been taken as the upper limit of the Silurian rocks in the Ludlow area.[2] Further investigation in other parts of the Clun-Forest district will be needed before a detailed account of the actual junction of Silurian and Old Red Sandstone rocks can be given.

It will be noticed that, although the general succession of the Temeside Shales is the same as at Ludlow, the beds in the area considered are about three times as thick. The paucity of Eurypterid and fish-remains in the greater part of these beds (except in the sandstone-band near the top) is paralleled by the absence of the Ludlow Bone-Bed in the Ludlow rocks, and by the absence of fish-remains in the *Platyschisma* Bands of the Downton-Castle Series.

The examination of this area has shown that the greater part of the rocks formerly mapped as Old Red Sandstone in the Clun Forest must be removed to the Silurian, and that the area occupied by true Old Red Sandstone rocks, if such be present, is very small.[3]

IV. Description of some Typical Sections.

(1) Near Bucknell Village.

Although there is no good continuous section from the Upper Ludlow through the Downton Beds on the east of the district,

[1] See note, p. 242.
[2] G. L. Elles & I. L. Slater, Q. J. G. S. vol. lxii (1906) p. 205.
[3] See note, p. 242.

the succession is fairly clear; the thickness of the various beds, however, can only be measured approximately.

The road from Weston to Bucknell Station, and along the adjoining railway.—About 320 yards east of the house marked Cubach on the 6-inch Ordnance Survey map,[1] beds are exposed on the side of the road, and in the railway-cutting adjoining, which have yielded *Chonetes striatella*, *Orthis lunata*, and *Rhynchonella nucula*, and are evidently typical *Chonetes* Beds. A short distance farther east along the road, and also in the lane to the north-east, are the greenish laminated mudstones previously mentioned as typical of the Upper *Chonetes* Beds (p. 230). From them *Spirifera elevata* has been obtained. These beds may be followed in the shallow gutter at the side of the road and about 45 yards west of the gate to the cart-track through the wood to the north, they give place to the greyish *Platyschisma* Shales, which form the base of the Temeside Group. These shales are not very distinctive in character, and they pass gradually through greenish shales into a thinly-bedded, yellow, micaceous sandstone, succeeded by massive yellow sandstone about 5 feet thick. This sandstone, in all respects identical with the Downton-Castle Sandstone in the type district, crops out in a small roadside quarry near the edge of the wood. In its upper portion the sandstone is more greenish and laminated. It is succeeded abruptly by rubbly green Temeside Shales, exposed also in a small quarry on the south side of the road. The calculated thickness of the Downton-Castle Sandstone Series from the base of the micaceous shales is about 110 feet, and of this the sandstone proper occupies only the upper 10 feet. Throughout the section the dip is steep (in the small quarries it amounts to about 30°). Although no beds higher than the rubbly green marls can be seen, there is hereabouts a marked change of colour in the soil from brown to red, and this can be distinctly traced through the fields to the north. About 400 yards farther east, immediately below the bridge over the railway, a small river-cliff reveals the presence of very micaceous green grit and hard, compact, green rock. No evidence has been noted of purplish sandstone or of other rocks that could be definitely assigned to higher beds than the Temeside Shales; hence it is probable that Temeside Shales occupy the whole of the low ground around Bucknell eastwards to the great fault.

A succession very similar to the above can be traced on the hill-slope north-west of Bucknell village.

(2) Five Turnings Outlier.

(*a*) Old Quarry 300 yards east of Black Garn Farm.—In the valley below the quarry greenish Upper *Chonetes* Beds crop out. Succeeding these beds are *Platyschisma* Shales, of the dark micaceous type seen in the quarry above. *Lingula minima* is abundant in the lower part of the quarry, while in the upper part are bands

[1] Shropshire 76 S.E.

from 3 to 4 inches thick of *Platyschisma* Limestone which have weathered to a soft brown rock. Six or seven of these bands can be seen in the quarry-face (about 25 feet high). They are lenticular in character, and several die out in the breadth of the quarry itself—about 30 feet. *Modiolopsis complanata* occurs in many of the *Platyschisma* bands, and other lamellibranchs are found in thin sandstone-bands in the upper part of the quarry. On the northern side of the quarry local folding of the beds has produced a sharp monocline, with its pitch in the direction of the prevalent dip.

Above the quarry on higher ground to the south-east *Platyschisma* Shales are again exposed, and they contain a few bands of sandstone and hard greenish flagstone.

(*b*) Section in the stream from New Invention up to Five Turnings.—In the low ground near New Invention the stream cuts through alluvium and subsoil of reddish colour, with blocks of greenish Upper *Chonetes* Beds. A short distance up the little wooded gorge *Platyschisma* Shales, with characteristic micaceous sheen, crop out. The succession includes numerous bands of hard limestone, 3 to 4 inches thick, consisting entirely of *Platyschisma helicites.* The same fossil occurs more sparingly in the shales themselves. The succeeding sandstones are not seen, as the banks of the stream are low and cultivated, but numerous blocks of yellow, micaceous tilestone may be found near. There are also blocks of greenish grit a short distance higher up the stream. The next beds exposed *in situ* are rubbly green marls (Temeside Shales) succeeded by marls exhibiting a more decided bedding, and then by green marl with large spheroidal structure. This is seen in the small wood near the spring (marked on the 6-inch Ordnance Survey map, Shropshire 76 N.W.). Similar beds are exposed in a small quarry immediately above the spring.

(*c*) Old Quarry near Five Turnings.—This quarry is of particular interest, since the passage from *Platyschisma* Shales to Temeside Shales is here seen, and a fault which, though of small throw, has a considerable effect on the structure of the district, is exposed.

On the eastern or downthrow side of the fault rubbly green marl (Temeside Shales) is exposed. The western part of the quarry shows the following succession :—

		Thickness in feet.
Temeside Shales.	Irregularly-bedded micaceous green grit	+3
Downton Sandstone.	Micaceous yellow tilestones	3
	Yellow bedded sandstones / Greenish bedded sandstones	9
	Platyschisma Shales seen for	2

The greenish sandstones have bands full of casts of *Bellerophon trilobatus*, and are often full of fragments of *Lingula minima.*

(3) South-eastern Margin of the Clun Outlier.

(*a*) Valley north-east of New Invention.—In a small quarry immediately above the farm Lower *Chonetes* Beds, succeeded by flaggy Upper *Chonetes* Beds, are exposed. Higher up the valley the latter become greenish and more rubbly, and contain a few thin bands of harder greenish flagstones. These beds are followed by *Platyschisma* Shales of considerable thickness. Above these comes a thin representative of the Downton Sandstone, which is overlain by very micaceous green sandstone (Temeside Shales) passing upwards into concretionary green marl. The exposures along the valley are scattered, and only the general succession can be followed.

(*b*) Valley near Menutton.—The *Chonetes* Beds are exposed in several places in the lower part of this valley. About 200 yards north of Menutton, on the left as one ascends the valley, is a small quarry with the following succession :—

Upper *Chonetes* Beds.	Flags with wavy surface	+6 feet.
	Soft micaceous shales	6 inches.
	Hard, blue, well-bedded flags	9 feet.
Lower *Chonetes* Beds.	Irregularly-bedded flagstones seen for	3 feet.

The quarry is of interest, as showing one of the thin bands of soft shale that occur at various horizons in the *Chonetes* Beds. A similar band is generally found in the Ludlow district a few inches below the Bone-Bed.

Above the quarry the greenish type of Upper *Chonetes* Beds can be traced, and immediately above the cottages marked Cwm Hall on the 6-inch map, silvery *Platyschisma* Shales are seen.

Concretionary green marl (Temeside Shales) is exposed near the source of the stream.

(4) Other Sections of Interest.

Quarry in the Redlake Valley, about a mile north-west of Bucknell.—This quarry shows the junction of the *Rhynchonella* and *Chonetes* Beds. The dip is about 15° north-westwards, and in the deeper south-western portion of the quarry typical *Rhynchonella* Beds, containing very few fossils, are exposed. About half-way up the face of the quarry a 1-foot band of hard, massive, blue flagstone can be seen. This band approximately marks the upper limit of the *Rhynchonella* Beds. About this horizon and in the northern part of the quarry there are more irregularly-bedded rocks containing *Chonetes striatella*, *Orthis*, and other fossils which indicate the base of the *Chonetes* Beds.

V. Tectonics.

The principal axis of folding in the district has a Caledonian trend, and strikes north-north-east and south-south-west. It is parallel both to the great Church-Stretton Fault and to the minor faults of the district. There is also a system of folds with axes approximately east and west, and at least one important fault runs a few degrees south of east to north of west. It probably extends for some distance westwards up the Redlake Valley, but there is entirely hidden by alluvium.

Jointing is well developed, especially in the *Rhynchonella* and *Chonetes* Beds.[1] The two principal directions are parallel to the two series of faults, and the jointing was obviously developed during the folding, as the inclination of the joint-planes to the vertical varies with the dip, but to a less extent.

VI. Summary and Conclusions.

The period of transition from Silurian to Old Red Sandstone times was one of violent earth-movements and volcanic upheaval in many parts of Great Britain, and a great unconformity separates the rocks of the later system—laid down in land-locked seas under continental conditions—from the fossiliferous marine rocks of the earlier. In that part of the country which is now occupied by South-East Shropshire, however, the transition was most emphatically a gradual one, and the change in the character of the rocks can be traced step by step.

During the tranquil Salopian period a great thickness of monotonous grey sediment was laid down. Perhaps the first sign of a change in conditions and a shallowing of the sea is the increased number of fossils in the upper part of the Lower *Chonetes* Beds. The flagstones of the Upper *Chonetes* Beds have (as mentioned above on p. 230) an undulating surface due doubtless to wave-action, and this points to a further shallowing of the sea. The bands of fossils of small individuals and the Ludlow Bone-Bed farther east indicate the commencement of conditions unfavourable to the marine fauna which had hitherto flourished. Later the increasing concentration of iron salts in the water caused the slightly-greenish tint of the Upper *Chonetes* Beds. A shallow-water fauna of gasteropods and *Lingulæ* gradually replaced the familiar forms of the *Chonetes* Beds, as, for example, *Chonetes*, *Rhynchonella*, and *Orthis*, and the occurrence of *Platyschisma* bands shows how well this fauna flourished for a short time during the deposition of the *Platyschisma* Shales. Then sediments of a very different nature were deposited: micaceous sandstones in place of calcareous silts. The succeeding Temeside Shales have many features in common with sediments of other ages which mark the commencement of arid conditions. Among the characteristics may be mentioned the green colour, the rubbly and marly nature, and the scanty fauna including ostracods (*Leperditia* and *Beyrichia*), and stunted lamellibranchs. Finally, even these few organisms died out and the succeeding rocks (Old Red Sandstone?)[2] assumed a red colour, since the natural process of oxidation of the iron salts was not hampered by the presence of decaying animal tissues.

[1] See R. I. Murchison, 'Siluria' 4th ed. (1867) p. 131.

[2] See note, p. 242.

In addition to demonstrating the uninterrupted transition from Upper Silurian through Downtonian rocks, one of the principal results of this investigation is the establishment of a succession in these strata of the Welsh Borderland identical with that determined by Miss Elles & Miss Slater for the Ludlow district of Shropshire.

Another feature of interest in the district is the increased thickness of all the Upper Ludlow rocks. A comparison of the thicknesses of the strata in the few districts which have been described in detail according to the new classification may be shown in tabular form:—

	Bucknell.	*Mocktree Hill*[1] (5 *miles east of Bucknell*).	*Ludlow*[1] (11 *miles east*).	*South Staffs*[2] (37 *miles E.N.E.*).	
	feet.	feet.	feet.	feet	inches.
Temeside Shales	350	120	110	33	6
Downton Sandstone ...	110	about 40	about 50	79	6
Chonetes Beds	350	160	150	}	
Rhynchonella Beds......	300	120	110	} 23	6
Dayia Beds	? 300	150	40	}	
Aymestry Limestone ...	—	250	75	11	6
	1410	840	535	148	0

It is not easy to compare the thicknesses in other districts, owing to the varied groupings of the strata which have been adopted. The following may be considered approximately correct:—

	Bucknell.	*Malvern and Ledbury* (32 *miles south-east*).	*Tortworth*[7] (50 *miles S.S.E.*).
	feet.	feet.	feet.
Temeside Shales	350	400[3]	?
Downton Sandstone	110	10–100[4]	?
Chonetes Beds	350	}	}
Rhynchonella Beds.........	300	} 100–200[5]	} 40
Dayia Beds	? 300	}	}
Aymestry Limestone	—	10–40 ?[6]	?
	1410	520–740	

[1] G. L. Elles & I. L. Slater, Q. J. G. S. vol. lxii (1906) p. 199.

[2] W. W. King & W. J. Lewis, Geol. Mag. dec. 5, vol ix (1912) pp. 437 *et seqq.*

[3] G. H. Piper, Trans. Woolhope Nat. F.C. 1895–97, pp. 310–13. This is assuming that the Ledbury Beds and the Temeside Shales are homotaxial, which, from the descriptions of the former, seems very probable.

[4] J. Phillips, Mem. Geol. Surv. vol. ii, pt. 1 (1848) p. 99; see also T. T. Groom, 'Geology in the Field' Jubilee vol. Geol. Assoc. (1910) p. 709.

[5] J. Phillips, *op. cit.* p. 94.

[6] T. T. Groom, *op. cit.* p. 709.

[7] J. Phillips, *op. cit.* p. 192.

It is seen that the aggregate thickness of Upper Ludlow and Temeside rocks in the Bucknell district far exceeds that recorded in any other district within 50 miles.

Finally, the examination of the area has shown that the greater part of the 'Old Red Sandstone' of the Survey maps must be considered as belonging to the Temeside Shales, and that the extent, if present, of true Old Red Sandstone rocks in the Clun Forest is very small.[1]

This paper would not be complete without a reference to the zonal work carried out by Miss G. L. Elles & Miss I. L. Slater on Upper Ludlow rocks. This investigation has confirmed, in every particular, the classification adopted by these authors, and proved the wisdom of their divisions, which have been found to hold good also for the district west of the original area. Mr. W. W. King & Mr. W. J. Lewis[2] have already shown this likewise to be the case in an area far away to the north-east.

In conclusion I wish to express my thanks to Dr. A. H. Cox, not only for suggesting the work and for valuable assistance during the course of the investigation, but also for reading through the manuscript. Thanks are also due to Dr. W. T. Gordon, who has facilitated in every way that part of the work which was carried out in the Geological Department of King's College (University of London), and who also read part of the manuscript.

NOTE.—I have to acknowledge the kindness of Mr. W. W. King in calling my attention to a paper by himself and Mr. W. J. Lewis[3] published shortly after this paper was written.

Fish-remains, indicating a Downtonian age, have been found in the red shales that rest on the Temeside shales in South Staffordshire. This discovery modifies very greatly the thicknesses given for Downtonian rocks of that area in the table (p. 241), and at the same time throws doubt on the Old Red Sandstone age of the rocks overlying the Temeside Shales in the Ludlow district.

In the Clun Forest my original determination of the age of the red sandstones occurring above Temeside Shales on Clun Hill rested entirely on the correlation with the Ludlow district, the rocks not being sufficiently exposed for careful examination. In the circumstances, therefore, it seems advisable to defer the attribution of a definite age to these purplish-red sandstones, until a more extended study can be undertaken.

[1] See C. Lapworth & W. W. Watts, 'Geology in the Field' Jubilee vol. Geol. Assoc. (1910) p. 760, on the 'Old Red Sandstone' of the Long Mountain. See also note, above.

[2] Geol. Mag. dec. 5, vol. ix (1912) pp. 437 *et seqq.*

[3] Proc. Birmingham Nat. Hist. & Phil. Soc. vol. xiv (1917) p. 90.

LIST OF FOSSILS.

			Upper Ludlow Group.			Temeside Group.		
	? Lower Ludlow.	*Dayia* Shales.	*Rhynchonella* Beds.	Lower *Chonetes* Beds.	Upper *Chonetes* Beds.	*Platyschisma* Beds.	Downton-Castle Sandstone.	Temeside Shales.
Cœlenterata.								
Cyathophyllum sp. ?	...	...	×					
Favosites sp. ?	...	...	×					
Annelida.								
Serpulites longissimus Murchison	...	...	×	×				
Serpulites sp.	...	...	×					
Echinodermata.								
Crinoid-stems and ossicles	...	...	×	×				
Brachiopoda.								
Lingula minima J. de C. Sowerby	...	...	...	...	...	×	×	
L. cornea J. de C. Sowerby	...	...	...	...	...	...	...	×
Discina rugata J. de C. Sowerby	...	...	×	×	×			
Crania implicata ? J. de C. Sowerby	...	...	×					
Spirifera elevata Dalman	...	...	...	...	×	×		
Dayia navicula (J. de C. Sowerby)	...	×						
Orthis lunata J. de C. Sowerby	...	...	×	×	×			
O. cf. *elegantula* Dalman	...	...	...	...	×			
O. cf. *orbicularis* J. de C. Sowerby	...	...	...	...	×			
Rhynchonella nucula J. de C. Sowerby	...	...	×	×	×			
Do. do. var. ?	...	...	...	...	×	×		
Chonetes striatella (Dalman)	...	...	...	×	×	×		
Do. do. var. ?	...	...	×	×				
Polyzoa	...	...	×	×	×			
Mollusca.								
Cucullæa antiqua J. de C. Sowerby	...	...	...	...	...	×		
C. sp.	...	...	×	×				
Cardiola interrupta J. de C. Sowerby	..	×						
Ctenodonta sp.	...	...	...	×				
Pterinæa asperula ? McCoy	...	...	×					
Pt. sp.	...	...	...	...	...	×		
Orthonota amygdalina J. de C. Sowerby.	...	...	×	×				
O. impressa ? J. de C. Sowerby	...	...	×					
O. solenoides J. de C. Sowerby	...	...	...	×				
O. sp.	×							
O. sp.	...	...	×					
Goniophora cymbæformis J. de C. Sowerby.	...	...	×	×				
Modiolopsis complanata J. de C. Sowerby.	...	...	...	...	..	×	×	?
M. nilssoni ? Hisinger	×							
M. sp.	...	...	...	...	...	×		
M. sp.	...	...	...	...	...	...	...	×
Mytilus ? sp.	...	...	...	×				

LIST OF FOSSILS (*continued*).

			Upper Ludlow Group.			Temeside Group.		
	? Lower Ludlow.	*Dayia* Shales.	*Rhynchonella* Beds.	Lower *Chonetes* Beds.	Upper *Chonetes* Beds.	*Platyschisma* Beds.	Downton-Castle Sandstone.	Temeside Shales.
MOLLUSCA (*continued*).								
Platyschisma helicites J. de C. Sowerby.	...	...	...	...	...	×	×	
Holopella sp.	...	...	...	...	...	×	×	
Bellerophon trilobatus J. de C. Sowerby.	...	...	...	...	...	...	×	
B. expansus J. de C. Sowerby	...	×						
CEPHALOPODA.								
Orthoceras ludense J. de C. Sowerby.	...	...	×	×				
O perelegans Salter	...	×	×	×				
O. gregarium ? J. de C. Sowerby	×							
O. striatum ? J. de C. Sowerby	×							
O. ibex J. de C. Sowerby	×	...	×	×				
O. marloense ? Phillips	...	..	×	×				
O. tracheale J. de C. Sowerby	×							
O. annulatum ? J. de C. Sowerby	..	...	×					
O. sp. (i)	...	...	×					
O. sp. (ii)	...	×						
O. sp. (iii)	...	×						
ARTHROPODA.								
Beyrichia wilckensiana Jones (=*tuberculatus*).	...	...	×					
B. klœdani McCoy	...	...	...	...	×	×	×	?
B. spp.	...	...	×	×	×	×	...	×
Agnostus sp.?	...	×						
Pterygotus problematicus ? Salter	...	...	...	...	...	×		
Eurypterus spp.	...	...	...	...	...	×	...	×
Leperditia sp.?	...	...	...	...	...	...	...	×

EXPLANATION OF PLATES XIX & XX.

PLATE XIX.

Fig. 1. Caer Caradoc, showing scarp and dip-slopes. Summit of Upper *Chonetes* Beds. (See p. 224.)

2. *Rhynchonella* Flags, Pentre Quarry. An example of jointing. The white streaks are lines of fungi along the softer layers of the flags. (See p. 240.)

PLATE XX.

Geological map of the Bucknell district, Shropshire, on the scale of 2 inches to the mile or 1 : 31,680. The map is oriented north and south. Also section across the district, on the same scale.

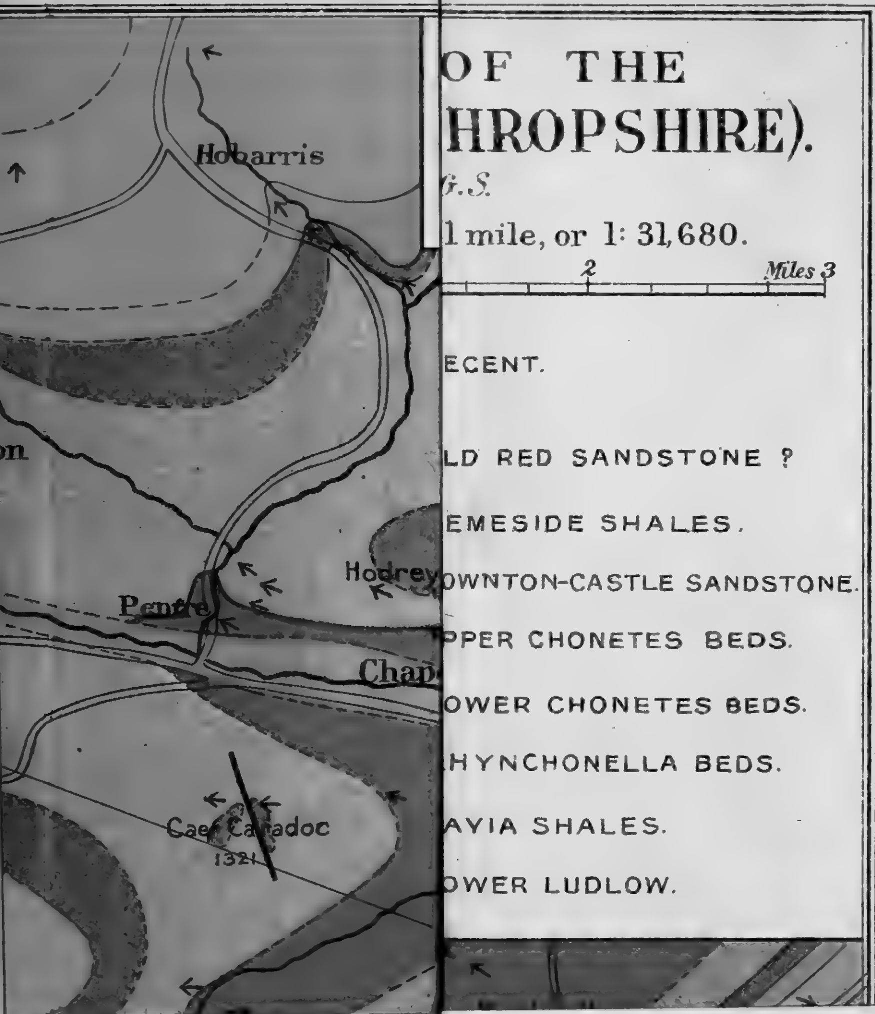
Fig. 1.—*Caer Caradoc, showing scarp and dip slopes.*

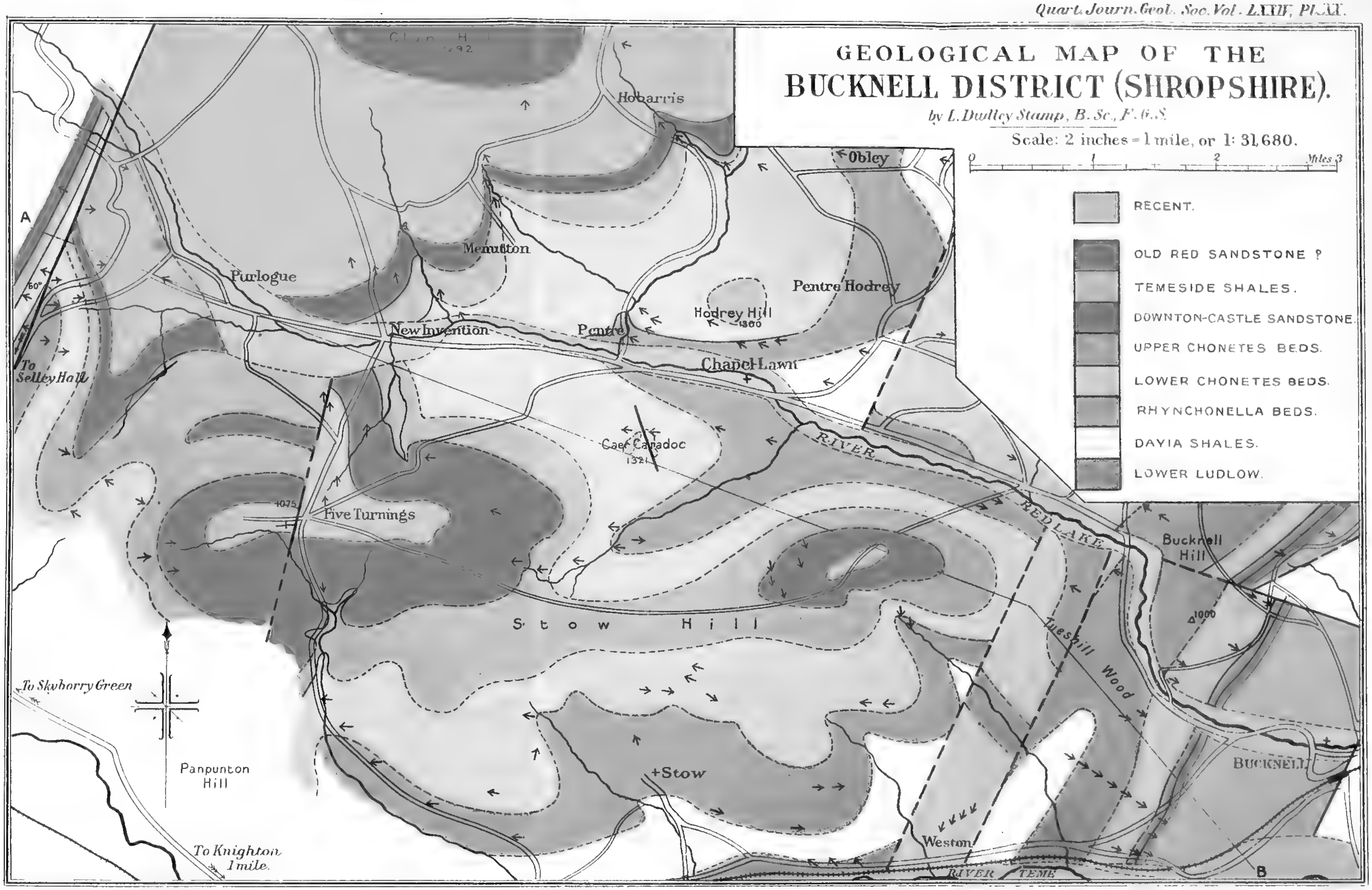
L. D. S. photo.

Fig. 2.—Rhynchonella *Beds, Pentre Quarry.*

L. D. S. photo.

[The height of the exposure is about 18 feet.]

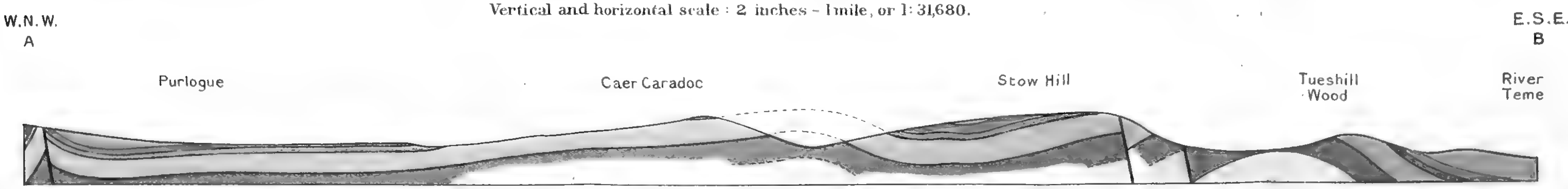

OF THE
HROPSHIRE).
G.S.
1 mile, or 1: 31,680.
2
Miles 3
ECENT.
LD RED SANDSTONE ?
EMESIDE SHALES.
OWNTON-CASTLE SANDSTONE.
PPER CHONETES BEDS.
OWER CHONETES BEDS.
HYNCHONELLA BEDS.
AYIA SHALES.
OWER LUDLOW.
Hobarris
Hodrey
Pentre
Chap
Caer Caradoc
1321



Indicates railway-line

SECTION FROM W.N.W. TO E.S.E. ALONG THE LINE A-B ON THE MAP.

Vertical and horizontal scale: 2 inches = 1 mile, or 1: 31,680.



Discussion.

Mr. W. Whitaker asked whether there was any stratigraphical break between the Silurian and the Old Red Sandstone.

Mr. G. W. Lamplugh, in commenting upon the attenuation of the successive divisions in the same direction, enquired if the character of the beds revealed whether they were deposited upon an original slope, or upon a plane which was gradually tilted.

Dr. A. Smith Woodward was surprised by the absence of fish-remains among the fossils. It was important to make special search for them, because they marked well the different horizons at the base of the Old Red Sandstone, and even fragments were often identifiable.

Dr. J. W. Evans remarked on the importance of work on the passage-beds between the Silurian and the Old Red Sandstone in Shropshire. The present limits of the Devonian throughout the world were primarily determined by those of the continental or Old Red Sandstone conditions in this area. There was, however, a difficulty in correlating the highest marine beds with those of other areas, because not only did the horizon in all probability vary from point to point, but the beds were laid down under abnormal conditions. It was quite possible that they might be of the same age as strata elsewhere (as, for example, in Belgium) referred to the Devonian by most authors. He enquired whether the Old Red Sandstone was represented only by sandstones, or whether, as was usually the case, the red marls were the most important feature of the lower portion of the formation.

Mr. R. B. Newton referred to the absence of *Lingula cornea* and *Onchus*-spines among the fossils exhibited by the Author, from the Clun-Forest district, both of which are characteristic of the uppermost division of Murchison's scheme of the Silurian strata, as published in Davidson's 'Monograph of the British Fossil Brachiopoda' (1866) part 7: 'The Silurian Brachiopoda,' p. 30. The occurrence of *Lingula minima*, which is considered to differ from *L. cornea* and to belong to a lower horizon, is, however, observed in the Author's collection. The suggestion is made, therefore, that the Clun-Forest fossils belong to the topmost part of the Upper Ludlow, as stated by the Author; but that the deposits at Kington, Downton, etc., with *Onchus* and *Lingula cornea*, would represent the passage-beds between the Silurian and the Old Red Sandstone.

Dr. A. H. Cox, replying on behalf of the Author, stated that there was no indication of any stratigraphical break either within the Silurian rocks themselves, or between the Silurian and the Old Red Sandstone. The fossil-bands of small individuals and also the 'Fragment-Bed,' were merely due to slight changes in conditions, such as changes in the salinity of the sea-water, but they did not imply breaks in deposition. The Author devoted a section of his paper to a discussion of the gradual oncoming of Old Red Sandstone conditions, the changes in lithology being in the main quite gradual. The first signs of a change are seen as low down as the *Rhynchonella* Beds, and they become more pronounced as the series is ascended. The most important palæontological change is that at the base of the Temeside Group. With regard to the exceptional thickness of the Upper Silurian deposits in the Clun-Forest district, there is abundant evidence that the whole deposit accumulated in not very deep water, so that, despite the regional tendency to an uplift due to the oncoming of continental conditions, there must also have been local subsidence due to the loading of the sea-floor by the great weight of sediments. Thus it was possible for a considerable thickness of sediments to accumulate in comparatively-shallow water, in accordance with the theory of isostasy. The sediments were accumulated near a shore-line, where the principal deposition usually takes place, and the rapid eastward thinning of the deposits was probably accounted for by the increased distance from the main land-area whence the clastic material was derived. The outcrop of Old Red Sandstone is so small that it is limited to a thin capping of sandstone on Clun Hill, with the result that the usual red marls are not displayed within the area mapped. The local absence of true 'bone-beds,' both from the Upper Ludlow and from the Temeside Group, suggested that (for some reason) fish-remains were not at all common in this particular district, which in this respect certainly displays a striking contrast with the Ludlow area. *Lingula cornea* occurred abundantly, and was restricted to the Temeside Shales; whereas *L. minima* was restricted to the underlying Downton Sandstones and *Platyschisma* Shales. In conclusion, the speaker wished to congratulate the Author on having completed his investigation, despite the difficult conditions under which he had been compelled to work.

[September 5th, 1919.]

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CONTENTS.

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[With Five Plates, illustrating Dr. A. E. Trueman's Paper.]

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TO BE HELD AT BURLINGTON HOUSE.

Session 1919–1920.

1919.	
Wednesday, December	3 —17*
1920.	
Wednesday, January	7*—21*
„ February (*Anniversary Meeting*, Friday, February 20th) .	4*—25*
„ March	10—24*
„ April	21*
„ May	5 —19*
„ June	9 —23*

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

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

10. *The* EVOLUTION *of the* LIPAROCERATIDÆ.

By ARTHUR ELIJAH TRUEMAN, D.Sc., F.G.S., University College of South Wales and Monmouthshire, Cardiff. (Read April 17th, 1918.)

[PLATES XXI–XXV.]

CONTENTS.

I. INTRODUCTION.

THE ammonites dealt with in this paper are characteristic of the uppermost zones of the Lower Lias (Charmouthian), and they are of three general types, namely:—

(1) A capricorn form, evolute slender whorls (serpenticone) with stout simple ribs.

(2) An involute form with swollen whorls (sphærocone), bituberculate, generally known as *A. striatus* or *A. bechei*.

(3) A form intermediate between these two, with capricorn inner whorls, the outer whorl swollen, with more numerous slender ribs bearing two rows of tubercles (usually known as *A. heterogenes*).

In order to name some ammonites collected at Lincoln, apparently similar to those called *A. striatus*, the relationships of these types were studied; it presently became clear that the classification of these ammonites, and the correlation of the beds in which they occur, needed to be considerably revised, and that such a revision must be preceded by an investigation of all available ammonites composing the family Liparoceratidæ. With this in view, a large number of these fossils was collected from practically all the English exposures, their precise horizons were noted, and developmental and sutural evidence was examined. The present paper includes the main results of this work. Several new specific names are proposed, but only where this is necessary to define a series: future work may show that many of the intermediate forms mentioned must also receive separate names, but, as this paper is mainly concerned with establishing the lineages and their geological ranges, minute description of species has not been undertaken.

In the course of this investigation much assistance has been received from other workers. Dr. W. D. Lang kindly placed at

my disposal his carefully collected material from the Dorset cliffs, while other specimens have been lent by Mr. S. S. Buckman, Mr. L. Richardson, Mr. J. W. Tutcher, and Mr. C. H. Watson.

Mr. C. P. Chatwin directed my attention to the Napton (Warwickshire) exposure, and this led to the discovery of an important series of ammonites.

For permission to examine material, and for assistance while working in the various museums, I am indebted to Mr. G. W. Lamplugh and Mr. H. A. Allen (Jermyn Street Museum), Dr. A. Smith Woodward and the late Mr. G. C. Crick (British Museum—Natural History), Mr. E. E. Lowe (Leicester), Mr. A. Smith (Lincoln), Prof. J. W. Carr (Nottingham), Mr. T. Woodhouse Parkinson (Whitby), Mr. S. E. Harrison (Cheltenham), and Mr. H. Woods (Sedgwick Museum, Cambridge).

In the field, help has been given by Mr. W. E. Howarth (in Lincolnshire and Yorkshire), by Mr. J. T. Sewell (Whitby), Mr. J. W. Gray (Cheltenham), and Mr. C. H. Watson (Napton).

Prof. T. F. Sibly kindly read my manuscript, and offered various suggestions; while Prof. G. Norwood and Mr. C. Brett have helped with the nomenclature.

My special thanks are due to Prof. H. H. Swinnerton for his continued advice and encouragement, and to Mr. S. S. Buckman for the help that he has so readily given in numerous ways.

II. Historical Notes.

Early in the last century Sowerby figured two ammonites which he called *Ammonites henleyi* and *A. bechei*, while Reinecke described a somewhat similar form as *A. striatus*. While these species are in themselves quite distinct when fully understood, there are so many apparently intermediate stages that it is not surprising that confusion quickly arose in the use of the names.

Thus A. d'Orbigny's *A. henleyi* (3,[1] pl. lxxxiii) is an ammonite which I consider to be closely related to those forms that have been called *A. striatus* Reinecke, while *A. henleyi* Reynès[2] is unlike any English fossil that I have seen. Similarly, a number of the specimens figured by Quenstedt (4, pl. xxix) are allied to *A. nautiliformis* J. Buckman, a member of quite a different series.

The naming of the capricorn ammonites presented similar difficulties: for, until the different species are closely compared, they appear to be very similar. The three best-known species are *A. capricornus* Schlotheim, *A. latæcosta* Sowerby, and *A. maculatus* Young & Bird; the first name has been most frequently used. E. F. Schlotheim[3] in describing this species gave no figure,

[1] These numbers in parentheses refer to the List of Literature, § VIII, p. 293.

[2] P. Reynès, 'Essai de Géologie & de Paléontologie Aveyronnaises' 1868, p. 88 & pl. i, figs. 2*a*–2*b*. Compare *Ægoceras spoliatum*, K. Futterer, 'Die Ammoniten des Mittleren Lias von Œstringen' Mitt. Bad. Geol. Landesanst. vol. ii (1893) pl. x, fig. 1.

[3] 'Die Petrefactenkunde' 1820, p. 71.

and, although Schlœnbach has more recently studied the type-specimens,[1] it is still uncertain precisely which species is covered by the name *A. capricornus*, and for the present it is perhaps better not to use the name. When the name *A. maculatus* has been employed it has nearly always been misapplied, as, for example, by Wright and Quenstedt; while the term *A. latæcosta*, which covers a species that is related to many of our English capricorns, has until lately been very little used.

All the above-mentioned writers, while they often figured sutures of these ammonites, made no use of the suture as a means of identification. F. von Hauer,[2] who described another capricorn in 1854, pointed out the features in its suture by which it might be distinguished from the ammonites that it resembled. Apparently his remarks have hitherto been overlooked.

In 1867 Hyatt proposed the three genera *Microceras*, *Androgynoceras*, and *Liparoceras*, to include respectively the capricorn ammonites, the ammonites of the *heterogenes*-type, and those of the *striatus*-type. Such an arrangement made generic identification simple, since each genus was comparatively distinct. Wright concluded, however, from a study of these fossils, that *A. henleyi* was descended from a capricorn form, *A. latæcosta*, and similarly that *A. heterogenes* had inner whorls resembling those of *A. capricornus* (8, p. 370). That is to say, Wright recognized two genetic series, each of which included capricorn and *heterogenes*-like forms. While Wright also noted that the outer whorl of *A. heterogenes* resembled *A. striatus*, he did not suggest that this latter ammonite was a further advance along the same line of descent, because the inner whorls of *A. striatus* show no trace of capricorn ornamentation. E. Haug[3] also noticed the smooth inner whorls of *A. striatus*, and suggested that they resembled *A. globosus*; still more recently Prof. J. Perrin Smith has included *A. bechei* and similar species with the Polymorphinæ, separating them from the remainder of the Liparoceratidæ, presumably for the same reason.[4]

Mr. S. S. Buckman suggested, however, in 1891,[5] that ammonites of the *A.-striatus* type are descended from capricorn ammonites, the capricorn style of ornamentation being omitted in the development of advanced members of the series as the quickest method of producing shells of globose form. This conclusion is supported by the details to be given later. Mr. Buckman accordingly revised

[1] Schlœnbach studied Schlotheim's type-specimens of *A. capricornus*, and said that they were identical with *A. maculatus* Quenstedt. See U. Schlœnbach, 'Ueber den Eisenstein des Mittleren Lias, &c.' Zeitschr. Deutsch. Geol. Gesellsch. vol. xv (1863) p. 465; but this is not sufficiently definite to be of value.

[2] 'Beiträge zur Kenntniss der Capricornier der Œsterreichischen Alpen' Sitzungsb. K. Akad. Wissensch. Wien, vol. xiii (1854) p. 94.

[3] 'Ueber die Polymorphidæ, &c.' Neues Jahrb. vol. ii (1887) p. 103.

[4] J. P. Smith in Eastman-Zittel, 'Text-book of Palæontology' 2nd ed. vol. i (1912) p. 67.

[5] S. S. Buckman, 'Monograph of the Inferior Oolite Ammonites' Palæont. Soc. p. 289 (footnote).

Hyatt's genera to express this interpretation, and limited each generic name to a series which evolves from capricorn to bituberculate sphærocone (1, vol. i, p. *iii*). That is to say, those generic names which were formerly applied to morphic equivalents on several lineages were made to include the heteromorphic stages of phylogenetic series. *Microceras* was applied to an earlier series, while *Androgynoceras* and *Liparoceras* were limited to series of those ammonites that have respectively elevated and depressed whorls. At a later date A. Hyatt[1] used the name *Amblycoceras* to include certain capricorns; the specimen then figured is peculiar in having costæ with a slight peripheral curve, and Mr. Buckman proposes to restrict the name for such a series.[2] *Oistoceras* was suggested for capricorns in which the ribs have a very distinct bend on the periphery, more marked than that shown by *Amblycoceras* (1, vol. i, p. *iv*).

Recognizing that there exists at least another series of ammonites passing through comparable stages, Mr. Buckman used Waagen's name *Ægoceras*[3] to indicate them, including here *A. nautiliformis* J. Buckman, which had frequently been confused with *A. bechei*, but from this it is separated by a very considerable time-interval (1, vol. i, p. *iii*).

Summarizing, then, the existing classification of these ammonites, we find the following genera in use:

Liparoceras—Depressed forms with coarse ornamentation.
Genotype selected by Mr. Buckman: *A. striatus* Bronn, *non* Reinecke.

Androgynoceras—Elevated whorl, finer ornamentation.
Employed to include *A. maculatus* Young & Bird, *A. heterogenes* Young & Bird, *A. bechei* Sowerby, *A. henleyi* Sowerby, and many English capricorns.
Genotype selected by Mr. Buckman: *A. hybrida* A. d'Orbigny.

Amblycoceras—Capricorns only hitherto described, with slight peripheral rib-curve. Not otherwise defined.

Oistoceras—A series with marked rib-curve on the venter.
Genotype, *A. figulinus* Simpson. Capricorn stage only known.

Ægoceras—Includes capricorns believed to lead to *A. nautiliformis* J. Buckman.
Genotype, *Ammonites planicosta* (=*capricornus*) A. d'Orbigny.

In constructing the above-named genera little attention has been paid to any characters, except whorl-shape and ornamentation; the sutures have not been compared, and the less obvious details of ontogeny have not been examined. Thus the characters hitherto described are not sufficient to identify a single genus with any certainty; indeed, the species referred to certain genera are in no

[1] In Eastman-Zittel, 'Text-book of Palæontology' 1st ed. vol. i (1900) p. 578.
[2] S. S. Buckman in 'Geology of the Country between Whitby & Scarborough' Mem. Geol. Surv. 2nd ed. (1915) p. 95.
[3] W. Waagen, 'Die Formenreihe des *Ammonites subradiatus*' 1869, p. 247.

way related. It is, therefore, necessary to revise the generic classification.

Each genus, as has been shown, includes ammonites of very different appearance, ranging from capricorn evolute forms to bituberculate involute forms; in constructing the revised classification offered here, the affinities of the various members of the genera have been ascertained by the establishment of continuous series of forms only separated by small differences attributable to accelerated development. Further, the sutures of each of these series have a number of features in common, and these constitute the readiest means of identification.

III. Stratigraphical Notes.

The time-ranges of these ammonite lineages are of importance to the stratigraphical geologist, for the ammonites of this group are dominant in the upper part of the Lower Lias, where it has been usual to recognize a *capricornus* zone overlying a *henleyi* or *striatus* zone. But it is quite clear that the *striatus*-like forms are descended from capricorn ammonites, and such a conclusion can only be reconciled with the facts of stratigraphy by supposing that there were below the *striatus* zone capricorns which gave rise to the involute forms of that horizon, and it is also probable that involute forms have evolved from the capricorns of the *capricornus* zone. Such capricorns of pre-*striatus* age, and involute forms of post-*capricornus* age, will be described from Napton (Warwickshire) and Lincoln respectively.

Until late years it has been supposed that almost all the *striatus*-like forms occurred in the so-called '*striatus* zone.' Recently, however, Dr. W. D. Lang [1] has carefully collected Liassic ammonites in the cliffs of Dorset with reference to their precise position. From a study of his specimens it appears that these forms occur at several distinct horizons, as follows:—

margaritatus zone.		Involute ammonites (of the ? *A. nautiliformis* group).
davœi zone.	*Oistoceras* sub-zone.	Capricorn ammonites (*Oistoceras*) and involute ammonites similar to *A. bechei*.
	Liparoceras sub-zone.	Involute ammonites similar to *A. henleyi*.
	latæcosta sub-zone.	Capricorn ammonites of the *A. latæcosta* group.
ibex zone.		Capricorn ammonites of the *Beaniceras* series (see p. 268). Involute ammonites of the *Liparoceras* series.

It will be noticed that involute ammonites of the *Liparoceras* series are only to be found in the upper part of the *ibex* zone,

[1] 'The Geology of the Charmouth Cliffs, &c.' Proc. Geol. Assoc. vol. xxv (1914) p. 293; 'The *Ibex* Zone at Charmouth, &c.' *ibid.* vol. xxviii (1917) p. 31.

while involute forms of the *henleyi* and *bechei* series occur respectively in the *Liparoceras*[1] and *Oistoceras* sub-zones of the zone of *Deroceras davœi.*

Around Cheltenham, beds with *striatus*-like forms are succeeded by beds with capricorns, these being immediately below the Middle Lias (Marlstone Series) of the district, and this has been accepted as the normal sequence. The *striatus*-like ammonites, however, are of the *Liparoceras* series, and are similar to those found in the upper part of the *ibex* zone of Dorset. Since no higher horizon with involute Liparoceratids has been detected in South Gloucestershire, it is extremely probable that most of the *davœi* zone is not represented there. Further, some of the capricorn ammonites of the Cheltenham district are similar to those found in the *latæcosta* sub-zone of Dorset, while others are of a different type, and probably indicate a horizon that is not represented in Dorset.[2]

At Napton-on-the-Hill (Warwickshire), at Dumbleton, and in some other parts of Gloucestershire, lower beds are present, containing capricorn ammonites of the *Liparoceras* series, of which involute forms only are known in Dorset. As the Napton pit was not in work at the time of my visits no thicknesses can, with any certainty, be assigned to these beds. The following general succession was determined :—

margaritatus zone.	Middle Lias.
latæcosta sub-zone.	Beds with capricorn ammonites of the *A. latæcosta* group.
ibex zone.	Beds with capricorn ammonites of another series (*Beaniceras*). Beds with involute *Liparoceras* (*L. obtusinodum* and other spp.). Beds with capricorns of the *Liparoceras* series. Beds with *Acanthopleuroceras valdani*. Beds with *Tragophylloceras ibex*.

The succession at Dumbleton is probably very similar (see Table I). At Radstock (Somerset) bituberculate sphærocones of a different type occur at a still lower horizon: namely, the *valdani* zone, and it is therefore probable that another group of capricorns will be found below this level.

South of Lincoln the upper part of the Lower Lias is again exposed, and the *Oistoceras* and *dædalicosta* sub-zones, which are presumably absent in Gloucestershire and Warwickshire, are represented by thin but very fossiliferous deposits. Fossils of the *Oistoceras* sub-zone may also be found in the lowest beds of the

[1] This is an unfortunate name, since by *Liparoceras* were meant involute ammonites of the *henleyi* series, which are here assigned to *Androgynoceras*, while *Liparoceras* is confined to lower beds. The name *dædalicosta* sub-zone is here proposed to take the place of Dr. Lang's *Liparoceras* sub-zone.

[2] See S. S. Buckman, 'Jurassic Chronology: I. Lias' Q. J. G. S. vol. lxxiii (1917–18) p. 264.

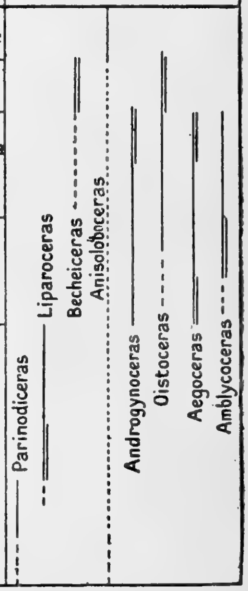
Middle Lias near Lincoln, and among them are bituberculate developments of *Oistoceras* (7, p. 104).

There are, therefore, not less than six widely-separated horizons with *striatus*-like forms, alternating with beds containing the different capricorn ammonites from which they have respectively evolved. Details of the correlation are given in Table I; the hemeral terms given for comparison are those recently proposed by Mr. S. S. Buckman, to whom I am indebted for the loan of his

TABLE I, *showing the chief areas where Liparoceratid horizons are developed.*

Hemeral Terms	Dorset	Cheltenham District	Warwickshire & N. Glos.	Lincoln	Yorkshire	Zones	
(MIDDLE LIAS with Liparoceratids)	×		×			margaritatus zone	
Oistoceras	×			×	×	davœi zone	Oistoceras sub-zone
'henleyi'	×			×		davœi zone	dædalicosta sub-zone
davœi	×			×		davœi zone	dædalicosta sub-zone
brevilobatum		×			?	davœi zone	latæcosta sub-zone
latæcosta	×	×	×	×	×	davœi zone	latæcosta sub-zone
Beaniceras	×	×	×	×	×	ibex zone	
carinatum	×	?				ibex zone	
cheltiense	×	×	×	?	×	ibex zone	
valdani	×	×	×	×		ibex zone	
ibex	×	×	×		?	ibex zone	

Ranges of Genera



[The hemeral terms used are mainly those proposed by Mr. S. S. Buckman in Q. J. G. S. vol. lxxiii (1917–18) pp. 264–266.]

notes on the correlation of these beds. The corresponding sub-zones are also shown. It must be borne in mind that an understanding of the relationships of the ammonites is only possible when their horizons are accurately known; the details of the ammonite succession within the sub-zones must, therefore, be studied. The best time-scale is obviously supplied by a sequence of forms which are genetically connected, but a time-scale based on an evolutionary series (or a number of such series) cannot readily be constructed for the Liassic rocks of England, because, except within small limits, the ammonites of the Lias did not evolve here, our faunas probably representing successive immigrations. Consequently, an ideal correlation is not at present possible.

IV. General Evolution.

It is shown in the preceding notes that in the upper zones of the Lower Lias occur ammonites of several genera, which evolve from slender capricorns with stout ribs to involute bituberculate forms with swollen globose whorls, and that the morphic equivalents on separate lines of descent are so similar in certain cases as to present some difficulty in identification, unless sutural and other minute characters are taken into consideration. Further, the several series are not quite contemporaneous, morphic equivalents of different genera occurring at considerable intervals, and thus the precise geological age of one of these ammonites can only be determined when its lineage is known. It will be convenient now to consider the general trend of evolution in the characters which are common to all the series.

Early capricorns of this family show lateral ribbing at a diameter of 3 mm. or thereabouts, no ribs being present on the periphery until much later. In more advanced capricorns, however, the ribs appear, by tachygenesis, at about the diameter of 2 mm.

In the latter forms, at a diameter of about 100 mm., the ribs of the last whorl are frequently more widely-spaced, and may acquire small tubercles. In slightly later members of each series this condition is accompanied by a rapid expansion of the last whorl, the ribs becoming more slender and bearing paired tubercles; the ammonite is then of the *heterogenes*-type. The whorls are at first smooth and thick, become slender and only slightly embracing, later becoming stout again, the development of this latter condition thus being indirect. From this point onwards the tendency in evolution is to shorten the period of slender costate whorls and to hurry on to the bituberculate condition. This is accomplished by

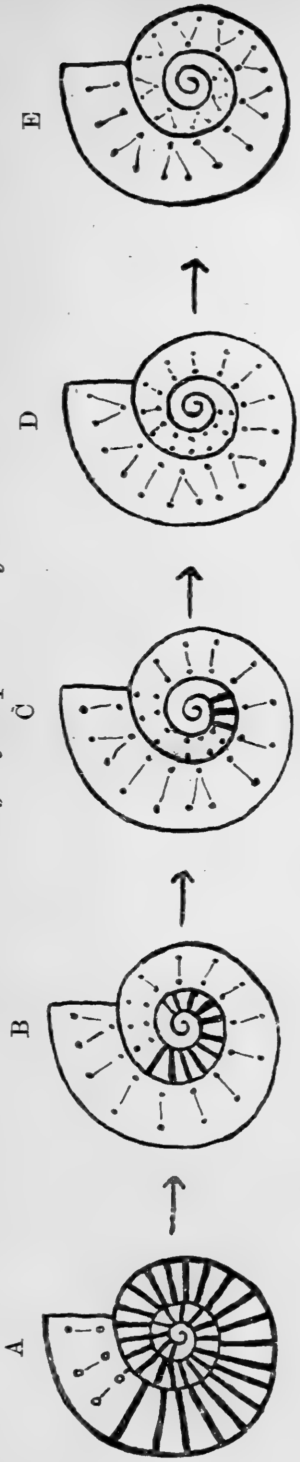
(1) The acceleration of the development of the (secondary) swollen whorls, and of the bituberculation.

(2) The prolongation of the stage of smooth and globose whorls.

As a result, the stage of slender whorls with capricorn ornament is ultimately 'skipped' entirely in development. An example will make this clear. In specimen A, shown diagrammatically in Table II, capricorn ornamentation is developed at a diameter of 2 mm., and the shell does not become bituberculate until a diameter of 90 mm. Succeeding forms (B, C) retain the smooth globose whorls until diameters of 3 mm. and 5 mm. respectively, the bituberculation commencing earlier in each; thus the length of whorl with capricorn ornament in successive specimens of a lineage gradually becomes shorter, until ultimately bituberculation appears without any previous capricorn stage (D, E). In the last-mentioned forms the primitive smooth condition is retained much longer than in the immediate ancestors.

The occurrence of such a series of specimens on each of the lineages examined confirms the conclusion that the smooth inner

TABLE II.—*Diagram illustrating the ornament stages of a series of five ammonites* (A–E) *from a lineage of imparinode forms.*



[The 'skipping' of the capricorn stage is shown, but coiling stages are not shown.]

whorls of the more advanced members are not an indication of different origin from the ammonites which pass through a capricorn stage; this skipping of the capricorn stage during development (saltative palingenesis)[1] being

> 'a compromise due to the necessity of attaining as perfect a condition as possible in as short a time as possible, for the sooner the adult condition is reached the sooner will the organism be able to reproduce its kind.'[2]

Owing to the method of origin of the tubercles as points on the ribs, they are at first necessarily arranged in pairs. When the whorl becomes swollen, however, the line of outer tubercles is much longer than the line of inner tubercles; in many series the number of outer tubercles progressively increases, until it may be double the number of the inner tubercles.

From this stage, therefore, two distinct groups of Liparoceratid ammonites may be recognized, namely:—

(1) An earlier group with tubercles paired in the globose stages (parinode forms).

(2) A later group with tubercles unpaired in the globose stages (imparinode forms).

Almost all British Liparoceratids belong to the second group[3]; Quenstedt's figures show, however (4, pl. xxviii, figs. 16–23), that ammonites of the first group (*A. striatus parinodus*) are of fairly common occurrence on the Continent. In considering the second group it is often convenient to express the ratio of outer to inner tubercles as a fraction, the ratio

[1] Since this paper was read Dr. W. D. Lang has suggested the term 'lipogenesis' in place of saltative palingenesis (Proc. Geol. Assoc. vol. xxx, 1919, p. 60).

[2] A. Dendy, 'Outlines of Evolutionary Biology' 2nd ed. (1912) p. 273.

[3] I have examined only nine British Liparoceratids in the sphærocone stage with paired tubercles; these were collected at a low horizon at Radstock, Somerset (see p. 264).

generally increasing with more advanced forms; this constitutes a ready method of determining approximately the stage of advance of any specimen.

It must be recognized that most Liparoceratids with unpaired tubercles have paired tubercles in their early stages; but, with acceleration of development, the stage of unpaired tubercles is reached earlier in successive members of a series (see Table II, D, E), and in very advanced forms the earliest ornamentation acquired may consist of unpaired tubercles, the outer row having double the number of the inner. The beginning of catagenesis, on the other hand, may be shown by a decrease in the ratio of the number of outer to inner tubercles on the outer whorl.

The following ornament stages may, therefore, be recognized in most lineages:—

(*a*) Capricorn ribs, regularly increasing in number on successive whorls.

(*b*) Capricorn ribs, widely spaced on the outer whorl.

(*c*) Capricorn ribs widely spaced, bituberculation commencing; prominent striations between the ribs on the periphery.

(*d*) Ribs more slender, bituberculate, tubercles paired; ribs dividing on the periphery.

(*e*) Similar, but with tubercles unpaired.

(*f*) Tubercles returning to the paired condition.

The stages *a* to *e* are anagenetic; stage *f* is catagenetic. In the later stages of many sphærocones also the tubercles are finer than in the early stage, leading to great similarity in the several series (homœomorphy). Catagenetic ornament, however, is occasionally seen in the old age of various capricorns, which do not attain the tuberculate stage, but pass directly from anagenetic costate to catagenetic subcostate and striate stages.

Successive members of the series are likewise often characterized by increasing involution and by greater complexity of suture-line. Thus the simple sutures of a capricorn in any lineage are closely comparable with the early sutures of the forms which evolved from it, and with the septal sections of their adult septa.[1]

Longitudinal striations appear to be developed in each of the series considered here, usually appearing first on the periphery soon after the whorls are swollen and bituberculate. In the young of advanced species, such as *Liparoceras cheltiense*, longitudinal striations are developed at a diameter of 20 mm. The shell is rarely well-preserved, and thin sections do not show details of structure: the slight corrugation of the outer shell-layer which gives rise to the striate appearance is often due to the presence underneath it of sharply-defined parallel ridges varying in width, but rarely more than ·5 mm. across, and not more than 1 mm. apart (see 4, pl. xxix, fig. 7 *x*). It is possible, however, that in some cases the underlying ridges are not present, or are lost in subsequent development.

[1] H. H. Swinnerton & A. E. Trueman, 'The Morphology & Development of the Ammonite Septum' Q. J. G. S. vol. lxxiii (1917–18) p. 26.

There are, therefore, five progressive characters which may be used to determine the position of any specimen in its series, namely:—

(1) Ornamentation, progressing from smooth, and costate, to bituberculate (paired) and possibly bituberculate (unpaired).
(2) Whorl shape.
(3) Involution.
(4) Sutural complexity.
(5) Development of longitudinal striations.

Certain of these characters are acquired at a relatively earlier stage in some series than in others; thus the sutures of the capricorns of *Androgynoceras* and *Liparoceras* are similar in degree of complexity, yet in the corresponding later forms the sutures of *Liparoceras* are much more complicated than those of specimens of *Androgynoceras* showing similar involution and tubercle-ratio. The differing associations of these characters will, therefore, be useful in determining the various lineages.

V. Systematic Study of the Genera.

While there are many features in the adult sutures which are common to all the genera, there are nevertheless some readily-distinguished sutural characters which make their identification easy. Once the genus is accurately determined the species within each genus are readily identified, for there is naturally much greater outward similarity between the capricorns of two series than between a capricorn and its later development in the same series—or, in other words, the chief difficulty lies in the distinction of morphic equivalents.

The sutures of the ammonites studied agree in having a deep external lobe, divided by a median saddle which is usually very high and narrow; external saddles high, often divided into three very unequal folioles by two denticulations, that of the dorsal side frequently cutting deeply into the saddle. The first lateral lobe is generally terminated by three lobules, sometimes asymmetrical. The first lateral saddle is narrow, and always smaller than the external saddle; the relatively simple auxiliaries are of variable number.

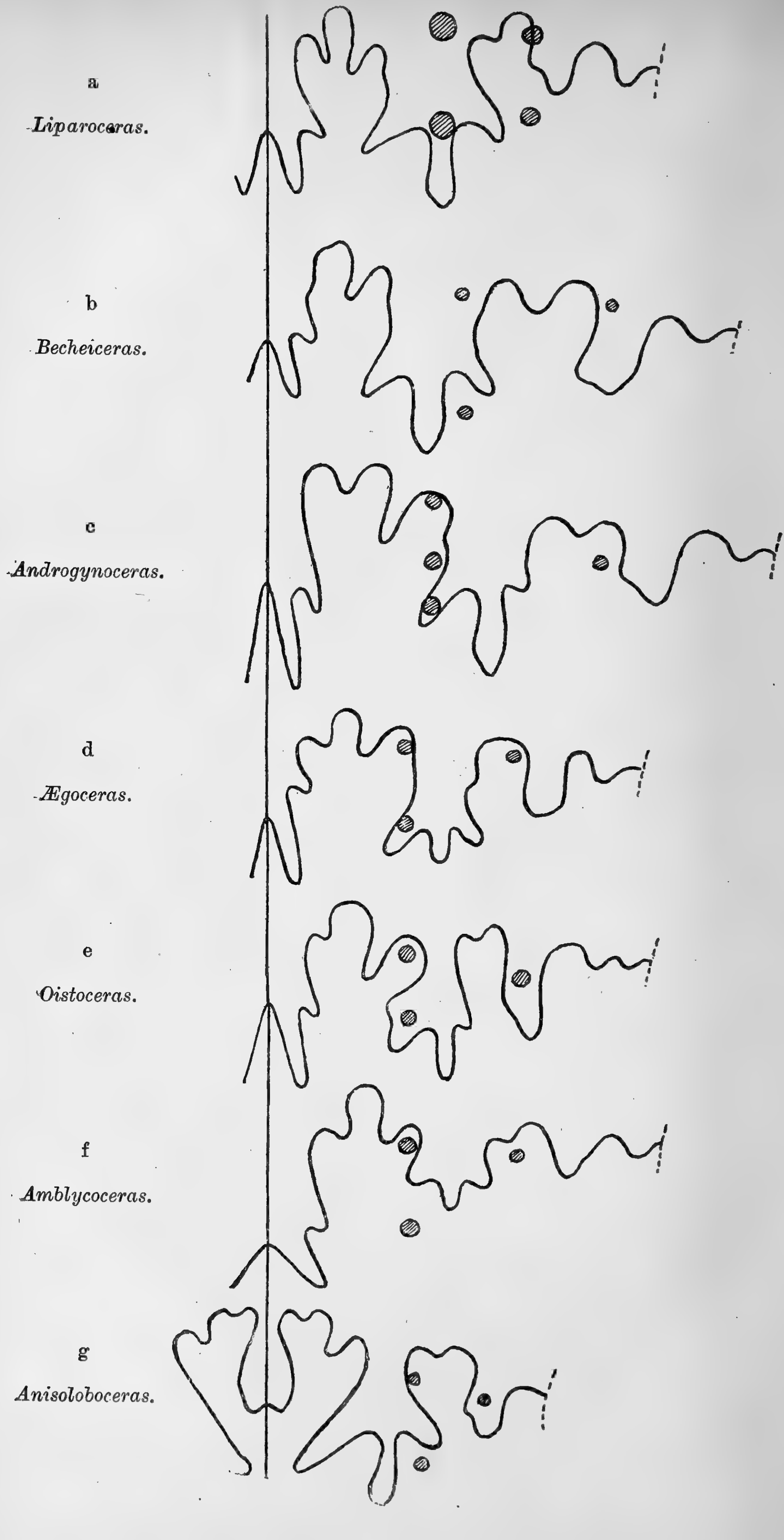
The most useful characters in classification are:

(1) The relative depths of the external and first lateral lobes.
(2) The relative widths of the external saddle and of the first lateral lobe.

The sutures of the chief genera are shown diagrammatically in fig. 1 (p. 258).

It is found that species of *Liparoceras* have a wide first lateral lobe and a narrow external saddle, the first lateral lobe and the external lobe being about equal in depth (fig. 1 *a*); the species which are at present referred to the genus *Liparoceras* all show these proportions. In addition *A. heterogenes*, which was formerly placed with *Androgynoceras* (1, vol. i, no. 46), evidently belongs

Fig. 1.—*Outline sutures of the principal Liparoceratid genera.*



to the genus *Liparoceras*; *A. bechei* and *A. henleyi*, which were formerly placed together as species of *Androgynoceras*, have very different sutures, that of the latter resembling the genotype of *Ægoceras* (fig. 1 *d*), while it is necessary to establish a new genus to include the *A. bechei* series (fig. 1 *b*). The sutures of *Amblyoceras* are likewise very characteristic, having a first lateral lobe much shallower than the external lobe (fig. 1 *f*).

A. nautiliformis, which Mr. Buckman inferred from stratigraphical and other evidence was the sphærocone of the *Ægoceras* series, has a suture[1] which differs markedly from that of all other British Liparoceratids, and resembles those of similar sphærocones in the Swabian Jura (4, pl. xxix, figs. 4–6) and of certain capricorns (as, for example, *A. adnethicus* and *A. ferstli*) also found on the Continent.[2] The suture of these ammonites has an external lobe much smaller than the first lateral lobe, the ventral lobules of which almost meet underneath the external lobe, a condition that recalls certain Deroceratids (fig. 1 *g*).

It is extremely probable that in the Lias of the Continent occur not only many species which are not represented in this country, but also several genera. It is not safe to assume, therefore, that the capricorns referred to *A. adnethicus* are the ancestors of *A. nautiliformis*; the range of this series (from the ? *valdani* zone to the *margaritatus* zone) would be unusually great. For this reason *A. adnethicus* and *A. ferstli* are only referred provisionally to the genus *Anisoloboceras*, which is proposed to include ammonites of the *A. nautiliformis* type. The Continental ammonites of the Liparoceratidæ should be fully studied before any attempt to classify them is made, since any arrangement based only on a consideration of the published figures would necessarily be provisional and would ultimately lead to greater confusion.[3]

(1) Series in which the Sphærocones have Unpaired Tubercles.

LIPAROCERAS Hyatt, 1867.

Genolectotype: *Ammonites striatus* Bronn.

Genus passing from costate serpenticone (capricorn) to bituberculate sphærocone. Whorl usually depressed, venter nearly flat or with a low arch; ornament generally coarse, the ribs passing with little or no curve across the periphery.

Body-chamber nearly one whorl.

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[1] I am indebted to Mr. Buckman for kindly supplying a sketch of the suture of the type-specimen, which was formerly in his possession and now is in the Manchester Museum.

[2] See F. von Hauer, 'Beiträge zur Kenntniss der Capricornier der Œsterreichischen Alpen' Sitzungsb. K. Akad. Wissensch. Wien, vol. xiii (1854) pp. 94–121, and P. Reynès, 'Monographie des Ammonites' 1879, pl. xxx, figs. 9 & 10.

[3] It may be mentioned here that many of the published figures of Continental forms are not mentioned in this paper, as they frequently do not show sufficient detail to allow of even approximate correlation, while in other cases the specimens are evidently quite different from anything that has been found in Britain.

Suture: EL and IL about equal in depth, wider than ES, IL generally trifid (fig. 1 *a*).

Species included:—

L. sparsicosta, sp. nov., *L. heterogenes* (Young & Bird), *L. obtusinodum*, sp. nov., *L. zieteni* (Quenstedt), *L. heptangulare* (Young & Bird), *L. cheltiense* (Murchison).

L. tiara, sp. nov.

L. pseudostriatum, sp. nov.

Geological horizon: Upper part of the *ibex* zone.

The ammonites comprising the genus *Liparoceras* range from stout capricorns to moderately involute thick-whorled forms with generally coarse bituberculation. The best-known English ammonite belonging to this series has been called *Liparoceras striatum*; Reinecke's figure of this species, however, shows an involute depressed Liparoceratid with paired tubercles on the outer whorl (5, pl. viii, figs. 65 & 66). Involute Liparoceratan forms from the British Lias have the tubercles unpaired, the outer being nearly twice as numerous as the inner. It is probable, therefore, that *L. striatum* (Reinecke) does not occur in this country, and it may be a representative of another lineage, probably allied to *A. striatus parinodus* Quenstedt (4, pl. xxix); *L. pseudostriatum* is here proposed for some of the English ammonites which have been called *L. striatum*. The similar fossils from Gloucestershire are members of the same genus, and include a number of forms closely allied to *L. cheltiense*.

The capricorns from which these ammonites arose have not hitherto been noticed, but are here described as *L. sparsicosta* (Pl. XXI, fig. 2), while *L. heterogenes* is a later stage (biologically, at least) in the same series, having fine paired tubercles on the outer whorl.

A number of intermediate forms unite this with ammonites resembling *L. obtusinodum*, which has fine paired tubercles on the inner whorls, but develops coarse unpaired tubercles on the outer whorl. A further stage is shown by *L. cheltiense*, in which the earliest tubercles are fine and unpaired, later becoming stronger, and finally transversely elongated on the last whorl, the commencement of catagenesis being indicated by a tendency to return to paired tubercles. More advanced ammonites of this lineage have finer tubercles on the outer whorl. *Liparoceras heptangulare* is probably a related species, which may be connected with *L. zieteni*, since both these species have a peripheral arch more pronounced than is usual in the genus.

Several other series of Liparoceratan ammonites may be distinguished, although the material available for their study is insufficient for the establishment of lineages—one such series comprises ammonites that develop fine ornamentation only (*L. pseudostriatum*). The above forms usually become comparatively involute, but at least one series retained a moderately evolute form with coarse unpaired tubercles. This series includes *L. tiara* (Pl. XXI, fig. 1), which, notwithstanding its wide umbilicus, has a very complicated suture with deeply undercut saddles (fig. 4 *d*, p. 270), suggesting that it is at least as advanced as *L. cheltiense*.

ANDROGYNOCERAS Hyatt, 1867.

Genolectotype: *Ammonites hybrida* A. d'Orbigny (3, pl xxxv, figs. 1–3, *non* 4–5).

Develops from capricorn to bituberculate sphærocone. Whorl height usually about equal to whorl thickness. Ornamentation never so coarse as in some species of *Liparoceras*, and not usually so fine as in *Becheiceras*.

Suture: EL and IL about equal in depth, IL with lobules usually asymmetrical, very narrow, and ES very wide (fig. 1 *c*, p. 258). Body-chamber about three-quarters of a whorl.

Species included[1]:—

A. maculatum (Young & Bird), *A. obtusicosta*, sp. nov., *A. hybrida* (d'Orbigny), *A. divaricosta*, sp. nov.

Horizon: *Davœi* zone, extending from the *latæcosta* sub-zone to the *dædalicosta* sub-zone.

In the development of *Androgynoceras* the outer tubercles appear first; *A. henleyi* Reynès, in which the inner tubercles are much more prominent than the outer, probably belongs to a different series. Involution proceeds slowly, and no specimen has yet been examined in which the outer tubercles are twice as numerous as the inner.

The more involute forms of this lineage have hitherto been found only at Lincoln (7, p. 104).

ÆGOCERAS Waagen, 1869.

Genolectotype: *Ammonites planicosta* A. d'Orbigny.

Develops from capricorn to bituberculate sphærocone. Whorl height usually about equal to whorl thickness. Ornamentation moderately fine, usually a little coarser than that of *Androgynoceras*.

Suture: EL and IL about equal in depth; IL usually small, and terminated by three fairly-symmetrical lobules; the median lobule frequently short; ES very wide (fig. 1 *d*, p. 258). Body-chamber nearly a whorl in length.

Species included:—

A. æquicosta, sp. nov., *A. latæcosta* (Sowerby), ? *A. henleyi* (Sowerby), *A. dædalicosta*, sp. nov.

Horizon: *Davœi* zone, extending from the *latæcosta* sub-zone to the *dædalicosta* sub-zone.

The ammonites of this series are not very different from those of the *Androgynoceras* series; generally the first lateral lobe in *Ægoceras* is smaller and more symmetrical than in *Androgynoceras*. The sphærocones are also distinct, but the separation of these series is not easy.

The young, before ribs are developed on the periphery, are scarcely distinguished from similar stages in the *Amblycoceras* and *Oistoceras* series. Thus ribs appear at approximately the same diameter, and sutural development at first proceeds similarly in each group. It seems, therefore, probable that these four genera had a common origin, and are much more closely related than any other Liparoceratid genera dealt with in this paper. (See Table III, p. 286.)

[1] Several earlier species (*A. integricostatum*, *A. siphunculare*) are also referred to this genus (see p. 290), but it is probable that the genera *Ægoceras* and *Androgynoceras* had not at that time become separated.

AMBLYCOCERAS Hyatt, 1900.

Genoholotype: *A. capricornus* Hyatt.[1]

Develops from capricorn to a form with bituberculate swollen outer whorl. The costæ are very little diminished on the periphery of the capricorns, and shw a distinct forward bend, less sharp than that of *Oistoceras*.

Suture: IL much shallower than EL, which usually has a short and wide median saddle. IL has three subequal terminal lobules. ES wide, with three terminal cells (fig. 1 *f*, p. 258).

Species included:—

A. crescens Hyatt, *A. dissotypum*, sp. nov., *A. brevilobatum*, sp. nov.

Horizon: *Davœi* zone (*latæcosta* sub-zone to *Oistoceras* sub-zone).

The ammonites of this genus are of two series: the earlier, which includes *A. brevilobatum*, has slender elevated whorls with close and uniform costæ; and the later, including *A. crescens*, has stout whorls, with prominent costæ separated by wide concave spaces on the outer whorl. Bituberculate forms are known in both series. The *A. crescens* series is not derived from the earlier, for *A. crescens* retains the primitive depressed whorl; its inner whorls, however, have numerous ribs and are similar in form to the young of *A. brevilobatum*. It is probable that this latter group represents an offshoot from a primitive *crescens*-like stock.

OISTOCERAS S. S. Buckman, 1910.

Genoholotype: *O. figulinum* (Simpson). (Refigured, 1, vol. i, No. 26.)

Develops from a capricorn to a bituberculate form with swollen whorls; the costæ are little diminished on the periphery, where they have a very marked forward curve, much greater than in *Amblycoceras* ('arrow-like peripheral costæ').[2]

Suture: EL and IL about equal in depth, EL narrow and with a high median saddle in the later forms; IL frequently asymmetrical (fig. 1 *e*, p. 258).

Species included:—

O. figulinum (Simpson), *O. allœotypum*, sp. nov., *O. omissum* (Simpson), *O. curvicornum* (Schlœnbach).

Horizon: ? *dædalicosta* sub-zone to lower part of *margaritatus* zone (at Lincoln only). Dominant in the *Oistoceras* sub-zone.

Two series may be recognized among the ammonites of this genus, namely:—

(1) With squared venter, developing coarse bituberculation (*O. curvicornum* Wright, *non* Schlœnbach).

(2) With a rounded or subangular venter, developing fine bituberculation (*O. allœotypum*, Pl. XXV, fig. 1). Some forms of the latter series have a peripheral rib-curve not much stronger than that of *Amblycoceras*; they may be distinguished from the latter genus, however, by sutural characters. Similarly, occasional specimens of *Amblycoceras* have a rib-curve equal to that of *Oistoceras* (see p. 279).

[1] In Eastman-Zittel, 'Text-book of Palæontology' 1st ed. vol. i (1900), fig. 1204, p. 578.

[2] See 1, vol. i, p. *iv*.

Although the genera *Androgynoceras*, *Ægoceras*, *Amblycoceras*, and *Oistoceras* have typically ribs almost straight, slightly curved, and markedly curved on the periphery, *Amblycoceras* must not be considered as intermediate between *Oistoceras* and *Androgynoceras* or *Ægoceras*, for the sutures of *Oistoceras* are frequently very similar to the sutures of *Androgynoceras* (compare, for example, the first lateral lobes in fig. 8 *c*, p. 278 & fig. 12 *a*, p. 285), while the sutures of *Amblycoceras* often resemble those of *Ægoceras*, except that the first lateral lobe is shallower in *Amblycoceras*. It may, therefore, be suggested that *Oistoceras* and *Amblycoceras* arose from primitive members of the *Androgynoceras* and *Ægoceras* stocks respectively: probably before the latter had acquired peripheral costæ, but after the sutural characters of the two last-named genera had become distinct.

BECHEICERAS, gen. nov.

Genoholotype: *A. bechei* Wright (8, pl. xli, figs. 1 & 2).
In this series sphærocones only are known [1]; these are finely ornamented, bituberculate (unpaired). In development of the sphærocones the capricorn stage is omitted. Longitudinal striations are well developed.
Suture: EL not so deep as IL, which is often wider than ES, thus the greater part of IL is frequently ventral to the outer tubercles (fig. 1 *b*, p. 258).
Horizon.—*Dædalicosta* and *Oistoceras* sub-zones.

The suture is most like that of *Liparoceras*, differing mainly in the deeper first lateral lobe: *Becheiceras* is, therefore, very similar to the finely-ornamented involute *Liparoceras*, but its horizon is much higher.

ANISOLOBOCERAS, gen. nov.

Genoholotype: *A. nautiliformis* J. Buckman (1, vol. i, No. 37).
Includes capricorn forms and very stout bituberculate sphærocones with fine ornament.
Suture: EL much shallower than IL, the ventral lobules of the IL almost uniting under the EL (fig. 1 *g*, p. 258).
Species included:—
? *A. adnethicus* Hauer, ? *A. ferstli* Hauer, *A. spinellii* Hauer, *A. nautiliformis* J. Buckman.
Horizon.—The sphærocones, which alone occur in Britain, are found in the *margaritatus* zone; the horizon of the capricorn forms which are provisionally referred to this genus is probably near the *ibex* zone.

A. nautiliformis was placed with *Ægoceras* by Mr. Buckman, who had not compared the sutures of these ammonites. The difference in sutural proportions has already been pointed out (p. 259).

The capricorns from the Adneth Shales described by F. von Hauer,[2] are provisionally referred to this genus, but their precise

[1] *Ægoceras capricornu* var. *nodosa* Futterer, 'Die Ammoniten des Mittleren Lias von Œstringen' Mitt. Bad. Geol. Landesanst. vol. ii (1893) pl. xi, figs. 1 & 2, may be near the capricorns of this series.

[2] 'Beiträge zur Kenntniss der Capricornier der Œsterreichischen Alpen' Sitzungsb. K. Akad. Wissensch. Wien, vol. xiii (1854) p. 101.

horizon is unknown, and apparently no comparable forms have been discovered in this country. *A. spinellii*, also described by F. von Hauer,[1] is the small young of the sphærocone in which the capricorn stage is omitted[2]; the sutural proportions are suggestive of this genus.

Of *A. nautiliformis*, Mr. Buckman figured two specimens, of which the former (the holotype) is somewhat stouter (1, vol. i, No. 37). Some ammonites figured by Quenstedt (4, pl. xxix) agree in whorl shape, suture, and position of tubercles; the horizon given by Quenstedt is similarly considerably higher than the horizon of other sphærocones.

(2) Series in which the Sphærocones have Paired Tubercles.

It is not possible to offer any detailed classification of these forms, which do not occur commonly in this country and of which very little material is available. It appears, however, that three series may be recognized, namely:—

(1) A parinode series with depressed whorl; this includes *A. striatus* Reinecke. No representative of the group has been recorded in this country.

(2) A parinode series with elevated whorl; this includes *A. striatus parinodus* Quenstedt (4, pl. xxviii, figs. 16–23), *A. striatus lævis* Quenstedt (4, pl. xxviii, fig. 6), *A. striatus reineckii* Quenstedt (4, pl. xxviii, fig. 5). Sphærocones of this series, in the collections of Mr. S. S. Buckman and Mr. J. W. Tutcher, from the *valdani* zone of Radstock, resemble the last-named species.

To cover this series the genus *Parinodiceras* is here proposed. Genoholotype, *Ammonites striatus parinodus* Quenstedt (4, pl. xxviii, fig. 16).

(3) A parinode series with round whorls; the tubercles of the inner row are placed high up the whorl, so that the two rows are unusually close together. Only three examples are known, in the collection of Mr. J. W. Tutcher, who obtained them from the *valdani* zone of Radstock.

The name *Vicininodiceras* is proposed for this series. Genoholotype, *V. simplicicosta*, sp. nov. (Pl. XXIV, fig. 4.)

It will be noted that all the parinode forms which have been observed in England occur at a lower horizon than any imparinode forms, and probably represent a more primitive stage in evolution.

Notes on Phricodoceras Hyatt, 1900.

Genoholotype: *Phricodoceras (Ammonites) taylori* (A. d'Orbigny). (3, pl. cii, figs. 3 & 4.)

This genus of Liparoceratid ammonites is not fully considered

[1] 'Ueber die Ammoniten aus dem sogenannten Medolo der Berge Domaro' Sitzungsb. K. Akad. Wissensch. Wien, vol. xliv (1861).

[2] *Ammonites henleyi* Hauer, 'Ueber die Cephalopoden aus dem Lias der Nordöstlichen Alpen' Denkschr. K. Akad. Wissensch. Wien, vol. xi (1856). p. 60 & pl. xx, figs. 4–6, may be a coarsely-tuberculate form of this genus.

here, since its evolution is different from that of the series described above. *Phricodoceras* includes the *taylori* group of ammonites: these forms rapidly acquire bituberculation or even trituberculation, without any marked expansion of the whorl such as is characteristic of the genera hitherto dealt with.

Mr. Buckman has called my attention to a specimen of *Phricodoceras lamellosum* (A. d'Orbigny) from the *armatus* zone of Radstock, in his collection (No. 2917), in which the strongly tuberculate stage is followed by a stage with feeble ornament and a great increase in the size of the whorl, the outer whorls thus bearing some resemblances to the involute forms of the preceding genera. It is distinguished by

(1) The greater elevation of the outer whorl,
(2) Enlargement of the whorl subsequent to the acme of ornamentation,
(3) The close approximation of the outer tubercles to the ventral margin.

Ammonites striatus bicornis Quenstedt (4, pl. xxviii, fig. 24) and *A. taylori* Quenstedt (4, pl. xxvii, fig. 19) show a similarly expanded outer whorl with catagenetic ornament.

VI. Study of Species and Developmental Details.

A. Liparoceras.

Liparoceras sparsicosta, sp. nov. (Pl. XXI, figs. 2 *a*–2 *b* & 3 *a*–3 *e*; text-figs. 2 *a*–2 *g*, p. 266.)

Dimensions of holotype:—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
35 mm.	32 per cent.	35 per cent.	44 per cent.

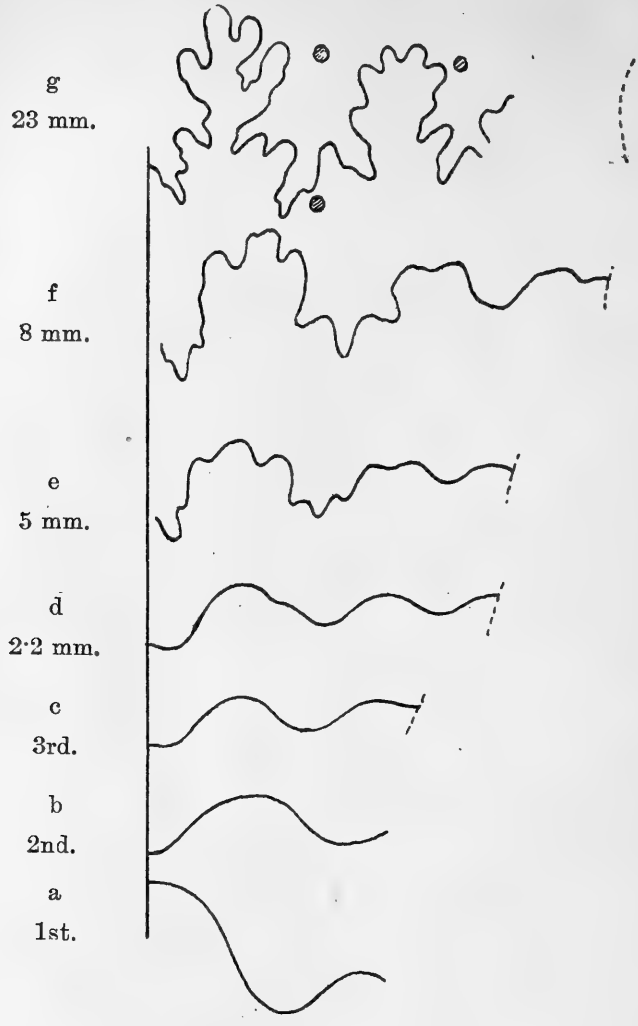
A small capricorn ammonite, with depressed whorl; strong but widely-spaced ribs, feeble on the venter. Until the diameter of 6 mm. the whorls are smooth, stout ribs separated by wide concave spaces appearing at that diameter. Thirteen ribs on the outer whorl, of which the last nine have paired tubercles; periphery broad, with the low arch characteristic of the genus.

At 22 mm. diameter the suture is moderately simple, but shows the feature of the genus, namely: the first lateral lobe is wider than the external saddle, and about equal in depth to the external lobe, thus part of the first lateral lobe is ventral to the outer line of tubercles (text-fig. 2 *g*, p. 266).

The type-specimen was collected by Mr. L. Richardson, F.G.S., from a well at Queen's Wood Cottages, Prestbury, near Cheltenham. Specimens may also be obtained at a similar horizon at Napton (Warwickshire), and at Dumbleton (Gloucestershire).

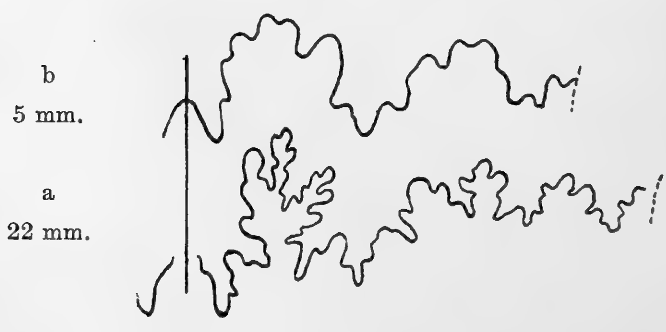
Development. (Pl. XXI, figs. 3 *a*–3 *e*.)—In studying the development several small specimens collected at Napton were used. In this locality fine specimens of the capricorns and of the *heterogenes* stage of *Liparoceras* may be found, fortunately with the inner whorls well preserved in calcite.

Fig. 2.—*Sutural development of* Liparoceras sparsicosta.



[g=L. Richardson Coll., figured in Pl. XXI, fig. 2 *a*.]

Fig. 3.—*Sutures of* Beaniceras *spp. (Napton).*



The protoconch shows the usual characters (Pl. XXI, fig. 3 *d*), its length being 0·68 mm. Shell development proceeds normally for some time; thus there is a general increase in the size of the whorl, whorl height at first increasing proportionately more rapidly than whorl thickness. The shell remains smooth until a diameter of 5 mm. is reached, when there appear on the sides widely-separated ribs, which do not cross the venter until later (diameter 10 mm.). The whorl thickness increases regularly, but the whorl remains depressed much longer than is usual in capricorns (see Pl. XXI, fig. 3 *a*) which generally acquire slender, nearly round whorls at a diameter of 3 mm. Thus, it will be seen from the following table that, in *Liparoceras sparsicosta*, the whorl height is less than the whorl thickness, even at a diameter of 20 mm. This retention of the early depressed shape and smooth whorls may point to the primitive nature of *L. sparsicosta*; it is probable, however, that these features indicate that this ammonite is already beyond the true capricorn stage, and that the depressed inner whorls are due to the prolongation of the primitive globose form.

Diameter. mm.	Whorl height. per cent.	Whorl thickness. per cent.	Umbilicus. per cent.
·58	48	119	—
·68	42	96	28
1·14	42	69	30
1·8	40	65	—
3·6	39	55	29
8·0	28	55	—
16·0	28	46	36
20·0	33	45	35

The first suture shows typical angustisellate characters (text-fig. 2 *a*). At the second suture the azygous saddle is divided by a fairly deep ventral lobe, which is deeper than the corresponding lobe in the second suture of other capricorns (text-fig. 2 *b*). In the third suture the ventral lobe has a small median saddle; there is little advance on this stage during the next whorl, the median ventral saddle becoming slightly more pronounced and an auxiliary saddle appearing at the umbilical margin (text-fig. 2 *d*). A very feeble denticulation appears on the dorsal margin of the external saddle at a diameter of 4·5 mm., and a little later the saddle has three terminal cells and the first lateral lobe three lobules. Subsequent development leads to the increase in height of the external saddle and in depth and width of the first lateral lobe; these attain adult proportions at a diameter of 10 mm., all the elements later becoming complicated by minor denticulations.

Distinctions.—*Androgynoceras maculatum* is the only capricorn among the British Liparoceratidæ from which *Liparoceras sparsicosta* is not readily distinguished; *A. maculatum* has similarly widely-spaced ribs (about seventeen to a whorl; some capricorns may have thirty) which are feeble on the venter. In *A. maculatum*, however, whorl height is greater than whorl thickness, while the venter is well rounded and does not show the low arch of *Liparoceras*.

It is more difficult to separate *L. sparsicosta* from certain species of *Beaniceras*. Mr. Buckman proposed this latter genus to include *A. luridum* (1, vol. ii, p. *iii*) placing it with the Liparoceratidæ, but its affinities are with the Dactyloids rather than with the Liparoceratids (see p. 292). *Beaniceras luridum* is a capricorn form, probably a catagenetic descendant of a tuberculate cadicone (that is, a form with the whorl thickest at the ventral margin); such cadicones of the *Beaniceras* series have been detected at Napton and elsewhere, and with them also occur ammonites which resemble *B. luridum*, and have strongly-ornamented cadicone inner whorls, the outer whorl having normal capricorn ornament, in some cases very similar to that of *L. sparsicosta*. The young of such a form is figured in Pl. XXIII, fig. 2, the shape of the whorl being very different from that of the young of *Liparoceras sparsicosta* (Pl. XXI, fig. 3 *a*). The chief points of distinction of these series are:

(1) The stronger ornament of the inner whorls of *Beaniceras*; the capricorns of the *Beaniceras* series are catagenetic, those of the Liparoceratidæ are anagenetic.

(2) The steep central part of the umbilicus of *Beaniceras* (due to the cadicone inner whorls).

(3) The suture of *Beaniceras* frequently shows a ∧-shaped median cell, as was pointed out by Mr. S. S. Buckman (1, vol. ii, No. 73).

This last-named character, however, is not constant; it is not always present in *Beaniceras*, and may sometimes be seen in other capricorns. The arrangement of the sutural elements is somewhat similar in *Liparoceras* and *Beaniceras*: in Napton specimens of the latter the first lateral lobe is relatively wider. In development, the sutures of *Beaniceras* are more complicated than the sutures of *Liparoceras* at similar diameters. Thus the suture of *Beaniceras* at 5 mm. (text-fig. 3 *b*, p. 266) is quite as advanced as that of *L. sparsicosta* at 15 mm.

LIPAROCERAS HETEROGENES (Young & Bird). (Fig. 4 *e*, p. 270.)[1]

Refigured, *Androgynoceras heterogenes* (Young & Bird), S. S. Buckman (1, vol. i, No. 46).

Retains capricorn form up to a diameter of 60 mm., the last whorl being swollen; bituberculation commences earlier than in *L. sparsicosta*, certainly before a diameter of 20 mm. If *L. heterogenes* is properly assigned to the *Liparoceras* series it is probably a little more advanced than *L. sparsicosta*.

This species was formerly referred to the genus *Androgynoceras*, but it appears to belong to *Liparoceras*, since it shows whorl height

[1] The sutures shown in figs. 4 (*a*, *e*, *f*), 7, 8 (*a*, *b*), 10 (*b*, *c*), and 13 were drawn from the left-hand side of the specimens, but are here reversed for convenience in comparing them with others.

less than whorl thickness, and a broad low-arched venter, with the outer row of tubercles near the edge of the whorl. Although in the type-specimen no sutures are visible, yet specimens from Napton and Yorkshire which appear to be identical show sutures of the *Liparoceras* pattern (fig. 4 *e*) intermediate in degree of complexity between *L. sparsicosta* and *L. obtusinodum*.

A complete series of specimens may be arranged, transitional between *L. heterogenes* and *L. obtusinodum*. In successive members at a given diameter the whorl is stouter, the ratio of the numbers of outer to inner tubercles is greater, and the sutures are more complex. Further, the stage at which capricorn ornamentation is developed steadily becomes later, while bituberculation appears earlier, so that ultimately the capricorn stage is omitted, as shown in the table :—

	Diameter. mm.	Whorl height. per cent.	Whorl thickness. per cent.	Umbilicus. per cent.	Capricorn from diameter	to diameter.	Tubercle on last whorl.
From Napton, Warwick.	50	27	33	33	5	50	Paired.
	35	29	34	29	6	19	Paired.
	50	44	52	30	8	12	23/15
From Battledown, Cheltenham.	60	47	57	23	—	—	25/15
	60	48	56	20	—	—	23/12
	70	51	61	17	—	—	24/12

Liparoceras obtusinodum, sp. nov. (Fig. 4 *c*, p. 270.)

Dimensions of holotype (from Napton, Warwickshire) :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
45 mm.	44 per cent.	52 per cent.	33 per cent.

Compare *Ammonites striatus* Bronn.[1]

Whorl depressed, venter nearly flat, umbilicus fairly small, the tubercles unpaired, about 22/18.

The inner whorls of *L. obtusinodum* have no capricorn stage, but the tubercles are fine and paired until the diameter of 25 mm.

L. obtusinodum occurs in Dorset in the Belemnite Stone and the beds immediately below it.[2] One such form (W. D. L. Coll. 1493) has the following dimensions :—

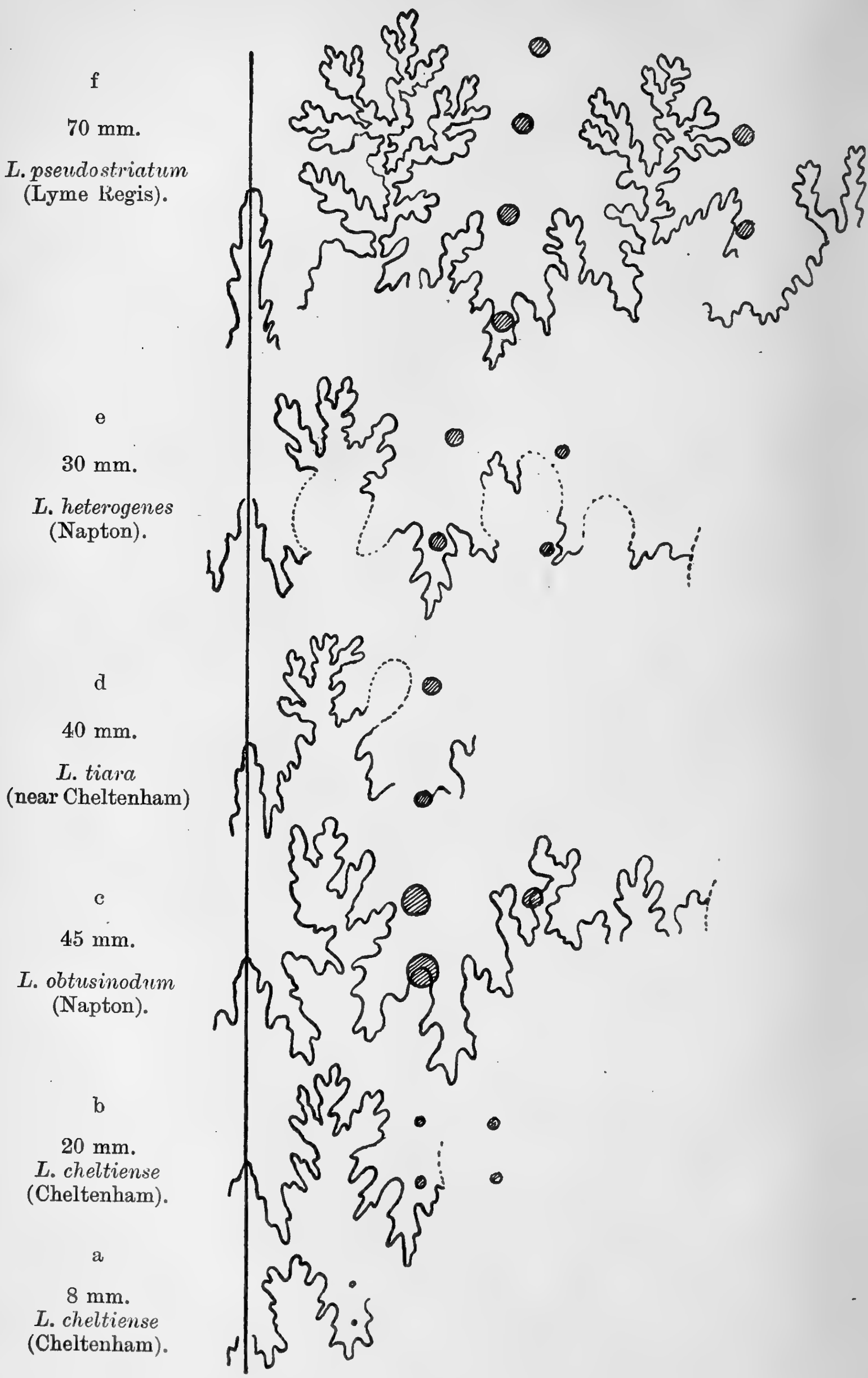
Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
25 mm.	44 per cent.	68 per cent.	28 per cent.
19	42	63	26

The suture is a little more complicated than that of *L. heterogenes* (fig. 4 *c*).

[1] H. G. Bronn, 'Lethæa Geognostica' vol. i (1835–37) p. 449 & pl. xxiii, fig. 7.

[2] W. D. Lang, 'The *Ibex* Zone at Charmouth, &c.' Proc. Geol. Assoc. vol. xxviii (1917) p. 33.

Fig. 4.—*Sutures of* Liparoceras *spp.*



LIPAROCERAS CHELTIENSE (Murchison). (Pl. XXI, figs. 4 *a*–4 *d*; text-figs. 4 *a* & 4 *b*, p. 270.)

Refigured, 'Palæontologia Universalis' pt. iii, ser. 1 (1905) No. 67.

Dimensions of figure :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
93 mm.	45 per cent.	67 per cent.	24 per cent.

In the type-specimen the early part of the last whorl is similar in shape and ornament to *L. obtusinodum*. Towards the end of the whorl, however, the whorl height increases and the periphery becomes more strongly arched, while the unpaired rounded tubercles give place to paired bullæ or transversely extended tubercles: this return to paired tubercles is the first indication of catagenesis.

The details of the suture in the type-specimen are not discernible; but it is clear that the external saddle is narrower than the first lateral lobe, the latter being mainly ventral to the outer tubercles. (British Museum—Natural History, No. 74955 *a*.)

Development of *Liparoceras cheltiense*.—The specimen examined was collected at the Battledown Pit, Charlton Kings, Cheltenham (Pl. XXI, figs. 4 *a*–4 *d*). The innermost whorls are not preserved, but at a diameter of 10 mm. the shell is quite smooth, the whorl being stouter and the form more involute than in the adult. The whorl thickness is equal to nearly three-quarters of the diameter until a much later stage; it is interesting to note that this condition is lost in *L. sparsicosta* at a diameter of 1 mm. In *L. cheltiense* there is a gradual change from the young to the adult form of whorl.

Fine tubercles are seen at a diameter of 10 mm.; they are already unpaired and are united by very feeble ribs which cross the venter (Pl. XXI, figs. 4 *c* & 4 *d*). Faint longitudinal striation is also present.[1] The young suture is more complicated than that of *L. sparsicosta*; for example, the suture of *L. cheltiense* at 8 mm. diameter has the first lateral lobe nearly as deep as the external lobe, a condition which is not attained by *L. sparsicosta* until much later.

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
70 mm.	48 per cent.	56 per cent.	20 per cent.
38	50	70	19
25	50	72	—
13	54	73	15

Young specimens of *L. cheltiense* (up to a diameter of 30 mm.) bear a superficial resemblance to *Becheiceras bechei*. They may be distinguished by their sutures (even at this diameter the first lateral lobe of *B. bechei* is deeper than the external lobe) and by the more depressed whorl of *L. cheltiense*; further, while tubercles

[1] Compare *A. striatus* Quenstedt, 'Petrefactenkunde Deutschlands: Cephalopoden' vol. i (1849) p. 135 & pl. ix, fig. 24.

appear in the young of *Liparoceras cheltiense* at a diameter of 10 mm., they are not present in *B. bechei* until twice that diameter.

Other specimens found at Battledown, apparently of this same lineage, show post-*cheltiense* stages in which the whorl is more slender, the ornament finer, and the tubercles generally paired. This latter character distinguishes *L. cheltiense* from the finely-ornamented sphærocones of the *Becheiceras* series.

LIPAROCERAS ZIETENI (Quenstedt).

Ammonites striatus zieteni Quenstedt (4, pl. xxviii, figs. 1 & 2).

Dimensions of figure :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
64 mm.	50 per cent.	64 per cent.	22 per cent.

This presents a similar stage to *L. obtusinodum*, but differs in the greater arch of the periphery.

LIPAROCERAS HEPTANGULARE (Young & Bird).

(Refigured, 1, vol. ii, No. 108.)

This ammonite has a more slender whorl than *L. cheltiense*; the strongly-arched periphery may indicate a connexion with *L. zieteni*.

LIPAROCERAS TIARA, sp. nov. (Pl. XXI, figs. 1 *a* & 1 *b*; text-fig. 4 *d*, p. 270.)

Compare *Ammonites henleyi* A. d'Orbigny (3, pl. lxxxiii).

Dimensions of holotype :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
63 mm.	41 per cent.	57 per cent.	29 per cent.

Stout whorl, evolute, with prominent unpaired tubercles (20/14) united by strong folds, dividing at the outer tubercles into two or three flattened ribs which cross the periphery.

Irregular longitudinal striation very marked.

Suture has a deep external lobe, divided by a high median saddle; first lateral lobe wide. Sutural elements very deeply undercut (text-fig. 4 *d*, p. 270).

This species, undoubtedly a Liparoceratid, differs from those previously considered in combining coarse ornament with an evolute form and very complex sutures.

The type-specimen was collected by Mr. L. Richardson in the Yellow Lias (hemera of *Beaniceras*), during excavations for a bridge at Manor Farm, Gotherington, near Cheltenham.

LIPAROCERAS PSEUDOSTRIATUM, sp. nov. (Fig. 4 *f*, p. 270.)

Compare *Ægoceras striatum* Wright (8, pl. xlii, figs. 1 & 3).

Dimensions of type-specimen :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
100 mm.	47 per cent.	65 per cent.	16 per cent.

Differs from other species of *Liparoceras* in having stout whorls and involute form accompanied by unpaired fine tubercles.

Occurrence.—Upper part of the *ibex* zone, Dorset.

L. pseudostriatum is similar in appearance to *Androgynoceras divaricosta*, but has a stouter whorl, smaller umbilicus, unpaired tubercles, and more complicated suture of a different pattern.

The holotype is in the collection at University College, Cardiff.

B. ÆGOCERAS.

ÆGOCERAS aff. *latæcosta* (Sowerby). (Pl. XXIII, figs. 3 *a* & 3 *b*; text-fig. 5, p. 274.)

Compare *Ammonites latæcosta* Sowerby.[1]

Dimensions :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
72 mm.	32 per cent.	33 per cent.	47 per cent.
50	30	30	46

Slender whorls little embracing, coiling regular; on the outer whorl are about thirty slightly-curved ribs, sharp on the sides and less prominent on the venter. On the last half-whorl, striæ are present between the ribs, especially on the venter. Feeble bituberculation commencing. Suture fairly complicated, external saddle very wide, first lateral lobe narrower and trifid, symmetrical. Collected by Dr. W. D. Lang (Coll. No. 1566) in the Lower Limestone (*latæcosta* sub-zone) of Dorset.

Development of *Ægoceras latæcosta*. (Pl. XXIII, figs. 4 *a*–4 *d*.)—The development was studied in a small specimen (W. D. Lang Coll. No. 534) from the *latæcosta* sub-zone (?), Stonebarrow. The young specimen, at a diameter of 14 mm., shows a body-chamber equal to half a whorl.

The protoconch is of normal form, preserved in calcite: an examination by transmitted light shows the so-called 'prosiphon' of Munier-Chalmas (Pl. XXIII, fig. 4 *d*). This structure is not always to be seen in ammonite protoconchs, owing to differences in preservation, and several investigators have failed to find any trace of it. Recently, however, Grandjean has shown it to be a solid structure extending from the end of the siphon to the inner wall of the protoconch.[2] The 'prosiphon' of *Ægoceras latæcosta* resembles the second type described by Grandjean, consisting of one long 'bandelette,' thus differing from *Æ. planicosta*, in which it is relatively short.

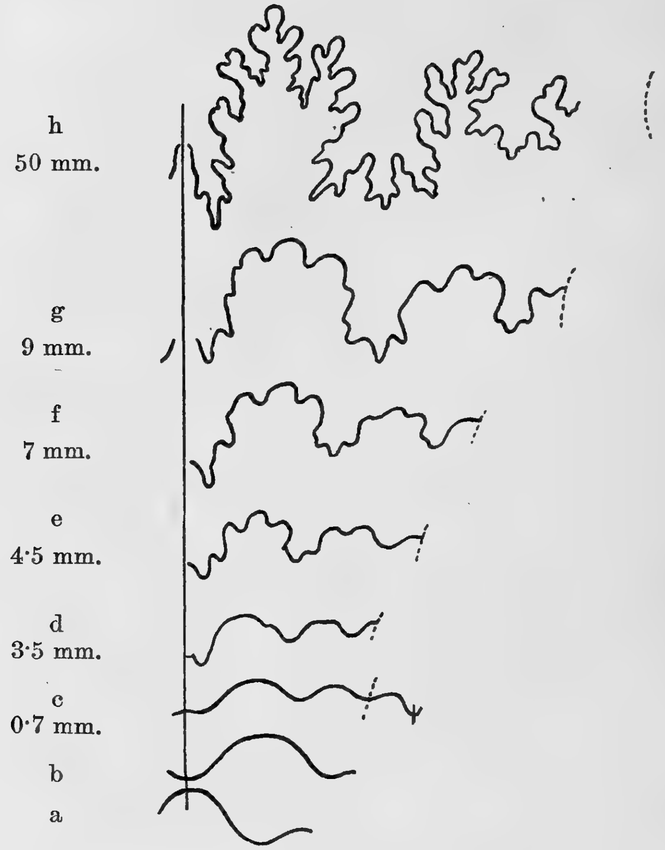
Shell-development proceeds normally, and, until *Æ. latæcosta* attains a diameter of over a millimetre, it is scarcely to be distinguished from other young capricorns. At a diameter of 4 mm. (Pl. XXIII, fig. 4*a*) the whorl height of *Æ. latæcosta* is less than

[1] 'Mineral Conchology' vol. vi (1829) pl. dlvi, fig. 1.

[2] F. Grandjean, 'Le Siphon des Ammonites, &c.' Bull. Soc. Géol. France, ser. 4, vol. x (1910) p. 496.

the whorl height of the capricorns of *Amblycoceras* and *Oistoceras* at the same diameter; the whorl shape, however, does not differ markedly from that of *Liparoceras sparsicosta* until the diameter

Fig. 5.—*Sutural development of* Ægoceras latæcosta (*Sowerby*).



[a–g, W. D. Lang Coll. (figured in Pl. XXIII, fig. 4).
h=Specimen figured in Pl. XXIII, fig. 3: W. D. Lang Coll. No. 1566.]

of 10 mm. is reached, when *Ægoceras latæcosta* is less depressed. Low folds appear at a diameter of 3·5 mm.; but there are no ribs on the periphery until the shell is nearly twice that size, only becoming fairly prominent at a diameter of 11 mm.

Diameter. mm.	Whorl height. per cent.	Whorl thickness. per cent.	Umbilicus. per cent.
·84	43	79	26
1·2	40	67	32
2·5	40	68	?40
4·2	35	67	52
8·0	35	50	40
14·0	29	36	46

The early sutures of the capricorn forms are similar; indeed, the sutures from the third to the tenth are almost identical in each species, the second suture having a ventral lobe which becomes divided by a minute median saddle in the next suture (text-fig. 5 *c*, p. 274). The first signs of denticulations appear in *Ægoceras latæcosta* at a diameter of 3·5 mm. and by 4·5 mm. the external saddle has three unequal terminal cells; the relatively-small first lateral lobe is feebly trifid (text-fig. 5*d*, *e*, p. 274). This lobe remains narrower than the external saddle but becomes deeper, and is as deep as the external lobe by the time that a diameter of 9 mm. is attained. The features of the suture may now be said to have reached the proportions characteristic of the adult.

In many young examples of this species the suture is tilted; that is to say, the saddles of one side are in advance of those of the other. If, therefore, only one side of such a specimen is examined, its sutures appear to resemble those of either *Amblyoceras* or *Becheiceras*.

ÆGOCERAS ÆQUICOSTA, sp. nov

Compare *Ægoceras maculatum* Wright (8, pl. xxxiv, figs. 1 & 3).

Dimensions of holotype:—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
70 mm.	28 per cent.	26 per cent.	45 per cent.

Whorl slender, almost circular in section, with uniformly-spaced ribs, little diminished on the periphery, which they cross without any curve. Thirty ribs on the outer whorl, where they are rounded; the ribs of the inner whorls, like those of *Æ. latæcosta*, are more acute. Suture of typical *Ægoceras* form, with large external saddle and narrow first lateral lobe.

Ægoceras æquicosta is proposed to include the English ammonites which were formerly called *Ammonites capricornus* Schlotheim, a name which is not used here, since its precise application is not known.

Occurrence.—Type-specimen, from the *latæcosta* sub-zone of Lincoln.

Ægoceras æquicosta differs from other capricorns in

(1) Nearly round whorl (the outer whorl of *Æ. latæcosta* is more elevated).

(2) Ribs very little diminished on the periphery (distinguishing it from most capricorns without a peripheral rib-curve).

With *Ægoceras æquicosta* at Lincoln occur specimens which show a catagenetic subcostate-striate stage.

In the *latæcosta* sub-zone of Dorset Dr. Lang has found ammonites, presumably of this lineage, which show a more advanced stage, resembling *A. henleyi* Sowerby in the moderately-round whorl, with flattened sides, and it is suggested that these ammonites (W. D. L. Coll. No. 3861) are intermediate between *Æ. latæcosta* and *Æ. dædalicosta*. They have swollen whorls, moderately wide umbilicus, just becoming imparinode, and show the irregular costæ seen in *Ægoceras dædalicosta.*

Dimensions of W. D. L. Coll. No. 3861 :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
80 mm.	46 per cent.	57 per cent.	25 per cent.
47	44	51	25

These specimens are morphic equivalents of *Androgynoceras divaricosta,* from which they differ in the greater symmetry of the first lateral lobe (text-fig. 6, below) which resembles that of *Ægoceras latæcosta.*

ÆGOCERAS DÆDALICOSTA, sp. nov. (Pl. XXII, figs. 3 *a* & 3 *b*.)

Dimensions of holotype :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
? 190 mm.	50 per cent.	47 per cent.	13 per cent.

Whorl rounded, periphery arched, sides flattened, umbilicus small. Ribs irregular, especially on the venter, where they occasionally

Fig. 6.—*Suture of* Ægoceras *sp., intermediate between* Æ. latæcosta *and* Æ. dædalicosta. *(W. D. Lang Coll. No. 3861.)*

57 mm.

show small but distinct bends ; they divide sometimes on the lateral area, and do not always unite with the outer tubercles. Tubercles distinctly unpaired (about 7/4 on a quarter of a whorl). The suture has the proportions characteristic of the genus ; the lobules of the first lateral lobe are practically equal in length, a feature shown by *Ægoceras latæcosta.*

There is very little trace of longitudinal striation on the outer whorl ; at a diameter of 40 mm. the ornamentation is finer and more regular, and striation is well-marked.

The type-specimen was collected by Dr. Lang in the Red Band (*dædalicosta* sub-zone), St. Gabriel's Water, Dorset (No. 3862).

Æ. dædalicosta differs from other species of *Ægoceras* in having markedly unpaired tubercles and greater involution. The young has fine paired tubercles until a diameter of 30 mm.

C. Androgynoceras.

Androgynoceras maculatum (Young & Bird).

Refigured by S. S. Buckman (1, vol. i, No. 45).

Non A. maculatum Wright (8, pl. xxxiv).
Non A. maculatum Quenstedt (4, pl. xxxiv).

Androgynoceras obtusicosta, sp. nov. (Pl. XXII, figs. 2 *a* & 2 *b*.)

Compare *A. maculatum* (=*capricornum*) Wright (8, pl. xxxiv, figs. 4 & 5).
A. maculatum Quenstedt (4, pl. xxxiv, fig. 5).

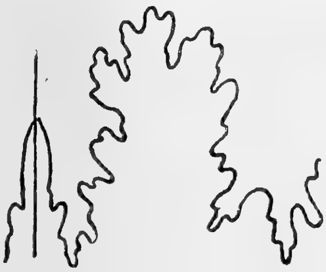
Dimensions of holotype :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
80 mm.	34 per cent.	26 per cent.	46 per cent.

An evolute capricorn, bituberculation commencing. Whorl round up to a diameter of 50 mm., after which it becomes more elevated. Ribs pass directly across the venter and are very little diminished;

Fig. 7.—*Suture* of Androgynoceras obtusicosta (*Lincoln*).

50 mm.



round, 23 on the outer whorl, separated by wide spaces. Fine striæ between the ribs, especially on the periphery.

The suture shows a deep external lobe divided by a high median saddle; wide external saddles, first lateral lobes narrow and asymmetrically divided (text-fig. 7).

Occurrence.—*Latæcosta* sub-zone, Lincoln.

Distinguished from *Ægoceras latæcosta* by the suture and by the prominence of ribs on the periphery. With *A. obtusicosta* occur other ammonites in which the outer whorl is swollen, the capricorn stage commencing later and bituberculation earlier. These forms constitute a transition to *A. hybrida* (A. d'Orbigny).

Androgynoceras hybrida (A. d'Orbigny).

Ammonites hybrida d'Orbigny (3, pl. lxxxv, figs. 1–3, *non* figs. 4–5); compare *A. intracapricornus* Quenstedt (4, pl. xxix, fig. 9).

This is the *heterogenes*-stage of this series; its connexion with these ammonites is supported by the asymmetrical first lateral lobe and the proportions of the suture. The young figured by A. d'Orbigny probably is from a different ammonite, resembling *Oistoceras*.

Androgynoceras divaricosta, sp. nov. (Pl. XXII, figs. 1 *a*–1 *c* & text-fig. 8.)

Dimensions of holotype :—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
142 mm.	42 per cent.	57 per cent.	27 per cent.

Whorls swollen, nearly round, sides slightly flattened, moderately involute ; flattened costæ with two rows of tubercles. From the umbilical margin the ribs slope back to the inner tubercles ; between the tubercles they often divide, usually uniting again at the outer tubercles, splitting into two or three ribs which pass directly across

Fig. 8.—*Sutural development of* Androgynoceras divaricosta *(Lincoln).*

the periphery. Tubercles usually paired, but the outer are slightly more numerous than the inner (imparinode stage commencing, 34/29).

The tubercles of the type-specimen are rounded knobs, but in specimens with a well-preserved shell they are moderately sharp. Longitudinal striations are present. Involution does not reach the inner row of tubercles.

Development.—The form of the shell throughout life changes very little, the whorls being nearly round and merely increasing in size. The shell is quite smooth up to a diameter of 4 mm., after which it has closely-set ribs for about a quarter of a whorl; bituberculation commences at a diameter of 20 mm.

Diameter. mm.	Whorl height. per cent.	Whorl thickness. per cent.	Umbilicus. per cent.
14	43	50	—
22	46	52	—
50	48	54	27
120	48	56	30

Occurrence.—*Dædalicosta* sub-zone, Bracebridge and Waddington, near Lincoln (7, p. 104).

Androgynoceras divaricosta closely resembles specimens found in Dorset which are intermediate between *A. latæcosta* and *A. dædalicosta*, having a round whorl with slightly-flattened sides, tubercles nearly paired, and a moderately-wide umbilicus. The sutures indicate, however, that they belong to different series.

A. divaricosta has a superficial resemblance to *Liparoceras pseudostriatum*, from which it may be distinguished by

(1) Greater arch of the periphery and rounder whorl.

(2) Suture less complicated and having a large external saddle.

(3) The tubercles are only just becoming imparinode, and sometimes show longitudinal elongation. (Extension of tubercles in *Liparoceras* is usually, but not always, transverse.)

The young have a wider umbilicus than the young of sphærocones of *Becheiceras* and *Liparoceras*.

D. Amblycoceras.

Amblycoceras brevilobatum, sp. nov. (Pl. XXIV, fig. 3; text-fig. 10 *c*, p. 283.)

Holotype: *Liparoceras capricornu* Richardson.[1]
Compare *Amblycoceras capricornum* Hyatt.[2]
Compare *A. maculatum* Quenstedt, 4, pl. xxxiv, figs. 7–9.

Dimensions of holotype:—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
48 mm.	29 per cent.	27 per cent.	44 per cent.

A capricorn with elevated whorl and strong ribs, which are not much diminished on the periphery, where they curve forwards. The peripheral rib-curve is generally much less than that of *Oistoceras*, but often varies in individual specimens; thus some examples resemble *Oistoceras*, but are easily distinguishable by their sutural proportions. Sutures moderately complicated; first lateral lobe shallow and narrow, the ventral lobe has a broad median saddle, and the external saddle has three subequal terminal folioles (text-fig. 10 *c*, p. 283).

Development.—(Studied in specimens of *A. brevilobatum* from the Brick-Pit, Pilley, Leckhampton.)

The young forms in which the development was studied, had at

[1] L. Richardson, 'Geology of Cheltenham, &c.' 1904, pl. xv, fig. 7.

[2] A. Hyatt, in Eastman-Zittel, 'Text-book of Palæontology' 1st ed. vol. i (1900) p. 578, fig. 1204.

a diameter of 7 mm. a body-chamber already equal in length to more than three-quarters of a whorl. The inner whorls are smooth, and costæ are not acquired until the diameter of 3 mm. is reached. From this stage onwards the whorl becomes more elevated. Sutural development similar to that in *Amblycoceras crescens*, which will be next described: thus denticulations appear in each species at the same diameter and in the same order, and the sutures are remarkably similar (text-fig. 10 *b* & *c*, p. 283).

Diameter. mm.	Whorl height. per cent.	Whorl thickness. per cent.	Umbilicus. per cent.
0·7	50	75	—
1·4	43	55	35
3·0	42	60	33
4·7	40	51	32
7·5	37	40	33

Occurrence.—*Latæcosta* sub-zone, Brick-Pit, Pilley, Leckhampton.

Distinction: Suture and rib-curve distinguish *A. brevilobatum* from all species except *A. crescens*, which differs in having a stouter form.

With *A. brevilobatum* occur somewhat more advanced specimens having the outer whorl expanded, bituberculation commencing (S. S. Buckman Coll. No. 2817). This may be *Microceras sinuosum* Hyatt (2, p. 82), which is described as a bituberculate form with peripheral rib-curve; Mr. Buckman placed this species with *Oistoceras*,[1] but Hyatt refers to the shallow first lateral lobe of its suture, a character which suggests *Amblycoceras*.

Amblycoceras crescens Hyatt. (Pl. XXIV, figs. 1 *a*–1 *b* & 2 *a*–2 *b*; text-figs. 9 & 10 *b*, pp. 281, 283.)

Compare *Ægoceras capricornum* Geyer.[2]

Dimensions of specimen figured here:—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
32 mm.	31 per cent.	34 per cent.	40 per cent.

A small capricorn, with stout thick whorls; ribs very prominent on the sides and periphery, where they have a forward bend. Ribs of the last whorl widely spaced (18 to the whorl).

Suture fairly simple; first lateral lobe very shallow; external lobe with broad and short median saddle (fig. 10 *b*, p. 283).

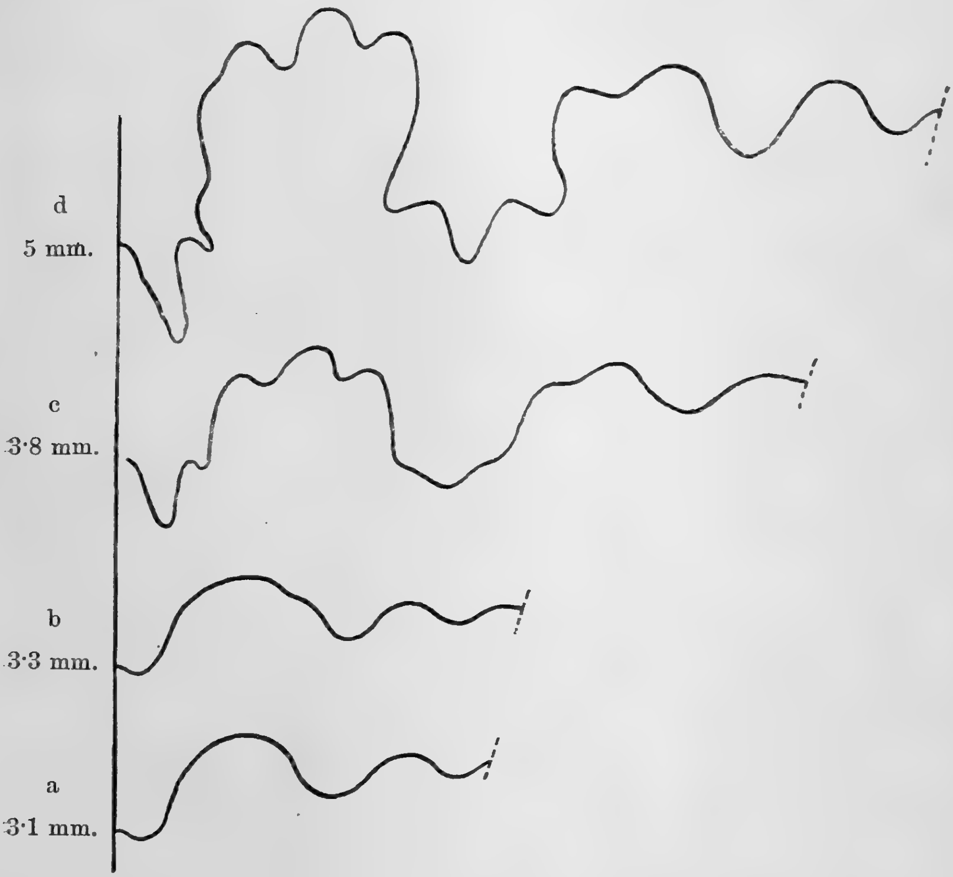
Hyatt named this species, but gave no figure; and the name has not been generally used. The specimen here figured agrees with Hyatt's description in having a shallow 'superior' lateral lobe and stout whorl.

[1] 'The Geology of the Country between Whitby & Scarborough' Mem. Geol. Surv. 2nd ed. (1915) p. 96.

[2] G. Geyer, 'Die Mittelliasische Cephalopoden-Fauna des Hinter-Schafberges in Ober-Œsterreich' Abhandl. K.-K. Geol. Reichsanst. vol. xv (1893) pt. 4, pl. iii, fig. 9.

Development (Pl. XXIV, figs. 2*a* & 2*b*).—Studied in a specimen from the *dædalicosta* sub-zone, Lincoln. The innermost whorls are not usually preserved; at a diameter of 2 mm. the shell is smooth with a depressed whorl, ribs appearing as folds on the lateral area at a diameter of 3 mm. This condition continues until over a whorl later, when at a diameter of 7 mm. faint folds cross the periphery with a decided forward curve. The whorl height has increased meanwhile, so that the whorl is almost circular in section; *A. crescens*, from this diameter onwards, is much stouter than any

Fig. 9.—*Sutural development of* Amblycoceras crescens (*Lincoln*).



other capricorn described. The ribs are regular and closely placed, until a diameter of 20 mm. (25 to a whorl), after which they are separated by wider spaces (18 to a whorl). The arrangement of the ribs on the inner whorls thus resembles that in *A. brevilobatum*.

Diameter. mm.	Whorl height. per cent.	Whorl thickness. per cent.
2	45	64
3·8	43	60
11	39	43
42	36	38

The suture at a diameter of 2 mm. has already a median ventral saddle, and the second lateral saddle is present as a low fold near the umbilical line (text-fig. 9 *a*, p. 281). The first denticulation of the suture appears on the dorsal margin of the external saddle at a diameter of 3·5 mm. A little later (after two sutures) the saddle is divided into three nearly equal terminal folioles (fig. 9 *b*). At the diameter of 3·8 mm. the first lateral lobe is feebly trifid, while the first lateral saddle has two unequal divisions (fig. 9 *c*). These features become more distinct in the next whorl: the second lateral saddle, though still undivided, is of greater size, and the first auxiliary is present.

Occurrence.—The specimens figured are from the *dædalicosta* sub-zone of Bracebridge (Lincoln), where similar forms also occur in the *Oistoceras* sub-zone. It is also found in Yorkshire at a similar horizon.[1]

A. crescens is distinguished by its stout form from all capricorns except *Liparoceras sparsicosta*, from which it differs in having costæ undiminished and slightly curved on the periphery and in having a very shallow inferior lateral lobe.

AMBLYCOCERAS DISSOTYPUM, sp. nov. (Pl. XXIII, figs. 1 *a*–1 *c*; text-fig. 10 *a*, p. 283.)

Dimensions of holotype:—

Diameter.	Whorl height.	Whorl thickness.
100 mm.	44 per cent.	36 per cent.
65	45	?44
46	37	40

A transitional form, showing capricorn inner whorls, the outer whorl expanded and bituberculate. Suture more complicated, but otherwise similar to that of *A. crescens*.

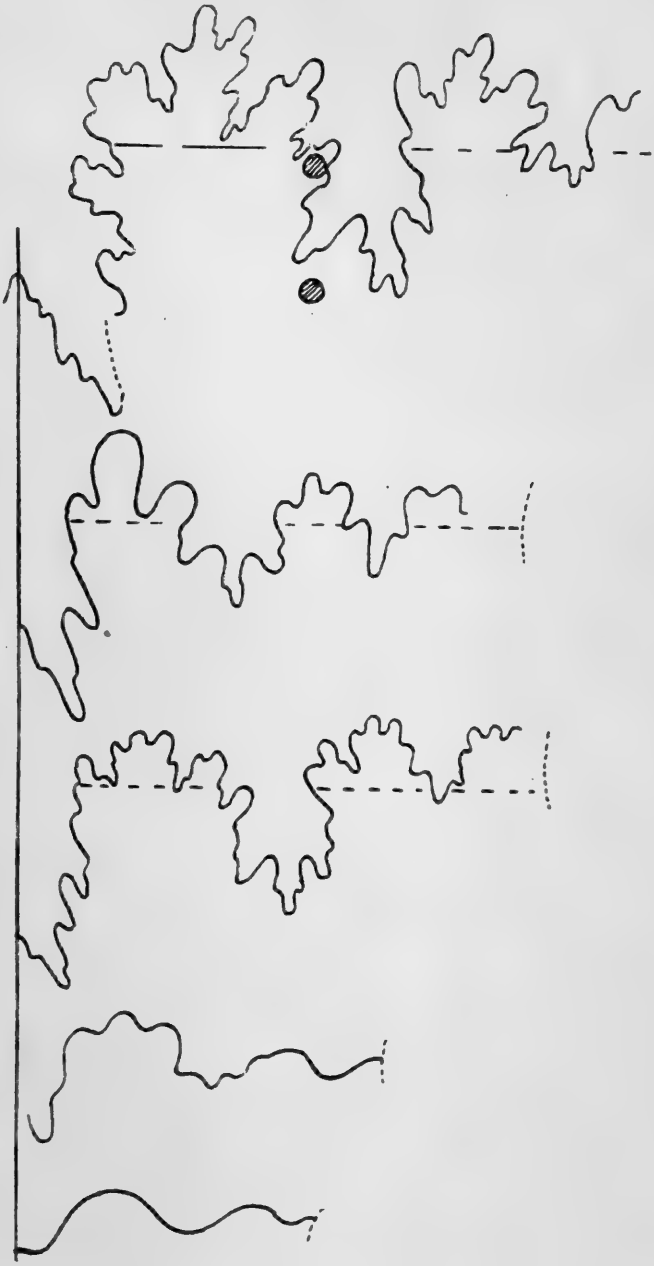
Development.—Capricorn ornamentation commences early in development, fine ribs being present (20 to a whorl) up to a diameter of 12 mm. From this stage the ribs are more widely spaced (14 to a whorl): such a sparsicostate stage precedes the development of a bituberculate swollen whorl in several series. After the diameter of 36 mm. is reached, the ribs divide into two or three on the venter; tubercles appear on the outer margin at 60 mm. diameter, and the ribs are much less prominent. The inner tubercles are but feebly developed.

The arrangement of costæ and the depressed shape of the inner whorls in this ammonite thus recall *A. crescens*, from which it presumably is derived.

Occurrence.—The type-specimen of *A. dissotypum* was collected in the *dædalicosta* sub-zone at Bracebridge, near Lincoln. It is distinguished from other Liparoceratids of this stage by its suture, with shallow first lateral lobe, and by its peripheral rib-curve.

[1] S. S. Buckman, 'Geology of the Country between Whitby & Scarborough' Mem. Geol. Surv. 2nd ed. (1915) p. 69.

Fig. 10.—*Sutures of* Amblycoceras *spp.*



a
50 mm.
A. dissotypum
(Lincoln). See
Pl. XXIII, fig. 1.

b
18 mm.
A. crescens
(Lincoln). See
Pl. XXIV, fig. 1.

c
30 mm.
A. brevilobatum
(Leckhampton).
See Pl. XXIV,
fig. 3.

d
3·5 mm.
(The same.)

e
2 mm.
(The same.)

E. Oistoceras.

Oistoceras omissum (Simpson). (Pl. XXV, figs. 2 *a*–2 *h*; text-fig. 11, p. 284.)

Refigured, 1, vol. i, No. 27.

Compare *A. maculatum angulatum* Quenstedt (4, pl. xxxiv, figs. 11 & 12).

Dimensions of figure (in 1, No. 27):—

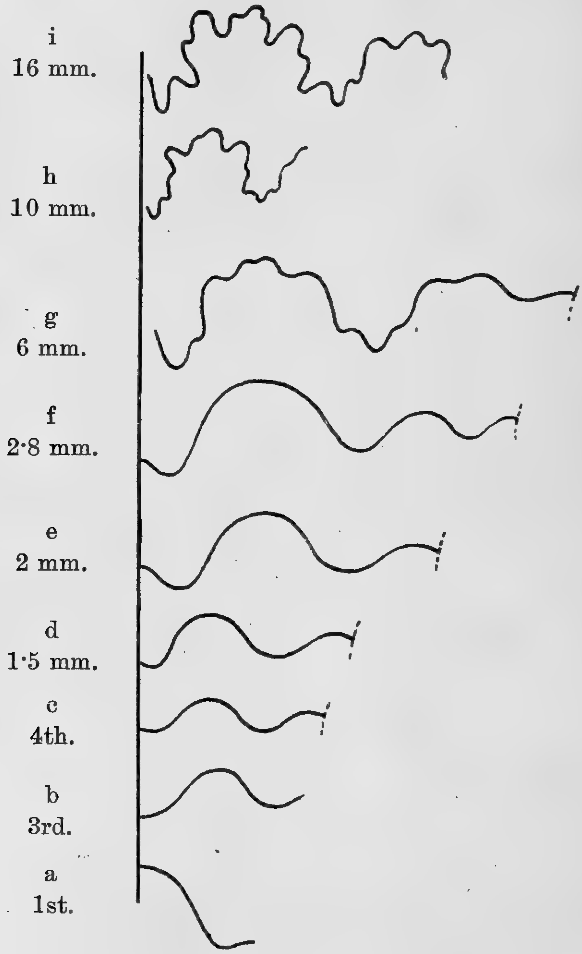
Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
28 mm.	25 per cent.	? 32 per cent.	54 per cent.

Suture simple; first lateral lobe narrow, external saddle wide with three unequal folioles (fig. 11 *i*, below).

Development (Pl. XXV, figs. 2 *a*–2 *h*).—Specimens studied were from the *Oistoceras* sub-zone, Waddington, near Lincoln (7, p. 104).

The protoconch is about 0·63 mm. long, and is of normal shape with a narrow azygous saddle. Ribs appear at a diameter of

Fig. 11.—*Sutural development of* Oistoceras omissum (*Lincoln*). *Specimen figured in Pl. XXV, fig. 2.*



2 mm. at the commencement of the second whorl, but do not cross the venter until a diameter of 9 mm. is reached. The ribs have an arrow-like forward projection on the periphery. Throughout development the ribs are fine and regularly spaced, the number of ribs to a whorl increasing steadily with growth; thus, at a diameter of 30 mm., there are usually thirty ribs on the last whorl. In some species (*Oistoceras figulinum*) the number becomes reduced in the adult or in old age.

Diameter. mm.	Whorl height. per cent.	Whorl thickness. per cent.
0·8	40	73
1·5	43	64
3·5	42	56
8·0	42	42
16·0	36	37
28·0	28	28

The shell is usually very thick, and the sutural development is therefore difficult to study in well-preserved specimens such as those found at Waddington. The sutural development resembles that of other capricorns in that:

(1) The first suture has a narrow, undivided, median saddle (fig. 11 *a*).

(2) The second suture has a shallow external lobe without a siphonal saddle (fig. 11 *b*).

(3) A minute siphonal saddle has appeared in the external lobe, which is deeper than the lateral lobes, by the fourth suture (fig. 11 *c*).

(4) The first denticulation appears on the dorsal side of the external saddle.

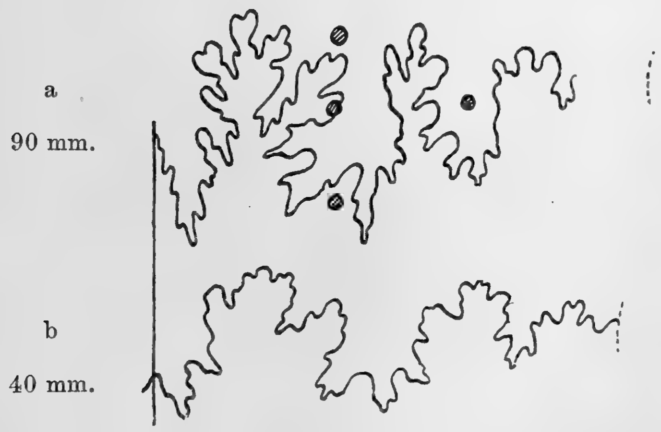
Occurrence.—*Oistoceras* sub-zone, Yorkshire and Lincolnshire.

OISTOCERAS FIGULINUM (Simpson). (Fig. 12 *b*.)

Refigured, 1, vol. i, No. 26 *a*.

An advance on *Oistoceras omissum*; the number of ribs on

Fig. 12.—Oistoceras allœotypum (*a*) *and* O. figulinum (*b*); *both from Lincoln.*



[a = Specimen figured in Pl. XXV, fig. 1.]

a whorl increases in early development, but the ribs of the last whorl are more widely spaced.

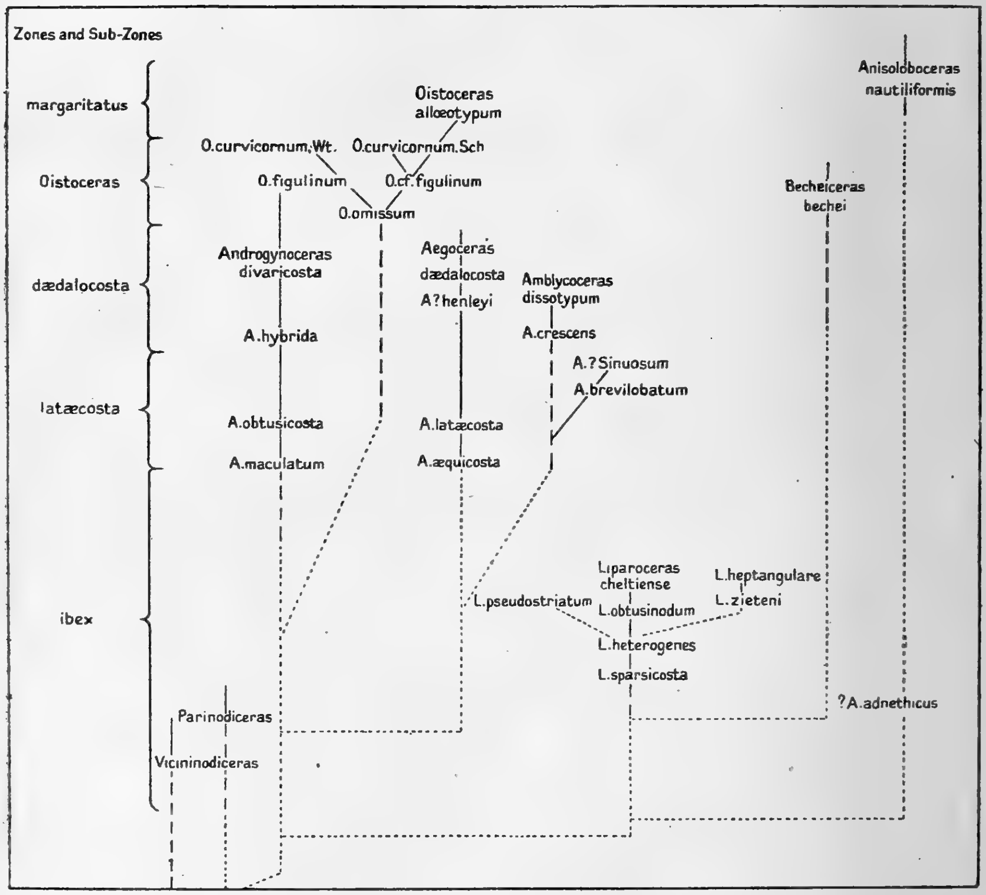
Occurrence.—*Oistoceras* sub-zone, Yorkshire, Lincolnshire, ? Dorset.

OISTOCERAS CURVICORNUM (Schlœnbach).

Ammonites curvicornis Schlœnbach, 'Ueber den Eisenstein des Mittleren Lias in Nord-West Deutschland, &c.' Zeitschr. Deutsch. Geol. Gesellsch. vol. xv (1863) p. 522 & pl. xii.

This differs from *A. curvicornum* Wright (8, pl. xxxi, figs. 3 & 4) in having a rounded venter, that of the latter being flattened. Wright's form has also more prominent tubercles. The probable relations of these species are shown in Table III.

TABLE III, *showing the probable relationships of the species of the Liparoceratidæ.*



[Continuous vertical lines = proved range of the genus; broken lines = probable range; dotted lines indicate affinity; for *dædalocosta* read *dædalicosta*.]

O. curvicornum (Schlœnbach *non* Wright) may be represented at Waddington, near Lincoln. The form figured by Wright occurs at a corresponding level (the *Oistoceras* sub-zone) in Dorset.

In each of these series three types may be distinguished:

(1) With peripheral costæ sharp and distinct.

(2) With a fold passing straight across the venter, the rib-curve being indicated by striations only.

(3) Without folds on the periphery; curved striations only.

It does not seem necessary at present to create new species for these forms.

OISTOCERAS ALLŒOTYPUM, sp. nov. (Pl. XXV, figs. 1 *a* & 1 *b*; text-fig. 12 *a*, p. 285).

Dimensions:—

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
90 mm.	40 per cent.	37 per cent.	38 per cent.
45	35	35	44

A *heterogenes*-like form (morphic equivalent of *Androgynoceras hybrida*) with capricorn ornament on the inner whorls, the last half of the outer whorl swollen and having more slender costæ and two rows of tubercles. The forward curve of the ribs on the periphery is clearly shown.

Capricorn ribs are retained until a diameter of 70 mm., when the shell is scarcely different from *O. figulinum*. The costæ are regular up to a diameter of 40 mm., after which they are more widely spaced. Two rows of tubercles are present on the outer whorl, but those of the inner row are very feeble. The ribs divide at the outer tubercles, passing with a sharp bend across the slightly-angular (convexi-fastigate) venter. Suture complex, but on the same plan as *Oistoceras omissum*; deep and narrow external lobe with a high median saddle, half as high as the external saddle. This latter is asymmetrically divided, being deeply undercut on the dorsal side. The first lateral lobe is nearly as deep as the external lobe, and is terminated by three unequal lobules.

Occurrence.—Lower *margaritatus* zone, Bracebridge (Lincoln).

O. allœotypum is distinguished by its whorl shape from its morphic equivalents in other series, its subangular venter most resembling *A. hybrida*. Its generic position is indicated by its peripheral rib-curve and its suture.

F. BECHEICERAS, gen. nov. (See p. 263.)

BECHEICERAS BECHEI (Sowerby). (Fig. 13, p. 288.)

Compare *Ammonites bechei* A. d'Orbigny (3, pl. lxxxii) and *Ægoceras bechei* Wright (8, pl. xli, figs. 1–2).

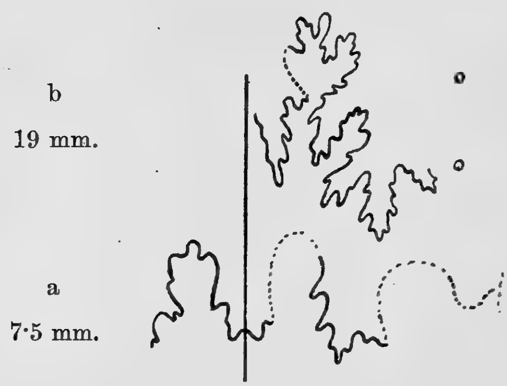
A. bechei, formerly considered by many workers to be synonymous with *A. striatus* or *A. henleyi*, has generally been applied in more recent years to the finely-ornamented sphærocones of several series of the Liparoceratidæ. The sutural characters pointed out (fig. 1 *b*, p. 258) restrict the name to ammonites of the *Becheiceras* series only.

A typical example of *Becheiceras bechei* was obtained by Dr. Lang from the Upper Limestone (*Oistoceras* sub-zone) of Dorset (W. D. Lang Coll. No. 4073). This remains smooth until the diameter of nearly 20 mm., when it becomes finely bituberculate; the capricorn stage through which this series presumably passed is omitted in development.

There is, therefore, little change in whorl shape.

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
6 mm.	46 per cent.	67 per cent.	—
12	50	58	16 per cent.
28	56	56	11
41	53	53	—

Fig. 13.—*Sutural development of* Becheiceras bechei *(W. D. Lang Coll. No. 4073).*



Ammonites which constitute an earlier stage in the *B. bechei* series occur in the *dædalicosta* sub-zone of Dorset; they have a somewhat wider umbilicus than *B. bechei.*

It has already been indicated that *B. bechei* is very similar to certain finely-ornamented forms in other series. The following points of distinction are useful:—

(1) The sutural proportions (text-fig. 1 *b*, p. 258).

(2) At all stages in development the whorl thickness of *B. bechei* is less than in corresponding stages of *Liparoceras.*

(3) The young of *B. bechei* is smooth for a longer period than the young of other forms.

G. Parinodiceras, gen. nov. (See p. 264.)

Parinodiceras reineckii (Quenstedt) (4, pl. xxviii, fig. 5).

A compressed sphærocone with smooth inner whorls (no capricorn stage). Bituberculate, tubercles paired, regular, nearly forty in each row, the two rows widely separated. The ribs do not divide on the lateral area, but divide into two or three on the periphery, where they are very prominent. No longitudinal striations visible. Suture complex; external lobe deep and narrow, with a high median saddle, external saddle high, not extending quite to the outer row of tubercles, first lateral lobe a little deeper than the external lobe. This species differs from *P. parinodum* (Quenstedt) 4, pl. xxviii, figs. 16–17, in the greater arch of the periphery.

A typical specimen in the collection of Mr. Buckman (No. 2098), from Radstock, Somerset (*valdani* zone), has the dimensions:

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
140 mm.	60 per cent.	39 per cent.	9 per cent.

H. VICININODICERAS, gen. nov. (See p. 264.)

VICININODICERAS SIMPLICICOSTA, sp. nov. (Pl. XXIV, figs. 4 *a* & 4 *b*.)

Diameter.	Whorl height.	Whorl thickness.	Umbilicus.
87 mm.	51 per cent.	58 per cent.	20 per cent.

A bituberculate sphærocone; whorls round, inner whorls smooth (no capricorn stage). Tubercles paired, at wide intervals on the outer whorl (about twenty in each row); the two rows very close together, the inner row being high up on the whorl. Ribs simple, annular, with a faint backward curve on the periphery, not dividing at the tubercles; only about a sixth of the ribs of the outer whorl bear tubercles. Except in one case the tubercles are broken off; they are longitudinally elongated, and appear to be placed on one rib, touching the ribs on each side.

Suture very complicated, with a deep external lobe and high median saddle, the first lateral lobe wide and slightly deeper than the external lobe; the whole of the external saddles and part of the first lateral lobe are ventral to the outer row of tubercles.

V. simplicicosta is distinguished by its paired tubercles from all Liparoceratids, except *Parinodiceras* and *A. striatus* Reinecke, from both of which it differs in having undivided ribs and the tubercles placed close together; it is further distinguished by the form of the whorl.

Only three specimens of this ammonite have been examined; they are in the collection of Mr. J. W. Tutcher, who obtained them at Radstock, Somerset (*valdani* zone).

VII. PHYLOGENY AND GENERAL CONSIDERATIONS.

Early Capricorn Forms.

Although the capricorns of the Liparoceratidæ are most abundant in the *davœi* zone, yet more primitive capricorns have been found as low as the *oxynotum* and *raricostatum* zones. Two such forms have been described as *Androgynoceras siphunculare* and *A. integricostatum*, which occur in the *gagateus* band (*oxynotum* zone) of Robin Hood's Bay. These ammonites are smooth until a diameter of 3 mm., and their sutures are simpler than those of the later forms at corresponding diameters.[1]

The species figured by Reynès (6, pl. l, figs. 26–32, pl. xlv, figs. 47–49) from the *raricostatum* zone (*A. sirius* and *A. vesta*) are very little more advanced than these forms. *A. circumdatus* Reynès (6, pl. xxviii, figs. 19–22) described from the *bucklandi* zone and placed by Mr. Buckman on the line of descent of the capricorns,[2] is probably a member of another series, and cannot be considered as the early ancestor of the Liparoceratidæ; but it may represent an offshoot from their ancestral stock.

It is probable, however, that the capricorn forms possessed their essential characters at a comparatively early date; thereafter evolution proceeded slowly for some time, and consisted solely in the acceleration of the capricorn ornament and the increase of complication of the sutures. The development of bituberculation and the sphærocone form in each series was comparatively sudden; this period of rapid evolution appears to have frequently followed the arrival of a series in this area.

The Pre-Capricorn Ancestor.

It has been shown that the inner whorls of the Liparoceratidæ are invariably smooth and depressed, with a relatively-narrow umbilicus; the young of many ammonites of various families have a similar form. Prof. J. Perrin Smith has suggested[3] that the *Glyphioceras*-like young may be explained in two ways:—

(1) They may indicate that all ammonites are descended from a *Glyphioceras*-like ancestor.

(2) This form of shell may be cœnogenetic and not palingenetic; that is, it may be acquired owing to its suitability during the early life of all ammonites, and may have no reference to the form of the ancestor.

In support of the latter view it may be mentioned that the protoconch of every ammonite has a depressed form of aperture; it is, therefore, probable that the succeeding whorls will gradually become more elevated until they attain the adult shape. That is to say, the depressed inner whorls may be a result of the form of the protoconch, and may be independent of the form of the ancestor.

[1] Thus the suture of *A. siphunculare* (Whitby Museum, No. 485) at a diameter of 20 mm. has an external saddle divided simply into three terminal folioles, and a first lateral lobe with three small lobules, a stage which is attained by the suture of the capricorns described previously at a much smaller diameter (figs. 2 *e*, 9 *d*, 11 *g*, pp. 266, 281, 284).

[2] S. S. Buckman, Q. J. G. S. vol. liv (1898) table ii, facing p. 451.

[3] 'Acceleration of Development in Fossil Cephalopods' Stanford Junior University Publications, 1914.

The former view has been maintained by Mr. Buckman,[1] who suggested that *Cymbites* is the ancestor of many Mesozoic ammonites; the inner whorls of ammonites are remarkably similar in form to those of the adult *Cymbites*, but also the sutural development of many ammonites suggests that they arose from a *Cymbites*-like ancestor. It must further be noticed that there are numerous transitional forms which appear to connect globose (*Glyphioceras*-like) species with ammonites of many families,[2] a fact which appears to indicate the truth of Mr. Buckman's suggestion, but cannot easily be reconciled with the second view put forward by Prof. J. P. Smith.[3]

These globose ammonites have generally been called *Cymbites globosus*: the name has probably been used, however, to cover several species which differ little in outward form, but have a long vertical range[4]; from this central group the various ammonite-families may have arisen at different times.

The Triassic ancestor of *Cymbites* (and so, perhaps, of most Jurassic ammonites) is probably an involute form, with a depressed whorl and simple suture comprised of few elements. Mr. Buckman suggested that *Nannites* may be the ancestral form[5]; but, as this acquires constrictions in the adult,[6] which are not reproduced in *Cymbites*, it is probably only safe to assume that it is near the line of descent of the ammonites.

General Considerations.

A genealogy of Jurassic ammonites was given by Mr. Buckman in 1898.[7] Since that date his own views have undergone considerable modification, and it must be stated that some of the differences between that genealogy and the one given here have been suggested to me by Mr. Buckman's subsequent writings.

[1] 'On the Genus *Cymbites*' Geol. Mag. dec. 4, vol. i (1894) p. 360.

[2] For example, in the nodules of the *planicosta* sub-zone of Dorset the following series may be found:

(1) *Cymbites* sp. of the *C.-lævigatus* pattern, more evolute than *C. globosus*.
(2) *Cymbites* sp. of the *C. berardi* pattern, with broad lateral costæ and smooth periphery.
(3) Ammonites with broad costæ, which pass across the periphery.
(4) Ammonites of the *planicosta* group, frequently smooth up to a diameter of 8 mm.

[3] If the 'skipping of stages' demonstrated in this paper has been of frequent occurrence, it may often prove impossible to judge ancestry from ontogenetic evidence, and the tracing of numerous connecting forms will be necessary in determining genealogies.

[4] Thus the sutural development of examples from the Middle Lias proceeds more rapidly than that of specimens from the Lower Lias.

[5] *Op. supra cit.* 1894, p. 360.

[6] A. Hyatt & J. P. Smith, 'Triassic Cephalopod Genera of America' U.S. Geol. Surv. Prof. Paper, No. 40 (1905) p. 78.

[7] S. S. Buckman, 'Divisions of so-called Jurassic Time' Q. J. G. S. vol. liv (1898) table ii, facing p. 451.

The early evolution of the Echioceratidæ and the Liparoceratidæ is parallel, both families developing capricorn ornamentation at approximately the same time. In subsequent evolution, however, while the Liparoceratidæ become expanded and bituberculate, the Echioceratidæ always remain slender, never develop bituberculation, and in later stages acquire a carina. Although the early evolution of the two families was parallel, separation must have occurred at a comparatively early date, for the sutures, even in the young forms, are very distinct.

It is extremely probable that the Hildoceratidæ arose from a similar stock at a later date; the early evolution resembles that of the Echioceratidæ and the sutures are similar, but the carina becomes more prominent. The Hildoceratidæ may comprise several parallel lines of descent from a *globosus*-like form. Some specimens of *Frechiella*, a globose ammonite with keeled venter (1, vol. i, No. 23), have typical Hildoceratan sutures and may be intermediate between the ancestral form and one of the later branches of the Hildoceratidæ.

It seems probable, therefore, that the Liparoceratidæ, Echioceratidæ, Hildoceratidæ, Polymorphidæ,[1] and Deroceratidæ [2] may have developed directly from a globose ancestor. Other families, however, while they have probably descended from a similar globose form, have passed through a subsequent cadicone stage; thus Hyatt[3] regarded *Cœloceras pettos*, a broad-ventered (cadicone) tuberculate ammonite, as the acmic tertiary radical of the Dactyloidæ. Some members of the Dactyloidæ pass through a *pettos*-like stage with cadicone whorls and smooth venter.[4] Later Dactyliocerates omit the cadicone stage altogether in development, an omission which is comparable with the skipping of the capricorn stage in the development of the later Liparoceratidæ.

The *Beaniceras* series, to which reference has already been made, passes from a tuberculate cadicone to a capricorn, similar in outward appearance to the anagenetic capricorns of the Liparoceratidæ. Mr. S. S. Buckman, who placed *Beaniceras* with the Liparoceratidæ (1, vol. ii, p. *iii*), now agrees with me that its affinities are with the Dactyloids, which it resembles in sutural characters and in the cadicone ancestry.

The Amaltheidæ likewise pass through a cadicone stage, and may perhaps be considered as related to the Dactyloids rather than,

[1] A. E. Trueman, 'Observations on the Genus *Polymorphites*' Geol. Mag. dec. 6, vol. iv (1917) p. 442.

[2] The Deroceratidæ have sutural characters (particularly a deep suspensive auxiliary lobe) which separate them from the greater part of the Lias Ammonites.

[3] A. Hyatt, 'The Genesis of the Arietidæ' Smithsonian Contributions to Knowledge, No. 673 (1889) p. 23. See also A. Hyatt, 'The Non-Reversionary Series of the Liparoceratidæ, &c.' Proc. Bost. Soc. Nat. Hist. vol. xv (1872–73) p. 4.

[4] *Cœloceras fonticulum* has a *pettos*-like stage from the diameter of 5 mm. to that of 10 mm. After this stage ribs appear on the venter. Some species of *Porpoceras* and *Peronoceras* show corresponding stages.

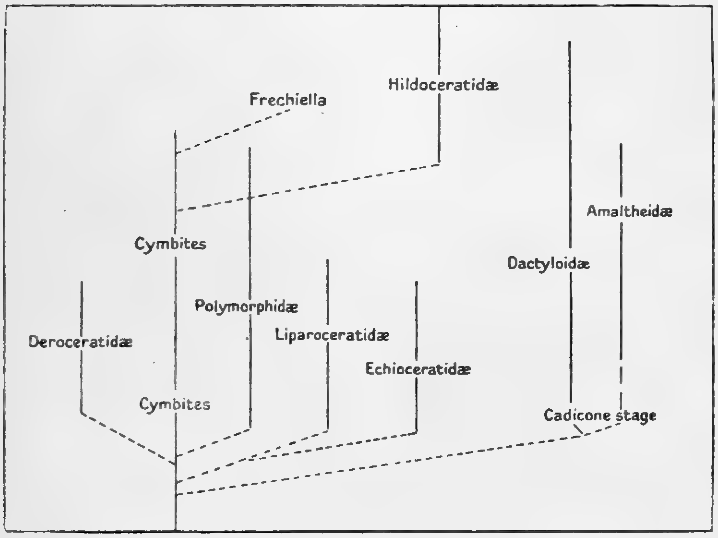
as Mr. Buckman suggested, to the Liparoceratidæ (1, vol. ii, p. *vii*).

That is to say, two main groups of ammonites may be recognized in the families mentioned :—

(1) Those which evolved directly from a globose ancestor (Liparoceratidæ, Hildoceratidæ, Polymorphidæ, Echioceratidæ, Deroceratidæ).

(2) Those which have passed through an intermediate cadicone stage (Amaltheidæ, Dactyloidæ). (See Table IV, below.)[1]

Table IV.—*Diagram showing the possible relationships of the chief Liassic families of Ammonites.*



It is interesting to note that a carinate venter is acquired independently in several families of each of these groups, typically in the Hildoceratidæ and Amaltheidæ, less prominently in the Echioceratidæ and the Polymorphidæ and in some members of the Deroceratidæ. The development of a carina is a normal progressive feature; and, while it leads to a certain similarity between some forms, it does not necessarily imply any close relationship.

VIII. References to Literature.

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2. A. Hyatt, 'Fossil Cephalopods of the Museum of Comparative Zoology' Bull. Mus. Comp. Zool. Harv. vol. i, 1867.
3. A. d'Orbigny, 'Paléontologie française : Terrain jurassique—I. Céphalopodes. 1842–51.
4. F. A. Quenstedt, 'Die Ammoniten der Schwäbischen Jura : Der Schwarze Jura (Lias)' vol. i, 1883-1885.
5. J. C. M. Reinecke, 'Maris protogæi, &c.' 1818.
6. F. Reynès, 'Monographie des Ammonites' 1879. (Text incomplete.)
7. A. E. Trueman, 'The Lias of South Lincolnshire' Geol. Mag. dec. 6, vol. v, pp. 64–73, 101–111, 1918.
8. T. Wright, 'Monograph of the Lias Ammonites of the British Islands' Palæontographical Society, 1878–1886.

[1] It does not necessarily follow, however, that the cadicone form of whorl has not been developed in groups that are unrelated.

EXPLANATION OF PLATES XXI–XXV.

[All the specimens, except where otherwise stated, were collected by the Author, and are now in the collection of the Geological Department, University College, Nottingham.]

Plate XXI.

Fig. 1. *Liparoceras tiara*, sp. nov. × ·8.
Yellow Lias (hemera of *Beaniceras*), collected during excavations for a bridge near Manor Farm, Gotherington, Cheltenham. (L. Richardson Coll.)

2. *Liparoceras sparsicosta*, sp. nov. × ·7.
From a well at Queen's Wood cottages, Prestbury, near Cheltenham. (L. Richardson Coll.)

3. *Liparoceras sparsicosta*, sp. nov.
From Napton (Warwickshire).
a. Section showing the retention of the depressed form of whorl × 3; *b* & *c*. Inner whorls, at a diameter of 1·14 mm. × 4; *d* & *e*. Early chambers × 20, showing protoconch and siphonal cæcum.

4. *Liparoceras cheltiense* Murchison.
From the Battledown Brick-Pit, Cheltenham.
a & *b*. Specimen × ·54. *c* & *d*. Inner whorls of the same × 1·6, showing the fine ornamentation, the first tubercles being unpaired.

Plate XXII.

Fig. 1. *Androgynoceras divaricosta*, sp. nov. *a* & *b* × ·45; *c*. Inner whorl at the diameter of 22 mm. From the *dædalicosta* sub-zone, Bracebridge Pit, Lincoln.

2. *Androgynoceras obtusicosta*, sp. nov. × ·5. From the *latæcosta* sub-zone, Bracebridge Pit, Lincoln.

3. *Ægoceras dædalicosta*, sp. nov. × ·28. From the Red Band, St. Gabriel's Water (Dorset). (W. D. Lang Coll., No. 3862.)

Plate XXIII.

Fig. 1. *Amblycoceras dissotypum*, sp. nov. *a* & *b* × ·6; *c* = Whorl shape at the diameter of 44 mm. From the *dædalicosta* sub-zone, Bracebridge Pit, Lincoln.

2. *Beaniceras* sp. Inner whorls. × 2·5. From Napton (Warwickshire). (C. H. Watson Coll.)

3. *Ægoceras* aff. *latæcosta* Sowerby. *a* × ·4; *b* = Whorl shape × ·8. From the Lower Limestone, *latæcosta* sub-zone, Dorset. (W. L. Lang Coll., No. 1566.)

4. *Ægoceras* aff. *latæcosta*, development. *a*, *b*, & *c*. Inner whorls at the respective diameters of 1·4 mm., ·95 mm., ·7 mm.; *d*. Earlier chambers, showing 'prosiphon,' × 20. From the (?) *latæcosta* sub-zone, Stonebarrow (Dorset). (W. D. Lang Coll., No. 534.)

Plate XXIV.

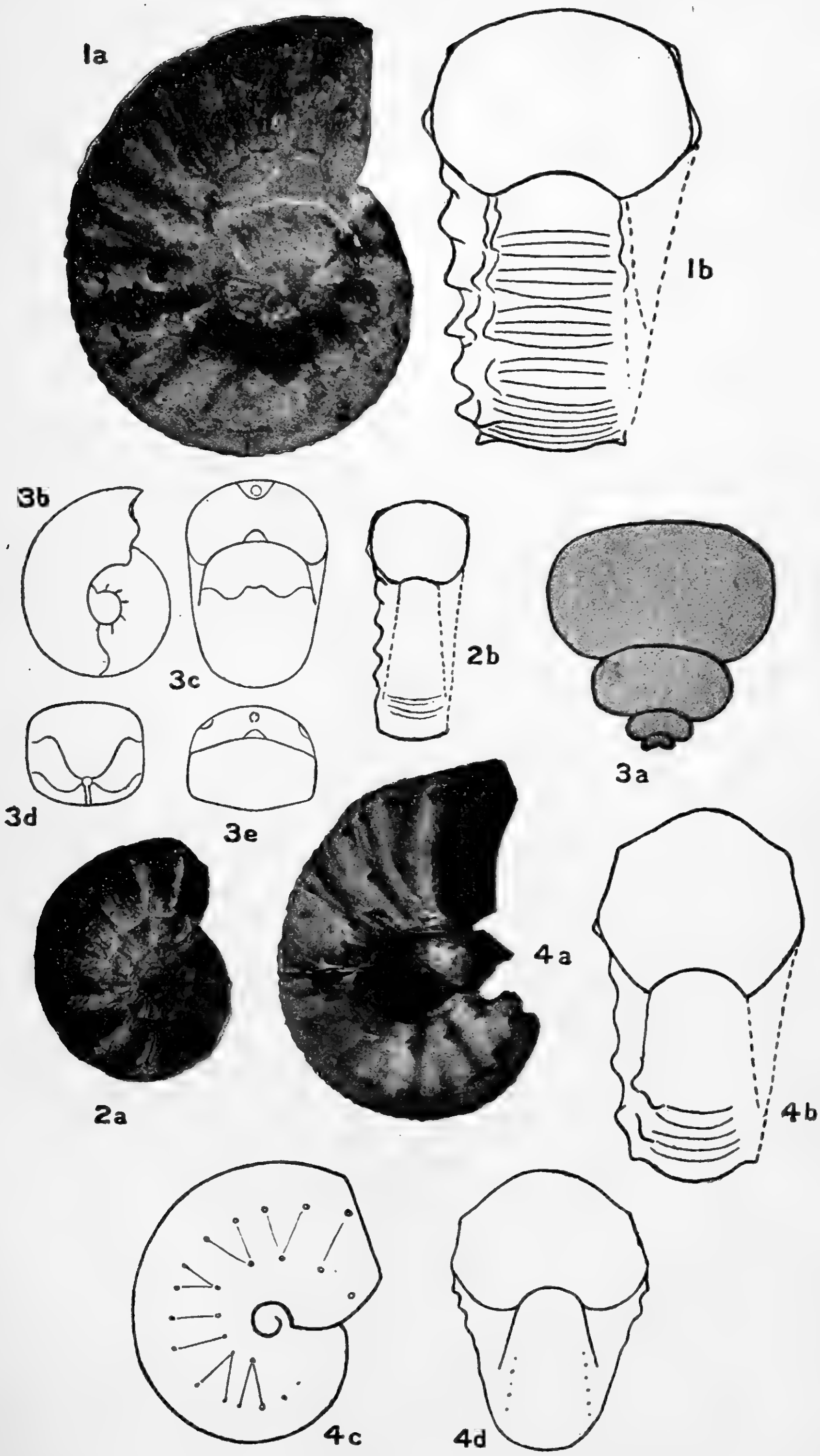
Fig. 1. *Amblycoceras crescens* (Hyatt). × ·73. From the *dædalicosta* sub-zone, Bracebridge, near Lincoln.

2. The same. Inner whorls at the diameter of 3·7 mm. × 11.

3. *Amblycoceras brevilobatum*, sp. nov. × 6·5. Front view of holotype, figured by Mr. L. Richardson (in 'The Geology of Cheltenham, &c.' 1904, pl. xv, fig. 7).

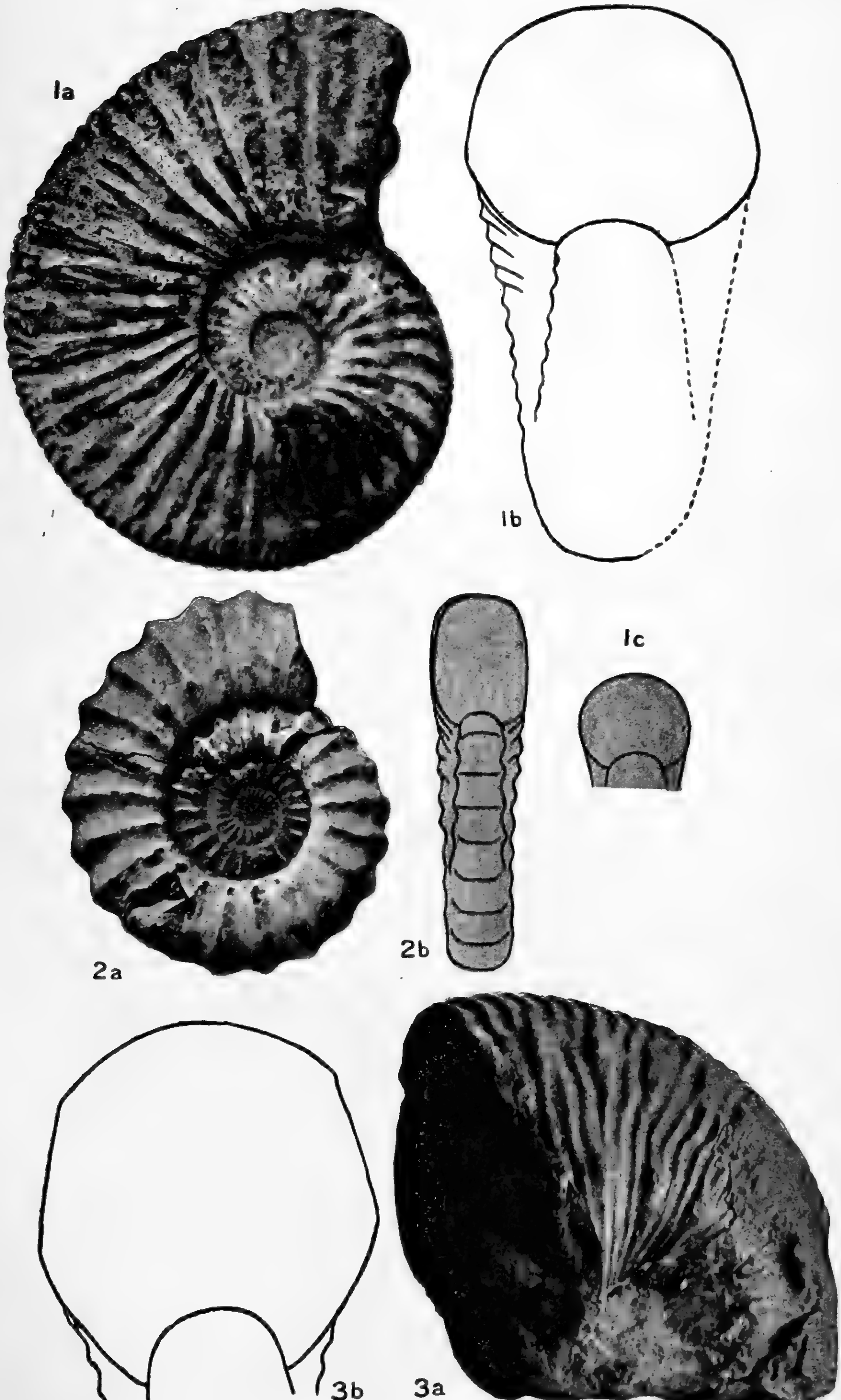
4. *Vicininodiceras simplicicosta*, sp. nov. × ·65. From the '*valdani*-zone,' Radstock (Somerset). (J. W. Tutcher Coll.)

5. *Cymbites* sp. From the *planicosta* sub-zone, Lyme Regis (Dorset). Sections of inner whorls. *a*, × 4; *b*, × 20.



A. E. T. del. et photo

LIPAROCERAS.



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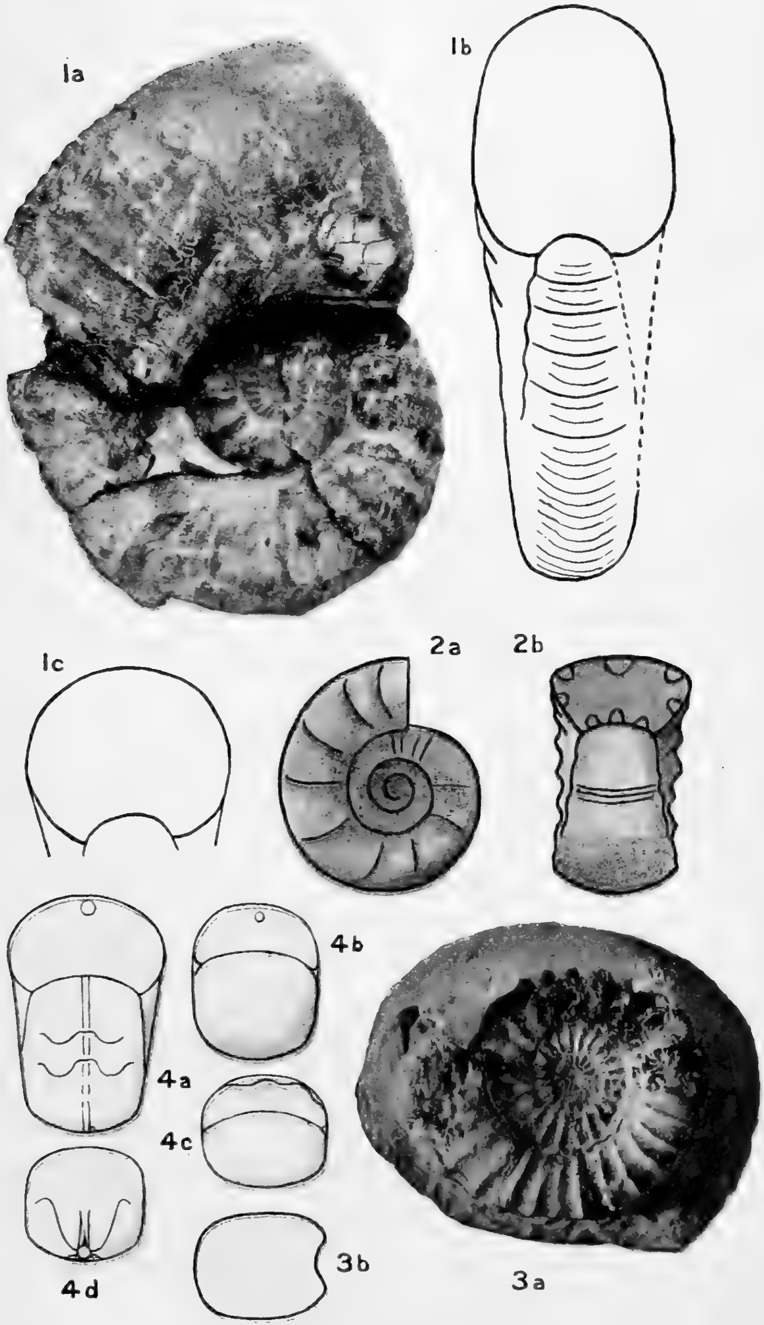
ANDROGYNOCERAS, ÆGOCERAS.



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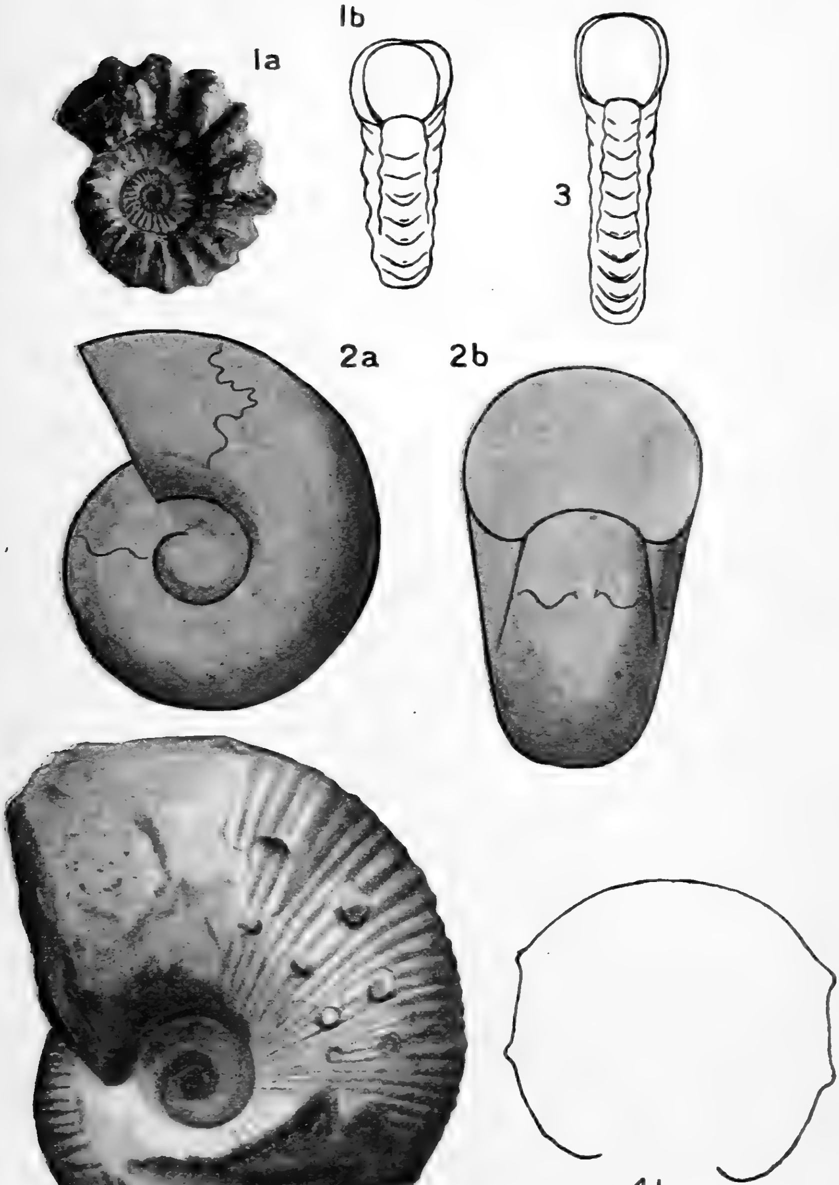
AMBLYCOCERAS, BEANICERAS, ÆGOCERAS.



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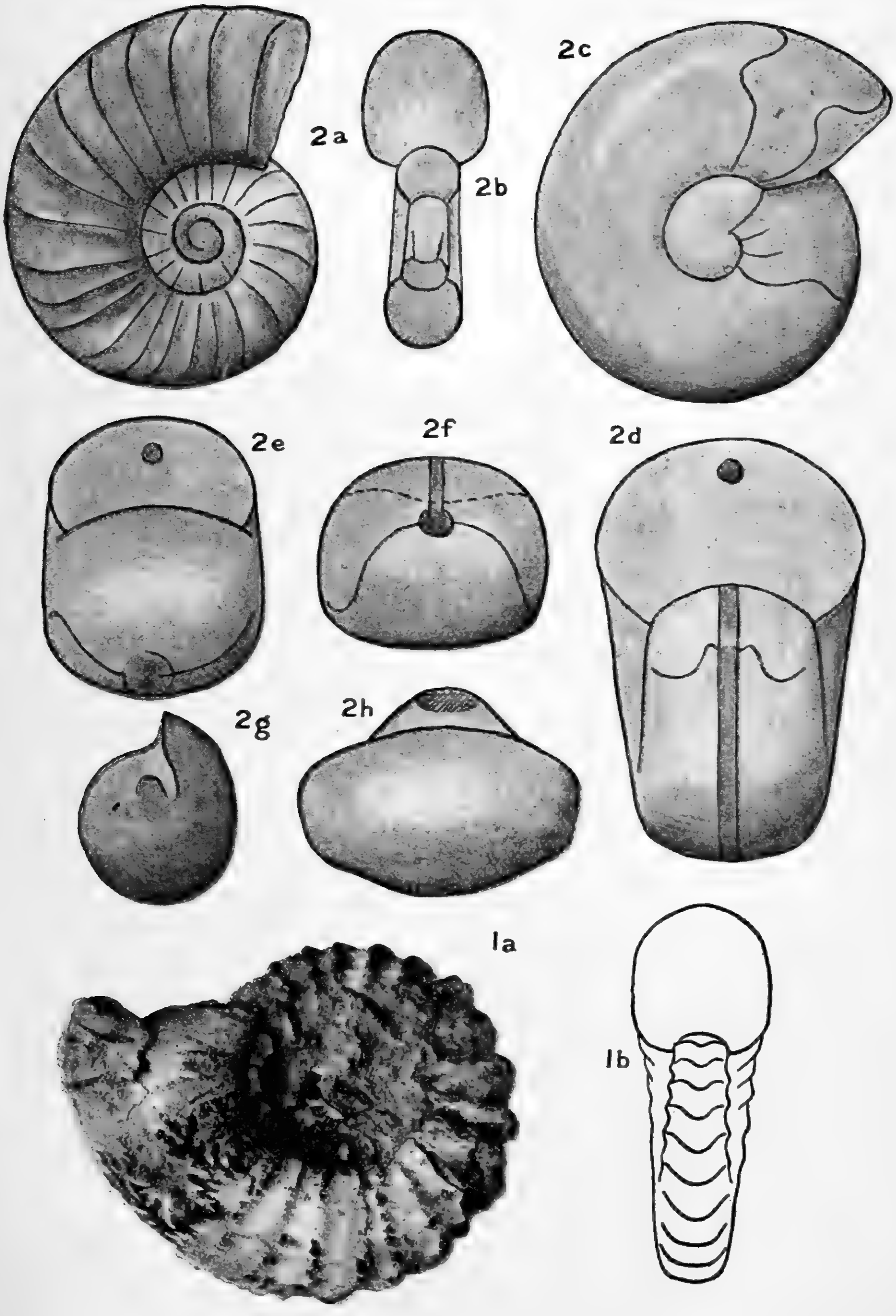
AMBLYCOCERAS, VICININODICERAS, CYMBITES.



A.E.T. del. et photo.

OISTOCERAS.

PLATE XXV.

Fig. 1. *Oistoceras allœotypum*, sp. nov. × ·52. From the lower beds of the *margaritatus* zone, Bracebridge Pit, Lincoln.

2. *Oistoceras omissum* Simpson. Development. From the *Oistoceras* sub-zone, Waddington, near Lincoln. *c*, *d* = Inner whorls × 32; *e*, *f* = Inner whorls × 37; *g*, *h* = Protoconch × 47.

DISCUSSION.

The PRESIDENT (Mr. G. W. LAMPLUGH) congratulated the Author on his lucid exposition of an intricate subject, and commented on the high importance, both to biologists and to stratigraphers, of intensive palæontological studies of this kind. He wished, at the same time, to call attention to the difficulties felt by the field-geologist, when robbed of his crude nomenclature of the commoner fossils by the precise definition and complicated analysis now attempted by the palæontologists. For general service some kind of name was essential, but was becoming increasingly difficult to acquire or retain. For example, it was most desirable to be able to express, as proof that certain beds were Upper Lias, that they yielded *Ammonites communis*, *bifrons*, and *serpentinus*, for every geologist would understand the statement. It might be based, quite soundly, on material so poor that no palæontologist could name the specimens, or so good that only a very small number of specialists in these particular forms would dare to do so. The growing difficulty would have to be met by some means, even if it entailed a duplication of nomenclature. We might have to continue to use indispensable names in a general sense, perhaps with some indication by type or symbol to warn the specialist.

The SECRETARY read the following communication from Mr. S. S. BUCKMAN:—

The title of this paper is a tribute to Alpheus Hyatt. It is just over 50 years ago that Hyatt published his remarkable scheme of Ammonite families and genera—a scheme so advanced for its time and so revolutionary that it found no acceptance in Europe for many long years. Here the later but far more modest scheme of Waagen held the field, yet even that was very strongly condemned as an undesirable innovation. I can remember in the 'seventies' the discussions of leading geologists and my father when they met at his table after their field excursions—the prophecies of disaster to palæontology, which would become quite distasteful to students from the multitude of new names. And now we see how these predictions have been falsified. A young student in almost his first paper takes one of Hyatt's original families, actually only a small portion of Waagen's genus *Ægoceras*, and finds it now divided into five genera, which he accepts. But in his critical analysis he discovers that these genera are insufficient: he promptly increases them by 80 per cent., admitting at the same time that many foreign species of the family must remain outside of them, so that the number of genera in this one family is not quite complete. Further, he shows his grasp of the subject by clearly stating the distinctions of the genera in a few words.

The family Liparoceratidæ is very interesting. In its geological distribution it illustrates the principle of faunal repetition alluded to in my last paper communicated to the Society. In its morphology, showing successive waves of capricorns developing into bituberculate sphærocones, which may perhaps unduly hearten the protagonists of orthogenesis, it shows the difficulties that confront the field-geologist until a study like the Author's places facts in a clear light. In its biological development it illustrates the various phases of palingenesis which in 'Yorkshire Type Ammonites' I have called saltative, cunctative, precedentive. In the last, the hastening in development of one feature faster than another, we seem to have the clue to the origin of species—it makes for diversity of genera; while tachygenesis, or the earlier acquirement of characters, gives the differences of species. What was the cause of precedentive palingenesis touches the debatable ground between Weismannism and Neo-Lamarckism. I confess to a predilection for the latter—that the variations of the germ-plasm were not fortuitous, but, in some way, reflect modifications of the somatic cells induced by their responses to differences of environment. Data for solving this problem are required, and evolutionary studies such as those presented by the Author may be of great assistance.

Time forbids notice of many other interesting points in regard to the Liparoceratidæ, but one especially may call for remark. Again and again the genera reach the position of flourishing sphærocones, only to die out suddenly. By analogy with other Ammonite stocks there should have been a long period of catagenesis in front of them, passing to serpenticone stages again, with loss of ornament, and even with possibilities of renewed anagenesis. But nothing of this kind seems to happen—each stock appears to come to a dead end at the height of its career, or thereabouts; while the latest genus of all is the most flourishing sphærocone of the family.

In the Geological Table of his abstract the Author places *Beaniceras* as a capricorn, though, later, excluding it from the Liparoceratidæ. *Beaniceras* is a catagenetic capricorn following a unituberculate cadicone: the others are anagenetic capricorns. The family position of *Beaniceras* is doubtful. It occurs to me to ask where in the Liparoceratids is the unituberculate stage which in other Ammonite stocks precedes the bituberculate: do the massive ribs of capricorns really represent it? When he had nearly completed his investigations the Author showed me some of his interesting results, and, if I remember rightly, he had found in the ontogeny of some Liparoceratids traces of a temporary catagenetic capricorn condition. Now, it may be suggested that there is a non-sequence in the ontogeny of the capricorns (saltative palingenesis); that in the phylogeny there was a unituberculate cadicone stage which is omitted in the capricorn ontogeny, in the same way as the capricorn stage is omitted in the ontogeny of the sphærocones; and that *Beaniceras* is the genus which has preserved this unitubercular cadicone stage in its ontogeny, and shows it fading into capricorn. Is the temporary catagenetic capricorn condition a relic of this?

In conclusion, I congratulate the Author on an excellent piece of work. It is to be hoped that he will deal with other families in the same way, though in some (owing to mineral condition) suitable material is hard to come by, numerous though the specimens be.

Dr. A. M. Davies congratulated the Society and the Author on a first paper so valuable and so clearly set forth. He confined his comments to one aspect of the subject: What was the meaning of such developments as that from ribbed capricorn to tuberculate sphærocone, repeated time after time in the same stock? Was it adaptation to a changed environment? He found it difficult to believe this, and felt that we must here face a problem of evolution more fundamental than even that of Darwinism *versus* Lamarckism, both of which deal with adaptative evolution. He had been led to a conception of a varying 'margin of elasticity' between organism and environment. When this margin is narrow we have strictly adaptative evolution, as in the striking case of the

Mammalia; but, when it is wide, evolution may cease to be guided by environment, and orthogenesis may have free play. If change of environment narrows the margin, a possible result may be sudden extinction. The mode of life which appeared to afford the widest margin of elasticity was the microphagous; and he put forward as a speculation that the ammonites were not carnivores like modern cephalopods, but had reverted to the microphagous habit.

Prof. H. H. Swinnerton said that he had been in close touch with the Author while the work was being done, and could testify to the care with which the material had been collected. The Author had exercised due restraint in making new species; and, in the formation of new genera, had attempted to give them names descriptive of the ammonite, and therefore capable of being incorporated ultimately into a scientific nomenclature. He had been interested in the account of the way in which the capricorn stage was eliminated from development, and suggested that one factor in the process may have been the close similarity in general form between the globose early stage and the sphærocone late stage. He congratulated the Author upon the clearness with which he had set forth the subject-matter of his paper.

Dr. W. D. Lang suggested that the potentiality (demonstrated in this paper in the case of Liparoceratid Ammonites, and by other writers in various groups of animals), in primitive or radical forms for producing similar, definite, and progressively more complex structures in all its descendant lineages, should be distinguished from the Mendelian Factor, which, at first sight, it would appear to resemble. For example, it might be said that an evolute Liparoceratid carried the factor for involution; that, by the liberation of an inhibiting factor, the involution became actual. But, on the theory of the Mendelians, each such factor has a corresponding structural basis, so that the more (inhibited) factors are present, the more complex the structure of the nucleus that carries them. With potentiality, on the other hand, the simpler the organism is, the greater are its potentialities; and, though (as exemplified in Corals and Polyzoa, for example), the method of evolution often suggests that inhibitions are removed (perhaps by environmental changes affecting metabolism generally, and internal secretions in particular), whereby latent potentialities are liberated freely, as seen in wholesale outbursts or waves of evolution; yet, there is no reason to suppose that a potentiality is correlated with a definite structure. And, even in the case of the Mendelian Factor, such an assumption is in danger of ultimately leading to absurdity, if, as many Mendelians hold, a new character can only arise by the removal of an inhibiting factor: for the simplest organisms must then have the most complex nuclei—which, if not absurd, is at least improbable.

The Author, in reply to the President, pointed out that, while it was undesirable to use the names *Ammonites striatus* and *A. capricornus* with the wide meaning formerly given to them by stratigraphical workers, yet such terms as 'capricorn ammonite' and '*striatus*-like ammonite' could be so used. He agreed with Mr. Buckman that there is little indication of the catagenetic changes which one would expect to follow the sphærocone stages; the beginning of catagenesis is shown, however, by a tendency to return to paired tubercles in some imparinode series. A unituberculate stage occurs in some series, and it did not seem necessary to him to suppose a *Beaniceras*-like ancestor representing this stage. Replying to Dr. Davies and Prof. Swinnerton, the Author said that the 'skipping' of the capricorn stage was accompanied by the omission of the slender-whorled stage, leading to the direct development of the involute form. He did not think that changes in the nature of deposits had any relation to changes in the form of the shell. In conclusion, he wished to thank the Fellows present for the kind reception accorded to his paper.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXXIV.

[November 25th, 1919.]

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CONTENTS.

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