THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

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

VOLUME THE FIFTY-EIGHTH.

1902.

LONDON:

LONGMANS, GREEN, AND CO.

PARIS: CHARLES KLINCKSIECK, 11 RUE DE LILLE.
LEIPZIG: T. O. WEIGEL.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

MDCCCCII.

List

OF THE

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Elected February 21st, 1902.

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P. 725. Line 7 from the top, col. 5 of numerals, *for* '3 per cent.' *read* '31 per cent.'

VOL. LVIII (1902).

P. li. Line 3 from the top, *for* 'Gustav' *read* 'Gustaf.'
P. 274. Stratigraphical Table, etc., top of col. 8, *for* 'S.E. Worcester' *read* 'S.E. Warwick.' Also in the vertical scale, *for* '1 inch=16 feet' *read* '1 inch=80 feet.'
P. 405. Lines 21–22 from the top, *for* 'north of the Padinawela wood' *read* 'north of Padinawela.'
P. 422. Line 22 from the top, *for* 'Kurumegala' *read* 'Kurunegala.'
P. 437. Line 9 from the bottom, *for* 'Taw y Graig' *read* 'Tan y Graig.'
P. 450. Line 25 from the top, *for* 'have' *read* 'has.'
P. 469. Line 9 from the top, *for* 'Upper Pleistocene' *read* 'Lower Pleistocene.'

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BESIDES THOSE IN THE PLATES.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1901–1902.

November 6th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Note on a Submerged and Glaciated Rock-Valley recently exposed to view in Carmarthenshire.' By Thomas Codrington, Esq., M.Inst.C.E., F.G.S.

2. 'On the Clarke Collection of Fossil Plants from New South Wales.' By E. A. Newell Arber, Esq., B.A. (Communicated by Prof. T. McKenny Hughes, M.A., F.R.S., F.G.S.)

3. 'On an Altered Siliceous Sinter from Builth (Brecknockshire).' By Frank Rutley, Esq., F.G.S.

The following specimens, photographs, and maps were exhibited:—

Rock-Specimens and Microscope-Sections, exhibited by Frank Rutley, Esq., F.G.S., in illustration of his paper; also Lantern-Slides and Photographs by Frederick Chapman, Esq., A.L.S., F.R.M.S.

Specimens of Permo-Carboniferous and Triassic Plants from New South Wales, exhibited in illustration of the paper by E. A. Newell Arber, Esq., B.A.

Photographs of the Towy Valley at Dryslwyn (Carmarthenshire), exhibited by Thomas Codrington, Esq., M.Inst.C.E., F.G.S., in illustration of his paper.

Photographs of Tertiary Volcanoes of the North-east of Ireland, taken and exhibited by Arthur T. Metcalfe, Esq., F.G.S.

Nine Sheets of the Carta Geologica della Calabria, $\frac{1}{100,000}$, by E. Cortese & G. Di Stefano, presented by the Royal Geological Survey of Italy.

Folios 59 to 71 of the Geologic Atlas of the United States, presented by the U.S. Geological Survey.

November 20th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

George Elmsley Coke, Esq., The Ropewalk, Nottingham; William George Fearnsides, Esq., B.A., Addingford Hill, Horbury (Yorkshire); J. Malcolm Maclaren, Esq., B.Sc., 62 Sydney Street, S.W.; and Harry Edward Heath Smedley, Esq., F.L.S., 13 Havergal Villas, Green Lanes, South Tottenham, N., were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. Vaughan Cornish, in exhibiting Photographs of Waves and Ripples in Water, Cloud, Sand, and Snow, said that he need only refer to the photographs showing the action of wind upon snow, which were the most recent of the series of pictures which he was exhibiting that evening. He had spent from December to March in the winter of 1900–1901 studying the snow in the provinces of Quebec, Manitoba, and British Columbia. When the wind blew, one saw the processes of wind-erosion and of the accumulation of drifted material proceeding with a rapidity which is not attained when wind acts upon heavier or harder materials. He particularly commended to geologists the study of wind-erosion of snow hardened by pressure and low temperature. The cutting and carving, and the revelation of previously invisible stratification, went on at a surprising rate, and one could see the structures change from form to form under one's very eyes, and thus quickly gain such an insight into the processes of wind-erosion as, in the case of more stubborn rock, could only be obtained by prolonged study. The advantage, moreover, of studying the process in snow was not merely one of time, but consisted partly in the recognition of transitional stages which were so apt to be missed when observations were necessarily intermittent, as was the case with those of erosion of harder rocks.

The following communications were read:—

1. 'Notes on the Genus *Lichas*.' By Frederick Richard Cowper Reed, Esq., M.A., F.G.S.

2. 'Some Remarks on the Meteorological Conditions of the Pleistocene Epoch.' By Dr. Nils Ekholm. (Communicated by Prof. W. W. Watts, M.A., F.G.S.)

3. 'On the Origin of certain Concretions in the Lower Coal-Measures.' By Herbert Birtwhistle Stocks, Esq., F.I.C., F.C.S. (Communicated by Prof. W. W. Watts, M.A., F.G.S.)

In addition to the photographs mentioned on p. ii, the following specimens, etc., were exhibited :—

Specimens of *Lichas*, exhibited by F. R. C. Reed, Esq., M.A., F.G.S., in illustration of his paper.

Copies of Memoirs containing Charts, etc., exhibited in illustration of Dr. Nils Ekholm's paper.

Specimens and Lantern-slides of Lower Coal-Measure Concretions, exhibited in illustration of the paper by H. B. Stocks, Esq., F.I.C., F.C.S.

December 4th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

Edward Alexander Newell Arber, Esq., B.A., Trinity College, Cambridge; Stanley Clay, Esq., The Gold Coast Amalgamated Mines, Limited, 10 & 11 Austin Friars, E.C.; John Smith Flett, M.A., D.Sc., Geological Survey of England, 28 Jermyn Street, S.W.; Guy Mortimer Fry, Esq., 1 Wynn Road, Tankerton, Whitstable; Thomas Stephen Hart, Esq., M.A., School of Mines, Ballarat (Victoria); the Rev. George John Lane, The Manse, Croft Terrace, Alston (Cumberland); Thomas Henry Digges La Touche, Esq., Superintendent, Geological Survey of India, Calcutta; Harford John Lowe, Esq., The Oaklands, Abbey Road, Torquay; Frederic Philip Mennell, Esq., The Rhodesia Museum, Bulawayo (South Africa); Alexander Mitchell, M.D., 87 Regent Street, W.; Arthur Berry Nowell, Esq., Assoc.M.Inst.C.E., Wise House, Dacca, Eastern Bengal (India); Ernest Hubert Lewis Schwarz, Esq., Assistant Geologist, Geological Survey of the Cape of Good Hope, South African Museum, Cape Town; Clement H. Stott, Esq., Pietermaritzburg (Natal); the Rev. Francis St. John Thackeray, M.A., F.S.A., Mapledurham Vicarage, Reading; and Luke Williams, Esq., Mount Reid Mine, Mount Reid (Tasmania), were elected Fellows of the Society.

The List of Donations to the Library was read.

Prof. Bonney, in exhibiting a series of specimens of Smaragdite-Euphotide from the Saasthal, remarked that they illustrated its variations in mineral composition: the pyroxenic constituent being sometimes diallage, sometimes rather acicular hornblende, sometimes glaucophane, but generally smaragdite; the felspathic constituent passing from a rather changed felspar to the so-called saussurite; garnets are sometimes common, and white mica occasional; these different kinds pass one into another. The rock also varies greatly in coarseness, and often exhibits a distinctly streaky structure. He described the locality where the rock occurs *in situ*.

Dr. VAUGHAN CORNISH, in exhibiting photographs of 'Snow-Mushrooms' taken by him in January 1901, at Glacier House, near the summit of the Canadian Pacific Railway in the Selkirk Mountains, west of the Rockies (British Columbia), altitude 4000 feet, said that the snowfall had been 25 feet measured, then represented by a 5-foot layer upon the ground. It is said that there is not much wind here, and that the snow mostly falls at a temperature near the melting-point. It has the reniform habit in great perfection, and its clinging masses are very beautiful. The most remarkable thing about it is the formation of symmetrical caps, which overhang by a yard and more the supporting pedestal. The stumps of the felled trees usually have bases 2 to 4 feet in diameter, which support the whole depth of snow and are frequently of such a height as to produce, with the cap of snow, an almost perfect reproduction of a mushroom. Their nearly perfect symmetry was attained, he believed, by gradual growth until the limit of cohesion was reached in all directions. The tree-stumps being almost exactly circular, the complete cap is also circular. These caps are very stable, the great weight of superincumbent snow welding the lower layers into a tenacious mass. Their study has, at least, a suggestive value for geologists.

Prof. LAPWORTH referred to the good work that Dr. Vaughan Cornish was doing in observational science by his photographs of the various surface-shapes assumed by water, sand, snow, etc., under the undulatory movements of the wind. He spoke of the resemblances of many of these shapes to well-known geological fold-forms, and gave it as his opinion that the symmetrical mushroom-like snow-shapes shown upon these beautiful photographs were the effects of symmetrical wind-eddies, and might be compared with the so-called 'mushroom-folds' and mountains without roots of the pre-Alpine regions, shapes also probably due to more or less symmetrical tri-dimensional movements.

The following communications were read:—

1. 'On a new Genus belonging to the Leperditiadæ, from the Cambrian Shales of Malvern.' By Prof. Theodore Groom, M.A., D.Sc., F.G.S.

2. 'The Sequence of the Cambrian and Associated Beds of the Malvern Hills.' By Prof. Theodore Groom, M.A., D.Sc., F.G.S. With an Appendix on the Brachiopoda by Charles Alfred Matley, Esq., B.Sc., F.G.S.

The following specimens were exhibited, in addition to those mentioned on pp. iii–iv:—

Specimens and Lantern-slides of Malvern Fossils, exhibited by Prof. Theodore Groom, M.A., D.Sc., F.G.S., and C. A. Matley, Esq., B.Sc., F.G.S., in illustration of the former's paper and the latter's appendix.

December 18th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

John T. Bebbington, Esq., 28 Coningsby Road, Anfield, Liverpool; Henry T. Leighton, Esq., 37 Arch Street, Rugeley (Staffordshire); Alexander Gordon Milne Thomson, Esq., Maybank, Maryfield, Dundee; and Thomas Leonard Walker, M.A., Ph.D., Professor of Mineralogy & Petrology in the University of Toronto (Canada), were elected Fellows; and Dr. Alexander Petrovich Karpinsky, of St. Petersburg, and Prof. Alfred Lacroix, of Paris, were elected Foreign Members of the Society.

The List of Donations to the Library was read.

Prof. H. G. Seeley drew attention to a Skull of *Equus fossilis* from Keswick, exhibited by Mr. J. Postlethwaite, F.G.S., and said that it belonged to a species of horse, but the skull appeared to be broader and flatter in front of the orbits than in *Equus caballus*; and it gave evidence on the upper surface of being an aged specimen, an inference which was supported by the palatal conditions. The teeth are worn down, so as to approximate to the condition of aged teeth of *Equus fossilis*, as sometimes found in river-valley gravels; but he was not aware that these teeth had previously been met with in association with this form of skull. He understood that the specimen had been found near the surface beneath an ancient building at Keswick, and that there was no evidence as to its geological antiquity.

Mr. Postlethwaite said that the skull which the previous speaker had described was found beneath the floor of one of the rooms of a farmhouse known as 'Birketfield,' the property of Mr. J. M. Moorsom, about 6 miles east of Keswick. The house, which is of considerable age, was being altered and repaired, and it was in taking up one of the floors, for the purpose of relaying, that the skull was found. The surface-deposit on the farm is Glacial Drift.

Prof. W. W. Watts called attention to the exhibited set of Twenty-two Photographs, the first of three sets to be published as typical examples of Geological Photographs by the British Association Committee on Geological Photographs.

The following communications were read:—

1. 'Coal- and Petroleum-Deposits in European Turkey.' By Lieut.-Colonel Thomas English, F.G.S.

2. 'On the Geological and Physical Development of Dominica: with Notes on Martinique, St. Lucia, St. Vincent, and the Grenadines.' By Prof. Joseph William Winthrop Spencer, Ph.D., M.A., F.G.S.

3. 'On the Geological and Physical Development of Barbados, with Notes on Trinidad.' By Prof. Joseph William Winthrop Spencer, Ph.D., M.A., F.G.S.

In addition to the exhibits mentioned on p. v, the following specimens, etc., were exhibited:—

Specimens of Coal- and of Petroleum-Deposits, and Lantern-Slides of Views of the Country north of the Gulf of Xeros, in European Turkey, exhibited by Lieut.-Colonel Thomas English, F.G.S., in illustration of his paper.

January 8th, 1902.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

James Foulds, Esq., A.R.C.S., F.C.S., Myrtle Grove, Dymond Road, Heckmondwike (Yorkshire); and William Maclay, Esq., Thornwood, Langside, Glasgow, were elected Fellows of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: Horace W. Monckton, Esq., F.L.S., and Bedford McNeill, Esq.

The List of Donations to the Library was read.

The following communications were read:—

1. 'A System of Glacier-Lakes in the Cleveland Hills.' By Percy Fry Kendall, Esq., F.G.S., Lecturer in Geology at the Yorkshire College, Leeds.

2. 'The Glaciation of Teesdale, Weardale, and the Tyne Valley, and their Tributary Valleys.' By Arthur Richard Dwerryhouse, Esq., B.Sc., F.G.S.

Lantern-Slides and Diagrams were exhibited by Mr. P. F. Kendall and Mr. A. R. Dwerryhouse in illustration of their respective papers.

January 22nd, 1902.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

Alfred William Gibb, Esq., M.A., B.Sc., 1 Belvidere Street, Aberdeen; and Theodore Heinrich Watermeyer, Esq., 90 Louisville Road, Balham, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Fossiliferous Silurian Beds and Associated Igneous Rocks of the Clogher Head District (County Kerry).' By Charles Irving Gardiner, Esq., M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S.

2. 'A Process for the Mineral Analysis of Rocks.' By William Johnson Sollas, D.Sc., LL.D., F.R.S., F.G.S., Professor of Geology in the University of Oxford.

The following specimens and maps were exhibited:—

Rock-specimens, Microscope-Sections, and Lantern-Slides, exhibited by C. I. Gardiner, Esq., M.A., F.G.S., and Prof. S. H. Reynolds, M.A., F.G.S., in illustration of their paper.

Lantern-Slides and Apparatus, etc., exhibited by Prof. W. J. Sollas, D.Sc., LL.D., F.R.S., F.G.S., in illustration of his paper.

Geological Map of Iceland by T. Thoroddsen, $\frac{1}{600,000}$ (published by the Karlsberg Fund).

Livraison IV, containing 7 sheets, of the Carte Géologique Internationale de l'Europe $\frac{1}{1,500,000}$.

February 5th, 1902.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

Frederic John Dixon, Esq., Assoc.M.Inst.C.E., Ganstead Rise, Harrogate; George Enoch Lawton, Esq., Aidenswood House, Lawton (Cheshire); Francis Hylton Molesworth, Esq., Turramurra, Sydney (New South Wales); and Herbert Kelsall Slater, Esq., Bangalore, Mysore Province (India), were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. H. Bauerman, in exhibiting a remarkable Crystal of Cinnabar from the mercury-mines in the province of Kwei-chau (China), observed that it was a completely developed penetration-twin of two rhombohedra, attached to a mass of crystalline quartz. He drew attention to the simple character of the form from this locality, as compared with those of the crystals from Almaden and Avala.

The following communications were read:—

1. 'The Matrix of the Suffolk Chalky Boulder-Clay.' By the Rev. Edwin Hill, M.A., F.G.S.

2. 'On the Relation of certain Breccias to the Physical Geography of their Age.' By Prof. Thomas George Bonney, D.Sc., LL.D., F.R.S., F.G.S.

The following specimens, etc. in addition to that mentioned above, were exhibited:—

Specimens of the Matrix of the Suffolk Chalky Boulder-Clay, exhibited by the Rev. Edwin Hill, M.A., F.G.S., in illustration of his paper.

Diagrams and Lantern-Slides of Breccias from the Flysch of Sepey and from the Rothliegende near Eisenach, exhibited by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., in illustration of his paper.

ANNUAL GENERAL MEETING,

February 21st, 1902.

J. J. Harris Teall, Esq., M.A., F.R.S., President, in the Chair.

Report of the Council for 1901.

The Society shared the general sorrow at the death of Her late Majesty, Queen Victoria. The President gave expression to the grief felt by the Fellows by adjourning the Meeting of January 23rd, 1901, immediately after the formal business had been taken; and at a later period the President and Council, on behalf of themselves and the Fellows, presented an Address to the King, expressing their sorrow for the death of the late Queen and welcoming His Majesty's accession to the throne. The text of this Address will be found at p. lxxxvii of the Proceedings of the last Session. To this Address a gracious reply was received.

The financial prosperity of the Society is again a matter for congratulation. The number of Fellows has undergone scarcely any change: 52 Fellows were elected (the same number as in 1899, but 7 less than in 1900), of whom 34 paid their Admission Fees before the end of the year. 17 Fellows who had been elected in the previous year paid their Admission Fees in 1901, the total accession of new Fellows during the past twelve months amounting therefore to 51.

On the other hand, there was a total loss of 55 Fellows—36 by death, 13 by resignation, and 6 by removal from the List because of non-payment of their Annual Contributions.

From the foregoing statistics it will be seen that the actual decrease in the number of Fellows is 4 (as compared with a decrease of 10 in 1900).

Of the 36 Fellows deceased, 5 had compounded for their Annual Contributions, 25 were Contributing Fellows, and 6 were Non-Contributing Fellows. On the other hand, 7 Fellows during 1901 became Compounders.

The total accession of Contributing Fellows is thus seen to be 44 (51 − 7), and the total loss being also 44 (25 + 13 + 6), the number of Contributing Fellows during 1901 remained stationary, as compared with an increase of 1 in 1900 and of 12 in 1899.

Turning now to the Lists of Foreign Members and Foreign Correspondents, it may be recalled that, at the close of 1900, there was one vacancy in the List of Foreign Correspondents. This was filled up early in the year, during the course of which the Society suffered the loss, by death, of 2 of its Foreign Members. The vacancies thus arising were filled up, but the 2 resulting vacancies in the List of Foreign Correspondents still remain unfilled.

The total number of Fellows, Foreign Members, and Foreign Correspondents, which stood at 1334 on December 31st, 1900, had decreased to 1329 at the end of the year under review.

Proceeding now to consider the Income and Expenditure of the Society during the first year of the twentieth century, the figures set forth in detail in the Balance-sheet may be summarized as follows:—

The total Receipts, including the Balance of £388 14*s.* 10*d.* brought forward from the previous year, amounted to £3503 17*s.* 8*d.*, being £285 14*s.* 10*d.* more than the estimated Income.

The total Expenditure during 1901 amounted to £3100 5*s.* 5*d.*, being £196 7*s.* 7*d.* less than the estimated Expenditure for that year. These figures include a very large item of non-recurring Expenditure, namely, the cost of Redecoration of the Society's Apartments. It was estimated that this would involve an Expenditure of £500, and, as will be seen from the Balance-sheet, the actual cost was £508 11*s.* 11*d.*, which is perhaps as close an approximation to the Estimate laid before the Fellows at the last Annual General Meeting as could fairly be expected.

The Council have to announce the completion of Vol. LVII and the commencement of Vol. LVIII of the Quarterly Journal.

Mr. C. Davies Sherborn, F.G.S., who, during the past year, prepared and edited the Catalogue-slips which the Society supplies to the Regional Bureau of the International Catalogue of Scientific Literature, has undertaken to continue this work on the Society's behalf during 1902. These slips, as before explained, deal solely with geological papers published in the British Islands, and therefore do not cover the same ground as the Society's own Record of Geological Literature.

The attention of the Council having been drawn to the necessity of a new catalogue of the Society's Library, a Committee was recently appointed to enquire into this matter, and, after full consideration, its report was adopted by the Council in the following terms:—

(1) All books in the Library relating to geology are to be catalogued.
(2) All papers of a geological nature are to be catalogued, whether separate or in serials.
(3) In the catalogue each separate publication or paper in a serial is to be included under three heads:—(*a*) Author, (*b*) Subject, and (*c*) Locality.
(4) A sum of £80 shall be placed on the estimates for 1902 for the commencement of the work.

This new Catalogue is to be, in the first instance, a manuscript card-catalogue, the question of printing and publishing it being reserved for further consideration. The Council are glad to announce that they have secured the valuable services of Mr. C. Davies

Sherborn, who has undertaken to carry out the work on the lines laid down. This work will necessarily take a considerable time to complete.

A full account of the Proceedings at the Special General Meeting held on March 27th, 1901, to consider the state of the Society's Museum, has been published at pages xcii–xciii of the last volume of the Quarterly Journal. After that meeting the Rev. J. F. Blake made an offer to undertake, without any remuneration, the task of editing and preparing for publication a catalogue of the type- and other important specimens in the Society's Museum, based on Mr. C. Davies Sherborn's manuscript catalogue. This offer was accepted by the Council, and on this arduous work the Rev. J. F. Blake has been now engaged for many months past. It is estimated that the cost of printing and publishing this Catalogue will amount to £100, an item which is accordingly included in the Estimates for the current year. The Council recommend that no further action be taken with regard to the Museum, till this Catalogue has been placed in the hands of the Fellows.

On April 22nd, the Rev. J. F. Blake addressed a communication to the Council referring to the 'Suggestions for Certain Improvements, 1901,' which he had caused to be printed and issued to the Fellows generally. The matters dealt with in the pamphlet have been for some time under the consideration of the Council, and certain of them have been reserved for future deliberation.

One of the chief points dealt with was the present method of election of the Council and the Officers. The Council desire to point out that, at the time of the revision of the Bye-Laws in 1889, the draft of the Bye-Laws as revised was submitted to Counsel and approved by him; but, without laying great stress on this point, they think that before making any radical change in the method of balloting, the following modifications of the usual practice should be tried:—

(*a*) Fellows should be invited to send in to the Secretaries before January 1st in each year the names of any person or persons whom they may desire to see placed on the Council, and the Council should carefully consider all such names in making their recommendations to the Fellows at the Annual General Meeting.

(*b*) That the names of those recommended for retirement by the Council be printed in italics at the foot of the first column in the existing form.

(*c*) That the names of those recommended for election by the Council be printed in italics at the foot of the second column in the existing form.

The proposals *b* and *c* will be found embodied in the Balloting-Lists sent out for the present Annual General Meeting.

With regard to some of the other matters raised in the Rev. J. F. Blake's pamphlet,

(*d*) The Council do not recommend that questions should be allowed to be put to the Secretaries at Ordinary General Meetings. It is always open to any Fellow to address the Secretaries in writing on any point concerning the Society, and due attention is always given to such communications.

(*e*) They consider that the Report of the Council should only be taken as read when a motion to that effect is carried *nemine contradicente.*

(*f*) They consider that it is within the province of any Fellow to ask at the Annual General Meeting for a separate vote on any item of the Estimates, subject to the approval of the Chairman.

(*g*) They do not consider it desirable that the scope of the Annual General Meeting should be enlarged so as to encroach upon the functions of Special General Meetings. They desire to call attention to the fact that free comment on the affairs of the Society is provided for under Bye-Laws, Section X, Article 20, and to recommend that the usual practice should be followed in this respect.

The late Mr. Daniel Pidgeon, F.G.S., by his will dated March 17th, 1898, gave expression to the following wishes, leaving their fulfilment to the discretion of Mrs. Pidgeon:—

'First that she will give or bequeath One Thousand Pounds to the Council of the Geological Society of London in trust for the creation of an Annual Grant derivable from the interest on said One Thousand Pounds to be used at the discretion of said Council in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than 28 years of age.'

The testator died on March 13th, 1900, and Mrs. Pidgeon, having decided on giving immediate effect to her husband's wishes, executed a Deed on January 6th of the present year, establishing a Trust to be known as the Daniel Pidgeon Fund, and the sum of One Thousand Pounds was placed by her solicitors at the Society's disposal for the purpose of carrying out the provisions of the Trust. The Council have drawn up a provisional scheme for the administration of the aforesaid Trust, the particulars of which will be announced in due course.

Attention having been drawn to the imperfection of the present method of reporting the Discussions on papers read before the Society, the Council have had the subject under their consideration, and it is hoped that by giving to the Secretaries fuller discretion a better result may be obtained. For the future, the Secretaries are empowered to report the remarks of a Fellow who does not send in a written abstract, although such report is to be submitted to him for approval before publication.

The following Awards of Medals and Funds have been made by the Council:—

The Wollaston Medal is awarded to Dr. Friedrich Schmidt, in recognition of the value of his researches concerning the mineral structure of the earth, and more particularly for his contributions to our knowledge of the Cambrian and Silurian Rocks and Fossils of Esthonia and Livonia and his geological exploration of Siberia.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Mr. Frederic William Harmer, in recognition of his numerous and valuable papers on the Glacial and Pliocene Deposits of East Anglia.

This year it has been decided to award two Lyell Medals. One of these Medals, together with a sum of Twenty-five Pounds from the Lyell Geological Fund, is awarded to Prof. Anton Fritsch, in recognition of his contributions to the Palæontology of the Palæozoic Rocks of Bohemia.

The other Lyell Medal, together with a sum of Twenty-five Pounds from the Lyell Geological Fund, is awarded to Mr. Richard Lydekker, in recognition of his valuable additions to our knowledge of the Palæontology of the Vertebrata, especially in India and South America.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. Leonard James Spencer, in recognition of his services to Mineralogy, and to encourage him in further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. Thomas H. Holland, as an acknowledgement of his contributions to the study of the Rocks of British India, and to assist him in further work.

The Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. Wheelton Hind, in recognition of the value of his researches among the Carboniferous Rocks of Great Britain, and to stimulate him to further work.

A sum of Twenty-one Pounds from the Proceeds of the Barlow-Jameson Fund is awarded to Mr. William Maynard Hutchings, in recognition of his valuable contributions to Petrology, and to encourage him in further work.

Report of the Library and Museum Committee for 1901.

The Additions made to the Library show no falling off, either in number or interest, from the usual standard.

During 1901 the Library received by donation 186 Volumes of separately published Works, 291 Pamphlets and detached Parts of Works, 186 Volumes and 60 detached Parts of Serial Publications, and 18 Volumes of Newspapers.

The total number of accessions to the Library by Donation is thus seen to amount to 390 Volumes, 291 Pamphlets, and 60 detached Parts.

The number of Maps, which have been presented by various Donors, is also considerable. Without reckoning the 12 latest published folios of the Geologic Atlas of the United States, 200 Sheets of Maps were received, 58 of which were Ordnance Survey Maps.

Although the task of selection from among the numerous Donations mentioned in the foregoing paragraphs is necessarily difficult, your Committee may perhaps be allowed to direct special attention to the following:—The late Lady Prestwich's Essays, Descriptive & Biographical (with a Memoir by her sister, Louisa E. Milne); the late Prof. Lindström's 'Researches on the Visual Organs of the Trilobites'; Mr. A. C. Seward's Catalogue of the Mesozoic Plants in the Natural History Museum; the Geological Survey Memoir on Central & Western Fife & Kinross-shire; the late Sir J. William Dawson's 'Fifty Years of Work in Canada'; Prof. A. Issel's work on 'Bradyseismic Oscillations of the Earth's Crust,' and 35 other memoirs by the same author; Dr. F. L. Kitchin's monograph of the Jurassic Brachiopoda of Cutch; Mr. F. R. C. Reed's 'Geological History of the Rivers of East Yorkshire'; Prof. A. G. Nathorst's 'Two Summers amid the Arctic Ice'; the Egyptian Geological Survey memoirs on the Dakhla Oasis and the Kharga Oasis; Part IV of Dr. A. Smith Woodward's Catalogue of the Fossil Fishes in the Natural History Museum; and Dr. J. C. Thresh's Report on the Water-Supply of the County of Essex. Moreover, numerous publications were received from the Geological Survey Departments of Canada, the various States of the Australian Commonwealth, India, Mysore, Denmark, Sweden, Norway, Finland, Russia, Saxony, Hungary, Servia, Portugal, and Japan. The wonted liberality of the United States Geological Survey was supplemented by that of the Survey Departments of the various States, such as Alabama, Arkansas, Indiana, Iowa, and Maryland. The Institution of Mining & Metallurgy presented a complete set of their Transactions, beautifully bound; and Dr. Henry Woodward & Mr. Horace B. Woodward presented two copies (one framed) of their Table of the British Strata.

Among the Maps, special interest attaches to Mr. J. E. Dunn's gift of the first edition (1873) of his Geological Sketch-map of Cape Colony. From the Geological Survey of Italy 11 Sheets of Maps were received; from that of Japan, 14 Sheets; from that of Rumania, 5 Sheets; from that of Hesse, 4 Sheets; and from that of the United States (exclusive of the Geologic Atlas), 97 Sheets.

The Books and Maps enumerated above were the gift of 174 Personal Donors; 111 Government Departments and other Public Bodies; and 180 Societies and Editors of Periodicals.

The Purchases made on the recommendation of the standing Library Committee included 58 Volumes and 12 Parts of separately published Works; 26 Volumes and 8 Parts of works published serially; and 8 Sheets of Maps.

The total Expenditure incurred in connexion with the Library during 1901 was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased..........	56	10	11
Binding of Books and Mounting of Maps....	129	11	2
	£186	2	1

The Society's Collection of Portraits of eminent Geologists has been enriched by the following Donations:—A Framed Engraving of Wollaston, presented by Dr. Henry Woodward; and a Framed Photographic Portrait of Sir Archibald Geikie, presented by himself.

Museum.

No addition has been made to the Collections during the past year, but great progress was made with the work of glazing the drawers, no less than 814 being thus rendered fairly impervious to dust, at a total cost of £26 12*s.* 1*d.*

For the purpose of study and comparison the Collections were examined on 10 different occasions during the year, the contents of about 50 drawers being thus examined.

The Rev. J. F. Blake was engaged on 46 days in the summer and autumn in going through the Collections for the purposes of the Catalogue which he has voluntarily undertaken to prepare. He was assisted on several occasions in the course of this investigation by Mr. W. P. D. Stebbing. The proposed Catalogue and other matters connected with the Museum are referred to more fully in the Council's Annual Report.

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review:—

I. Government Departments and other Public Bodies.

Alabama Geological Survey. University (Ala.).
American Museum of Natural History. New York.
Argentine Government.
Arkansas Geological Survey. Little Rock (Ark.).
Australian Museum. Sydney (N.S.W.).
Austria.—Kaiserlich-königliche Geologische Reichsanstalt. Vienna.
——. Kaiserlich-königliches Naturhistorisches Hofmuseum. Vienna.
Bavaria.—Königlich Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & des Beaux-Arts de Belgique. Brussels.
——. Musée Royal d'Histoire Naturelle. Brussels.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
Birmingham, University of.
Bohemia.—Royal Museum of Natural History. Prague.
British Guiana.—Department of Mines. Georgetown.
British South Africa Company. London.
Buenos Aires.—Museo Nacional.
California.—State Mining Bureau. San Francisco.
California University. Berkeley.
Cambridge (Mass.).—Museum of Comparative Zoology, Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
Chicago.—'Field' Columbian Museum.
Christiania.—The University.
Denmark.—Danmarks Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Geological Survey. Cairo.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Dépôt de la Marine. Paris.
——. Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.

Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. India Office. London.
——. Ordnance Survey. Southampton.
Holland.—Departement van Kolonien. The Hague.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
India.—Geological Survey. Calcutta.
——. Indian Museum. Calcutta.
Indiana.—Department of Geology. Indianapolis (Ind.).
Iowa Geological Survey. Des Moines (Iowa).
Italy.—Reale Comitato Geologico. Rome.
Japan, Earthquake Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Jassy, University of.
Kingston (Canada).—Queen's College.
La Plata, University of.
La Plata Museum. La Plata.
London.—City of London College.
——. Royal College of Surgeons.
——. University College.
Maryland Geological Survey. Baltimore (Md.).
Mexico.—Instituto Geologico. Mexico City.
Michigan College of Mines. Houghton (Mich.).
Michigan Geological Survey. Lansing (Mich.).
Minnesota.—Geological & Natural History Survey. Minneapolis (Minn.).
Missouri.—Geological Survey. Jefferson City (Mo.).
Munich.—Königliche Bayerische Akademie der Wissenschaften.
Mysore Geological Department. Bangalore.
New Jersey Geological Survey. Trenton (N.J.).
New South Wales.—Agent-General for, London.
——. Department of Lands. Sydney.
——. Department of Mines & Agriculture. Sydney.
——. Geological Survey. Sydney.
New York Museum. Albany (N.Y.).
New Zealand.—Department of Mines. Wellington.
Norway.—Meteorological Department. Christiania.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Pisa.—Royal University.
Portugal.—Commissão dos Trabalhos geologicos. Lisbon.
Prussia.—Ministerium für Handel & Gewerbe. Berlin.
——. Königliche Preussische Geologische Landesanstalt. Berlin.
Queensland.—Agent-General for, London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Redruth School of Mines.
Rome.—Reale Accademia dei Lincei.
Rumania.—Museum of Geology & Palæontology. Bucharest.
Russia.—Comité Géologique. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
Saxony, Geological Survey of. Leipzig.
South Australia.—Agent-General for, London.
——. Government Geologist. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
St. Petersburg.—Académie Impériale des Sciences.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Tiflis.—Kaukasisches Museum.
Tokio.—Imperial University.
——. College of Science.
Toronto, University of.
Tufts College (Mass.).

Turin.—Reale Accademia delle Scienze.
——. Regio Museo Industriale Italiano.
United States Geological Survey. Washington (D.C.).
——. Department of Agriculture. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala University.
—— ——. Mineralogical & Geological Institute.
Victoria (Austr.).—Agent-General for, London.
—— (——). Department of Mines, Melbourne.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington (D.C.).—Smithsonian Institution.
Western Australia.—Agent-General for, London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.
Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).

II. Societies and Editors.

Adelaide.—Royal Society of South Australia.
Alnwick.—Berwickshire Naturalists' Club.
Auckland (N.Z.).—New Zealand Institute of Mining Engineers.
Bahia.—Instituto Geographico & Historico.
Barnsley.—Midland Institute of Mining, Civil, & Mechanical Engineers.
Basel.—Naturforschende Gesellschaft.
Bath.—Natural History & Antiquarian Field Club.
Belfast.—Natural History & Philosophical Society.
Belgrade.—'Annales géologiques de la Péninsule balkanique.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. 'Zeitschrift für Praktische Geologie.'
Bern.—Schweizerische Naturforschende Gesellschaft.
Bishop Auckland.—Wearside Naturalists' Field Club.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston Society of Natural History.
Boston (Mass.).—American Academy of Arts & Sciences.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie, de Paléontologie & d'Hydrologie.
——. Société Malacologique de Belgique.
Budapest.—Földtani Közlöny (Geological Magazine).
Buenos Aires.—Instituto Geografico Argentino.
——. Sociedad Científica Argentina.
Calcutta.—'Indian Engineering.'
——. Asiatic Society of Bengal.
Cambridge.—Philosophical Society.
Cape Town.—South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chicago.—Academy of Sciences.
——. 'Journal of Geology.'
Christiania.—'Nyt Magazin for Naturvidenskaberne.'
Cincinnati Society of Natural History.
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—'Colorado College Studies.'
Copenhagen.—Dansk Geologisk Forening.
Córdoba (Argentine Republic).—Academia Nacional de Ciencias.
Cracow.—Académie des Sciences (Akademia Umiejetnosci).
Croydon Microscopical & Natural History Club.
Darmstadt.—Verein für Erdkunde.
Davenport (Iowa).—Academy of Natural Sciences.
Denver (Colo.).—Colorado Scientific Society.
Dijon.—Académie des Sciences.
Dorpat.—Naturforschende Gesellschaft.
Douglas.—Isle of Man Natural History & Antiquarian Society.
Dresden.—Naturwissenschaftliche Gesellschaft.
Dublin.—Royal Dublin Society.
Edinburgh.—Geological Society.

Edinburgh.—Royal Physical Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
——. Scottish Natural History Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Geneva.—Société Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Glasgow.—Geological Society.
Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.
Halifax (N.S.).—Nova Scotian Institute of Science.
Hamilton (Canada).—Hamilton Association.
Hampstead Scientific Society.
Hereford.—Woolhope Naturalists' Field Club.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaften.
Hertford.—Hertfordshire Natural History Society.
Hull Scientific & Naturalists' Club.
Indianapolis.—Indiana Academy of Science.
Kiev.—Société des Naturalistes.
Lausanne.—Société Vaudoise des Sciences Naturelles.
Lawrence.—'Kansas University Quarterly.'
Leeds.—Yorkshire Geological & Polytechnic Society.
Leicester Literary & Philosophical Society.
Leipzig.—'Zeitschrift für Krystallographie & Mineralogie.'
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences.
Lille.—Société Géologique du Nord.
Lima.—'Revista de Ciencias.'
Lisbon.—Sociedade de Geographia.
Liverpool Geological Society.
London.—'Academy.'
——. 'Athenæum.'
——. British Association for the Advancement of Science.
——. British Association of Waterworks Engineers.
——. 'Chemical News.'
——. Chemical Society.
——. 'Colliery Guardian.'
——. East India Association.
——. 'Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining & Metallurgy.
——. Iron & Steel Institute.
——. 'Iron & Steel Trades' Journal.'
——. 'Knowledge.'
——. Linnean Society.
——. 'London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'Nature.'
——. Palæontographical Society.
——. 'Quarry.'
——. Ray Society.
——. Royal Agricultural Society.
——. Royal Astronomical Society.
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society of Great Britain.
——. Royal Society.
——. Society of Arts.
——. Society of Biblical Archæology.
——. Society of Public Analysts.
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.

Madison.—Wisconsin Academy of Sciences.
Manchester Geological Society.
——. Literary & Philosophical Society.
Mexico.—Sociedad Científica 'Antonio Alzate.'
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Montreal.—Natural History Society.
Moscow.—Société Impériale des Naturalistes.
Nancy.—Académie de Stanislas.
New Haven (Conn.).—'American Journal of Science.'
——. Connecticut Academy of Sciences.
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. Brooklyn Institute of Arts & Sciences.
Newcastle-upon-Tyne.—Institution of Mining Engineers.
——. North of England Institute of Mining & Mechanical Engineers.
Northampton.—Northamptonshire Natural History Society.
Nürnberg.—Naturhistorische Gesellschaft.
Ottawa.—Royal Society of Canada.
Padua.—Reale Accademia di Scienze, Lettere & Arti.
Paris.—'Revue Scientifique.'
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
——. Wagner Free Institute of Science.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Portland (Me.).—Society of Natural History.
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Salem (Mass.).—Essex Institute.
Santiago de Chile.—Deutscher Wissenschaftlicher Verein.
——. Sociedad Nacional de Mineria.
——. Société Scientifique du Chili.
Scranton (Pa.).—'Mines & Minerals.'
Spezia.—Società Gerolamo Guidoni.
St. John (N.B.).—Natural History Society of New Brunswick.
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stuttgart.—'Centralblatt für Mineralogie, Geologie & Paläontologie.'
——. 'Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.'
——. Verein für Vaterländische Naturkunde in Württemberg.
——. 'Zeitschrift für Naturwissenschaften.'
Sydney (N.S.W.).—Australasian Association for the Advancement of Science.
——. Australasian Institute of Mining Engineers.
——. Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Topeka (Kan.).—Kansas Academy of Sciences.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Vienna.—'Berg- & Hüttenmännisches Jahrbuch.'
——. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Biological Society.
——. Philosophical Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Abel, O.
Ahlenius, K.
Allen, H. A.
Allen, R.
Ameghino, F.
Ami, H. M.
Andrews, C. W.

Ball, J.
Baltzer, A.
Bauerman, H.
Beadnell, H. J. L.
Becker, G. F.
Belinfante, L. L.
Bennett, F. J.
Bielavski, J. B. M.
Birge, E. A.
Blatchly, W. S.
Blanford, W. T.
Bœhm, A.
Bonney, T. G.
Branner, J. C.
Brown, H. Y. L.
Brown, J.
Bullen, Rev. R. A.
Burckhardt, C.

Choffat, P.
Clark, W. B.
Claypole, E. W. (the late).
Clinch, G.
Coghlan, T. A.
Cole, G. W.
Collins, J. H.
Coomára-Swámy, A. K.
Cornish, V.
Crane, Miss A.
Credner, H.
Crick, G. C.

Dawson, G. M. (the late).
Dawson, R.
Dieseldorff, A.
Dollfus, G. F.
Doyle, P.
Dunn, E. J.

Ekholm, N.
Elsden, J. V.
Emmons, S. F.

Fisher, Rev. O.
Forster, A. E.
Foster, C. Le N.
Francis, W.
Frick, J.

Galton, F.
Geer, G. de.
Girardot, A.
Gosselet, J.
Gray, C. J.
Greenwell, A.
Gresley, W. S.
Groom, T. T.

Habershon, M. H.
Hamberg, A.
Hanks, H. G.
Harlé, E.
Harmer, F. W.
Harris, G.
Hauthal, R.
Hawell, J.
Hayden, H.
Hayden, H. E.
Herbertson, A. J.
Hill, E.
Hobson, B.
Hœgbom, A. G.
Holland, T. H.
Hollender, A.
Holmes, T. V.
Howard, F. T.
Hume, W. F.

Issel, A.

Jackson, B. D.
Jenny, F.
Jones, T. R.

Kalecsinski, A. von.
Kerforne, F.
Keyes, C. R.
Kuemmel, H. B.

Lambe, L. M.
Lapparent, A. de.
Lebedev, N. I.
Lebesconte, P.
Lebour, G. A.
Liebisch, T.
Lindgren, W.
Lindström, G. (the late).
Lobley, J. L.
Loriol, P. de.
Louis, H.
Lyman, B. S.

Maclaren, J. M.
Maclehose, J.
Malfatte, P.
Mansel-Pleydell, J. C.
Martin, E. A.
Matosch, A.
Meli, R.
Merrill, G. P.
Milne, Miss L. E.
Mojsisovics, E. von.
Monckton, H. W.
Moreno, F. P.
Morton, Miss.
Mullner, J.
Muret, E.
Murray, Sir John.

Nægele, E.
Nares, Sir George S.
Nathorst, A. G.
Newton, E. T.
Nordenskiöld, O.

Omboni, G.

Parkinson, J.
Pavlow, A. P.
Penck, A.
Perkins, H. I.
Péroche, J.
Pittman, E. F.
Platt, S. S.
Pratt, J. H.

Rabot, C.
Ramond, G.
Raulin, V.
Reade, T. M.
Reed, F. R. C.
Renevier, E.
Richter, E.
Richthofen, Baron F. von.
Rigaux, E.
Rowe, A. W.

Sacco, F.
Sarasin, C.
Sawyer, A. R.
Schardt, H.
Schwarz, E. H. L.
Seeley, H. G.
Sheppard, T.
Sherborn, C. D.
Small, E. W.
Smeeth, W. F.
Smyth, B. B.
Somervail, A.
Spurr, J. E.
Stache, G.
Stebbing, W. P. D.
Stirling, J.
Stobbs, J. T.

Thomann, P.
Thresh, J. C.
Thureau, G.
Tietze, E.
Tœrnquist, S. L.
Tornquist, A.
Trechmann, C. O.

Van Hise, C. R.
Vesterberg, A.
Vinassa de Regny, P.

Walker, B. E.
Watts, W. W.
Wellburn, E. D.
Westlake, E.
Whitaker, W.
Winchell, N. H.
Woodward, H.
Woodward, H. B.

Zeiller, R.

Comparative Statement of the Number of the Society at the Close of the Years 1900 and 1901.

	Dec. 31st, 1900.		Dec. 31st, 1901.
Compounders	283	......	285
Contributing Fellows	924	......	924
Non-contributing Fellows	48	......	42
	1255		1251
Foreign Members	40	......	40
Foreign Correspondents	39	......	38
	1334		1329

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1900 and 1901.

Number of Compounders, Contributing and Non-contributing Fellows, December 31st, 1900			1255
Add Fellows elected during the former year and paid in 1900			17
Add Fellows elected and paid in 1900			34
			1306
Deduct Compounders deceased		5	
Contributing Fellows deceased		25	
Non-contributing Fellows deceased		6	
Contributing Fellows resigned		13	
Contributing Fellows removed		6	
		—	55
			1251
Number of Foreign Members and Foreign Correspondents, December 31st, 1900		79	
Deduct Foreign Members deceased	2		
Foreign Correspondents elected Foreign Members	2		
	—	4	
		75	
Add Foreign Members elected	2		
Foreign Correspondent elected	1		
	—	3	
		—	78
			1329

Deceased Fellows.

Compounders (5).

Blake, J. H., Esq.
Edwards, T., Esq.
Johnson, D., Esq.
Reader, G. F., Esq.
Tate, Prof. R.

Resident and other Contributing Fellows (25).

Black, C., Esq.
Bott, A., Esq.
Boyle, A. R., Esq.
Browne, A. R., Esq.
Claypole, Dr. E. W.
Crane, E., Esq.
Dawson, Dr. G. M.
Dixon, J., Esq.
Eunson, H. J., Esq.
Evans, J. J., Esq.
Forster, G. B., Esq.
Halder, A. H., Esq.
Henry, L. C., Esq.
Hodgson, Rev. J.
Jeffcock, T. W., Esq.
Kirby, C., Esq.
Lewis, H., Esq.
Manson, R. T., Esq.
Nelson, Rev. G. H.
Rothwell, R. P., Esq.
Saunders, Sir E.
Schvarcz, Prof. J.
Shipman, J., Esq.
Wardell, F. N., Esq.
Williams, A., Esq.

Non-contributing Fellows (6).

Beardsley, A., Esq.
Mathews, W., Esq.
Paull, J. M., Esq.
Powrie, J., Esq.
Ridsdale, E. L. J., Esq.
Saxton, Maj.-Gen. G. H.

Deceased Foreign Members (2).

Lindström, Prof. G.
Nordenskiöld, Baron A. E.

Fellows Resigned (13).

Bates, Rev. J. C.
Chadwick, S., Esq.
Colville, H. K., Esq.
Draper, D., Esq.
Gardiner, H. J., Esq.
Lapage, R. H., Esq.
Leverson, Lt.-Col. J. J.
Merritt, W. H., Esq.
Regester, W., Esq.
Rollo, Lord.
Sessions, W., Esq.
Symes, R. G., Esq.
Whitty, I. J., Esq.

FELLOWS REMOVED (6).

East, J. J., Esq.
Fawns, S., Esq.
Foote, J. A., Esq.
Kilgour, G., Esq.
Markes, J. F., Esq.
Thomas, W., Esq.

The following Personages were elected Foreign Members during the year 1901:—

Dr. Alexander Petrovich Karpinsky, of St. Petersburg.
Prof. Alfred Lacroix, of Paris.

The following Personage was elected a Foreign Correspondent during the year 1901:—

Prof. Friedrich Johann Becke, of Vienna.

After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to Mr. J. J. H. Teall, retiring from the office of President.

That the thanks of the Society be given to Mr. H. W. Monckton and Mr. W. Whitaker, retiring from the office of Vice-President.

That the thanks of the Society be given to Mr. William Hill, Prof. J. W. Judd, Mr. H. W. Monckton, Mr. F. W. Rudler, Mr. W. Whitaker, and Mr. H. B. Woodward, retiring from the Council.

After the Balloting-glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

OFFICERS AND COUNCIL.—1902.

PRESIDENT.

Prof. Charles Lapworth, LL.D., F.R.S.

VICE-PRESIDENTS.

Sir Archibald Geikie, D.Sc., D.C.L., LL.D., F.R.S. L. & E.
J. E. Marr, Esq., M.A., F.R.S.
Prof. H. A. Miers, M.A., F.R.S.
Prof. H. G. Seeley, F.R.S., F.L.S.

SECRETARIES.

R. S. Herries, Esq., M.A.
Prof. W. W. Watts, M.A.

FOREIGN SECRETARY.

Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S., F.L.S.

TREASURER.

W. T. Blanford, LL.D., F.R.S.

COUNCIL.

F. A. Bather, M.A., D.Sc.
W. T. Blanford, LL.D., F.R.S.
Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S.
Prof. E. J. Garwood, M.A.
Sir Archibald Geikie, D.Sc., D.C.L., LL.D., F.R.S. L. & E.
Prof. T. T. Groom, M.A., D.Sc.
Alfred Harker, Esq., M.A.
R. S. Herries, Esq., M.A.
W. H. Hudleston, Esq., M.A., F.R.S., F.L.S.
Prof. Charles Lapworth, LL.D., F.R.S.
Lieut.-General C. A. McMahon, F.R.S.
J. E. Marr, Esq., M.A., F.R.S.
Prof. H. A. Miers, M.A., F.R.S.
Right Rev. John Mitchinson, D.D., D.C.L.
E. T. Newton, Esq., F.R.S.
G. T. Prior, Esq., M.A.
Dukinfield H. Scott, M.A., Ph.D., F.R.S., F.L.S.
Prof. H. G. Seeley, F.R.S., F.L.S.
Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S.
Arthur Sopwith, Esq., M. Inst. C.E.
J. J. H. Teall, Esq., M.A., F.R.S.
Prof. W. W. Watts, M.A.
Henry Woodward, LL.D., F.R.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1901.

Date of Election.

1874. Prof. Albert Gaudry, *Paris.*
1877. Prof. Eduard Suess, *Vienna.*
1880. Prof. Gustave Dewalque, *Liége.*
1880. Baron Adolf Erik Nordenskiöld, *Stockholm.* (*Deceased.*)
1880. Prof. Ferdinand Zirkel, *Leipzig.*
1884. Commendatore Prof. G. Capellini, *Bologna.*
1885. Prof. Jules Gosselet, *Lille.*
1886. Prof. Gustav Tschermak, *Vienna.*
1887. Prof. J. P. Lesley, *Philadelphia, Pa., U.S.A.*
1888. Prof. Eugène Renevier, *Lausanne.*
1888. Baron Ferdinand von Richthofen, *Berlin.*
1889. Prof. Ferdinand Fouqué, *Paris.*
1889. Geheimrath Prof. Karl Alfred von Zittel, *Munich.*
1890. Prof. Heinrich Rosenbusch, *Heidelberg.*
1891. Prof. Charles Barrois, *Lille.*
1892. Prof. Gustav Lindström, *Stockholm.* (*Deceased.*)
1893. Prof. Waldemar Christofer Brögger, *Christiania.*
1893. M. Auguste Michel-Lévy, *Paris.*
1893. Dr. Edmund Mojsisovics von Mojsvár, *Vienna.*
1893. Dr. Alfred Gabriel Nathorst, *Stockholm.*
1894. Prof. George J. Brush, *New Haven, Conn., U.S.A.*
1894. Prof. Edward Salisbury Dana, *New Haven, Conn., U.S.A.*
1894. Prof. Alphonse Renard, *Ghent.*
1895. Prof. Grove Karl Gilbert, *Washington, D.C., U.S.A.*
1895. Dr. Friedrich Schmidt, *St. Petersburg.*
1896. Prof. Albert Heim, *Zürich.*
1897. M. E. Dupont, *Brussels.*
1897. Dr. Anton Fritsch, *Prague.*
1897. Prof. Albert de Lapparent, *Paris.*
1897. Dr. Hans Reusch, *Christiania.*
1898. Geheimrath Prof. Hermann Credner, *Leipzig.*
1898. Mr. Charles Doolittle Walcott, *Washington, D.C., U.S.A.*
1899. Prof. Marcel Bertrand, *Paris.*
1899. Senhor Joaquim Felipe Nery Delgado, *Lisbon.*
1899. Prof. Emmanuel Kayser, *Marburg.*
1899. M. Ernest Van den Broeck, *Brussels.*
1899. Dr. Charles Abiathar White, *Washington, D.C., U.S.A.*
1900. M. Gustave F. Dollfus, *Paris.*
1900. Prof. Paul Groth, *Munich.*
1900. Dr. Sven Leonhard Törnquist, *Lund.*
1901. Dr. Alexander Petrovich Karpinsky, *St. Petersburg.*
1901. Prof. Alfred Lacroix, *Paris.*

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1901.

Date of Election.

1866. Prof. Victor Raulin, *Montfaucon d'Argonne.*
1874. Prof. Igino Cocchi, *Florence.*
1879. Dr. Émile Sauvage, *Boulogne-sur-Mer.*
1889. M. R. D. M. Verbeek, *Buitenzorg, Java.*
1890. Herr Felix Karrer, *Vienna.*
1890. Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Kiel.*
1892. Major John W. Powell, *Washington, D.C., U.S.A.*
1893. Prof. Aléxis Pavlow, *Moscow.*
1893. M. Ed. Rigaux, *Boulogne-sur-Mer.*
1894. Prof. Joseph Paxson Iddings, *Chicago, Ill., U.S.A.*
1894. M. Perceval de Loriol-Lefort, *Campagne Frontenex.*
1894. Dr. Francisco P. Moreno, *La Plata.*
1894. Prof. August Rothpletz, *Munich.*
1894. Prof. J. H. L. Vogt, *Christiania.*
1895. Prof. Konstantin de Kroustchoff, *St. Petersburg.*
1895. Prof. Albrecht Penck, *Vienna.*
1896. Prof. S. L. Penfield, *New Haven, Conn., U.S.A.*
1896. Prof. Johannes Walther, *Jena.*
1897. M. Louis Dollo, *Brussels.*
1897. Mr. Alpheus Hyatt, *Cambridge, Mass., U.S.A.* (*Deceased.*)
1897. Prof. Anton Koch, *Budapest.*
1897. M. Emmanuel de Margerie, *Paris.*
1897. Prof. Count H. zu Solms-Laubach, *Strasburg.*
1898. M. Marcellin Boule, *Paris.*
1898. Dr. W. H. Dall, *Washington, D.C., U.S.A.*
1899. Prof. Charles Emerson Beecher, *New Haven, Conn., U.S.A.*
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Göttingen.*
1899. Prof. Franz Lœwinson-Lessing, *Dorpat.*
1899. M. Michel F. Mourlon, *Brussels.*
1899. Prof. Henry Fairfield Osborn, *New York, U.S.A.*
1899. Prof. Gregorio Stefanescu, *Bucharest.*
1899. Prof. René Zeiller, *Paris.*
1900. Prof. Arturo Issel, *Genoa.*
1900. Prof. Ernst Koken, *Tübingen.*
1900. Prof. Federico Sacco, *Turin.*
1901. Prof. Friedrich Johann Becke, *Vienna.*

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. G. A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. H. Falconer.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron L. von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy.
1844. Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir 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. W. T. Blanford.
1884. Prof. Albert Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Des Cloizeaux.
1887. Mr. J. Whitaker Hulke.
1888. Mr. H. B. Medlicott.
1889. Prof. Thomas G. Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John W. Judd.
1892. Baron Ferdinand von Richthofen.
1893. Prof. Nevil S. 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. Prof. Grove K. Gilbert.
1901. Prof. Charles Barrois.
1902. Dr. Friedrich Schmidt.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. G. A. Mantell.
1836. 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. S. P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Prof. G. P. Deshayes.
1857. Dr. S. 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. Mr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. John W. Judd.
1874. Dr. Henri Nyst.
1875. Prof. L. C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. R. Etheridge, Jun.
1878. Prof. William J. Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay H. Traquair.
1882. Dr. George J. Hinde.
1883. Prof. John Milne.
1884. Mr. E. Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Mr. Benjamin N. Peach.
1888. Mr. John Horne.
1889. Dr. A. Smith Woodward.
1890. Mr. W. A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville A. Derby.
1893. Mr. John G. Goodchild.
1894. Mr. Aubrey Strahan.
1895. Prof. W. W. Watts.
1896. Mr. Alfred Harker.
1897. Dr. Francis A. Bather.
1898. Prof. E. J. Garwood.
1899. Prof. J. B. Harrison.
1900. Mr. George T. Prior.
1901. Mr. Arthur W. Rowe.
1902. Mr. Leonard J. Spencer.

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. 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. Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. W. C. Brögger.
1892. Prof. A. H. Green.
1893. Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustav Lindström.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. { Mr. Benjamin N. Peach.
Mr. John Horne.
1900. Baron A. E. Nordenskiöld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. Mr. Alfred Bell.
1874. Prof. Ralph Tate.
1875. Prof. H. G. Seeley.
1876. Dr. James Croll.
1877. Rev. John Frederick Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James W. 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. Mr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward Wethered.
1891. Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. G. J. Williams.
1894. Mr. George Barrow.
1895. Mr. Albert C. Seward.
1896. Mr. Philip Lake.
1897. Mr. S. S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Mr. Thomas H. Holland.

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 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.'

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. G. 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. E. Tulley Newton.
1894. Prof. John Milne.
1895. Rev. John Frederick Blake.
1896. Dr. A. Smith Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Mr. John Edward Marr.
1901. Dr. Ramsay H. Traquair.
1902. { Prof. Anton Fritsch.
{ Mr. Richard Lydekker.

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. Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. A. J. Jukes-Browne.
1886. Mr. D. Mackintosh.
1887. Rev. Osmond Fisher.
1888. Mr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. M. Louis Dollo.
1890. Mr. C. Davies Sherborn.
1891. Dr. C. I. Forsyth-Major.
1891. Mr. George W. Lamplugh.
1892. Prof. J. Walter Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Mr. 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.

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 acknowledgement 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 C. Marsh.
1879. Prof. Edward D. Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Mr. J. J. Harris Teall.
1891. Dr. George M. Dawson.
1893. Prof. William J. Sollas.
1895. Mr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. E. David.
1901. Mr. George W. Lamplugh.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of Microscope.
1881. Purchase of Microscope-Lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Prof. Theodore T. Groom.
1902. Mr. W. M. Hutchings.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				175	0	0
Due for Arrears of Admission Fees	113	8	0			
Admission Fees, 1901	200	0	0			
				313	8	0
Arrears of Annual Contributions	160	0	0			
Annual Contributions, 1902, from Resident Fellows and Non-Residents	1750	0	0			
Annual Contributions in advance	50	0	0			
				1960	0	0
Sale of Quarterly Journal, including Longmans' Account				150	0	0
Sale of Transactions, Library Catalogue, General Index, Hutton's 'Theory of the Earth' vol. iii, Hochstetter's 'New Zealand,' and List of Fellows				5	0	0
Dividends on £2500 India 3 per cent. Stock ..	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock.	8	0	0			
				351	16	0
Balance against the Society*				100	0	0
				£3055	4	0

* The Expenditure in excess of the expected Income is provided for by the Balance in hand at the commencement of the year.

the Year 1902.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes		15	0			
Fire Insurance	15	0	0			
Electric Lighting	40	0	0			
Gas	8	0	0			
Fuel	40	0	0			
Furniture and Repairs	130	0	0			
House-repairs and Maintenance	30	0	0			
Annual Cleaning	15	0	0			
Washing and Sundries	35	0	0			
Tea at Meetings	20	0	0			
				333	15	0
Salaries and Wages, etc.:						
Assistant Secretary	350	0	0			
,, Half Premium Life Assurance	10	15	0			
Assistant Librarian	150	0	0			
Assistant Clerk	120	0	0			
Office Boy	36	0	0			
House Porter and Upper Housemaid	91	12	0			
Under Housemaid	47	12	0			
Charwoman and Occasional Assistance	10	0	0			
Accountant's Fee	10	10	0			
				826	9	0
Office Expenditure:						
Stationery	35	0	0			
Miscellaneous Printing	45	0	0			
Postage and Sundry Expenses	85	0	0			
				165	0	0
Library (Books and Binding)				200	0	0
Library Catalogue				80	0	0
International Catalogue of Scientific Literature				60	0	0
Museum				20	0	0
Museum Catalogue				100	0	0
Publications:						
Quarterly Journal, including Commission on Sale	900	0	0			
Record of Geological Literature	135	0	0			
List of Fellows	35	0	0			
Postage on Journal, Addressing, etc.	90	0	0			
Abstracts, including Postage	110	0	0			
				1270	0	0
				£3055	4	0

W. T. BLANFORD, *Treasurer.*

January 25th, 1902.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1901:						
On Current Account	122	17	2			
On Deposit Account	250	0	0			
,, Balance in the hands of the Clerk at January 1st, 1901	15	17	8			
				388	14	10
,, Compositions				234	10	0
,, Admission Fees:						
Arrears	113	8	0			
Current	207	18	0			
				321	6	0
,, Arrears of Annual Contributions	186	7	6			
,, Annual Contributions of 1901:						
Resident Fellows	1764	0	0			
Non-Resident Fellows	11	0	6			
,, Annual Contributions in advance	54	12	0			
				2016	0	0
,, Publications:						
Sale of Quarterly Journal:						
,, Vols. i to lvi *	127	11	8			
,, Vol. lvii	72	7	5			
				199	19	1
,, Record of Geological Literature ...	1	4	6			
,, List of Fellows		3	0			
,, General Index to Quarterly Journal, vols. i to l		15	0			
,, Hutton's 'Theory of the Earth' ...	1	4	0			
,, Transactions		10	0			
,, Hochstetter's 'New Zealand'		9	4			
,, Ormerod's Index		3	6			
				4	9	4
,, Dividends (less Income Tax):—						
£2500 India 3 per cent. Stock....	70	18	10			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	14	4	5			
£2250 London & North-Western Railway 4 per cent. Preference Stock	85	6	3			
£2800 London & South-Western Railway 4 per cent. Preference Stock	106	3	4			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	49	2	0			
				325	14	10
,, Interest on Deposit				13	3	7
				£3503	17	8

* Due from Messrs. Longmans, in addition to the above, on Journal, Vol. lvii, etc. £66 6 4

Year ended December 31st, 1901.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House Expenditure:						
Taxes		15	0			
Fire Insurance	15	0	0			
Electric Lighting	54	5	0			
Gas	8	4	0			
Fuel	46	2	2			
Furniture and Repairs	38	1	10			
House-repairs and Maintenance	36	16	10			
Annual Cleaning	13	14	6			
Washing and Sundries	26	11	3			
Tea at Meetings	20	7	11			
				259	18	6
,, Salaries and Wages:						
Assistant Secretary	350	0	0			
,, One-half Premium Life Assurance	10	15	0			
Assistant Librarian	150	0	0			
Assistant Clerk	120	0	0			
Office Boy	31	4	0			
House Porter and Upper Housemaid	91	12	0			
Under Housemaid	44	18	10			
Charwoman and Occasional Assistance	15	19	8			
Accountant's Fee	10	10	0			
Assistant Clerk: Allowance for Rooms during Alterations	6	15	0			
				831	14	6
,, Office Expenditure:						
Stationery	28	9	11			
Miscellaneous Printing	51	8	0			
Postages and Sundry Expenses	76	16	7			
				156	14	6
,, International Catalogue of Scientific Literature				60	0	0
,, Library				186	2	1
,, Museum				26	12	1
,, Publications:						
Quarterly Journal, Vols. i to lvi, Commission on Sale thereof	10	15	0			
Quarterly Journal, Vol. lvii, Commission on Sale thereof	5	16	6			
Paper, Printing, and Illustrations	657	14	6			
Record of Geological Literature	146	16	3			
List of Fellows	36	9	8			
Postage on Journal and Addressing	70	16	4			
Abstracts, including Postage	104	17	10			
				1033	6	1
,, Electric-Light Installation				37	5	9
,, Redecoration				508	11	11
,, Balance in the hands of the Bankers at December 31st, 1901:						
On Current Account	132	4	2			
On Deposit Account	250	0	0			
,, Balance in the hands of the Clerk	21	8	1			
				403	12	3
				£3503	17	8

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

BEDFORD McNEILL, HORACE W. MONCKTON, } *Auditors.*

W. T. BLANFORD, *Treasurer.*

January 25th, 1902.

Statement of Trust Funds: December 31st, 1901.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1901	31	18	3	By Award to Mr. Arthur W. Rowe, and Medal	31	18	3
" Dividends (less Income Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	8	10	" Balance at the Bankers', December 31st, 1901	30	8	10
	£62	7	1		£62	7	1

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1901	20	10	2	By Award to Mr. Alfred John Jukes-Browne	10	10	0
" Dividends (less Income Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	37	18	8	" " Mr. Thomas Sargeant Hall	28	3	4
				" Cost of Medal		17	0
				" Balance at the Bankers', December 31st, 1901	18	18	6
	£58	8	10		£58	8	10

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1901	52	15	1	By Award to Dr. Ramsay Heatley Traquair	25	0	0
" Dividends (less Income Tax) on the Fund invested in £2010 1*s*. 0*d*. Metropolitan $3\frac{1}{2}$ per cent. Stock	66	10	10	" " Dr. John William Evans	21	14	3
				" " Mr. Alexander McHenry	21	14	0
				" Cost of Medal	1	1	0
				" Balance at the Bankers', December 31st, 1901	49	16	8
	£119	5	11		£119	5	11

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1901	8	15	4	By Balance at the Bankers', December 31st, 1901	22	1	7
" Dividends (less Income Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	13	6	3				
	£22	1	7		£22	1	7

'Bigsby Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1901	9	10	0	By Cost of Medal for Mr. George William Lamplugh....	12	9	10
„ Dividends (less Income Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	5	19	2	„ Balance at the Bankers', December 31st, 1901	2	19	4
	£15	9	2		£15	9	2

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1901	10	1	7	By Grants	2	2	0
„ Dividends (less Income Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock..............	3	18	10	„ Balance at the Bankers', December 31st, 1901	11	18	5
	£14	0	5		£14	0	5

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1901........	12	14	3	By Balance at the Bankers', December 31st, 1901	29	9	9
„ Dividends (less Income Tax) on the Fund invested in £591 1*s.* 4*d.* India 3 per cent. Stock	16	15	6				
	£29	9	9		£29	9	9

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

W. T. BLANFORD, *Treasurer.*

January 25th, 1902.

BEDFORD M^cNEILL,
HORACE W. MONCKTON, } *Auditors.*

Statement of the Society's Property: December 31st, 1901.

PROPERTY.	£	s.	d.		£	s.	d.
Due from Longmans & Co., on account of Quarterly Journal, Vol. LVII, etc.	66	6	4	Balance in favour of the Society	12,228	9	10
Balance in the Bankers' hands, December 31st, 1901:							
On Current Account	132	4	2				
On Deposit Account	250	0	0				
Balance in the Clerk's hands, December 31st, 1901	21	8	1				
Funded Property:—							
£2500 India 3 per cent. Stock	2623	6	0				
£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				
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502	15	3				
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	1850	19	6				
Arrears of Admission Fees	113	8	0				
Arrears of Annual Contributions	162	4	6				
	£12,228	9	10		£12,228	9	10

[*N.B.—The above does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications.*]

W. T. BLANFORD, *Treasurer.*

January 25th, 1902.

Note.—The investments in Stocks are valued at their cost price.

Award of the Wollaston Medal.

In handing the Wollaston Medal, awarded to Dr. Friedrich Schmidt, F.M.G.S., of St. Petersburg, to Prof. H. G. Seeley, for transmission to the recipient, the President addressed him as follows:—

Professor Seeley,—

Friedrich Schmidt is our chief living authority upon the rocks and fossils of the Baltic Provinces of Russia. The work of ascertaining the order and organic remains of the richly fossiliferous strata of Esthonia, from the base of the Cambrian to the summit of the Devonian, originally commenced in broad outline by Eichwald, Pander, and others between the years 1830 and 1850, was taken up in great detail in 1853 by Schmidt, who was at that time Professor at the University of Dorpat. In the year 1856 he published his first work, 'Die Silurische Formation von Estland, Nordlivland und Œsel,' which at once became the standard and was referred to in detail by Murchison in his own paper on the subject in the Quarterly Journal of this Society for 1857. Even at that time Dr. Schmidt had recognized between 400 and 500 fossils in these Esthonian rocks, had separated the Lower and Upper Silurian faunas, and had proved the existence of *Eurypterus* and *Cephalaspis* in the highest beds of his country.

For the next thirty years he continued these researches, and by the year 1882 he had completed a general survey of the region, had separated the Lower Palæozoic formations into the three faunal divisions of Cambrian, Ordovician, and Silurian, and distinguished some fifteen zones and sub-zones in the collective succession. He also published a map showing the distribution of the major zones, in readiness for the International Geological Map of Europe. Dr. Schmidt's results have enabled the whole of the Russian Palæozoic Series to be paralleled with the corresponding rocks of Scandinavia and other parts of the world.

In constant connection with the stratigraphical work, he has especially busied himself in the development and description of the palæontology of the Palæozoic succession. He has figured and des scribed the Trilobites of the entire series, publishing the first part of his 'Revision der Ostbaltischen Silurischen Trilobiten' in 1881, the fourth part in 1894, and the fifth part in 1898. He has also worked out the Eurypteridæ and the Leperditiadæ, the final parts of this work appearing in 1900. In 1888 he made known the discovery of *Olenellus* in the Lower Cambrian rocks of Esthonia, and he has subsequently described and figured the first Russian *Olenellus* (*O. Michwitzia*).

Dr. Schmidt's work, both palæontological and stratigraphical, bears the impress of unsparing labour, modest caution, and thoroughness; and the results that he has obtained have been invaluable in the development of our knowledge of the geology and fossils of the Baltic Provinces. He is one of the last survivors of the heroic age of Geology, being the contemporary and occasional colleague of Eichwald, Pander, Keyserling, De Verneuil, Murchison, and Barrande. The award of our Wollaston Medal to this eminent Russian geologist and palæontologist is not only expressive of our hearty recognition of his life-long devotion to the study of the rocks and fossils of his native land, but is also a grateful acknowledgement of the important services which he and his countrymen have rendered to the general advancement of geological science.

Prof. Seeley replied in the following words:—

Mr. President,—

Dr. Friedrich Schmidt desires to express his thanks for the honour of the award of the Wollaston Medal, and to say how much he regrets his inability to be present here, for he gratefully appreciates this expression of generous sympathy with his work. In early life he wandered through Siberia, where he learned the English language, which enabled him to contribute to the Society's Journal.

I have known Dr. Schmidt as Administrator of the Geological Museum of the Imperial Academy of Sciences of St. Petersburg, where I examined the materials described in his memoirs; and, in common with members of the International Geological Congress, I have been guided by him along the southern coast of the Gulf of Finland, from St. Petersburg to Œsel, to the principal scenes of his work among the Cambrian and Silurian rocks and the Drift-deposits in the Eastern Baltic Provinces of Russia. And I may be permitted to say that all his work seems to me characterized by breadth of treatment and lucidity. In Schmidt, the gifts and attainments of the naturalist illuminate the work of the geologist; and his search for truth never wearies and never hastes, till all available facts are brought into illustrative relation with his research. His many-sided studies of nature have given a philosophical character to all Dr. Schmidt's contributions to science; and it is impossible not to realize that his scientific writings, which are many and valuable, give but inadequate expression to a personality which has powerfully influenced many to follow his methods and emulate his results. He has passed his 70th year, but works on, and looks forward to the early completion of his final memoirs on the Trilobites.

He will warmly appreciate the terms in which the presentation of this Medal has been made, no less than the manner in which the Geological Society has endorsed the award of the Council.

Award of the Wollaston Donation Fund.

The President then presented the Balance of the Proceeds of the Wollaston Donation Fund to Mr. Leonard James Spencer, M.A., F.G.S., of the Mineralogical Department, Natural History Museum, addressing him as follows:—

Mr. Spencer,—

Your researches in Scientific Mineralogy during the last seven years constitute an important and solid contribution to natural knowledge. It is appropriate that the Council of this Society should mark their recognition of your labours by awarding to you the Balance of the Proceeds of the Wollaston Fund, which was instituted to promote researches concerning the mineral structure of the earth.

In a series of papers on individual species you have shown yourself to be a master of the methods of crystallographic and mineralogical research, and you have applied these methods with signal success to the investigation of difficult minerals, some of which had baffled the efforts of previous workers.

Special interest attaches to those researches which you have carried out in collaboration with Mr. Prior, to whom an Award from this Fund was made two years ago; since these have led to the elucidation of species which had previously been misinterpreted, and have proved the identity of several rare minerals which were formerly ranked as different species. The most conspicuous instance is your joint study of binnite, whereby that mineral, regarded for 45 years as a distinct species, was proved to be identical with the well-known mineral tennantite.

Such researches naturally attract little attention outside the circle of mineralogists, but they are the sort of researches upon which accurate science is based.

The Council have pleasure in marking their appreciation of your patient and effective labours by this Award, and hope that their recognition of your work will encourage you to proceed with similar investigations.

Award of the Murchison Medal.

In presenting the Murchison Medal to Mr. Frederic William Harmer, F.G.S., the President addressed him in the following words :—

Mr. Harmer,—

The Council of this Society have awarded to you the Murchison Medal, in recognition of your long-continued labours among the Pliocene and later deposits of East Anglia.

In speaking of your earlier work, it is impossible to separate your name from that of Searles V. Wood, Junior, who I believe discovered you on the Cromer coast nearly forty years ago, when you were trying to solve the riddle of its complicated Drifts. Wood, who had previously made a Drift Survey of the whole of Essex on the scale of 1 inch to the mile, soon enlisted your services in Norfolk while he continued his work in Suffolk; and in the course of about four years you were together able to bring before the British Association at Norwich a summary of the results at which you had arrived, from the mapping of the Crag and Glacial Beds. Your map was published on a reduced scale by the Palæontographical Society in 1872, with a Memoir in which you and Mr. Wood elaborated many points touched upon in your previous work. These original surveys formed an excellent basis for your further researches into the structure and method of formation of these deposits, and for the labours of all who have followed in your footsteps. Freed from the cares of business and of municipal duties, which occupied much of your time in earlier years, your attention has latterly been given to a study of the minuter divisions of the Crag Series, not only in this country, but abroad—in Holland and Belgium: thereby, dealing with the zonal succession in the Crag Series and with the distribution of molluscan life generally in the Pliocene Period, you have enlarged our knowledge of the physical and climatal conditio under which both Pliocene and Pleistocene deposits were laid down, and have drawn especial attention to the way in which Meteorology can aid in the solution of geological problems.

While it is a matter for regret that Searles V. Wood, Junior, did not live to receive from this Society any token of its appreciation of his labours, it is a great satisfaction to place this Medal in the hands of his partner, who has so strenuously carried on the work with which his name will always be associated.

Mr. Harmer replied as follows:—

Mr. President,—

It is impossible to thank the Council as I could wish for the great honour that they have conferred upon me, or yourself, Sir, for the words which you have just spoken. The pleasure that this Award gives to me has been much increased by your kind reference to my dear old master and friend, Searles V. Wood the younger, with whom, as you have said, I had so long the privilege of working; to whom, indeed, the credit of anything that I was able to accomplish in my younger days is largely due. I am glad to think that this Medal recognizes also the value of the far more important labours of the distinguished man to whose teaching and influence I owe so much.

I regret that during my best years the demands on my scanty leisure left me no time for geological investigation, and that I have only been able to return to it in the evening of life: first, because I can hardly expect to do much to show myself more worthy of this great distinction; and next, because I shall have to leave to my successors many important and interesting problems in East Anglian geology, in the solution of which I once hoped to have taken part.

Award of the Murchison Geological Fund.

The President then presented the Balance of the Proceeds of the Murchison Geological Fund to Mr. Thomas H. Holland, F.G.S., of the Geological Survey of India, addressing him in the following words:—

Mr. Holland,—

The Records of the Geological Survey of India, the Journal of this Society, and other periodicals bear testimony to your scientific activity during the past decade. I can only refer to a few of your more important contributions to the advancement of science.

In your Memoir on the Charnockite Series you have made us familiar with the field-relations, the mineralogical composition, and the microscopic structure of an important and interesting group of Archæan rocks; in your contribution to the 'Manual of the Geology of India' you have given us a valuable treatise on the natural history of corundum; and in your paper on the elæolite-syenites of Sivamalai you have added a new group to the foliated crystalline series.

But you have not confined your attention to the crystalline rocks. In the 'Report on the Geological Structure & Stability of the Hill-Slopes around Naini Tal,' you have brought your geological knowledge to bear on questions affecting the security of life and property, and have laid down general principles which must be of great utility to all those who are responsible for the safety of the inhabitants of those hilly districts, in which denudation is going on with exceptional rapidity.

I have much pleasure in handing you the Balance of the Murchison Geological Fund, which has been awarded to you by the Council of the Geological Society, in recognition of your valuable contributions to Indian geology.

Award of the Lyell Medals.

In handing the Lyell Medal awarded to Mr. Richard Lydekker, B.A., F.R.S., to Dr. F. A. Bather for transmission to the recipient, the President addressed him as follows:—

Dr. Bather,—

Mr. Lydekker's labours in the domain of Vertebrate Palæontology commenced, I believe, with a study of the Siwalik fossils, which resulted in numerous and valuable additions to the classic work of Falconer & Cautley on the Siwalik Fossils.

Many other Tertiary vertebrata from various parts of India and Burmah, from Perim Island, Sind, the Nerbudda, and the Irrawaddy Valley, have been examined and described by him. He has also given us an account of the Pleistocene fauna of the Karnul Caves, and has contributed to our knowledge of Indian Mesozoic reptilia.

During his residence in India as an officer of the Geological

Survey he was necessarily much occupied with field-work; and we have to thank him for a detailed account of the vast mountainous area comprised within the territories of Kashmir.

Since his return to this country he has not been idle. He has contributed no less than ten volumes to the Official Catalogue of the British Museum ; he has visited the Museums of Argentina and added much to our knowledge of the remarkable Tertiary fauna of South America ; and he has furnished to this and other Societies numerous descriptions of vertebrata from the Mesozoic and Tertiary formations of various countries. His extensive knowledge of fossil forms has enabled him to contribute to two of the most remarkable zoological books published during the last decade of the nineteenth century. I refer to 'Mammals, Living & Extinct,' by Sir William Flower and him, and to the 'Dictionary of Birds' by Prof. A. Newton. Of late years he has devoted himself more especially to the study of recent forms; but in his work on the Geographical History of Mammals he has successfully brought his wide knowledge of the mammalian life of past times to bear on the important question of geographical distribution.

As an old fellow-student of his at Cambridge, it gives me the greatest pleasure to be the means of transmitting to him the Lyell Medal on behalf of the Council of the Geological Society. In making this Award the Council desire especially to commemorate the important services which he has rendered to Vertebrate Palæontology.

Dr. Bather, having expressed on behalf of the recipient the latter's regret that an engagement at Norwich prevented him from being present in person to receive the Medal, read the following communication from Mr. Lydekker:—

'The award of a Lyell Medal would under any circumstances be a cause of great gratification to the recipient. But I have special reason to be gratified at the reward that the Council have been good enough to bestow on me, because in matters scientific I seem to have passed unconsciously through a kind of evolutionary process, and to have departed further and further from the line of study connected with the Geological Society. During my term of service on the Geological Survey of India I was largely occupied with Geology proper, although devoting a considerable proportion of my time to Vertebrate Palæontology. For several years after my return to this country that fascinating subject occupied the greater share of my attention. But of late years I have been led, by the force of circumstances, to transfer my time more and more to recent animals and geographical distribution. Moreover, I regret to say, much of my time has been given to popular or semi-popular writing, rather than to strictly scientific work. Under these circumstances it is especially gratifying to find that the Geological Society is not unmindful of my past efforts to add to our knowledge of extinct vertebrates; a task which I hope, as opportunity occurs, may to some extent be resumed in the future. To you, Sir, as representing the Council, I have the pleasure of tendering my best thanks for the honour now conferred upon me; and I may add that my pleasure is intensified by receiving the Medal at the hands of a Cambridge contemporary who has risen to the distinguished position now occupied by yourself.'

The PRESIDENT then handed another Lyell Medal, awarded to Prof. ANTON FRITSCH, F.M.G.S., of Prague, to Prof. H. G. SEELEY for transmission to the recipient, addressing him in the following words:—

Professor SEELEY,—

The Council of the Geological Society have awarded a Lyell Medal to Prof. Anton Fritsch, of Prague, in evidence of their appreciation of the value of his published works upon the Palæontology of Bohemia. In 1872, 1878, and 1887, Prof. Fritsch gave us a series of volumes on the Cephalopoda, Reptiles, Fishes, and Crustacea of the Bohemian Cretaceous rocks. But he is best known by his researches in Palæozoic Palæontology. Twenty years ago, after the publication of the first results of his labours on the Fossils of the Pilsen Coal-basin, this Society made to him an award from the Lyell Geological Fund. It is fitting, therefore, that he should receive the Lyell Medal on the completion of this great work, which represents twenty-five years of strenuous labour, and has gained for its author a position of great eminence in the palæontological world.

Much of the material with which he has had to deal would probably have been neglected by less accomplished observers. By careful drawing with his own hands, and by the aid of electrotype reproductions of perishable parts, he has brought vividly before us a new Permian terrestrial fauna, remarkable for its labyrinthodontia, fishes, arachnida, insects, and myriapoda. Prof. Fritsch has not only described a vast amount of new palæontological material, but he has also used the knowledge thus gained for the purpose of elucidating the affinities of the different extinct groups with each other and with their nearest living allies.

His studies of Labyrinthodontia demonstrated the wide range of structure in animals included in that group, and suggested the approximation of the several subdivisions which he described to different orders of reptiles.

In conveying this Medal to Prof. Fritsch I ask you to express to him our sympathy with his labours in Palæontology which have been carried on for fifty years, and our satisfaction at the completion of his great work on the Permian Fauna of Bohemia.

Prof. SEELEY replied as follows:—

Mr. PRESIDENT,—

It is a great pleasure to receive the Lyell Medal on behalf of Prof. Fritsch. He has successfully overcome difficulties in the mineral condition of material which might have stopped a less resolute man. His work, enriched with all the learning which a comparative anatomist could bring to palæontological problems, will, I believe, always rank as one of the more important contributions to knowledge made in the latter half of the nineteenth century. The Medal came as a happy surprise to Prof. Fritsch, and he writes to me:—

'In awarding to me the proceeds of the Lyell Fund twenty-one years ago the Society encouraged me in the heavy work of describing the rich fauna of the Permian strata in Bohemia, which I have happily finished after thirty years of labour.

'This second award will strengthen me in devoting the rest of my life to further elaboration of the beautiful palæontological materials in our Museum. The new revision of the Carboniferous Arachnida and descriptions of two large Saurians from our Chalk-formation, on which I am at work, will be the best thanks that I can pay to the Geological Society for this generous gift.'

AWARD OF THE LYELL GEOLOGICAL FUND.

The President then presented the Balance of the Proceeds of the Lyell Geological Fund to Dr. WHEELTON HIND, F.R.C.S., of Stoke-on-Trent, addressing him as follows:—

Dr. WHEELTON HIND,—

The Council of the Society have awarded to you the Balance of the Proceeds of the Lyell Fund as a mark of their appreciation of your enthusiastic labours among the Carboniferous rocks of this country. During the past twelve years, while residing in the interesting region of the Potteries, and largely occupied in arduous professional work, you have found time for a detailed study of the rocks and fossils of your district, and more especially of the neglected lamellibranchs of the Coal-Measures. Extending your labours into bordering and even distant Carboniferous areas, you have not only enriched our knowledge of the stratigraphical divisions, but you have initiated a study of the life-zones—a study which has borne good fruit, and in which we anticipate from you further important results. In addition to this, we are further indebted to you for the Monographs on Carboniferous Mollusca which you have contributed to the Palæontographical Society.

Award of the Barlow-Jameson Fund.

In handing the Proceeds of the Barlow-Jameson Fund, awarded to Mr. William Maynard Hutchings, F.G.S., of Newcastle-upon-Tyne, to Mr. George Barrow for transmission to the recipient, the President addressed him as follows:—

Mr. Barrow,—

In the midst of a busy professional life Mr. Hutchings has found time to carry out a series of laborious petrographical researches, and to contribute a number of important papers to the Geological Magazine and other scientific journals.

He has especially directed his attention to the composition of the finer-grained sedimentary rocks, and to the changes which are produced in them by normal decomposition and contact-action. The rocks on which he has worked have been comparatively neglected by petrologists, in consequence of the difficulties attending their investigation, but he has shown that, by the use of suitable sections and very high powers, these difficulties can be successfully surmounted.

The Council of the Geological Society have awarded to Mr. Hutchings a grant from the Proceeds of the Barlow-Jameson Fund, as a mark of their appreciation of his contributions to Petrographical Science, and as an expression of the hope that, in the future as in the past, he will be able to carry on the researches which have thrown so much light on the natural history of our sedimentary rocks.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

J. J. Harris Teall, Esq., M.A., F.R.S.

In Gustav Lindström, who was elected a Foreign Correspondent of our Society in 1885, a Foreign Member in 1892, and who was the recipient of the Murchison Medal in 1895, we have lost a leader among palæontologists, whose knowledge of Silurian life was more profound than that of any of his contemporaries. Born in Visby, the capital of Gotland, on August 27th, 1829, he began his researches on the fossils of that island while a master at the Grammar School of his native town. The thoroughness and originality characteristic of those early papers on the brachiopods and corals suggest that isolation from kindred minds and from the multitude of books may even benefit an earnest student by confining his attention to the facts of nature. But Lindström was more than earnest and persevering; by his zoological studies at Upsala and under Lovén, and by his translation, or rather adaptation, of Lyell's writings, he had admirably prepared himself to grapple with the problems of structure, of classification, and of stratigraphical distribution, presented by the varied fossil faunas of Gotland. The excellence of his work led to his being entrusted with the description of fossils from Spitsbergen and corals from the depths of the Atlantic; it ensured him a hearty welcome from London geologists in 1874; and in 1876 pointed to him as Angelin's natural successor in the keepership of the Fossil Invertebrata in the State Museum at Stockholm. Here he lived and laboured till his unexpected death on May 16th, 1901.

Most of Lindström's palæontological papers deal with corals; and of these one of the best known is the memoir on the operculate corals of the Palæozoic formations, wherein the enigmatic *Calceola* was first assigned to its true systematic position. Of no less worth were his monographs on the Silurian Gasteropoda and Pteropoda of Gotland, on the Ascoceratidæ and the Lituitidæ, on a *Cyathaspis* of Lower Wenlock age, and on the Eyes of the Trilobites. In conjunction with T. Thorell he described *Palæophorus nuncius,* a scorpion of Lower Ludlow age, at that time (1885) the oldest air-breather known. Many others of his writings are highly valued by palæontologists, while geologists may recall his papers on the elevation of Gotland, on the curiously disturbed strata of the

Carlsöar near Gotland, on post-Glacial depressions in Gotland, and on the stratigraphy of that island. For one, however, whose scientific activity extended over half a century, the number of Lindström's publications is not great—scarcely one for each year, all told. But everything he produced was well-considered, exhaustive, and as final as the then-known material permitted. Theories and systems are the fabric of a dream, but these massive piles of fact, accurately hewn and exquisitely put together, will last, as do the mediæval remains of Visby, to serve future generations for a quarry of beautiful detail, and a monument of a master-builder. [F. A. B.]

Baron ADOLF ERIK NORDENSKIÖLD, who was elected a Foreign Correspondent of our Society in 1869, and a Foreign Member in 1880, and to whom the Murchison Medal was awarded in 1900, died suddenly last August, at the age of 68. Descended from a Swedish family of scientific distinction, which had been settled for many generations in Finland, he was born at Helsingfors on November 18th, 1832. After receiving his scientific education at the University of Helsingfors and in Berlin, he settled in Sweden; and, following his father's studies in mineralogy, became Curator of the Mineral Collections of the Academy of Sciences at Stockholm. At the age of 26, Nordenskiöld made his first journey to Spitsbergen, as geologist to an expedition under Dr. Otto Torell. Three years later he accompanied Torell on his second voyage, and subsequently he himself took charge of an expedition to Spitsbergen for the special purpose of measuring the arc of a meridian. For the best five-and-twenty years of his life, Nordenskiöld was devoted to Arctic exploration, making successive journeys to Greenland and to Siberian waters, his work culminating in the memorable voyage of the *Vega* and the accomplishment of the North-east Passage. In all his Arctic work he lost no opportunity of geological study: at one time he would be busy unearthing fossil plants from Tertiary deposits in Greenland; at another time he was collecting the dust which had accumulated on the surface of the Arctic ice, or examining the enormous masses of metallic iron which he discovered at Ovifak. Glacial phenomena always attracted his attention. In the later years of his life, when his Arctic career had closed, he turned to the study of the early history of cartography, and this resulted in the publication of the 'Facsimile Atlas' and his work entitled 'Periplus.' Baron Nordenskiöld combined, in a remarkable manner, the qualifications of an energetic explorer and a far-sighted organizer with those of a patient student of ancient literature; but in this Society he will be best remembered as a close observer of natural phenomena, not indisposed to speculate with boldness upon their probable cause. [F. W. R.]

John Hopwood Blake, who became a Fellow of this Society in 1868, was born on July 22nd, 1843. After completing his education at King's College, London, he was apprenticed to Mr. R. P. Brereton, M.Inst.C.E., under whose directions he was engaged for several years in railway-work in Cornwall and South Wales. During his engineering experiences, he became interested in geology, and was thereby tempted to join the Geological Survey in April, 1868, at a time when the staff under Murchison was considerably augmented. During the first few years of his official career he was engaged in the re-survey of portions of Somerset, along the Mendip and Polden Hills, and subsequently at Watchet and Minehead. He was also occupied for a time in the first detailed Drift Survey of the area north-west of London. Later on he was transferred to Suffolk, to survey the country around Stowmarket, and that bordering the sea north and south of Lowestoft, whence he proceeded to Yarmouth and continued his investigations inland and along the coast as far north as Palling in Norfolk, and subsequently around East Dereham. Much time had been devoted to a careful study of the Forest Bed Series, and his published section of the cliffs at Kessingland, Pakefield, and Corton (1884) bears evidence of the painstaking character of his work. In 1884, Mr. Blake removed to Reading, and was for many years occupied in the re-survey (on the 6-inch scale) of that neighbourhood, giving especial attention to the Drifts, which before had only been partially mapped. A few years ago he proceeded to Oxford, from which important and interesting centre he laboured with much quiet enthusiasm, until on March 5th, 1901, he suddenly and quite unexpectedly succumbed to *angina pectoris* at the age of 57.

The record of his geological work is chiefly embodied in the geological maps of the districts which he surveyed, and in sundry Survey Memoirs. He contributed notes to the Geology of East Somerset (1876), to the Geology of Stowmarket (1881), the Geology of Norwich (1881), and the Geology of London (1889); and he personally wrote 'The Geology of the Country around East Dereham' (1888) and 'The Geology of the Country near Yarmouth &

Lowestoft' (1890). He had also prepared, in conjunction with Mr. W. Whitaker, a Memoir on the Water-Supply of Berkshire, which has lately been published, and had made some progress with a Memoir on the Geology of Reading.

Mr. Blake's other contributions to geological literature were few. In 1872 he contributed (with H. B. Woodward) 'Notes on the Relations of the Rhætic Beds to the Lower Lias & Keuper Formations in Somersetshire' (Geol. Mag. p. 196), and in 1877 he published an article 'On the Age of the Mammalian Rootlet-Bed at Kessingland' (*ibid.* p. 298). Reference may also be made to his addresses to the Norwich Geological Society (of which he was elected President in 1880–81); and to his Presidential Address to the Reading Literary & Philosophical Society in 1885. Mr. Blake was an active member of the Geologists' Association, and since 1885 had conducted a number of their excursions.[1]

Prof. Edward Waller Claypole was born at Ross (Herefordshire), on June 1st, 1835, and graduated in the University of London, becoming B.A. in 1862 and D.Sc. in 1888. He left England in 1871, and spent the remainder of his life in the United States of North America. He was Professor in Antioch College (Ohio) from 1873 to 1881; in Buchtel College, Akron (Ohio), from 1883 to 1898; and from that date until his death on August 17th, 1901, in the Throop Institute, Pasadena (California). He was also Palæontologist to the Second Geological Survey of Pennsylvania. Prof. Claypole paid frequent visits to his native country, and he became a Fellow of the Geological Society in 1879. He was well known to many of our Fellows and contributed three papers to the Quarterly Journal. His first contribution in 1883 contained a description of a new Fenestellid; but the two later papers related to the Upper Silurian Pteraspidian Fishes, of which he was the first discoverer in North America. He was especially interested in Palæozoic Fishes and wrote a series of papers on the Clark Collection, from the Upper Devonian (Cleveland Shale) of Ohio, in several volumes of the 'American Geologist.' He also published many purely geological papers. He was one of the original members of the American Geological Society at its inauguration in 1888, and was an editor of the 'American Geologist' from its foundation in the same year. He was much esteemed, by all who had the pleasure of his acquaintance, as a quiet, unassuming student of very wide interests.

[1] From a memoir by H. B. Woodward, Geol. Mag. 1901, p. 238.

He was not in any sense a specialist, but a representative of an old school which is rapidly diminishing in numbers. [A. S. W.]

Dr. George Mercer Dawson was the second son of the late Sir William Dawson, who, for upwards of forty-four years, held the post of Principal of McGill University. He was born at Pictou, in Nova Scotia, on August 1st, 1849. Six years later his father moved with his family to Montreal, where the local surroundings at that time were such as to stimulate young Dawson's inborn love of nature.

His early education was carried on for the most part under tutors. At the age of eighteen he entered the McGill College, where he attended lectures for one session (1868–69); but in the following year he came to London, and commenced a distinguished career as a student of the Royal School of Mines at Jermyn Street. His success at this institution is attested by the fact that he carried off both the Edward Forbes Medal in Palæontology & Natural History and the Murchison Medal in Geology.

On his return to Canada he spent some time in investigating the copper and iron-ore deposits of his native province of Nova Scotia. By bent and training Dawson was eminently fitted for the scientific exploration of unknown lands, and in 1873 he was fortunate in obtaining an appointment which exactly suited him—that of geologist and botanist to the British North American Boundary-Commission. The results of his work on the Commission were published in a Report which clearly shows his exceptional powers as a scientific pioneer, and is now literally worth its weight in gold.

In 1875 he was appointed to the staff of the Geological Survey of Canada, and soon afterwards commenced his long series of explorations in British Columbia and in the vast unknown regions of the North-west. Although he became familiar with the geology of every part of the Dominion, his name will always be especially associated with the North-west, where he was well known and greatly respected, and where Dawson City has arisen to commemorate his celebrated explorations, carried out during the years 1887 and 1888, on the Yukon River.

Dawson was no 'tenderfoot.' Although apparently of a fragile consitution and unfitted for arduous physical labour, his powers of endurance were remarkable. In one of his expeditions he covered a distance of 1300 miles by boat and a portage of 50 miles from the valley of the Liard to that of the Yukon. It may be that the love of Nature which led him to write—

> To rest on fragrant cedar-boughs
> Close by the western ocean's rim;
> While in the tops of giant pines
> The livelong night the sea-winds hymn,
> And low upon the fretted shore
> The waves beat out the evermore,—

combined with his extraordinary intellectual vigour and great determination, caused him to overtax his powers and shorten his valuable life.

To give a detailed account of his scientific work is impossible. Much of it will not be fully appreciated until the comparatively unknown tracts which he described so well become inhabited. His contributions are to be found in the Annual Reports of the Geological Survey of Canada, in our own Journal, in the 'American Journal of Science,' in the 'Canadian Naturalist,' and in many other publications. They are all characterized by lucidity and accuracy. He wrote freely but never carelessly, and all those who have followed him bear testimony to his thoroughness and reliability. His Reports are written from a scientific point of view, but they show a keen appreciation of the practical and economic side of geology and consequently command the attention of those who are actively engaged in developing the mineral resources of the country. A writer in the Victoria 'Colonist' says:—

> 'The development of the Kootenay, the hydraulic mines of Cariboo, and the gold-mines of the Yukon are all foretold in the interesting pages of Dr. Dawson's earlier reports. Therefore, when we find in the voluminous products of his pen anticipations of great mineral development in parts of the province that are yet unexplored, we feel almost as if such development were guaranteed.'

In July 1883 he was appointed Assistant-Director of the Geological Survey of Canada, and in 1895, on the retirement of Dr. Selwyn, he became Director and Deputy Head of the Department.

Although it is as a geologist that we commemorate him, it must not be forgotten that he was also a keen naturalist and an accomplished ethnologist. As one of the Commissioners appointed by Her Majesty Queen Victoria to prepare the British case for the arbitration on the Behring's Sea Fisheries, he visited the Northern Pacific and investigated the conditions of seal-life in that region. His services in connection with the arbitration were gracefully acknowledged by Lord Alverstone, who speaks of him 'as one of the most charming and unselfish characters' that he ever met. In recognition of these services Dawson was made a Companion of the Order of St. Michael & St. George.

He became a Fellow of this Society in 1875, and received the Bigsby Medal in 1891. He was elected a Fellow of the Royal Society of London in 1891, President of the Royal Society of Canada in 1894, and received the Gold Medal of the Royal Geographical Society of London in 1897. He was taken away from us most suddenly on March 2nd, 1901, after only one day's absence from his official post; but he has left behind a noble example of unselfish devotion to the cause of science.

The Hon. Clarence King was born at Newport (Rhode Island), and was educated in Yale University. He was best known to us in connection with the United States Geological Exploration of the Fortieth Parallel, of which he prepared the Geological and Topographical Atlas, published in 1876, and sundry reports. When in 1880 the several distinct surveys were consolidated as the United States Geological Survey, Mr. King was chosen as the first Director. He entered on these new duties with considerable enthusiasm, and as he was supported by an able staff, the investigations which he directed on Leadville in Colorado, on the Eureka district, and on the Comstock Lode in Nevada, were successfully carried out. Mr. King, however, found that administrative duties occupied so much of his time that he held office for a year only, and retired in 1881, when he was succeeded by Major J. W. Powell. Of late years Mr. King had not come prominently before the geological world, the only noteworthy contribution which he produced being an article on the age of the earth, which appeared in the annual report of the Smithsonian Institution for 1893. Mr. King became a Fellow of this Society in 1874. He died at Phœnix (Arizona) on December 24th, 1901. [H. B. W.]

Richard Pennefather Rothwell, born at Oxford (Ontario) on May 1st, 1836, was educated at Trinity College, Toronto, and the Rensselaer Polytechnic Institute of Troy (New York), where he graduated with honours in Civil Engineering in 1858. He subsequently passed through the complete course of study of the Ecole des Mines at Paris, and the practice of mining and ore-dressing at Freiberg. After a short period of service at Mr. Henlay's telegraph-cable works at North Woolwich, he returned to Canada, and subsequently established himself as a Mining Engineer at Wilkesbarre in the anthracite district of Pennsylvania, where he was for nearly ten years actively employed in laying out and improving the plant and machinery of different colliery-enterprises. In addition, he produced some remarkable coloured maps of the highly disturbed seams of the different coal-basins, which have become standard authorities for consultation on the opening of new workings, and have been adopted both by the United States Geological Survey and that of the State of Pennsylvania. He had a very thorough knowledge of the principles of colliery-ventilation and the methods of dealing with gas and underground fires, and on several occasions distinguished himself in the successful leading of rescue-parties after explosions and mine-fires. In 1874, with the co-operation of the late Mr. E. B. Coxes and Mr. M. Coryell, he inaugurated a movement which resulted in the formation of the American Institute of Mining Engineers, of which body he served as President in 1882. In 1874, he became joint editor, with Dr. R. W. Raymond, of the 'Engineering & Mining Journal' of New York, and shortly afterwards assumed the sole charge and proprietorship of that periodical, which, under his skilful guidance, has taken a prominent position among the technical journals of the world. A more remarkable enterprise was, however, started in 1893 under the title of the 'Mineral Industry: its Statistics, Technology, & Trade,' in which, year by year since that date, the whole field of the world's mineral production and its mining and metallurgical progress have been recorded in a manner that was entirely unparalleled in technical literature. Mr. Rothwell possessed in a high degree the power of interesting others in his work; and of this there can be no better evidence than the long list of eminent contributors from all countries whose monographs have appeared in the pages of the 'Mineral Industry.' His somewhat sudden death on April 17th, 1901, has left a gap among the leaders of technical literature which it will not be easy to fill. He had become a Fellow of this Society in 1897. [H. B.]

Geological science, especially in Nottinghamshire, has received a severe blow by the loss of Mr. James Shipman, whose tragically sudden death took place on November 21st last, at the age of 53 years. Owing to his extremely shy and retiring disposition, he was not so well-known outside his own locality as his great abilities and wide knowledge merited, for few men with equally restricted opportunities have done so much for local geology. While still a youth we find him attending the evening classes in geology at the Mechanics' Institution under the late Mr. Edward Wilson, in conjunction with whom he afterwards did much excellent work. His first published paper seems to have been 'On a Conglomerate at the Base of the Lower Keuper,' which appeared in the Geological Magazine for 1877; and this was followed at frequent intervals during the next 12 or 15 years by papers on the Triassic, Permian, and Carboniferous rocks of Nottinghamshire, the alluvial deposits of the Trent and Leen Valleys, the bone-caves of Cresswell Crags, etc. For several years before his first article appeared, however, he had been laboriously engaged in tracing and mapping the boundaries of the formations in and around Nottingham, and the results of his labours were incorporated in the second edition of the Geological Survey Map, issued in 1880, Mr. Aveling, in the accompanying Memoir, handsomely acknowledging the great assistance that he had derived from Mr. Shipman's work. In 1884 a large-scale geological map of the borough of Nottingham, by Mr. Shipman, was published by the Corporation as an Appendix to a Report of the Health Committee. He was elected a Fellow of the Geological Society of London in the following year.

It is hardly too much to say that for over 30 years not an excavation was made in Nottingham, whether for the foundations of a building, the construction of a sewer, new road, or railway, but Mr. Shipman might have been seen, note-book, tape-measure, and hammer in hand, carefully noting every variation in the strata, thickness and dip of the beds, direction and amount of throw of the faults, etc. Every boring for coal and water was visited time after time, the cores were carefully examined, and a detailed section of the borehole was drawn carefully to scale. No fact, however trifling, was deemed too unimportant for notice, and this extreme thoroughness and conscientiousness was the keynote of all his work.

Nor did he confine his attention to geology alone. The clearing away of condemned areas, the construction of new railways, and especially of the great Victoria Station, which have so profoundly changed the appearance of the centre of Nottingham during recent years, led to many archæological discoveries of the greatest interest and importance.

Not the least valuable part of Mr. Shipman's services to geology was the interest that he created in his favourite science among his fellow-citizens, and especially among working-men. He had long been a teacher at the Men's Sunday Morning Institute & Pleasant Sunday Afternoon Classes, and from these two bodies he gathered round him a band of men who formed themselves into a Saturday afternoon Rambling Club for outdoor work in geology. Of this Club he remained President and leader up to the last, preparing for the use of the members a set of beautiful maps and sections of the strata around Nottingham, which he had lithographed, and coloured by hand himself. Recently he drew up and published a coloured 'Table of the Stratified Rocks of the British Isles,' giving details of thickness, typical areas, conditions of deposit, characteristic fossils, etc., with a separate column on a larger scale showing the local (that is, the Nottinghamshire) development. He had been repeatedly urged to utilize his unrivalled knowledge in preparing a detailed work on the geology of Nottinghamshire, and it is believed that he had such a work in contemplation at the time of his death. It is greatly to be hoped that his papers have been left in such a condition that this desirable object may still be carried out.

Gentle as he was, self-effacing, and retiring to an unusual degree, only those who knew Mr. Shipman well were aware of the indomitable energy and industry which enabled him, in spite of scant leisure, straitened means, and health which was never robust, to accomplish an amount of work of which any man might have been proud. Among these his memory will long be cherished. [J. W. C.]

Information has only lately reached us of the death on December 9th, 1900, of the Rev. FREDERICK SMITHE, M.A., LL.D., vicar of Churchdown (Gloucestershire). Dr. Smithe, who belonged to an Irish family, was born in 1822 and educated at Trinity College, Dublin. He was presented to the living of Churchdown (or 'Chosen,' as it is locally pronounced) in 1858, and in the same year he was elected a Fellow of this Society. Residing, as he now did, on an outlier of the Middle and Upper Lias, these formations naturally attracted a large share of Dr. Smithe's attention, and he pursued his observations on Dumbleton Hill and elsewhere, the results being communicated to the Cotteswold Naturalists' Field Club. He discovered opercula of *Euomphalus* in the Wenlock Limestone on the borders of May Hill, and in addition to his studies on mollusca and brachiopoda, he contributed to the Proceedings of the Cotteswold Club papers on vivianite, celestite, and on the behaviour of granites when exposed to high temperatures.[1] [H. B. W.]

[1] Most of the above particulars are derived from the Presidential Address of Mr. E. B. Wethered to the Cotteswold Naturalists' Field Club, Proc. vol. xiv (1901) p. 2.

Prof. Ralph Tate, who was born in 1840 at Alnwick in Northumberland, was a nephew of George Tate, so well known in connection with the Berwickshire Naturalists' Club. After studying at the Cheltenham Training College and the Royal School of Mines, he received an appointment as teacher of natural science at the Philosophical Institution, Belfast. Here he devoted himself with great assiduity to a study of the natural history of the neighbourhood, and assisted in founding the Belfast Naturalists' Field Club. His researches on the Lias and on the Cretaceous rocks of Antrim were communicated to our own Society, and published in the Quarterly Journal. In 1864 he was appointed Museum Assistant to the Society (of which he had become a Fellow in 1861), and during three years worked chiefly at the Secondary fossils in our collections. One result of this was an important paper on the Secondary fossils from South Africa preserved in the Society's Museum.

In 1867 and 1868 he was occupied in exploring parts of Nicaragua and Venezuela for a mining company, and some of his observations were communicated to this Society. He was subsequently engaged in teaching, in the Trade & Mining School at Bristol. He now renewed his work on the Lias, and gave the results to this Society in a paper 'On the Palæontology of the Junction-Beds of the Lower & Middle Lias in Gloucestershire' Quart. Journ. Geol. Soc. vol. xxvi (1870).

In 1871 he became a teacher in the Mining School at Darlington, and afterwards at Redcar. Here he devoted his leisure-time to an exhaustive study of the Yorkshire Lias, and ultimately, in conjunction with the Rev. J. F. Blake, the well-known work on this subject was published. Meanwhile several geological papers had been written by Tate, notably those on the Lias about Radstock, and on the palæontology of Skye & Raasay, both of which added largely to our knowledge.

He had also prepared for Weale's Series a Rudimentary Treatise on Geology in two parts, the first of which was based on Portlock's excellent little work. He published, moreover, a valuable supplement to S. P. Woodward's 'Manual of the Mollusca.'

In 1875 Tate was appointed Elder Professor of Natural Science in the University of Adelaide (South Australia). This post he occupied until the close of his life. His time was now given mainly to a study of the Tertiary and recent fauna and flora of the colony, his observations extending into the Northern Territory during an expedition in 1882. The list of his scientific papers relating to Australia is a lengthy one, and this has lately been published.[1] He was the chief founder of the Royal Society of South Australia, and he was chosen President of the Australasian Association for the Advancement of Science in 1893.

He died on September 20th, 1901. [H. B. W.]

Although he had resigned his Fellowship a few years ago, it will not be inappropriate to refer to the death of Samuel Rowles Pattison, who joined the Society in 1839, and would have been one of our oldest Fellows, for he was born in 1809. In early years, when resident at Launceston, he worked at the geology of parts of Cornwall, communicating a number of papers to the journals of local societies. Both De la Beche and John Phillips, during their investigations on the rocks and fossils of the West of England, received help from Mr. Pattison, whose collection from the Upper Devonian Limestone of South Petherwin aroused much interest. In De la Beche's Report (p. 107) there is a sketch of a road-section near Launceston, made, in 1837, by him 'in company with Mr. Pattison, of Launceston, and Mr. Holl'—Dr. Harvey B. Holl.

To our Quarterly Journal (vol. x) Mr. Pattison contributed a paper on an auriferous quartz-rock at Davidstowe, in Northern Cornwall.

Throughout his long life he was a quiet and unostentatious worker at geology, although his time was greatly occupied in his profession as a solicitor. He served on our Council, and his legal knowledge was for many years of great service to us. He also took much interest in the Geologists' Association, of which body he was for a short time Treasurer.

In 1849 he published a little book entitled 'Chapters on Fossil Botany,' and he issued other works, some being pamphlets, on geology in its relation to Biblical records.

He died on November 27th, 1901, at the advanced age of ninety-two. [H. B. W.]

[1] See obituary notice by the Rev. J. F. Blake (Geol. Mag. 1902, p. 87). To this article and to the 'South Australian Advertiser' of Sept. 21st, 1901, we are indebted for many of the above particulars.

THE EVOLUTION OF PETROLOGICAL IDEAS.

Last year I selected as the subject of my address the evolution of petrological ideas during the nineteenth century, but considerations of time and space obliged me to confine my remarks to the igneous rocks. On the present occasion I propose to continue the subject, by treating of the sedimentary rocks and the crystalline schists from the same point of view.

The numerous and exacting duties which have devolved upon me in consequence of the change in my position have prevented me from giving that attention to the subject which its importance demands, and I have therefore to ask for your indulgence. What I have to offer to you must be regarded only as a brief and imperfect sketch.

Let us consider, first of all, the

Sedimentary Rocks.

The resemblance of many of the stratified rocks to the deposits formed in rivers, lakes, and seas was recognized at the beginning of the century; and the true principles by which their origin can be explained were clearly realized by Hutton and Playfair; but so long as the catastrophic theory of Cuvier and others dominated the world of geological thought, any great advance was impossible. The first volume of Lyell's 'Principles' appeared in 1830, the second in 1832, the third in 1833, and from that time onward the idea that observed facts, so far at least as the sedimentary rocks are concerned, must be explained by causes now in operation has influenced geological research and controlled geological thought in this country. The same idea spread more slowly in Germany, where its progress was retarded by the influence of Von Humboldt and Von Buch, and still more slowly in France, where the catastrophic theory of Cuvier was supported by Élie de Beaumont and Alcide d'Orbigny. But it finally prevailed, and the growth of our knowledge with regard to the sedimentary rocks became slow and sure. So far as we are in a better position than our ancestors, this is due to the fact that we have more knowledge of the chemical, physical, and organic processes involved; a deeper insight into the nature of the rocks themselves; and a better acquaintance with the deposits now in course of formation.

The growth of knowledge in each of these three departments has largely influenced the evolution of ideas, but to trace this influence in detail is obviously impossible within the limits of an address like the present. All that I can do is to call attention to the more salient features, and to illustrate my remarks by a few examples of exceptional interest or importance.

The great work on Chemical & Physical Geology by Gustav Bischof—the English translation of which appeared in 1854—marks an epoch in the history of our knowledge of the chemical and physical processes involved in the production of sedimentary rocks. It still remains a classic, for no writer since his time has combined the same knowledge of the facts of both chemistry and geology with the same powers of lucid exposition. He cannot, however, be regarded as a true prophet on all points, for in the preface to the English edition, after pointing out the necessity of further experimental research for the purpose of extending our knowledge of the processes concerned in the destruction, formation, and metamorphosis of rocks, he says :—

'The plutonic explanations, founded frequently on untenable hypotheses, will then retire more and more into the background, and at length vanish entirely out of science.'

But his pronounced neptunism detracts but little from the value of the work, for it is always possible to separate fact from theory, and, so far at least as the sedimentary rocks are concerned, his neptunism is not altogether out of place.

The striking feature of Bischof's original work lies in the fact that it consisted very largely of experimental research suggested and controlled by an intimate knowledge of the facts of geology. He has had but few followers ; nevertheless it is satisfactory to note that during recent years there has been a tendency to return to his methods. This is seen in such researches as those of Murray & Irvine 'On the Chemical Changes which take place in the Composition of the Sea-Water associated with Blue Muds on the Floor of the Ocean'[1] and 'On the Manganese-Oxides & Manganese-Nodules in Marine Deposits'[2]; of Van 't Hoff and his students on the conditions under which the Stassfurt salts were deposited ; and of various Russian observers[3] on the chemical, physical, and physiological processes involved in the formation of the deposits of the

[1] Trans. Roy. Soc. Edin. vol. xxxvii (1893) p. 481.

[2] *Ibid.* vol. xxxvii (1894) p. 721.

[3] Guide des Excursions du VII$^{\text{ème}}$ Congrès Géologique International (1897): No. xxix, 'La Mer Noire' by Prof. N. Andrussov.

Black Sea and its inlets. In the same category we must place the paper 'On the Origin of certain Concretions in the Lower Coal-Measures' recently communicated to this Society by Mr. Stocks.

At the beginning of the century but little was known as to the composition of the sedimentary rocks. The methods available for their examination were of a very primitive character, and wholly insufficient in many cases to supply the necessary data for ascertaining their mode of formation. The discovery and application of precise methods of chemical analysis, and the introduction of the microscope, have placed us in an entirely different position from that occupied by our ancestors. Just as Bischof's name stands out pre-eminently in the domain of chemical geology, so does that of Ehrenberg in the field of microscopic petrology as applied to sedimentary rocks. The proof which he supplied of the important part played by minute organisms in building up siliceous and calcareous deposits enormously enlarged our conceptions of the duration of geological time, and threw a flood of light on the conditions under which certain groups of stratified rocks have been formed. The work which he inaugurated was carried still farther by the introduction of the study of thin slices, and has been continued with uninterrupted success up to the present time. It is too well known to need more than a passing reference.

Much chemical and petrographical work has been done on sedimentary rocks: at the same time it is very small, in comparison with what remains to be done. Petrologists have been content for the most part to leave these rocks to the palæontologists, who have searched them for fossils with the greatest zeal, but who, in most cases, have had neither the time nor the inclination to pay attention to the structure and composition of the deposits. This is a misfortune, for it is only by a combination of petrographical, palæontological, and stratigraphical work that the natural history of the sedimentary rocks can be made out. In reading papers of the greatest stratigraphical importance, in which the distribution of fossils is described, and in studying the rocks in the field, I have often been much struck with the extreme meagreness of the published information as to the nature of the deposits and the mode of occurrence of the fossils. It is, perhaps, too much to expect one man to study these rocks from all points of view; and if so, the remedy must be found in co-operation, which is certainly becoming more and more necessary as the complexity of the problems increases. It must not, however, be forgotten that there are some notable exceptions to the general statement that I have just made. I may refer, for example, to the important paper by Gunnar Andersson on the Cambrian and Silurian phosphatic rocks of Sweden, to which I have directed attention in another place, and to the work of Cayeux, William Hill, and Hume on the French and English Chalk.

But, after all, it is to the increase in our knowledge of the sediments now in course of formation in depressions and hollows of the lithosphere, that the evolution of ideas is mainly to be attributed. So long as geologists were acquainted only with the deposits forming along sea-margins and in areas of open drainage, they were insufficiently supplied with the data necessary to enable them to investigate the natural history of many stratified deposits. Geographical and oceanographical exploration during the latter half of the century have greatly enlarged our conceptions, and given precision and definiteness to ideas that must otherwise have remained vague and uncertain.

We now know that ocean-basins and desert-regions are the principal areas of deposition, and that the rocks which are forming in both these areas have their geological representatives. Ocean-basins form the ultimate receptacle for the mechanical detritus washed down by rivers from areas of open drainage. This detritus, together with that worn from the coast-lines, is distributed by waves, tides, and currents along the margins of the continents in such a way that the coarser deposits are laid down near the shores, and the finer deposits out at sea. A narrow zone of shingle spreads along the shore, then a broader zone of sand, and, finally, a still broader zone of mud, generally blue, but sometimes red, where tropical rivers supply the sediments from regions in which the surface-weathering is of the lateritic type. The mechanical sediments shade into the organic, and these again into the abyssal red clays. Areas of open drainage have, as a rule, a moist climate, and the mechanical sediments deposited in the open ocean therefore represent the more or less insoluble residues of the crystalline rocks, and consist largely of such substances as quartz, mica, zircon, rutile, ilmenite, cyanite, hydrated aluminous silicates, and the oxides of iron and manganese. The soluble constituents—lime, magnesia, and the alkalies—may be carried to an indefinite distance from the land, and can only be separated by organic or chemical agencies.

Organisms are abundant, and their hard parts are often preserved in the deposits; moreover, the presence of organic matter exercises an important influence on the nature of the deposits. The work of Russian observers in the Black Sea, and that of Murray & Irvine, to which reference has already been made, is so suggestive and important from the latter point of view, that I make no apology for giving a brief account of it, especially as it introduces a new idea.

The surface-waters of the Black Sea contain free oxygen, and support an abundance of organic life; but the deeper and denser waters are charged with sulphuretted hydrogen, and the only organisms present are anaërobic bacteria. The amount of sulphuretted hydrogen increases with depth. At 100 fathoms there are 33 cubic centimetres in 100 litres, at 200 fathoms 222 c.c., and at 1185 fathoms 655 c.c. According to the researches of Zelinsky and Brussilovsky, the anaërobic bacteria play an important part in the chemical changes which result in the formation of sulphuretted hydrogen. Several bacteria have been observed, but one only *(Bacterium hydrosulphuricum ponticum)* has been studied in detail. This bacterium possesses the power of liberating sulphuretted hydrogen, not only from organic matter containing sulphur, but also directly from sulphates and sulphites; and the authors just named maintain that the whole of the sulphuretted hydrogen in the sea-water has been derived from the sulphates in this way. While accepting the view that a large part of the sulphuretted hydrogen has thus been formed, Prof. Andrussov believes that a portion of it is due to the putrefaction of the sulphur-bearing organic matter which falls from the surface into the deeper stagnant waters. But all are agreed that the sulphates of the sea-water are acted upon, and that as a final result sulphuretted hydrogen and carbonates are formed.

Changes of the opposite kind take place in the zone where the water containing sulphuretted hydrogen comes into contact with that containing oxygen. This zone occurs at a depth of about 200 fathoms. Here the sulphuretted hydrogen becomes oxidized, and sulphates are formed at the expense of carbonates. According to the researches of Yegunov and Vinogradski, the change is brought about by the so-called sulphur-bacteria. Like the iron-bacteria, which give rise to important deposits of bog-iron ore, and the nitrifying bacteria which produce saltpetre and probably assist in the decomposition of many rocks, these sulphur-bacteria derive the energy necessary for their existence from the oxidation of inorganic compounds. Sulphuretted hydrogen and carbonates are necessary for their existence. They separate sulphur in their cells in the form of soft oily globules, and the oxidation of this sulphur supplies the necessary vital energy, and converts the carbonate present into sulphate with the liberation of carbon-dioxide. Thus under anaërobic conditions, such as those which exist in the deeper portions of the Black Sea, carbonates are formed at the expense of sulphates, while under aërobic conditions, such as those which exist at a depth of about 200 fathoms in the same sea, sulphates are formed at the expense of carbonates.

The deposits found in the Black Sea are such as would be expected under these conditions. It is only in shallow water that oxides of iron and manganese are found. The deposits which underlie the deeper stagnant waters are analogous with the blue muds of the open ocean, from which they differ in containing a variable amount —in some cases over 40 per cent.—of amorphous carbonate of lime, and a much greater amount of sulphide of iron. The last-mentioned constituent is of special interest. It is found in all the deposits from 220 fathoms down to the greatest depths, usually as minute spherules, disseminated through the mud or deposited in the diatoms, but sometimes occurring as larger spherules or in elongated irregular forms suggestive of minute twigs. These observations throw important light on the origin of the pyritized diatoms of the London Clay, and the minute spherules and twig-like forms of pyrites so common in the washings of Kimmeridge and many other fine-grained argillaceous deposits.

In regions where there is a free vertical circulation the chemical conditions which prevail throughout the greater portion of the Black-Sea basin are found only in the deposits themselves, and chiefly in the blue muds, the waters of which often contain sulphuretted hydrogen. The chemical changes which go on both in and at the surface of these muds have been worked out in great detail by Murray & Irvine, and the results are published in the papers to which I have already referred. Iron and manganese are often found in solution in the head-waters of streams as carbonates, especially in those streams which drain peat-bogs; but they are soon thrown down as oxides on pebbles and other objects on the beds of the streams. These oxides may be rubbed off the pebbles, carried out to sea, and deposited along with the fine argillaceous material. Owing to the presence of organic matter in the blue muds, reduction takes place. The iron is fixed in the deposit as a sulphide, but the manganese-sulphide is decomposed by carbonic acid, which is necessarily present, thus giving rise to sulphuretted hydrogen and a soluble bicarbonate of manganese, which diffuses upward until it comes into contact with sea-water containing free oxygen. Here the manganese is thrown down, either at the surface of the deposit, or on any objects that may be lying exposed on the sea-bed. In this way the manganese-nodules so common in certain portions of the Clyde sea-area are accounted for. It will be noted that the reactions lead to a concentration of the manganese at the surface of the deposit, and to a chemical separation of manganese from iron.

My object in going into these details has been to show that recent oceanographical research has greatly enlarged our conceptions of the processes involved in the formation of marine sedimentary deposits, and that we may look forward to a rapid advance in knowledge when these deposits are examined in the same way and by the same methods as those to which I have referred.

But the natural history of our sedimentary formations requires for its elucidation, not only a study of the phenomena taking place in sea-basins and areas of open drainage, but also of those of desert-regions and areas of closed drainage. The recognition of this fact, by Ramsay and others between thirty and forty years ago, marks a distinct advance in the evolution of ideas. Our knowledge of the phenomena of desert-regions has been greatly increased since Ramsay wrote his suggestive papers, by the observations of Blanford, O. Fraas, Schweinfurth, Zittel, Richthofen, Walther, and others. Dr. Blanford's paper on the superficial deposits of Persia,[1] communicated to this Society nearly thirty years ago, gives us a vivid picture of the essential features of desert-regions. Vast plains of fine, pale-coloured, sandy earth, covered in places by shifting sand-dunes and often impregnated with salts; gentle slopes of gravel and boulders with a surface-inclination of from 1° to 3°, reaching upward from the borders of the plains towards the high ground, and often attaining a width of from 5 to 10 miles; and broad valleys choked with débris debouching on the plains. It is a picture of an old, uneven land-surface, which is being slowly buried under its own ruins.

Of late years Prof. Walther has made a special study of desert-regions from a geological point of view, and his fascinating book, 'Das Gesetz der Wüstenbildung,' based on personal observations in the deserts of Egypt, Arabia, Turkestan, and North America, must be read by all those who desire to realize the conditions under

[1] Quart. Journ. Geol. Soc. vol. xxix (1873) p. 493.

which our great continental formations, such as the Torridonian, the Old Red Sandstone, and the Trias, have originated.

Deserts and areas of closed drainage, like ocean-basins, are the receptacles for the detritus worn from the surrounding lands; but the phenomena of denudation and deposition are widely different in the two cases. Dry weathering, torrential rains, and wind are the three most potent agents in arid climates, and by their combined action inland rock-basins of vast extent become filled with enormous accumulations of detrital material. The violent extremes of temperature not only detach fragments from every exposed surface, but often loosen the constituents of crystalline rocks, so that at the slightest touch a piece of apparently solid granite will crumble into sand, leaving the felspars as fresh as when they formed a part of the original rock.

Cloud-bursts follow at intervals of months or years, and the vast accumulations of detritus of all kinds, both large and small, mingling with the waters, are swept along in one tumultuous flood and spread out over the plains in extensive flat fans. The action is so sudden and catastrophic, that there is no time for that careful sorting of materials according to size and specific gravity, which takes place during the formation of marine deposits. Sand-dunes wander over the plains, and cover up the coarse breccias and conglomerates formed by the torrential rains, and then follows another cloud-burst.

Wind sweeps the deserts free from dust, and spreads it far and wide over the surrounding districts to form, under favourable circumstances, the thick beds of lœss with which Richthofen has familiarized us.

But areas of closed drainage are not entirely desert. The rainfall may be sufficient to form temporary or permanent streams ending in salt-marshes, salt-lakes, or inland seas which may contain the dwarfed relics of a marine fauna, rich in individuals but poor in species, and give rise to the formation of beds of rock-salt and gypsum, such as those with which the geologist is familiar.

Thus geographical and oceanographical researches during the latter half of the century, combined with a study of the stratified rocks, have brought into prominence the contrast between continental and marine formations, and have familiarized us with the different 'facies' of these two strongly contrasted types. We can now picture to ourselves the onward sweep of the sedimentary zones, as the sea slowly advances upon the land and deposits its sediments upon a plain of marine denudation, and the gradual disappearance of the inequalities of an area of closed drainage beneath terrestrial accumulations of enormous thickness, represented by lœss, sand-dunes, dry deltas, screes, and the subaqueous deposits of salt-lakes. If similar conditions prevailed in the past, two strongly contrasted types of unconformity may be expected to occur: one characterized by marine deposits resting on a plain of denudation, and the other by continental formations resting on an old uneven land-surface. The North-west of Scotland and the South-west of England present us with admirable examples of both types of unconformity. The base of the Torridonian is an old, uneven land-surface, whose mountains and valleys lie buried under huge accumulations of sandstone, conglomerate, and breccia; but the base of the Cambrian is a smooth plain, whose inequalities are due to the later earth-movements. Similarly, in the West of England the base of the New Red Sandstone is uneven, whereas that of the marine Cretaceous is smooth and approximately horizontal.

The point at which we have arrived may now be briefly summarized. The sedimentary rocks form a well-defined natural group. They arise in consequence of complex chemical, physical, and organic processes, depending on reactions between the hydrosphere and atmosphere on the one hand and the lithosphere on the other.

Crystalline Schists and Metamorphic Rocks.

I now approach the most difficult portion of my task—that which deals with the history of opinion on metamorphic rocks and the crystalline schists. It is scarcely possible even to enumerate all the diverse views that have been expressed as to the origin of the crystalline schists. Some geologists have maintained that they are portions of the original primitive crust; others that they are chemical precipitates from a primordial ocean; others that they are the result of a peculiar kind of metamorphosis, diagenesis, acting on the chemical precipitates of such an ocean; others that they are due to metamorphic processes operating upon ordinary sediments without seriously disturbing, or in any way obliterating, the original order of stratification; and others that they are the result of dynamic and thermal agencies affecting complex systems of igneous and sedimentary rocks. On looking back at the nineteenth century we see all these ideas, and many others, struggling for existence. Natural selection has been at work, to the detriment, as it seems to me—and I make no claim to the position of impartial historian in this matter,—of all those theories that would explain the crystalline schists by reference to physical conditions essentially different from those which have prevailed during successive geological periods.

Most of the earlier ideas were based on the assumption that the crystalline schists form a natural group, whose origin must therefore be explained by some comparatively simple hypothesis; but the detailed researches of the later decades have shown that this assumption is wrong. It is now generally recognized that these rocks present us with structural and petrographical problems of great complexity. Excluding the gneisses of igneous origin, which form a large portion of the group, I believe that the other rocks may for the most part be classed as rocks of either mixed or metamorphic origin. I propose, therefore, to limit my remarks almost entirely to the growth of ideas on the subject of metamorphism.

Hutton's 'Theory of the Earth' (vol. i, pp. 375–76) contains this remarkable passage. I have quoted it before, but it will bear repetition:—

'If, in examining our land, we shall find a mass of matter which had evidently been formed originally in the ordinary manner of stratification, but which is now extremely distorted in its structure, and displaced in its position,—which is also extremely consolidated in its mass, and variously changed in its composition,—which therefore has the marks of its original or marine composition extremely obliterated, and many subsequent veins of melted mineral matter interjected; we should then have reason to suppose that here were masses of matter which, though not different in their origin from those that are gradually deposited at the bottom of the ocean, have been more acted upon by subterranean heat and the expanding power, that is to say, have been changed in a greater degree by the operations of the mineral region. If this conclusion shall be thought reasonable, then here is an explanation of all the peculiar appearances of the Alpine schistus masses of our land, those parts which have been erroneously considered as primitive in the constitution of the earth.'

Hutton made no attempt to frame a classification of rocks in accordance with his theory; but this was done some forty years later by Lyell, who crystallized the main ideas which are expressed in this paragraph in the one word, metamorphic.

Modern ideas on the subject of metamorphism have been slowly elaborated by a long course of observation and experiment. Sir James Hall was the first to realize the value of experiment for the purpose of verification. Hutton's theory required that ordinary limestone should pass into crystalline marble under the combined influence of heat and pressure. Hall enclosed the powder of limestone in hermetically sealed tubes and proved that this actually took place. It was a laborious research extending over many years, and involving more than 500 experiments. He sums up his results as follows:—

'By this joint action of heat and pressure the carbonate of lime, which had been introduced in the state of the finest powder, is agglutinated into a firm mass, possessing a degree of hardness, compactness, and specific gravity, nearly approaching to these qualities in a sound limestone; and some of the results by their saline fracture, by their semi-transparency, and their susceptibility of polish, deserve the name of marble. The same trials have been made with all calcareous substances; with chalk, common limestone, marble, spar, and the shells of fish.'[1]

But Hutton's theory, even after this striking verification by Hall, attracted little attention until it was resuscitated by Lyell. Then it began to spread. In 1856, 'The Metamorphism of Rocks' was made the subject of the Bordin Prize by the Academy of Sciences of Paris, and two years later the award was made to Daubrée, whose classic essay contains an account of the celebrated experiments on the effect of superheated water and saline solutions on glass, obsidian, and other substances.

The growth of ideas on the subject of metamorphism has, however, been mainly determined by observation, and especially by the study of the effects produced in connection with the intrusion of masses of molten material. Here, again, the example was set by Sir James Hall. In his remarkable paper on 'The Vertical Position & Convolutions of certain Strata & their Relation with Granite,'[2] he says:—

'The quality of this stratified mass [the Lower Palæozoic formations of the Southern Uplands of Scotland], from one side of the island to the other, seems to be uniform throughout, except in the immediate neighbourhood or contact of the granite, where it assumes a micaceous character, approaching to the nature of gneiss or mica-slate. This furnishes a most notable indication of the action of heat, since the granite, by its local intensity, has performed the very effect which Dr. Hutton ascribes to the general heat below, as acting upon the lower beds, and converting them into gneiss.'

An immense amount of information as to the phenomena accompanying the intrusion of igneous rocks has been gained since Hall's time. Innumerable granite-masses have been mapped, and the contact-rocks have been examined by modern petrographical methods. We are now familiar with the changes which take place in limestones, dolomites, slates, sandstones, cherts, greywackes, diabases, andesites, and many other kinds of sedimentary and igneous rocks

[1] Trans. Roy. Soc. Edin. vol. vi (1805) p. 95.
[2] *Ibid.* vol. vii (1812) pp. 106–107.

as granite-margins are approached. In areas like the Lake District and the Vosges, where the contact-phenomena have been so well described by Ward and Rosenbusch, granite was intruded into folded sediments after the folding-stresses had ceased to act. There is no appreciable change in the chemical composition of the sediments. The rocks are simply crystallized.

But the contact-effects are not always so simple as in these cases. The intrusive origin of many gneisses advocated long ago by Scrope and Darwin is now universally accepted. Any comparative study of contact-areas, therefore, must not be limited to granite-contacts, it must take into consideration also the phenomena associated with the intrusion of gneiss. Now, it is precisely by this comparative study of contact-areas that our ideas on the subject of metamorphism have been so greatly enlarged during the last decade of the century. The principle is one which has been applied with success in other branches of geology. It consists in studying a denudation-series. We cannot artificially prepare horizontal sections of the earth's crust, so as to reveal the structure of a mass at different levels; but Nature has furnished us with a series of such sections in different areas, and by piecing these together in the proper order we can give an insight into the phenomena which belong to the deeper zones. The importance of this principle has been strongly emphasized by M. Michel Lévy, and applied by Prof. Barrois with most interesting results to the various granite-masses of Britanny.

In connection with work of this kind a question of great importance has arisen: namely, the extent to which mixed rocks—or mictosites, as they may be called, if a special term be thought desirable—are produced. Although in many cases, especially those which belong to the higher levels, there is a sharp contrast between the intruding rock and that into which the intrusion has taken place, in others the contrast is less marked, and hand-specimens may be obtained which are neither igneous nor sedimentary, but a mixture of the two. I may illustrate the point by a case which came under my own observation—that of a cordierite-gneiss from Aberdeenshire. The igneous portion of the rock is composed of oligoclase, biotite, micropoikilitic orthoclase, and quartz; the sedimentary portion of cordierite, quartz, biotite, sillimanite, iron-ores, and a green spinel. The sedimentary rock into which the granite-magma was intruded is now represented by somewhat ill-defined shreds, patches, and streaks, in a paste of igneous origin. M. Michel Lévy recognizes two types of intermixture: the one taking place by superposition, the other by injection *lit par lit*. In the former type the impregnation is of a most intimate character, so that there is no distinct separation of the two elements; in the latter type the compound rock consists of alternating folia of granite and sedimentary material. Excellent examples of *lit-par-lit* injection have been described by Messrs. Horne & Greenly in their joint paper 'On Foliated Granites & their Relations to the Crystalline Schists in Eastern Sutherland.'[1] Prof. Lehmann's 'injected mica-schists' (Injicirte Glimmer-schiefer) illustrate the same point.

But mixed rocks may also be formed by the injection of one kind of igneous rock with another. Basic rocks are often seen to be veined and brecciated by acid material, and the gradual passage of such complex masses into banded gneisses under the influence of differential movement has been described by Prof. Lawson, myself, Messrs. Bonney & Hill, and many other observers. Prof. Sollas greatly enlarged our conceptions as to this class of phenomena by his important paper on the relations of the granite and gabbro of Barnavave in the district of Carlingford; and the same ideas have still further been expanded by Mr. Harker, Prof. Cole, and Mr. Parkinson. We now know that the surrounding rocks may, under certain circumstances, be disintegrated and the fragments (xenoliths) and individual minerals (xenocrysts) so uniformly distributed through the invading magma as to produce mixed rocks on a large scale. We are also asked to believe that the process of absorption may proceed still further, and give rise to magmas of intermediate composition, which in the solidified form may contain no visible evidence of the manner in which they have been produced.

Any account of the evolution of ideas on the subject of contact-metamorphism would be incomplete, without a reference to deep-seated fumarole or pneumatolytic action. Exhalations of boracic, hydrofluoric, and hydrochloric acids have often produced important effects, as shown in the development of such minerals as tourmaline, topaz, axinite, datolite, and scapolite in the surrounding rocks.

In the simplest cases of igneous contacts the intrusions have taken place after the folding movements have ceased, and the contact-minerals sometimes contain records of these earlier movements in the arrangement of the inclusions; but, in other cases, there is evidence of intrusion while these movements were still going on. The plutonic rocks, the mixed rocks, and the surrounding metamorphic rocks may then receive a common foliation. The

[1] Quart. Journ. Geol. Soc. vol. lii (1896) p. 633.

effects of the intrusion of a plutonic magma under the influence of the stresses involved in mountain-building have recently been discussed by Dr. Weinschenk,[1] who has suggested that the presence of such minerals as epidote and zoisite in some of the central gneisses of the Alps may be due to crystallization under these conditions, or, as he terms it, to piezo-crystallization.

I have now to refer to what is generally termed dynamometamorphism. The idea may be said to have originated with the mechanical theory of cleavage. This theory was definitely established by the observations of Bauer (1846) and Sharpe (1847), and by the experiments of Sorby (1853), Tyndall (1856), and Daubrée (1861). Sharpe and Darwin connected foliation with cleavage; but Lossen (1867) was, I believe, the first to introduce the idea that holocrystalline schists may be produced by the deformation of rocks under the influence of earth-stresses. Lossen employed the term dislocation-metamorphism, which has since almost entirely disappeared in favour of Rosenbusch's term dynamometamorphism. Now it must always be remembered that both these terms are somewhat ill-chosen to express the views of those who are mainly responsible for the development of the idea. They emphasize only one of the two great physical agents involved in the production of crystalline schists, and convey the impression that heat is excluded. Yet in Lossen's paper on the crystalline schists of the Taunus the action of heat in the presence of water is expressly invoked, the mechanical theory of heat is referred to, and it is pointed out that if work is done on rocks the temperature must be raised. Again, Prof. J. Lehmann, who has perhaps done more than anyone else to extend the idea, has pointed out that the deformations usually take place under plutonic conditions, and therefore at temperatures above those which prevail at the surface.

The point that I am endeavouring to emphasize can be well illustrated by a reference to the recent experimental researches of Messrs. Adams & Nicolson on the flow of marble.[2] These authors have definitely proved that, when marble is deformed at ordinary temperatures by differential pressures exceeding the elastic limit of the rock, the flow is due partly to a crushing of the individual constituents and partly to a change in their forms brought about by

[1] 'Mémoire sur le Dynamométamorphisme & la Piézocrystallisation Comptes-rendus du VIIIème Congrès Géol. Internat. (1900) p. 326.

[2] Phil. Trans. Roy. Soc. vol. cxcv (1901) A, pp. 363–401.

twinning and gliding—that is without crushing; but that, when the deformation takes place at about 400° C., no cataclastic structures are produced, the whole of the movement being due to twinning and gliding. It would perhaps clear the air if, instead of speaking of dynamo-metamorphism when treating of the origin of certain crystalline schists, we were to employ the term thermodynamic metamorphism. At any rate, the reference to rocks which have been powerfully affected by dynamic action and yet not crystallized, as well as to others which are holocrystalline and devoid of cataclastic structure, would be seen at once to have no bearing whatever on the theory which Lossen, Lehmann, and others have advanced. The fundamental conception underlying this theory is that solid rocks, such as gneiss, granite, quartzite, and limestone, may undergo deformation—may be folded, kneaded, and stretched like wax or clay under the influence of the earth-stresses, without ever passing into the magmatic condition. The observations of Baltzer, Heim, Reusch, Lehmann, Lapworth, and many others have placed this fact beyond all possibility of doubt. Prof. Lehmann's work must for ever remain a classic, so far as this subject is concerned, on account of the wonderful atlas of photographs with which it is illustrated. Words are after all but a poor substitute for the facts of Nature, and sketches not unfrequently illustrate the views of the author or the artist, rather than the objects which they are intended to represent; but a properly taken photograph often shows almost as much as the object itself, and gives the reader an opportunity of judging of the correctness of the author's conclusions. The photographic illustrations accompanying Lehmann's work enable the facts to speak for themselves.

The deformation of a rock-mass can only be produced by a relative movement of some, or all, of its parts. Two extreme cases may arise: the strain may be distributed throughout a considerable mass of rock, in which case the microscopic character of the rock will be altered; or it may be localized along special planes, in which case the parts enclosed between these different planes will retain their original characters. At first sight, it appears as if there were a radical difference between these two types of deformation; but, as a matter of fact, we find in Nature a most perfect gradation between them. Deformation of the first type is usually referred to as plastic deformation, although the use of this expression is not intended to imply that the individual minerals have changed their form without changing their character or losing their individuality;

all that it implies is that the change in the shape of the rock-mass is not due to the formation of visible cracks.

The microscopic examination of rocks which have been subjected to plastic deformation has thrown great light on the nature of the process. In some cases, it is due to a re-arrangement of the mineral particles, as in certain slates; in others, it is due to fracture and trituration of the constituent minerals, as in the rocks for which Prof. Lapworth has proposed the term mylonite; and in others it is accompanied or followed by recrystallization, as in the typical granulites, granulitic gneisses, and phyllites. It is quite possible that deformation at ordinary temperatures has never produced holocrystalline schists.

How far will the ideas to which I have briefly referred furnish us with an explanation of the origin of the crystalline schists? Thermometamorphism will not account for the facts, neither will dynamic metamorphism; but if we combine the two ideas, and recognize the fact that thermodynamic metamorphism may be associated with the intrusion of molten mineral matter and the formation of mixed rocks, we find ourselves in possession of a powerful intellectual weapon wherewith to attack many problems connected with this puzzling group.

In saying this, however, I am far from wishing to imply that our stock of ideas is sufficient to enable us to deal in a satisfactory manner with the rocks in question. It is quite impossible to wander over extensive regions composed of crystalline schists, without feeling the inadequacy of current theories. Our ideas will change and new ideas will arise, but there is every reason to hope that these petrographical hieroglyphics, as they have been termed, will ultimately be read as easily as we now read the records of the stratified rocks.

My duties as your President are over. I thank the officers, who have rendered my task an easy one, and I thank you all for the honour which you conferred upon me two years ago, as well as for the support which you have accorded to me during my term of office.

February 26th, 1902.

Prof. Charles Lapworth, LL.D., F.R.S., President, in the Chair.

Edwin Walter Bonwick, Esq., c/o Messrs. Bewick, Moreing & Co., Palmerston Buildings, Auckland (New Zealand), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On some Gaps in the Lias.' By Edwin A. Walford, Esq., F.G.S.

2. 'On the Origin of the River-System of South Wales, and its Connection with that of the Severn and Thames.' By Aubrey Strahan, Esq., M.A., F.G.S.

The following specimens, etc. were exhibited:—

Specimens and Microscope-Sections, exhibited by Edwin A. Walford, Esq., F.G.S., in illustration of his paper.

Lantern-Slides, exhibited by Aubrey Strahan, Esq., M.A., F.G.S., in illustration of his paper.

Eleven Photographic Platinotype Portraits (Cabinet size) of Fellows of the Society, presented by Messrs. Maull & Fox.

March 12th, 1902.

Sir Archibald Geikie, D.C.L., LL.D., F.R.S., Vice-President, in the Chair.

Edward Margrett, Esq., The Firs, Hamilton Road, Reading, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The Rev. H. H. Winwood thanked the Chairman for allowing him to introduce the water-colour drawings by his friend, Miss Breton, of some of the grandest cañons in North America. The geological accuracy of the drawings might be attributed to the fact that Miss Breton was the daughter of an old Fellow of the Geological Society.

The following communications were read :—

1. 'The Crystalline Limestones of Ceylon.' By Ananda K. Coomára-Swámy, Esq., B.Sc., F.L.S., F.G.S.

2. 'On some of the Proterozoic Gasteropoda which have been referred to *Murchisonia* and *Pleurotomaria*, with Descriptions of New Subgenera and Species.' By Miss Jane Donald. (Communicated by J. G. Goodchild, Esq., F.G.S.)

Besides the water-colours mentioned on p. lxxix, the following specimens were exhibited :—

Rock-Specimens, Microscope-Sections, and Lantern-Slides, exhibited by A. K. Coomára-Swámy, Esq., B.Sc., F.L.S., F.G.S., in illustration of his paper.

Specimens and Casts, exhibited in illustration of the paper by Miss Jane Donald.

March 26th, 1902.

Prof. Charles Lapworth, LL.D., F.R.S., President, in the Chair.

Edgar Lines, Esq., Civil Engineer, Chesterfield, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On a Remarkable Inlier among the Jurassic Rocks of Sutherland, and its Bearing on the Origin of the Breccia-Beds.' By the Rev. John Frederick Blake, M.A., F.G.S.

2. 'On a Deep Boring at Lyme Regis.' By Alfred John Jukes-Browne, Esq., B.A., F.G.S.

The following specimens, etc. were exhibited :—

Lantern-Slides, exhibited by the Rev. J. F. Blake, M.A., F.G.S., in illustration of his paper.

Photographs of the Upper Jurassic Beds of Sutherland, taken by Mr. R. Lunn, and exhibited by the Director of H.M. Geological Survey.

Cores from the Boring at Lyme Regis, obtained through Mr. A. C. Pass, and exhibited by the Director of H.M. Geological Survey, in illustration of the paper by A. J. Jukes-Browne, Esq., B.A., F.G.S.

April 16th, 1902.

Prof. CHARLES LAPWORTH, LL.D., F.R.S., President, in the Chair.

James Grundy, Esq., Inspector of Mines for the Government of India, 27 Chowringhee Road, Calcutta; and Frank Parkin, Esq., The Limes, 5 Sherwood Rise, Nottingham, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Carlisle Earthquakes of July 9th & 11th, 1901.' By Charles Davison, Sc.D., F.G.S.

2. 'The Inverness Earthquake of September 18th, 1901, and its Accessory Shocks.' By Charles Davison, Sc.D., F.G.S.

3. 'The Wood's Point Dyke, Victoria (Australia).' By Frederic Philip Mennell, Esq., F.G.S.

A Photograph of a Ruined House was exhibited, in illustration of Dr. C. Davison's paper on the results of the 1901 earthquake at Inverness.

April 30th, 1902.

Prof. CHARLES LAPWORTH, LL.D., F.R.S., President, in the Chair.

John Dampier Green, Esq., Johannesburg (Transvaal); Everard Heneage, Esq., Marlborough Club, London; Edwin Sloper, Esq., 26 Wolseley Road, Crouch End, N.; and George Frederick Herbert Smith, Esq., British Museum (Natural History), Cromwell Road, S.W., were elected Fellows; and Prof. Thomas Chrowder Chamberlin, of Chicago; Dr. Thorvaldr Thoroddsen, of Reykjavik (Iceland); and Prof. Samuel Wendell Williston, of the University of Kansas, Lawrence (Kan.), were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

Mr. J. E. MARR exhibited some specimens from a Metamorphosed Metalliferous Vein several inches wide, which he had discovered in the basic andesites near the Shap Granite, in a quarry close to the high road, north of the spot where it crosses Longfell Gill.

The minerals of the vein include quartz, calcite, garnet, epidote, hornblende, galena, iron-pyrites, and copper-pyrites. Some of the garnets are about an inch in diameter. The epidote and the hornblende tend to form distinct bands on the margin of the vein. The other metamorphic phenomena recall those described by the exhibitor and Mr. Alfred Harker, in the case of large vesicles occurring in the same rocks.

The specimens are of interest as showing:—

(i) The existence of metalliferous veins in Ordovician rocks which have been formed in pre-Carboniferous times; for the Shap Granite which has produced the alteration is itself pre-Carboniferous.

(ii) The alteration of a metalliferous vein of complex composition by pyrometamorphism,—an occurrence which the exhibitor believed had not previously been recorded.

(iii) The possibility that some of the highly crystalline rocks of a complex of regionally metamorphosed rocks may owe their characters to hydrothermal action having formed veins along the parallel divisional planes of pre-existing rocks, these veins having been subsequently altered by pyrometamorphism.

Mr. H. W. Monckton exhibited a Flint-Implement which he had himself found on a heap of gravel, in a pit 278 feet above Ordnance-datum, at Englefield (Berkshire). The gravel is part of an elongated patch mapped 'Plateau-Gravel.' He had great pleasure in handing over the implement to Mr. O. A. Shrubsole, F.G.S., to be placed in the Reading Museum.

Mr. O. A. Shrubsole remarked that the implement was of palæolithic type, and of an advanced form of that type, as it had a cutting-edge all round. It had not been greatly rolled, and was probably made not far from the spot where it was found. Its patination showed that it belonged to the gravel in which it was found.

The following communications were read:—

1. 'The Origin and Associations of the Jaspers of South-eastern Anglesey.' By Edward Greenly, Esq., F.G.S.

2. 'The Mineralogical Constitution of the Finer Material of the Bunter Pebble-Bed in the West of England.' By Herbert Henry Thomas, Esq., B.A., F.G.S.

3. 'Revision of the Phyllocarida from the Chemung and Waverly Groups of Pennsylvania.' By Prof. Charles Emerson Beecher, Ph.D., F.C.G.S.

In addition to those mentioned above, the following specimens, etc. were exhibited:—

Rock-Sections, Lantern-Slides, Photographs, and Maps, exhibited by E. Greenly, Esq., F.G.S., in illustration of his paper: including Playertype Photographs of 6-inch Field-Maps of the Pentraeth and Newborough districts, and original 25-inch Maps of part of the latter district.

Rock-Sections and Lantern-Slides, exhibited by H. H. Thomas, Esq., B.A., F.G.S., in illustration of his paper.

Teeth of *Lamna*, from near the base of the Thanet Sands, Erith (Kent), exhibited by Prof. H. G. Seeley, F.R.S., V.P.G.S.

Palæolith from Welwyn (Hertfordshire), exhibited by A. E. Salter, Esq., B.Sc., F.G.S.

May 14th, 1902.

Prof. Charles Lapworth, LL.D., F.R.S., President, in the Chair.

George Steuart Corstorphine, B.Sc., Ph.D., Director of the Geological Survey of Cape Colony, South African Museum, Cape Town; Alfred William Oke, Esq., B.A., LL.M., 16 Bedford Row, W.C., and 8 Cumberland Place, Southampton; and Arthur Peacock, Esq., Smithies Bridge House, Heckmondwike (Yorkshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The President referred in feeling terms to the recent calamitous occurrences in the West Indies, and to the geological interest of the phenomena. The Council had been considering in what way they could best give expression to the sympathy of the Fellows, both with our own Colonies and with their French neighbours, and had requested Sir Archibald Geikie and himself to act as they thought best in the matter.

Prof. Boyd Dawkins moved that the Fellows express their sympathy with the sufferers in the two islands, and approve the action taken by the Council.

Mr. H. W. Monckton seconded the motion, which was carried.

The following communications were read:—

1. 'On Pliocene Glacio-Fluviatile Conglomerates in Subalpine France and Switzerland.' By Charles S. Du Riche Preller, M.A., Ph.D., A.M.I.C.E., M.I.E.E., F.G.S.

2. 'Overthrusts and other Disturbances in the Braysdown Colliery (Somerset), and the Bearing of these Phenomena upon the Effects of Overthrust-Faults in the Somerset Coalfield in general.' By Frederick Anthony Steart, Esq. (Communicated by Horace B. Woodward, Esq., F.R.S., F.G.S.)

The following specimens and map were exhibited:—

Specimens exhibited in illustration of the paper by F. A. Steart, Esq.

Sheet 21 of the 1-inch Map of the Geological Survey of Scotland—Arran, presented by the Director of H.M. Geological Survey.

May 28th, 1902.

Prof. CHARLES LAPWORTH, LL.D., F.R.S., President, in the Chair.

Cecil Wray, Esq., 12 South Hill Park Gardens, Hampstead, N.W., was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following specimens were presented :—

Two Microscope-Sections of Altered Siliceous Sinter from Builth (Brecknockshire), presented by Frank Rutley, Esq., F.G.S.

Sample of Volcanic Ash collected in Barbados, on May 7th–8th, 1902, presented by Dr. D. Morris, C.M.G., of the Imperial Department of Agriculture for the West Indies.

The PRESIDENT reported that in consonance with the resolution passed at the previous Meeting of the Fellows, he and Sir Archibald Geikie had forwarded letters to the French Minister of the Colonies and to H.M. Secretary of State for the Colonies, expressive of the sympathy of the Geological Society with the sufferers from the volcanic catastrophes in Martinique and St. Vincent.

The SECRETARY read the following letter regarding the recent fall of volcanic ash in Barbados, and reported that the thanks of the Council had been conveyed to the writer :—

'Imperial Agricultural Department
for the West Indies, Barbados,
9th May, 1902.

'DEAR SIR,

'I am sending you by this mail a small quantity of the volcanic ash that fell at Barbados soon after the volcanic eruption at St. Vincent on Wednesday last. I am also sending you newspaper reports, and you will obtain practically all particulars from them. There is a note about the ash in the 'Agricultural News' giving an estimate of the quantity per acre that fell in this island. It is singular that the circumstances correspond so exactly with what took place in 1812. Fortunately, within 4 hours after the fall of the ashes, we have had drenching showers which have, to a great extent, washed the ashes from the roofs of the dwellings and from vegetation, and also laid the dust which during yesterday was most trying and uncomfortable. The roads are still covered with a sandy coating, which is not at all muddy or sticky. Naturally, the chemical composition of the ash is of great interest to the planters, as it may have an appreciable effect on next year's crops. The old canes have nearly all been reaped, and the young canes are in such a condition that they should largely benefit by any fertilizing properties that may be in the ash. In the case of the ash that fell in 1812, Davy is said to have found it to contain silex, alumina, oxide of iron, and oxide of manganese. I noticed that the ash at first was rather coarse and of a brownish colour, then it became slightly redder, while the final deposits consisted of a whitish-grey, impalpable powder. I shall send you any further particulars that may come to hand.'

'With kind wishes, believe me,
Sincerely yours,
(Signed) D. MORRIS.'

'The SECRETARY,
Geological Society,
Burlington House,
Piccadilly, London.'

Prof. W. Boyd Dawkins exhibited a series of Photographs and Specimens of Sandworn Pebbles, collected by Lady Constance Knox in New Zealand. The district in which the specimens occur is near the coast of North Island, in the neighbourhood of the River Waitotara, on a tableland about 250 feet above sea-level:—

'On this tableland, above high cliffs, are rolling sand-dunes, which are continually shifting with every storm, and extend for several miles along the coast; among them are to be found interesting kitchen-middens. Directly inland from the sand-dunes is the district covered with sandworn stones, extending over an area of some miles. At first these stones are few and scattered, but they are found to increase in number as one approaches the Waitotara River. Projecting from the surface are masses of stratified rock, composed of shell-conglomerate: these also have been worn by the wind.'

The following communications were read:—

1. 'The Red Sandstone-Rocks of Peel (Isle of Man).' By William Boyd Dawkins, M.A., D.Sc., F.R.S., F.G.S., Professor of Geology in Owens College (Victoria University), Manchester.

2. 'The Carboniferous, Permian, and Triassic Rocks under the Glacial Drift in the North of the Isle of Man.' By William Boyd Dawkins, M.A., D.Sc., F.R.S., F.G.S., Professor of Geology in Owens College (Victoria University), Manchester.

3. 'Note on a Preliminary Examination of the Ash that fell on Barbados, after the Eruption at St. Vincent (West Indies).' By John Smith Flett, M.A., D.Sc., F.R.S.E., F.G.S. With a Chemical Analysis by William Pollard, M.A., D.Sc., F.G.S.

In addition to the specimens mentioned above, the following were exhibited:—

Rock-Specimens, Lantern-Slides, Microscope-Sections, and Fossils, exhibited by Prof. W. Boyd Dawkins, M.A., D.Sc., F.R.S., F.G.S., in illustration of his papers on the Isle of Man.

Specimens from the Peel Sandstone, collected by G. W. Lamplugh, Esq., F.G.S., exhibited by the Director of H.M. Geological Survey.

A Sample of Volcanic Ash collected in Barbados, May 7th–8th, 1902, exhibited in illustration of Dr. J. S. Flett's paper.

June 11th, 1902.

Prof. Charles Lapworth, LL.D., F.R.S., President, in the Chair.

William Edwards, Esq., Bryn End, Ruabon (North Wales); George Law Mackenzie, Esq., Craigweil, Ayr (N.B.); John Fossbrook Morris, Esq., B.E., Gwendoline Mine, Unsan, *via* Chemulpho (Korea); and Frederick Anthony Steart, Esq., 85 Elliscombe Road, Charlton (Kent), were elected Fellows of the Society.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the non-payment of the Arrears of their Contributions.

The List of Donations to the Library was read.

Prof. Bonney exhibited a mounted specimen of the Volcanic Dust which fell on the deck of the steamer *Roddam* during the great eruption of Mont Pelée on May 8th, for which, as well as for another from the Soufrière of St. Vincent, that had fallen in Barbados, he was indebted to Sir William Crookes, F.R.S. The dust from Mont Pelée consists of fragments of minerals and rock (the former, perhaps, slightly in excess of the latter), very commonly about ·007 to ·008 inch in diameter, but ranging from about ·005 to ·01 inch. A very little fine dust had been removed by levigation before mounting the specimen. The minerals are:—(1) Chips of felspar sometimes bounded by cleavage-edges, occasionally showing oscillatory twinning or zonal structure. The refractive index and extinction-angles suggest that the majority are labradorite. Some contain minute acicular microliths or small brownish enclosures (? vitreous), which now and then are regular in form and arrangement, like negative crystals, and not seldom contain little bubbles. (2) Pyroxene, occasionally with cleavage-edges, or even idiomorphic, generally of a light bottle-green tint. There are certainly two species: one showing a distinct pleochroism from green to brown with straight extinction,—a variety of hypersthene; the other barely pleochroic, with an extinction that proves it to be augite. He could not identify with certainty magnetite or any other mineral. The rock-fragments are chips of a brownish, often dirty-looking glass, with small cavities, sometimes showing microliths or adhering to minerals; much of it opaque, or nearly so, with transmitted light, and a brownish-grey by reflected light, once or twice reddish. As Dr. Flett had given an excellent description of the Barbados dust from the Soufrière at the previous meeting, the present speaker thought that he need say no more than that in the specimen now exhibited the fragments seem a shade smaller, and minerals are slightly more abundant, especially pyroxene, than in the Mont Pelée dust.

Notwithstanding the risk of generalizing from a single slide, Prof. Bonney inferred that the ejecta of the two volcanoes are generally similar. Both, compared with specimens in his cabinet from Cotopaxi, are more uniform in size. The travelled dust from the Soufrière is a little smaller than that from the actual summit of the Andean volcano, but coarser than similar material from Chillo (over 20 miles), Quito (35 miles), Ambato (45 miles), Riobamba (65 miles), and the summit of Chimborazo, about the same. All these vary much more in size and run distinctly smaller, especially the last.[1] That from Mattakava, Hick's Bay, New Zealand (fallen on June 16th, 1886), is rather coarser, more scoriaceous, with fewer mineral-

[1] All these (collected by Mr. E. Whymper) are described in Proc. Roy. Soc. vol. xxxvii (1884) pp. 114 *et seqq.*

fragments (especially of pyroxene), to which a dirty glass is often adherent. The dust from Barbados, ejected by the St. Vincent Soufrière in 1812, is very much finer-grained, but contains the same minerals, though pyroxene is less abundant. In neither had he found the clear glassy pumice, described by Miss Raisin[1] from the marls of that island.

The following communications were read:—

1. 'A Descriptive Outline of the Plutonic Complex of Central Anglesey.' By Charles Callaway, D.Sc., M.A., F.G.S.

2. 'Alpine Valleys in Relation to Glaciers.' By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.

3. 'The Origin of some "Hanging Valleys" in the Alps and Himalaya.' By Prof. Edmund Johnstone Garwood, M.A., F.G.S.

In addition to those described on p. lxxxvi, the following specimens, etc. were exhibited:—

Volcanic Ash collected at St. Pierre (Martinique) on May 11th by Arthur D. Whatman, Esq., and presented by George D. Whatman, Esq. (See the 'Times' of May 31st, 1902.)

Rock-Specimens and Microscope-Sections exhibited by Dr. C. Callaway, M.A., F.G.S., in illustration of his paper.

Geologically coloured 6-inch Manuscript Map of part of Anglesey, exhibited by the Rev. J. F. Blake, M.A., F.G.S.

Photographs, Lantern-Slides, and Maps, exhibited by Prof. E. J. Garwood, M.A., F.G.S., in illustration of his paper.

Conglomerate from the Gravel of Newlands Corner, Guildford, exhibited by E. A. Martin, Esq., F.G.S.

June 18th, 1902.

Prof. CHARLES LAPWORTH, LL.D., F.R.S., President, in the Chair.

George Maitland Edwards, Esq., 74 Endlesham Road, S.W., was elected a Fellow of the Society.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the non-payment of the Arrears of their Contributions.

The List of Donations to the Library was read.

[1] Quart. Journ. Geol. Soc. vol. xlviii (1892) pp. 181, etc.

The following communications were read :—

1. 'The Great Saint-Lawrence-Champlain-Appalachian Fault of America, and some of the Geological Problems connected with it.' By Henry M. Ami, M.A., D.Sc., F.G.S.

[At this stage of the proceedings, Mr. E. T. Newton, F.R.S., took the Chair at the President's request.]

2. 'The Point-de-Galle Group (Ceylon); Wollastonite-Scapolite-Gneisses.' By Ananda K. Coomáraswámy, Esq., B.Sc., F.L.S., F.G.S.

3. 'On the Jurassic Strata cut through by the South Wales Direct Line between Filton and Wootton Bassett.' By Prof. Sidney Hugh Reynolds, M.A., F.G.S., and Arthur Vaughan, Esq., B.A., B.Sc., F.G.S.

The following specimens, etc. were exhibited :—

Photographs and Lantern-Slides, exhibited by Dr. H. M. Ami, M.A., F.G.S., in illustration of his paper.

Rock-Specimens, Microscope-Sections, and Lantern-Slides, exhibited by A. K. Coomáraswámy, Esq., B.Sc., F.L.S., F.G.S., in illustration of his paper.

Specimens, Photographs, and Lantern-Slides, exhibited by Prof. S. H. Reynolds, M.A., F.G.S., and A. Vaughan, Esq., B.A., B.Sc., F.G.S., in illustration of their paper.

Mechanical Separating Apparatus, exhibited by Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S., F.G.S.

THE

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

Vol. LVIII.

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1. *On the* Clarke Collection *of* Fossil Plants *from* New South Wales.

By E. A. Newell Arber, Esq., B.A., Trinity College, Cambridge; University Demonstrator in Palæobotany. (Communicated by Prof. T. McKenny Hughes, M.A., F.R.S., F.G.S. Read November 6th, 1901.)

[Plate I.]

The earliest scientific descriptions of fossil plants, from the rocks of New South Wales, are those by Brongniart of the genera *Glossopteris* and *Phyllotheca*, published in his 'Prodrôme'[1] in 1828. In his 'Histoire,'[2] published in the same year, figures and specific descriptions of these, and other genera, are to be found. It was not, however, until some years later that the first systematic collections of fossil plant-remains from this region were begun by the Rev. W. B. Clarke, Count Strzelecki, and by Dana. In 1845 Morris[3] published an account of Strzelecki's collection; and two years later McCoy[4] examined the Clarke Collection, made between 1839 and 1844, which he described in a paper in the Annals & Magazine of Natural History, in 1847. Dana's[5] specimens were described in 1849. The Clarke Collection, numbering nearly 2600 specimens of all kinds, including some 80 fossil plant-remains, was, by the great generosity of its owner, presented to the Woodwardian Museum, Cambridge, in November 1844.[6]

As already stated, the more important palæobotanical specimens in this collection were described by McCoy in 1847, twelve being regarded as new types. It has been thought, however, that a re-examination of this early collection, in the light of the recent advancement of our knowledge with regard to the structure and

[1] Brongniart (28)[1]. The numbers in parentheses after the authors' names indicate the year of publication of the work, to which reference will be found in the bibliography at the end of this paper, p. 25.

[2] Brongniart (28)[2]. [3] Morris (45). [4] McCoy (47).

[5] Dana (49). [6] Clarke (78) pp. 118 & 151.

affinities of fossil plants from Australia, India, South Africa, and elsewhere, might not be without value, especially as the more modern memoirs on the fossil flora of Australia, by Feistmantel[1] and Tenison-Woods,[2] contain in several instances only the original descriptions of McCoy, without amplification.[3]

The exact geological age of the beds, from which these plants were obtained, has long been disputed. We may, however, first examine the plants forming the collection, reserving for the moment the evidence which they afford of geological age. The collection may be conveniently arranged in stratigraphical order, beginning with the Wianamatta Series, followed by the Newcastle Beds, and finally the plants from Arowa.

A. Wianamatta Beds.

Filicales.

I. Thinnfeldia, Ettingshausen, 1852.

Abhandl. d. k.-k. geol. Reichsanstalt, vol. i, pt. iii, no. 3, p. 2.

Thinnfeldia odontopteroides (Morris).

Woodwardian Mus. Camb., Foreign Plant Coll. Nos. 14, 16, & 17.
Locality.—Sandstone of Clarke's Hill, near Cobbity.

Thinnfeldia odontopteroides.
1878. Feistmantel (78) p. 80 etc. & pp. 165–69, pl. xiii, fig. 5, pl. xiv, fig. 5, pl. xv, figs. 3–7, pl. xvi, fig. 1; also pls. ix–xi.
1881. Feistmantel (81) vol. iii, p. 85 & pl. xxiii *a*, figs. 7–9.
1883. Tenison-Woods (83) pp. 103 etc.
1890. Feistmantel (90) pp. 101–106 & pls. xxiii–xxv, pl. xxvi, figs. 1 & 2, pl. xxviii, fig. 8, pl. xxix, figs. 2–4. [Mr. Seward, in his 'Jurassic Flora of the Yorkshire Coast' (p. 239), has pointed out that figs. 1 & 5 on pl. xxix should be referred to *Ctenozamites.*]
1899. Potonié, 'Lehrb. der Pflanzenpal.' p. 149, fig. 145.
Pecopteris odontopteroides.
1845. Morris (45) p. 249 & pl. vi, figs. 2–4.
1872. Carruthers, Quart. Journ. Geol. Soc. vol. xxviii, p. 355 & pl. xxvii, figs. 2, 3.
1875. Crépin, Bull. Acad. Roy. Belg. ser. 2, vol. xxxix, pp. 258–63 & figs. 1–5.
1878. Etheridge, Catal. of Austral. Foss. p. 98.
Gleichenites odontopteroides.
1847. McCoy (47) p. 147.
1850. Unger (50) p. 208.

The specimen described, but not figured, by McCoy as *Gleichenites odontopteroides* is a sandstone-cast of a dichotomously-branched frond of indifferent preservation. The form of the pinnules is indistinct, and the nervation totally unpreserved. In other respects it is very similar to that figured by Feistmantel in 1890 in pl. xxvi, fig. 2. Each branch is $4\frac{1}{4}$ inches long, and $\frac{3}{4}$ inch across. The

[1] Feistmantel (90). [2] Tenison-Woods (83).

[3] References to the early literature, as well as a full bibliography of the memoirs published on the fossil botany of Australia, will be found in Etheridge & Jack (81), Clarke (78) appendices, and Feistmantel (90) pp. 12 *et seqq.*

Clarke states, (78) p. 152, that a further collection was forwarded in 1855; but it is not known definitely whether this contained any fossil plant-remains.

essential characters of the species have been fully described by Feistmantel,[1] so that further description is unnecessary here.

Thinnfeldia odontopteroides is abundant in certain beds in Australia and Tasmania, and occurs also in India in the Lower Gondwanas, and in beds of Rhætic age in South America (Argentine Republic).[2] In New South Wales it is not known at a lower horizon than the Hawkesbury Beds.

McCoy[3] also describes, but does not figure, a new type from the same locality, under the name of *Odontopteris microphylla.* No plant in the collection bears this name; but two specimens (Nos. 16 & 17), without indication as to locality, are certainly those referred to by McCoy. The rock in each case is precisely similar to specimens labelled 'Clarke's Hill,' and the specimens themselves agree in every respect with the specific characters given under *Odontopteris microphylla*, McCoy.

These plants are neither more nor less than other forms of *Thinnfeldia odontopteroides* (Morris), a plant which varied extremely in habit. Specimen No. 16 is easily recognizable as the form of this plant figured by Feistmantel in his later memoir, pl. xxvi, fig. 1; while the other closely corresponds to that in pl. xxiii, fig. 1. *Odontopteroides microphylla*, McCoy, is therefore a synonym of *Thinnfeldia odontopteroides* (Morris). It is somewhat strange that this identity was not suspected by Feistmantel; but this is probably due to the fact that no figure of McCoy's species has ever appeared.

II. Pecopteris, Brongniart, 1822.

'Sur la Class. des Végét. foss.' Mém. Mus. Hist. Nat. [Paris] vol. viii, p. 233.

Pecopteris (?) tenuifolia, McCoy.

Type.—Woodwardian Mus. Camb., Foreign Plant Coll. No. 15 (figured).
Locality.—Clarke's Hill, near Cobbity.

Pecopteris (?) tenuifolia.
1847. McCoy (47) p. 152 & pl. ix, fig. 6.
1878. Feistmantel (78) p. 89.
1883. Tenison-Woods (83) p. 110.
1890. Feistmantel (90) p. 111.

McCoy's type is the only specimen known, and is unfortunately very badly preserved. It consists of a slender axis about $3\frac{1}{2}$ inches long, bearing narrow linear, distant, lateral members ($\frac{3}{4}$ inch or more long) apparently united by their entire base. It would not seem possible to identify this specimen with any of the later discoveries of fossil plants in New South Wales with which I am acquainted, and for the present, in the absence of further and better-preserved specimens, it is best relegated to the class 'incertæ sedis.'

[1] Feistmantel (90) p. 102.
[2] Szajnocha (88) p. 229.
[3] McCoy (47) p. 147.

Equisetales.

PHYLLOTHECA AUSTRALIS, Brongniart.[1]

Woodwardian Mus. Camb., Foreign Plant Coll. No. 12 (figured).
Locality.—Clarke's Hill, near Cobbity.

1847. *Phyllotheca Hookeri*, McCoy (47) p. 157 & pl. xi, fig. 4.

The locality from which this fossil was obtained has been disputed. Clarke,[2] in 1861, says that it was labelled 'Clarke's Hill' by mistake; yet in 1878 [3] the same author gives Clarke's Hill as the locality, without expressing any doubt on the subject. The rock is a greyish-brown sandstone, bearing a printed label 'Clarke's Hill,' much resembling other specimens from that locality, and is quite distinct from those brought from Mulubimba and elsewhere. There is, therefore, little doubt that it is correctly labelled as to locality.

The specimen consists of two or three unbranched stems, of which McCoy figures one, which is $2\frac{1}{2}$ inches long, and $\frac{1}{4}$ inch across. The nodes are slightly constricted, and the internodes ($\frac{7}{8}$ inch long) bear faintly marked opposite, and longitudinally disposed, furrows. In one instance the basal leaf-sheath ($\frac{1}{2}$ inch long) is preserved, from which free linear segments, $1\frac{1}{2}$ inches long, are given off. The sheath appears to be somewhat lax, and is half as long as the internode. The other fragments are similar portions of stems, but without leaves, one being 4 inches long, and with nodes quite an inch distant.

The reasons for placing this specimen under Brongniart's specific name will be fully discussed in dealing with the Newcastle specimens.

Ginkgoales.

BAIERA, Braun, 1843.

In Graf zu Münster's 'Beitr. zur Petrefactenkunde' pt. vi, p. 20.

BAIERA MULTIFIDA, Fontaine.

Woodwardian Mus. Camb., Foreign Plant Coll. No. 56.
Locality.—Clarke's Hill, Cobbity.

1883. *Baiera multifida*, Fontaine, U.S. Geol. Surv. Monogr. vol. vi, pl. xlv (double), fig. 3, pl. xlvi & pl. xlvii, figs. 1–2.
1886. *Jeanpaulia (?) palmata*, Ratte, Proc. Linn. Soc. N. S. Wales, ser. 2, vol. i, pp. 1078–81.
1887. *Salisburia palmata*, Ratte, *ibid.* vol. ii, p. 137 & pl. xvii.
1890. *Baiera palmata*, Feistmantel (90) p. 158.

The last specimen from Clarke's Hill to be mentioned is a fragment, which is almost certainly identical with the fine plant from the Wianamatta Shales, described by Ratte in 1886, and first referred by him to the genus *Jeanpaulia*, and afterwards to *Salisburia*. Unfortunately, neither of these generic terms can stand: *Salisburia* is a synonym of *Ginkgo*, and *Jeanpaulia* is now

[1] For other literature, see p. 14.
[2] Clarke (61) p. 358. [3] Clarke (78) pp. 123–24.

included under *Baiera*, to which genus this plant belongs. It is unfortunate also, as Feistmantel remarked, that the name *Baiera palmata* had already been adopted by Heer[1] for a fossil from the Jurassic of Siberia.

Mr. Seward & Miss Gowan[2], in their recent monograph on *Ginkgo*, have pointed out that *Salisburia palmata*, Ratte, bears 'a close resemblance' to Fontaine's *Baiera multifida* from Virginia. I have carefully compared the figures and descriptions of these two plants, and I am unable to find any real distinction between them. In the American specimens the ultimate segments appear to be somewhat narrower, and less deeply cut towards the petiole. Fontaine's figures, however, appear to be rather carelessly executed, and probably do not represent the true outline of the specimens. I therefore propose to adopt Fontaine's name for the Australian plant, which, being prior to Ratte's, solves the difficulty of nomenclature.

The Cambridge specimen is a fragment showing part of the petiole, and portions of the palmate divisions.

With *Baiera multifida* may be compared *Baiera (?) Steinmanni*, described by Count H. zu Solms-Laubach,[3] from the Rhætic of Chile, and *Ginkgo Simmondsi*, Shirley,[4] from the Trias of Queensland.

B. Newcastle Series.

Filicales.

I. Glossopteris, Brongniart, 1828.

'Prodr. Hist. Végét. foss.' p. 54.

1. Glossopteris Browniana, Brongniart.

Woodwardian Mus. Camb., Foreign Plant Coll. Nos. 36, 39, 40, 48, 61, 62, 64, & 65.
Localities.—Mulubimba and Jerry's Plains.

Glossopteris Browniana.
1828. Brongniart (28)[1] p. 54.
1828. Brongniart (28)[2] p. 223 & pl. lxii, figs. 1 & 2.
1845. Morris (45) p. 247 & pl. vi, figs. 1 & 1 *a*.
1847. McCoy (47) p. 150.
1849. Dana (49) p. 715 & pl. xii, fig. 13.
1869. Schimper (69) vol. i, pp. 645–46.
1872. Carruthers, Quart. Journ. Geol. Soc. vol. xxviii, p. 354.
1878. Etheridge, Catal. of Austral. Foss. p. 30.
1878. Feistmantel (78) pp. 90, 154 & many figs.
1881. Feistmantel (81) vol. iii, p. 102 & pl. xxvi *a*, fig. 2, pl. xxvii *a*, fig. 2, pl. xxix *a*, figs. 1, 3, 6, & 8, pl. xl *a*, fig. 5.
1883. Tenison-Woods (83) p. 122.

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[1] Heer, 'Flora fossilis arctica' vol. iv, pt. ii (1876) p. 115 & pl. xxviii, fig. 2 *a–d*.

[2] Seward & Gowan (00) p. 139.

[3] Solms-Laubach, 'Beitr. zur Palæont. von Südamerika, VII,' Neues Jahrb. Beilage-Band xii (1899) p. 593 & pl. xiv, fig. 1.

[4] Shirley, 'Add. to Foss. Flora of Queensl.' Geol. Surv. Queensl. Bull. No. 7 (1898) p. 12 & pl. ii.

1890. Feistmantel (90) p. 121 & pl. xiii, fig. 1, pl. xvi, figs. 3 & 4, pl. xvii, figs. 1, 3, 4, 5 (?), 7, pl. xx, fig. 2.
1890. Zittel, 'Handbuch der Paläont.' pt. ii, p. 134 & fig. 108.
1894. David (94) p. 249.
1896. Zeiller (96)[1] p. 362 & pl. xvi, figs. 1–4.
1897. Seward (97) p. 316 & pl. xxi, figs. 1–4 *a*, pl. xxii, fig. 4 *c*, pl. xxiii, fig. 1.
1899. Potonié, 'Lehrb. der Pflanzenpal.' p. 155 & fig. 154.
1900. Zeiller, 'Elém. de Paléobot.' p. 113 & fig. 86.

Glossopteris indica.
1869. Schimper (69) vol. i, p. 645.
1881. Feistmantel (81) vol. iii, p. 101 & many figs.

Glossopteris linearis.
1847. McCoy (47) p. 151 & pl. ix, figs. 5 & 5 *a*.
1878. Feistmantel (78) p. 91 & figs.
1883. Tenison-Woods (83) p. 123.
1890. Feistmantel (90) p. 126.

Glossopteris angustifolia.
1828. Brongniart (28)[2] p. 224 & pl. lxiii, fig. 1.
1876. Feistmantel, Journ. As. Soc. Bengal, vol. xlv, pt. ii, p. 374 & pl. xxi, figs. 2–4.
1881. Feistmantel (81) vol. iii, p. 105 & many figs.

Prof. Zeiller [1] and Mr. Seward [2] have both recently figured and described the various forms of *Gl. Browniana*, Brongt. at some length, and have proved conclusively that it is practically impossible to distinguish specifically between *Gl. Browniana*, Brongt., *Gl. indica*, Schimp., and *Gl. angustifolia*, Brongt. McCoy [3] states that both the former occur in nearly equal abundance in the Newcastle Beds. These authors have also shown that this plant is heterophyllous. In addition to the better-known fronds, smaller scale-leaves without a midrib occur. These are represented by a specimen (No. 65) in this collection, and will be mentioned more fully in relation to *Vertebraria.*

(*Glossopteris linearis*, McCoy) Specimens Nos. 4 & 63.—McCoy [4] described a new form of *Glossopteris*, with long, narrow, almost parallel-sided fronds, and an oblique nervation, under the name of *Gl. linearis.* A specimen (No. 4) from Woollongong, Newcastle Beds, was figured on pl. ix, figs. 5 & 5 *a* of his memoir. McCoy stated that this plant could only be confounded 'with *Gl. angustifolia*, Brongt., from the Indian coalfields,' from which it may be distinguished by its finer and more oblique nervation, anastomosing up to the margin. A comparison of the type-specimen with the figures given of *Gl. angustifolia* by Feistmantel in his 'Lower Gondwana Flora,' fails to show satisfactory evidence for separating these two plants. Feistmantel [5] has there figured side by side two specimens: one (pl. xxxiv *a*, fig. 3) a typical *Gl. angustifolia,* and another (pl. xxxiv *a*, fig. 2) which he says is probably *Gl. angustifolia*, but does not finally identify it,

> 'as it combines with the size and shape of the leaves of *Glossopteris angustifolia* a venation somewhat abnormal, and different from that of the latter species.'

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[1] Zeiller (96)[2]. [2] Seward (97).
[3] McCoy (47) p. 150. [4] McCoy (47) p. 151.
[5] Feistmantel (81) vol. iii, p. 105 & pl. xxvii *a*, pl. xxxiv *a*, fig. 3, pl. xxxix *a*, figs. 1 & 2.

This second specimen corresponds exactly in nervation and contour to McCoy's type. Prof. Zeiller[1] has also figured a specimen of *Gl. angustifolia* with oblique nervation, and this again corresponds very closely with *Gl. linearis*. There seems, therefore, no good reason for regarding *Gl. linearis*, McCoy, as distinct from *Gl. angustifolia*, Brongt.; and as the latter is now known to be a form of *Gl. Browniana*, McCoy's specimen can only be regarded as a variety of that plant.

McCoy states that this plant is not uncommon in the hard siliceous schists of Arowa. Doubt has been thrown on this statement by several authors. I have carefully examined all the specimens of *Glossopteris* in the collection, and I found no instance of any one being labelled 'Arowa,' or occurring in a rock at all similar lithologically to that containing undoubted specimens from Arowa. I conclude, therefore, that McCoy was in error in regard to this statement.

2. Glossopteris ampla, Dana.

Woodwardian Mus. Camb., Foreign Plant Coll. No. 29.
Locality.—Telegraph Hill, Mulubimba.

Glossopteris ampla.
1849. Dana (49) p. 717 & pl. xiii, fig. 1.
1878. Feistmantel (78) p. 91 & pl. xi, fig. 2, pl. xii, fig. 7.
1883. Tenison-Woods (83) p. 124.
1890. Feistmantel (90) p. 122 & pl. xix, figs. 1 & 2.

In his remarks on *Gl. Browniana*, McCoy[2] says that some of the fronds are of very large size. There is a specimen in the Clarke Collection, consisting of a slab of fine whitish sandstone, containing the impressions of four fragments, which are undoubtedly identical with the plant figured by Dana and Feistmantel as *Gl. ampla*. One of these, an apical portion, of probably the dorsal surface, is nearly 4½ inches long, 4 inches across, and beautifully preserved. The apex is obtuse; the margin entire, and undulate. The strong median nerve does not, as Feistmantel[3] states, extend to the apex. At a distance of 3½ inches from the apex, the median nerve is comparatively slender, and has begun to break up into a series of finer nerves, which, while at first pursuing a somewhat parallel course towards the apex, gradually diverge at a very acute angle, with regular dichotomy. The nervation is fairly open in the area of about an inch on either side of the midrib, and not unlike that of *Gl. Browniana*. Towards the margin the nervation becomes closer and finer: the secondary nerves pursuing a pseudo-parallel, and oblique course, forming a very transversely elongate reticulation. Another fragment is a curved portion of a frond, 8 inches long, in which the lamina is folded on itself along the midrib. The midrib is very strong and flattened, ¼ inch across. The close and fine pseudo-parallel reticulation at the margins is again very well shown.

The justice of a specific value being assigned to this fossil is

[1] Zeiller (96)[1] p. 370, fig. 15.
[2] McCoy (47) p. 151.
[3] Feistmantel (90) p. 122.

certainly open to considerable doubt, in view of the recent proof of identity of the various forms of *Glossopteris Browniana*, Brongt. Feistmantel[1] regarded it as intermediate between *Gl. indica*, Schimp., and *Gl. communis*, Feist., but Prof. Zeiller[2] has since shown that these two forms are identical. The fossil is, however, strongly characterized by the form of the marginal nervation, and the specific rank may perhaps be retained until further evidence is available.

(*Glossopteris tæniopteroides*, Feist.) Specimen No. 45.—There is another specimen in the collection, without reference to locality, but in all probability from the Newcastle Series, which would appear to be identical with the *Gl. tæniopteroides* of Feistmantel.[3] The frond is 4 inches long, and doubled on itself about the midrib, one side being an inch wide. The nervation is very oblique, and seems closely similar to the pseudo-parallel, elongate reticulation just described in *Gl. ampla*. So far as I can determine, there would seem to be no real distinction between these two plants. I regard Feistmantel's *Gl. tæniopteroides* as a smaller frond of *Gl. ampla*.

VERTEBRARIA, Royle, 1839.

'Illustr. of Bot. Himalayan Mts.' vol. i, p. xxix.*

VERTEBRARIA AUSTRALIS, McCoy.

Type.—Woodwardian Mus. Camb., Foreign Plant Coll. No. 1 (? type), also Nos. 38, 49–53, & 66.
Locality.—Whitish shales and clays, Mulubimba.

Vertebraria australis.
1847. McCoy (47) p. 147 & pl. ix, fig. 1.
1878. Feistmantel (78) p. 84, figured.
1883. Tenison-Woods (83) pp. 75 *et seqq.*
1890. Feistmantel (90) p. 87 & pl. xiv, fig. 6, pl. xv, figs. 1–3.
Clasteria australis.
1849. Dana (49) p. 719 & pl. xiv, figs. 3–5.
Sphenophyllum australe.
1850. Unger (50) p. 72.

In 1894 Mr. R. Etheridge, jun.[4] described some Australian specimens in which almost complete fronds of *Glossopteris* were preserved in organic continuity with a structure which he regarded as a rhizome. Judging by his figures, this rhizome is quite unlike *Vertebraria australis*.[5] Possibly it was preserved in a different manner, as an external impression, without the preservation of the wedge-like segments (as seen in transverse section) which are so characteristic of *Vertebraria*.[6] Whatever may be the structure of Mr. Etheridge's stem, and its relation to *Vertebraria*, there is a specimen in the Clarke Collection (No. 66) of an undoubted *Vertebraria* with

[1] Feistmantel (90) p. 123. [2] Zeiller (96)².
[3] Feistmantel (90) p. 128 & pl. xviii, figs. 1, 1 *a*.
[4] Etheridge (94) p. 228 & pls. xviii–xix.
[5] *Vertebraria* is now known to be the rhizome of *Glossopteris*; see Zeiller (96)¹ and Oldham (97).
[6] Prof. Zeiller (96)¹ has furnished an explanation of the origin of these structures.

fragments of *Glossopteris*-fronds in organic continuity. With this specimen occur also some seed-like fossils, which will be found described under the name of *Cardiocarpus* sp. (p. 20).

Vertebraria australis would seem to be closely similar to *V. indica*, Royle, but Feistmantel [1] concluded that they may perhaps be regarded as specifically distinct. It has also been pointed out by Mr. Oldham,[2] that the structure of the South African *Vertebraria*, in which Prof. Zeiller first proved the continuity, is again different from the Indian.

The type-specimen of *Vertebraria australis*, or rather the specimen which I take to be McCoy's type, but which does not correspond exactly to his figure, shows in transverse section four wedge-shaped segments each $\frac{1}{4}$ inch long. Probably eight or more of these were present in the complete specimen. In longitudinal section, the axis is $\frac{1}{4}$ inch long, and there are a number of somewhat irregular transverse furrows separating closely packed laminæ, which form the wedges above mentioned.

Before leaving the subject, a reference must be made to one of McCoy's statements, which has apparently puzzled many authors.[3] He says in relation to *Glossopteris Browniana*:—

'I believe I have ascertained the rhizoma of this species, which is furnished with ovate, clasping (or at least very convex), subcarinate scales, having a divaricating reticulated neuration, resembling that of the perfect frond, but much less strongly marked, ... the whole perfectly resembling (except in size) the rhizomal scales of *Acrostichium*,' etc.

I believe that McCoy is here referring to two specimens in the Clarke Collection, the one showing continuity between *Glossopteris* and *Vertebraria* (No. 66), and a specimen already referred to, with the detached scale-leaves (No. 65). It is interesting to notice that to McCoy is due the credit of first recognizing the nature of *Vertebraria*, and the heterophyllous character of *Glossopteris*, neither of which were admitted until a few years ago.

II. Sphenopteris, Brongniart, 1822.

'Sur la Class. des Végét. foss.' Mém. Mus. Hist. Nat. [Paris] vol. viii, p. 233.

1. Sphenopteris alata (Brongt.).

Woodwardian Mus. Camb., Foreign Plant Coll. No. 71.
Locality.—Mulubimba.

Sphenopteris alata.
1820–38. Sternberg, 'Vers. geogn.-botan. Darst. d. Flora d. Vorwelt' pt. ii, p. 131.
1847. McCoy (47) p. 149.
1850. Unger (50) p. 124.
1878. Feistmantel (78) p. 87.
1883. Tenison-Woods (83) p. 89.
1890. Feistmantel (90) p. 88.
Pecopteris alata.
1828. Brongniart (28)[2] p. 361 & pl. cxxvii.

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[1] Feistmantel (81) vol. iii, pp. 71–72. [2] Oldham (97).
[3] McCoy (47) p. 151; see also Etheridge (94) p. 233.

Aspidites alatus.
1836. Goeppert, 'Syst. Fil. Foss.' p. 358. [See also Nova Acta Acad. Leop.-Carol. Nat. Cur. vol. xvii, suppl.]
Sphenopteris alata var. *exilis.*
1845. Morris (45) p. 246 & pl. vii, figs. 4 & 4 *a*.
1878. Feistmantel (78) p. 88.
1883. Tenison-Woods (83) p. 90.
1890. Feistmantel (90) p. 89.

It is curious that many of the authors who have mentioned this fossil have fallen into error in some form or other, and the confusion that has arisen is considerable. The primary cause of this is due to the fact that Brongniart [1] described, and figured in 1828, two ferns with the specific title *alata*—(1) *Pecopteris alata* (p. 361 & pl. cxxvii) from New South Wales, and (2) *Sphenopteris alata* (p. 180 & pl. xlviii, fig. 4) from Germany. Some years later Sternberg [2] transferred the Australian plant to the genus *Sphenopteris*, so that in his 'Flora der Vorwelt' these two ferns are both described as *Sphenopteris alata*, and would, according to modern notation, be distinguished as (1) *Sph. alata* (Brongt.), and (2) *Sph. alata*, Brongt. The German type (2) is now known as *Sph. Grandini* (Goepp.),[3] and the only Sphenopterid with the specific title *alata* is the Australian plant *Sph. alata* (Brongt.).

Clarke [4] and others have confused the Australian plant with *Sph. Grandini* (Goepp.). But the confusion does not end here. In 1845 Morris [5] described and figured a fossil under the name *Sphenopteris alata* var. *exilis*, Morris, which he expressly stated to be synonymous with *Pecopteris alata*, Brongt. [now known as *Sph. alata* (Brongt.)], and *Aspidites alatus*, Goepp. Morris observed that

'this interesting species of fossil fern appears more nearly related to *Sphenopteris* than *Pecopteris*, and is easily distinguished by the slender and decurrent pinnula and the membranous or alate margin of the principal rhachis, as is observed in the recent species of *Hymenophyllum*.'

By the modern writers, such as Feistmantel and Tenison-Woods, Morris's plant is regarded as distinct from the original description of Brongniart, whereas the two are identical, as Morris shows by his synonyms. There is nothing in Morris's description of his plant to distinguish it from the *Sphenopteris alata* of Brongniart, and his somewhat unfortunate choice of the specific title '*alata* var. *exilis*' was probably made in order to get over the difficulty of two plants bearing the same name '*Sphenopteris alata*,' to which genus, as he says, the fossil must be referred. The specimen described by Morris is not in any sense a type. The real type of *Sphenopteris alata* (Brongt.) is, or was, in the Museum of the University of Edinburgh.

McCoy [6] mentions the occurrence of *Sph. alata* (Brongt.) in the Mulubimba Sandstone; and a large specimen in the Clarke Collection,

[1] Brongniart (28)[2].
[2] Sternberg, 'Vers. d. Flora d. Vorwelt' (1820–38) pt. ii, pp. 59 & 131.
[3] Schimper (69) vol. i, p. 404.
[4] Clarke (78) pp. 74 & 123.
[5] Morris (45) p. 246 & pl. vii, figs. 4 & 4 *a*.
[6] McCoy (47) p. 149.

without reference to locality, agrees very closely with Brongniart's figures and descriptions. The frond, which is $6\frac{1}{2}$ inches long, and more than 8 inches across, is bipinnate with a strongly alate rhachis. The pinnæ are long (5 or more inches), opposite, and lanceolate, and curved upwards. The pinnules ($\frac{3}{4}$ to 1 inch long, and $\frac{1}{2}$ inch broad) are subopposite, ovate, with three or more bluntly, and obliquely-cut segments on each side. The median nerve is strong, and gives off simple, or dichotomizing secondary nerves to each segment and tooth.

2. Sphenopteris germana, McCoy.[1]

Type.—Woodwardian Mus. Camb., Foreign Plant Coll. No. 5 (also No. 3).
Locality.—Mulubimba.

Sphenopteris germana.
1847. McCoy (47) p. 150 & pl. x, figs. 2 & 2 *a*.
1850. Unger (50) p. 127.
1878. Feistmantel (78) p. 88.
1883. Tenison-Woods (83) p. 91.
1890. Feistmantel (90) p. 92.

The Cambridge type is a small and incomplete specimen of a frond, about 2 inches long, the pinnæ of which are slightly less than an inch in length. In the absence of larger and more complete specimens from Australia, it would be unwise to dwell upon the characters of such a fragment. It is unfortunate that recent writers on the flora of Australia have not been able to obtain further specimens of this, and of other species of *Sphenopteris*, to be mentioned.

(*Sphenopteris plumosa.*) Specimen No. 3.—McCoy[2] also figured and described another type as *Sphenopteris plumosa*, from the same locality as the preceding. This is also a mere fragment; in all probability a pinna of a tripinnate frond. It is 2 inches long, and $\frac{5}{8}$ inch across. There is hardly any doubt that it is a portion of *Sph. germana*, already mentioned, probably a pinna from the median portion of a frond of that plant. The nervation of these two specimens, as figured by McCoy, agrees exactly.

3. Sphenopteris flexuosa, McCoy.

Type.—Woodwardian Mus. Camb., Foreign Plant Coll. No. 2 (also No. 59).
Locality.—Mulubimba.

Sphenopteris flexuosa.
1847. McCoy (47) p. 150 & pl. ix, figs. 4 & 4 *a*.
1850. Unger (50) p. 127.
1878. Feistmantel (78) p. 88.
1883. Tenison-Woods (83) p. 91.
1890. Feistmantel (90) p. 91.

This species appears to approach *Sph. polymorpha*, Feist.,[3] of the Lower Gondwanas of India in habit, but the number of segments in the pinnæ are smaller, and the nervation does not perhaps

[1] McCoy spells the specific name '*germanus*.'
[2] McCoy (47) p. 150 & pl. x, figs. 3 & 3 *a*.
[3] Feistmantel (81) vol. iii, pl. xvi *a bis*, fig. 1.

correspond very closely with any of Feistmantel's figures. The type occurs with *Glossopteris Browniana* on the same slab. The larger specimen of the figured types is $2\frac{1}{2}$ inches long. Here again further specimens are necessary, before attempting to establish this species as distinct from other Australian Sphenopterideæ.

4. Sphenopteris polymorpha, Feist. (Pl. I, figs. 4 & 5.)

Woodwardian Mus. Camb., Foreign Plant Coll. No. 72; also Nos. 25, 26, & 27.
Locality.—? Mulubimba.

Sphenopteris polymorpha.
1876. Feistmantel, Journ. Asiat. Soc. Bengal, vol. xlv, pt. ii, p. 356 & pl. xvi, figs. 5–7, pl. xvii.
1881. Feistmantel (81) vol. iii, p. 76 & pls. xv *a*, xvi *a*, fig. 3, xvi *a bis*, figs. 1–6.

There is a large specimen in the collection of a fern, which is in association with *Glossopteris,* but without record as to locality. From the character of the rock, however, we may infer that the specimen was in all probability obtained from Mulubimba. It consists of a portion of a large tripinnate frond, with a stout rhachis 7 inches long, bearing alternate primary pinnæ, 5 or more inches long. The secondary pinnæ average $1\frac{1}{2}$ inches in length, and $\frac{1}{2}$ inch in breadth, and consist of crowded, and, in parts, imperfectly preserved and indistinct pinnules. In places, however, the form and nervation of the pinnules is shown very clearly, and these appear to be identical with certain forms of the Indian fern *Sphenopteris polymorpha*, figured and described by Feistmantel.[1]

There are also several small fragments of a delicate frond, from the shale of Mulubimba (Pl. I, figs. 4 & 5), which resemble very closely in form and nervation the specimens figured by Feistmantel as *Sphenopteris polymorpha.*[2]

It will be remembered that specimens of *Sph. flexuosa* were stated (p. 11) to bear a general resemblance to *Sph. polymorpha*. Feistmantel[3] has also compared certain pinnules of *Sph. alàta* (Brongt.) with the same plant. It seems certain, therefore, that *Sph. polymorpha* of India occurs also in Australia, although neither Feistmantel nor Tenison-Woods has recorded it. This, again, is another point of contact between the Newcastle Beds and the Lower Gondwanas of India.

5. Sphenopteris hastata, McCoy.

Type.—Woodwardian Mus. Camb., Foreign Plant Coll. No. 7 (also No. 23).
Locality.—Mulubimba.

Sphenopteris hastata.
1847. McCoy (47) p. 149 & pl. x, figs. 1 & 1 *a*.
1850. Unger (50) p. 127.

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[1] Feistmantel (81) vol. iii, compare pl. xv *a*, fig. 1, pl. xvi *a*, fig. 3, pl. xvi *a bis*, figs. 2, 2 *a*, & 3.

[2] Feistmantel (81) vol. iii, pl. xvi *a bis*, figs. 2, 2 *a*, & 3. I believe that the specimens identified by Tenison-Woods (83) p. 114 & pl. vi, figs. 2 & 3, as *Merianopteris major*, should also be referred to this species.

[3] Feistmantel (81) vol. iii, p. 77.

1878. Feistmantel (78) p. 88.
1883. Tenison-Woods (83) p. 90.
1890. Feistmantel (90) p. 92.

The figured specimen is an imperfect fragment of a frond or pinna in association with *Glossopteris Browniana*. The specimen measures 2 inches, and only one half is well preserved. A perfect pinna, or secondary pinna, measures 1½ inches, and is pinnatifid, with entire and ovate lobes.

6. Sphenopteris lobifolia, Morris.

Woodwardian Mus. Camb., Foreign Plant Coll. No. 22.
Locality.—Mulubimba.

Sphenopteris lobifolia.
1845. Morris (45) p. 246 & pl. vii, figs. 3 & 3 *a*.
1847. McCoy (47) p. 149.
1849. Dana (49) p. 715 & pl. xii, fig. 12.
1850. Unger (50) p. 128.
1878. Feistmantel (78) p. 87.
1883. Tenison-Woods (83) p. 88.
1890. Feistmantel (90) p. 93.

The specimen of this plant in the collection is a small fragment about 2 inches long, also in association with *Glossopteris Browniana*. It consists of a pinna with alate rhachis, and alternate, linear, pinnatifid pinnules, with very acute, equal, approximate and rounded lobes. The median nerve gives off dichotomizing secondary nerves to each lobe. Dr. Szajnocha [1] has identified certain Argentine plants as belonging to this species, and has referred Morris's plant to Brongniart's *Pecopteris Schoenleiniana* [2] from the Keuper of Würtzburg. I am, however, unable to agree with this latter identification.

III. Gangamopteris, McCoy, 1861.

Trans. Roy. Soc. Vict. vol. v (1860) p. 107 note.

Gangamopteris angustifolia, McCoy.

Type.—Woodwardian Mus. Camb., Foreign Plant Coll. No. 18 (also No. 70).
Localities.—Guntawang, and Wilbertee, Mudgee.

Gangamopteris angustifolia.
1875. McCoy (74–78) dec. ii, p. 11 & pl. xii, fig. 1.
1876. Feistmantel, Rec. Geol. Surv. Ind. vol. ix, p. 120.
1878. Feistmantel (78) p. 102.
1883. Tenison-Woods (83) p. 127.
1890. Feistmantel (90) p. 130.
Cyclopteris angustifolia.
1847. McCoy (47) p. 148 & pl. ix, figs. 3 & 3 *a*.

McCoy's type-specimen consists of five or six fragments, the largest of which, the figured type (pl. ix, fig. 3), is an imperfectly preserved frond, 3½ inches in length, and slightly more than ¾ inch wide. The frond is sublinear, and has a broad, shallow, median longitudinal groove. There is no midrib. The lateral nerves arise by dichotomy from a subparallel group of central nerves, and at a very acute angle; they diverge gradually towards the margin of the frond,

[1] Szajnocha (88) p. 225.
[2] Brongniart (28)[2] p. 364 & pl. cxxvi, fig. 6.

with frequent anastomosis. The other fragments are similar, though smaller. One shows the broadly rounded apex of the frond. The nervation at the apex is similar to the lateral nervation.

This genus is closely allied to *Glossopteris*. Feistmantel[1] remarks that 'a *Gangamopteris* is a *Glossopteris* without a midrib.' It must be remembered, however, that since the discovery of the scale-leaves of *Glossopteris*, the presence of a midrib is no longer a necessary characteristic of that genus. It is, therefore, in the absence of all knowledge of the fructification of either type, extremely doubtful whether the genus *Gangamopteris* should not be merged in *Glossopteris*. Mr. Etheridge[2] has pointed out that certain forms of these genera closely resemble one another, and has called attention to the absence of good critical characters to distinguish them.

Equisetales.

Phyllotheca, Brongniart, 1828.

'Prodr. Hist. Végét. foss.' pp. 151 & 175.

1. Phyllotheca australis, Brongt.

Woodwardian Mus. Camb., Foreign Plant Coll. Nos. 8, 9, & 13 (figured), also Nos. 11, 31, 32, 33, 36, 37, 46, & 55.
Locality.—Mulubimba.

Phyllotheca australis.
1828. Brongniart (28)[1] p. 152.
1845. Morris (45) p. 250.
1847. McCoy (47) p. 156.
1849. Dana (49) p. 718 & pl. xiii, fig. 6.
1850. Unger (50) p. 73.
1869. Schimper (69) vol. i, p. 289.
1878. Feistmantel (78) pp. 83–84.
1883. Tenison-Woods (83) p. 72.
1890. Feistmantel (90) p. 79 & pl. xiv, figs. 2–5, ? fig. 1.
1898. Seward (98) pp. 287–91.
Phyllotheca ramosa.
1847. McCoy (47) p. 156 & pl. xi, figs. 2 & 3.
1850. Unger (50) p. 73.
1883. Tenison-Woods (83) p. 73.
1890. Feistmantel (90) p. 80.
Phyllotheca Hookeri.
1847. McCoy (47) p. 157 & pl. xi, figs. 4–6.
1850. Unger (50) p. 73.
1883. Tenison-Woods (83) p. 73.
1890. Feistmantel (90) p. 81.

In dealing with McCoy's specimens of *Phyllotheca*, mention must first be made of the nomenclature adopted by that author. He found[3] that Brongniart's description of *Ph. australis*, Brongt. did not exactly apply to his specimens, and consequently he instituted two new species, *Ph. ramosa*, McCoy, and *Ph. Hookeri*, McCoy. From his specific diagnosis it appears that *Ph. ramosa*[4] only differs from

[1] Feistmantel (90) p. 130. [2] Etheridge (94) pp. 240–41.
[3] McCoy (47) pp. 156–57.
[4] McCoy figures two specimens of this species, No. 13 in pl. xi, fig. 2, and No. 8 in pl. xi, fig. 3.

Ph. australis, Brongt., in possessing branched stems. On the other hand, *Ph. Hookeri* is distinguished from both *Ph. australis* and *Ph. ramosa* by coarsely sulcate or ridged stems, with a looser sheath, as long as the internode, the free segments of which are thick, and have a strong and prominent midrib. Three specimens are figured of this type by McCoy, one of which (pl. xi, fig. 7, No. 10) belongs to another species altogether.[1] Another (pl. xi, fig. 4, No. 12) is from Clarke's Hill, as already described. In it, the sheath certainly appears to be looser; but the stem is very faintly striated longitudinally, and the sheath extends only to half the length of the internode. In the specimen of *Ph. Hookeri* figured by McCoy from Mulubimba (pl. xi, figs. 5 & 6, No. 9), the largest fragment is $3\frac{1}{2}$ inches long, with nodes $1\frac{1}{8}$ inches long, and fairly lax sheaths $\frac{3}{8}$ inch in length. The stem is only faintly striated. The leaves appear better preserved, and show, in places, a prominent midrib. It therefore appears that *Ph. Hookeri* differs from *Ph. australis* and *Ph. ramosa* in its looser leaf-sheath and more prominent midrib. The stem is not, however, strongly grooved longitudinally, nor the leaf-sheath longer relatively to the internode. The character of the midrib, as a point of specific importance, may be dismissed at once, as most of the specimens are too badly preserved to show this structure. The looseness of the sheath is, therefore, the only real distinction between these species.

I would regard all the specimens of *Phyllotheca* just discussed, as belonging to *Ph. australis*, Brongt., enlarging Brongniart's definition to include branched specimens, and those with lax sheaths. Feistmantel[2] expressed himself strongly in favour of this conclusion.

In addition to the specimens already described there are others in the collection, which merit a word of description.

Specimen No. 13. [Figured by McCoy (47) pl. xi, fig. 2.]—This is the branched specimen, figured by McCoy as *Ph. ramosa*. The axis, which is $4\frac{1}{2}$ inches long and $\frac{1}{8}$ inch broad, is exceedingly badly preserved, and shows hardly any structural features. Apparently it bears no leaves. The nodes are $\frac{5}{8}$ inch apart. It is impossible to say how many branches come off at the node, but there is apparently always one from each. Possibly the axis is itself a primary branch bearing secondary branches, such as Prof. Zeiller[3] has described in the case of *Ph. Rallii*, but there is no evidence in this case. The branches, one of which is 3 inches long, have nodes $\frac{1}{2}$ inch apart, and sheaths, apparently closely appressed, extend at the most to half the length of the internode. The free portions of the leaves average $\frac{1}{4}$ inch in length. The leaves and sheaths in this specimen are much smaller than those previously mentioned, but only relatively to the smaller internodes.

As in the case of *Ph. Rallii* as figured by Prof. Zeiller,[4] numerous isolated leaf-sheaths occur in this, and other specimens (Nos. 33 &

[1] See p. 17.
[2] Feistmantel (90) p. 80.
[3] Zeiller (99) p. 65.
[4] Zeiller (99) pl. v, figs. 4–10 & 12.

44). These usually appear to be subcircular, with a diameter of $\frac{2}{16}$ to $\frac{3}{16}$ inch. The number of free segments appears to vary from fourteen to twenty-four, fourteen being the commoner number.

Specimen No. 8. [Figured by McCoy (47) pl. xi, fig. 3.]—The unbranched specimen, figured as *Phyllotheca ramosa*, is 2 inches long, and $\frac{5}{8}$ inch broad. It consists of two nodes and three internodes, with a surface very faintly striated; the striæ are, however, more prominent at the nodes. The distance between the nodes is exactly 1 inch. Immediately above a node is a subcircular depression $\frac{1}{8}$ inch in diameter, which is probably a branch-scar. No leaves or branches are borne on this specimen. In dealing with such leafless fragments, it is not strictly correct to refer them to the genus *Phyllotheca*, for in this condition it is difficult or impossible to discriminate between *Phyllotheca*, *Schizoneura*, and *Archæocalamites*, or even some *Calamites*.[1]

Specimen No. 11. (?) Fructification of *Phyllotheca*.—McCoy in his memoir figures this specimen (pl. xi, fig. 1) as the inflorescence of *Phyllotheca*, which he regards as agreeing very closely with 'the male flowers of *Casuarina stricta*.'[2] This is the earliest account of the fructification of the genus, and even at the present day our knowledge on this subject is very incomplete. A great contribution has been made quite recently by Prof. Zeiller,[3] who has described well-preserved fructifications of *Ph. Rallii*. In this species, the fructification consists of alternate verticils of sterile bracts, and sporangiophores. The latter are perpendicular to the axis, and bear four ovoid sporangia on the inner side of a distal, peltate disc. In *Ph. deliquescens*, described by Schmalhausen,[4] the fructification is somewhat different, there being several verticils of sporangiophores between two successive sterile whorls of bracts. These are practically the only two types in which fructification is known.[5]

McCoy's specimen, from Mulubimba, is an isolated fragment, $1\frac{1}{4}$ inches long. The axis consists of a number of short internodes, $\frac{3}{32}$ to $\frac{4}{32}$ inch long, striated longitudinally. A microscopic examination affords no evidence of leaf-sheaths for at least nine nodes, representing the greater part of the specimen. McCoy (*loc. cit.*) says that such leaf-sheaths occur, and are exactly the length of the internode, but I think that he has mistaken the striated internodes for leaf-sheaths. At one node only, a long leaf-like segment is given off. The preservation of the fossil is by no means good, and will only permit me to say that at each node, and on either side, a bunch occurs of several small ovate bodies, apparently closely attached to the node, which may be sporangia. I have not, however, been

[1] Seward (98) pp. 284–85. [2] McCoy (47) p. 155.

[3] Zeiller (99) p. 65.

[4] Schmalhausen (79); see also Solms-Laubach, 'Paläophytologie' Leipzig, 1887, pp. 184–85.

[5] See Seward (98) p. 286.

able to make out any sporangiophores, or further details. McCoy's specimen, if a fructification of a *Phyllotheca*, for which the evidence is slender, differs both from Zeiller's and Schmalhausen's specimens.

2. PHYLLOTHECA DELIQUESCENS (Goepp.).

Woodwardian Mus. Camb., Foreign Plant Coll. No. 10 (?).
Locality.—Mulubimba.

Phyllotheca deliquescens.
1879. Schmalhausen (79) pp. 12–14 & pl. i, figs. 1–3, pl. ix, figs. 16–17, pl. x.
1898. Seward (98) pp. 283–86.
1900. Zeiller, 'Elém. de Paléobot.' p. 165.
Anarthrocanna deliquescens.
1845. Goeppert, in Tchihatcheff's 'Voyage scientifique dans l'Altaï Oriental' pp. 379–88 & pl. xxv, figs. 1 & 2.
Phyllotheca Hookeri.
1847. McCoy (47) p. 157 & pl. xi, fig. 7.
Phyllotheca indica.
1861. Bunbury, Quart. Journ. Geol. Soc. vol. xvii, p. 335 & pl. xi, fig. 1.
Phyllotheca australis.
1890. Feistmantel (90) p. 79 & pl. xiv, fig. 5.

This specimen is probably that figured by McCoy as *Phyllotheca Hookeri*, from which, with other specimens to be described under the locality of Arowa, he drew his reference to 'coarsely sulcated' stems.[1] There must remain some doubt as to whether this is the actual figured specimen, as although one of the fragments agrees very closely with McCoy's figure, its relationship to the other is different from that there represented. The identity of McCoy's plant with *Ph. deliquescens* (Goepp.) was recognized long ago by Schmalhausen, from McCoy's figures, and Mr. Seward fully agrees with that determination. The ridges and grooves are much sharper, and deeper, than in *Ph. australis*, Brongt. Neither of the fragments figured shows branches or leaves. In all probability they are casts, not of the external surface, but of the pith, similar to that figured by Mr. Seward[2] in his text-book on 'Fossil Plants.'

Incertæ Sedis.

I. NOEGGERATHIOPSIS, Feistmantel, 1881.

Mem. Geol. Surv. India (Pal. Indica) 'Foss. Flora of the Gondwana Syst.' vol. iii, pt. i (1879) p. 23.

NOEGGERATHIOPSIS GOEPPERTI (Schmal.). (Pl. I, figs. 1 & 2.)

Woodwardian Mus. Camb., Foreign Plant Coll. Nos. 19–21.
Locality.—Mulubimba.

Rhiptozamites Goepperti.
1879. Schmalhausen (79) pp. 32–33, etc. & pl. iv, figs. 2–4, pl. vii, figs. 23–27, pl. xv, figs. 1–11.
1883. Schmalhausen (83) p. 429 & pl. i, figs. 5–7.
1897. Newton & Teall, Quart. Journ. Geol. Soc. vol. liii, p. 504, pl. xli, figs. 6–7.
Noeggerathia æqualis.
1845. Goeppert, in Tchihatcheff's 'Voyage scientifique dans l'Altaï Oriental' p. 385 & pl. xxvii, fig. 7.
1871. Geinitz, in Cotta's 'Der Altai' p. 175.

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[1] McCoy (47) p. 157, sp. char. of *Ph. Hookeri.*
[2] Seward (98) p. 285, fig. 67.

Noeggerathia distans.
1845. Goeppert, in Tchihatcheff's 'Voy. sc. dans l'Altaï Oriental' p. 385 & pl. xxviii.
1871. Geinitz, in Cotta's 'Der Altai' p. 176 & pl. iii, fig. 9.
Noeggerathia palmæformis.
1871. Geinitz, in Cotta's 'Der Altai' p. 176.
Noeggerathia elongata.
1849. Dana (49) p. 715.
Noeggerathiopsis elongata.
1892. Etheridge, Rec. Geol. Surv. N. S. W. vol. iii, pt. iii, p. 75.
Zeugophyllites elongatus.
1847. McCoy (47) p. 152.
1850. Unger (50) p. 332.
1872. Schimper (69–74) vol. ii, p. 505.
1878. Feistmantel (78) p. 95 & pl. xiii, figs. 6, 6 *a*.
1883. Tenison-Woods (83) p. 152.
1890. Feistmantel (90) p. 150 & pl. xxi, figs. 6, 6 *a*.

The nature and affinities of the fossils about to be described have long been the subject of speculation, and no little perplexity. McCoy identified specimens in the Clarke Collection, labelled 'from Mulubimba Carboniferous Series,' as *Zeugophyllites elongatus*, Morris.

Before discussing the nature and systematic position of these fossils, some description of the plants themselves may be given. Of the various fragments, the best is a group of three leaves (Pl. I, fig. 1) which appear to radiate from some axis, unfortunately missing. The largest of these is $3\frac{1}{2}$ inches long, and is the median portion of a leaf. Another is an apical portion, $3\frac{1}{4}$ inches long. Another slab (Pl. I, fig. 2) shows a basal portion, $1\frac{1}{4}$ inches long, part of the contracted base of the leaf, and an exceptionally well-preserved apical portion $1\frac{5}{8}$ inches long. The following are the essential characters of this plant, so far as these specimens are concerned. Rhachis absent. Leaf(?) elongate, spathulate, more than 4 inches long, and in breadth $\frac{1}{16}$ inch near the base, increasing to a maximum of $\frac{5}{8}$ or $\frac{7}{8}$ inch near the apex. Base sharply contracted to a petiole, 1 inch or more long. Margin entire, straight or slightly curved. Apex obtuse, rounded. No median vein. Veins, about twelve in the petiole, dichotomizing once or twice where the leaf begins to expand. Venation of the leaf parallel, with occasional dichotomy. The number of the veins at the point of maximum breadth is generally about 30. Veins equal in size, strong, close (less than $\frac{1}{32}$ inch apart), not contracting (that is, still parallel) at the apex.

With regard to the identity of this plant, there is in the first place much doubt as to the correctness [1] of Morris's [2] identification of his specimens with Brongniart's genus *Zeugophyllites*. Brongniart's [3] original description is as follows :—

'Feuilles pétiolées, pinnées; folioles opposées, oblongues ou ovales, entières, à nervures très-marquées, en petit nombre, confluentes à la base et au sommet, toutes d'une égale grosseur.'

The original specimen, on which the genus was founded, was called *Z. calamoides*, and was obtained from Raniganj, Bengal

[1] Etheridge, Rec. Geol. Surv. N. S. W. vol. iii (1892–93) p. 74.
[2] Morris (45) p. 250 & pl. vi, figs. 5, 5 *a*.
[3] Brongniart (28)[1] p. 121.

(India); but Brongniart never figured any species of his genus. Feistmantel [1] supposed at one time that Brongniart's plant was a *Schizoneura*, and certainly the characters—leaves opposite, oblong, entire, with a few, well-marked nerves confluent at both base and apex—agree exactly with *Sch. gondwanensis* from the same locality. But Brongniart later described *Schizoneura paradoxa* under the name of *Convallarites*, without any reference to his genus *Zeugophyllites*, a circumstance which would seem to negative this conclusion. I am inclined to think, however, that Brongniart overlooked the similarity between his two genera *Zeugophyllites* and *Convallarites*, and that *Z. calamoides*, if it could be found, might very possibly turn out to be the type of *Schizoneura gondwanensis*, especially as, of all the plants described by Feistmantel [2] from Raniganj, only *Sch. gondwanensis* at all corresponds to Brongniart's description. But apart from the question of the nature of *Z. calamoides*, at any rate Morris assigned the Australian specimens to Brongniart's genus on insufficient grounds. His plant afforded no evidence as to Brongniart's first three characters, and the nerves were not few in number, nor were they confluent at the apex.

In the second place, Mr. Etheridge,[3] from a careful investigation of actual specimens from the two localities, has recently shown that the Mulubimba plant, mentioned by McCoy, is not identical with that of Morris from the Mesozoic beds of the Jerusalem Basin (Tasmania).[4] Thus McCoy's determination was incorrect. Mr. Etheridge proposes that the specific name *elongata* should be retained for McCoy's plant; but if it should be retained at all, it should certainly be applied to the Tasmanian fossils, to whatever genus they may belong.

Various conjectures have been made as to the real genus to which McCoy's plant should be assigned. McCoy thought that it was a cycad; Feistmantel,[5] although he had never seen actual specimens, considered that it might be referred to *Podozamites*. In 1879 [6] Schmalhausen published a paper on the fossil flora of some Russian rocks, now regarded as of Permian [7] age. Among the plants described were some referred to a new genus *Rhiptozamites*, as *Rh. Goepperti*. Schmalhausen afterwards admitted that his genus was identical with Feistmantel's *Noeggerathiopsis*,[8] and the Russian plant is now known as *Noeggerathiopsis Goepperti* (Schm.). The genus also occurs in Australia, India, South Africa, and South America, but Schmalhausen's *N. Goepperti* has so far not been reported from these countries. After comparing Schmalhausen's

[1] Feistmantel (90) p. 149.
[2] Feistmantel (80) vol. iii, pt. ii, p. 5.
[3] Rec. Geol. Surv. N. S. W. vol. iii (1892–93) p. 75.
[4] Consequently Dr. Szajnocha's, (88) p. 237, identification of Argentine specimens with *Zeugophyllites elongatus* is inconclusive.
[5] Feistmantel (90) p. 150.
[6] Schmalhausen (79) pp. 29, 32, 49, 81 & pl. iv, figs. 2–4, pl. vii, figs. 23–27, pl. xv, figs. 1–11.
[7] See Zeiller (96)[2] p. 469, Seward (97) p. 325, footnote 5, and Newton & Teall, Quart. Journ. Geol. Soc. vol. liii (1897) p. 505, footnote 1.
[8] Feistmantel (80) vol. iii, pt. i, p. 23.

figures and descriptions with the Cambridge specimens, I regard them as identical. In the specimens from the Altai and Pechora-land, the nerves seem to be somewhat closer and finer, but in those from the Lower Tunguska the nervation agrees very exactly, while the contour of some of the leaves is almost identical. Another specimen, figured some years later by the same author [1] from the Altai, also agrees closely. I propose, therefore, to adopt the name *Noeggerathiopsis Goepperti* (Schmal.) for the Cambridge specimens from Mulubimba.

As regards the identity of *N. Hislopi* (Bunb.), the representative of this genus in India, South Africa, South America, and also probably in Australia, with *N. Goepperti*,[2] I have not been able to arrive at a definite conclusion. There is a great similarity of habit and detail between them.

Unfortunately, the specimens of this plant in the Clarke Collection do not add anything to our knowledge of the affinities of *Noeggerathiopsis*. Feistmantel [3] has recently so judiciously summed up this question, that it needs no further discussion here. One of his conclusions, that the Noeggerathiopsideæ may eventually be found to be the Indian and Australian representatives of the European and American Cordaiteæ is noteworthy. In many respects the Cambridge fossils present points of similarity to the leaves of *Cordaites*, especially in the nervation, which in some members of that group (the sub-group *Dorycordaites*) consists of nerves of the same size. It is interesting, in this connection, to recall the fact that Schmalhausen [4] has recorded both *N. Goepperti*, and species of *Cordaites*, from the Permian of Russia.

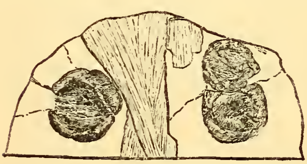
II. Cardiocarpus, Brongniart, 1828.

'Prodr. Hist. Végét. foss.' p. 87.

Cardiocarpus sp. (Text-figure.)

Woodwardian Mus. Camb., Foreign Plant Coll. No. 66.
Locality.—Mulubimba.

These seeds, as already mentioned, occur with a specimen of *Vertebraria* in organic continuity with *Glossopteris*.



Cardiocarpus sp. (Nat. size.)

Specific diagnosis.—Fructification of medium size, subcircular, compressed, 0·8 to 0·9 cm. in diameter, broadly winged (0·15 cm.). Wing of even width throughout, at one point emarginate. Central portion ovate, acuminate.

Only one species of *Cardiocarpus* has, so far as I am aware,

[1] Schmalhausen (83) pl. i, figs. 5–7.
[2] See Zeiller (96)[2] p. 485.
[3] Feistmantel 'Foss. Flora of Gondwana System' [Pal. Indica] vol. iv, pt. ii (1886) pp. 38–40 and (90) p. 152.
[4] Schmalhausen, Mém. Comité Géol. Russie, vol. ii (1887) no. 4, p. 37.

been described from Australia.[1] Clarke's specimen appears to be distinct from any of the European species, especially in the almost circular form, and the broad and even wing. It reminds one most of the much larger *C. orbicularis*, described by Ettingshausen[2] from Stradonitz in Bohemia.

C. Fossil Plants from Arowa.

Filicales.

Aneimites, Dawson, 1861.

Quart. Journ. Geol. Soc. vol. xvii, p. 5 ; see also Schimper (69–74) vol. iii, p. 489.

Aneimites ovata (McCoy).

Type.—Woodwardian Mus. Camb., Foreign Plant Coll. No. 6.

1847. *Otopteris ovata*, McCoy (47) p. 148 & pl. ix, fig. 2.

1888. *Aneimites austrina*, Etheridge, Proc. Linn. Soc. N. S. W. ser. 2, vol. iii, p. 1304 & pl. xxxvii.

McCoy's specimen, figured as *Otopteris ovata*, is one of the most interesting in the collection. Feistmantel,[3] from an examination of other specimens from Arowa, and elsewhere in Australia, believed it to be identical with the European *Rhacopteris inæquilatera*, Goepp., a plant best known in Britain as *Adiantites Lindseæformis*, Bunbury.[4] It must certainly be admitted that Feistmantel's figures present a strong resemblance to those of Goeppert, Stur, and Bunbury, but I am unable to identify McCoy's specimen with either his, or other figures of *Rhacopteris inæquilatera*. The general resemblance is admittedly close, but a careful examination of the nervation (as McCoy's excellent figure shows) discloses several points of disagreement. The nervation in the Cambridge specimen is finer, more graceful, and less rigid, and at the same time somewhat closer, more radiating, and spreading. The nerves also dichotomize more than once, in some cases as often as four times.

In 1888 Mr. Etheridge[5] figured a plant from the Lower Carboniferous of the Drummond Range (Queensland) as *Aneimites austrina*, Eth. This plant again, as he points out, much resembles *Rhacopteris inæquilatera*, yet it is different in detail. The chief differences appear to be the bipinnate nature of the frond, and spreading pinnæ, the less stiff and rigid, entire pinnules, with veins dichotomizing several times. The nervation of Mr. Etheridge's plant would seem to agree very closely with the Cambridge plant. Judging from his description, and more especially from the similarity of the nervation, I am inclined to regard these two plants as identical. Mr. Etheridge has expressed very fully his reasons for

[1] Carruthers, Quart. Journ. Geol. Soc. vol. xxviii (1872) pl. xxvii, figs. 4*a* & *b*, p. 356.

[2] Abhandl. d. k.-k. geol. Reichsanst. vol. i (1852) pt. iii, no. 4, p. 16.

[3] Feistmantel (90) p. 97.

[4] Kidston, Trans. Roy. Soc. Edin. vol. xxxv (1889) p. 424.

[5] Proc. Linn. Soc. N. S. W. ser. 2, vol. iii, p. 1304 & pl. xxxvii.

assigning the Queensland plant to Dawson's genus *Aneimites*, and in this I fully agree with him. Both the Australian specimens present many points of similarity in type to the British *Aneimites adiantoides* (L. & H.), referred by Mr. Kidston[1] to the genus *Sphenopteris*, and also to *Aneimites valida* (Dawson). I have therefore referred the Cambridge plant to this genus, at the same time instituting a comparison with *Neuropteris* (*Neuropteridium*) of Schimper.[2] I propose to transfer Mr. Etheridge's plant to McCoy's species, as the older determination of what I believe to be identical plants.

McCoy's specimen consists of a schist-like, flaggy rock crowded with portions of the pinnules of this fern. The part figured by McCoy consists of a stout rhachis bearing three large and fairly complete pinnules on one side, and two, less perfectly preserved, on the other. It is $1\frac{5}{8}$ inches long, and 1 inch across. The best preserved pinnules are $\frac{7}{8}$ inch long, and $\frac{5}{8}$ inch across.

Equisetales.

Phyllotheca.

Phyllotheca deliquescens (Goepp.). (Pl. I, fig. 3.)

Woodwardian Mus. Camb., Foreign Plant Coll. Nos. 43 & 44.
(For synonyms, see p. 17.)

McCoy[3] says that one of his species (*Ph. Hookeri*) is common in the siliceous schists of Arowa. There are two specimens of *Phyllotheca* in the collection labelled 'Arowa,' which seem to be identical with *Ph. deliquescens* (Goepp.). Neither of these was figured by McCoy, although the smaller closely resembles that figured (pl. xi, fig. 7) from Mulubimba. It consists of a fragment, $2\frac{1}{4}$ inches long and $\frac{5}{6}$ inch wide, showing a node and portions of two internodes. The internodes bear fairly sharp longitudinal ridges, opposite the nodes, and separated by shallow grooves, about $\frac{1}{32}$ inch across. The specimen is compressed, and shows about eighteen ridges on one side, and seventeen on the other.

The larger specimen (No. 44, Pl. I, fig. 3) is 3 inches long, and $1\frac{1}{4}$ inches broad. It is precisely similar to the smaller specimen, except in size. About twenty-three ridges are shown on one side.

As in the examples of this species from Mulubimba, neither of the specimens shows leaves or branches, and they are in all probability of the nature of pith-casts. It is therefore possible, if these rocks at Arowa should eventually prove to be of Lower Carboniferous age, that they may have to be referred to some other genus, such as *Archæocalamites*.[4]

[1] Brit. Mus. Catal. of Pal. Plants (1886) p. 73.
[2] Schimper (69) vol. i, p. 447 ; see also Feistmantel (81) vol. iii, p. 10.
[3] McCoy (47) p. 157.
[4] These are the only two types of fossil plants in the collection that are labelled 'Arowa.' There is no trace of any specimen of *Glossopteris linearis* from that locality, nor in any rock similar to labelled specimens from Arowa.

Conclusions.

List of the Plants described.

		McCoy's determination.
A. Wianamatta Series.		
1.	*Thinnfeldia odontopteroides* (Morris)	= *Gleichenites odontopteroides*, McCoy. *Odontopteris microphylla*, McCoy.
2.	*Pecopteris* (?) *tenuifolia*, McCoy.	= Do. (type).
3.	*Phyllotheca australis*, Brongt.	= *Phyllotheca Hookeri*, McCoy.
4.	*Baiera multifida*, Fontaine.	
B. Newcastle Series.		
1.	*Glossopteris Browniana*, Brongt.	= *Gl. Browniana*, Brongt. *Gl. linearis*, McCoy.
2.	*Glossopteris ampla*, Dana.	= *Gl. Browniana*, McCoy.
3.	*Vertebraria australis*, McCoy.	= Do. (type).
4.	*Sphenopteris alata* (Brongt.)	= Do.
5.	*Sphenopteris germana*, McCoy.	= *Sphenopteris germanus*, McCoy (type). *Sphenopteris plumosa*, McCoy.
6.	*Sphenopteris flexuosa*, McCoy.	= Do. (type).
7.	*Sphenopteris polymorpha*, Feist.	
8.	*Sphenopteris hastata*, McCoy.	= Do. (type).
9.	*Sphenopteris lobifolia*, Morris.	= Do.
10.	*Gangamopteris angustifolia*, McCoy.	= Do. (type).
11.	*Phyllotheca australis*, Brongt.	= *Phyllotheca ramosa*, McCoy. *Phyllotheca Hookeri*, McCoy.
12.	*Phyllotheca deliquescens* (Goepp.)	= *Phyllotheca Hookeri*, McCoy.
13.	*Noeggerathiopsis Goepperti* (Schm.)	= *Zeugophyllites elongatus*, Morris.
14.	*Cardiocarpus* sp.	
C. Arowa.		
15.	*Aneimites ovata* (McCoy).	= *Otopteris ovata*, McCoy (type).
16.	*Phyllotheca deliquescens* (Goepp.)	= *Phyllotheca Hookeri*, McCoy.

Of the twelve new types described by McCoy, five (namely, *Odontopteris microphylla*, *Sphenopteris plumosa*, *Glossopteris linearis*, *Phyllotheca ramosa*, and *Ph. Hookeri*) are no longer considered as such.

The Age of the Beds.

There remains to be discussed the palæobotanical evidence as to the age of these beds. The following is the succession in New South Wales, in descending order:—

4. Wianamatta & Hawkesbury Beds.
3. Newcastle Beds.
2. Series of Marine Beds, or Muree Beds.
   1. Upper Marine Beds.
   2. Lower Coal-Measures (Greta, Stony Creek, etc.).
   3. Lower Marine Beds.
1. *Lepidodendron*-beds (Arowa ?, Smith's Creek, etc.).

In this paper we are concerned only with the age of the

Wianamatta, Newcastle, and Arowa Beds. The various views, which have been held on this question, are shown in the following table:—

Author {	McCoy (47).	Dana (49).	Clarke (78).	Tenison-Woods (83).	Wilkinson,[1] 1887.	Feistmantel (90).
Wianamatta Series.	Oolitic.	......	Supra-Carboniferous (? Mesozoic).	Jurassic.	......	Trias.
Newcastle Series.	Oolitic.	Permian.	Upper Coal-Measures.	Trias (?)	Permian.	Permian.
Arowa.	......	......	Lower Coal-Measures.	Permian (?)	Carboniferous.	Lower Carboniferous.

With regard to the Wianamatta Beds, such evidence as the few plants in the Clarke Collection afford supports Feistmantel's conclusion as to the Triassic age of these beds. *Thinnfeldia odontopteroides*, a characteristic plant of this horizon in both Australia and India, occurs in South America in beds of undoubted Rhætic age.[2] The identification of Ratte's *Salisburia palmata* with the Triassic *Baiera multifida* of America, and a comparison with the Rhætic *Baiera Steinmanni* of Chile, is a new point in favour of this conclusion.

The *Glossopteris*-flora is well developed not only in the Newcastle Beds, but also in the Muree Series. It is generally customary to speak of these as Permo-Carboniferous. The question arises whether the Newcastle Beds can be regarded as equivalent to the European Permian in age. In Australia there is no record of any admixture of typical Southern and Northern types,[3] such as *Glossopteris* and *Sigillaria* or *Lepidodendron*, as is known to occur in South Africa[4] and in South America.[5] The similarity between the fossil flora of the Lower Gondwanas of India and that of the Newcastle Series of Australia is well known, and an additional point of contact has been shown here in the occurrence of *Sphenopteris polymorpha* in Australia. In South America, Dr. Kurtz[6] has shown that at Bajo de Velis (Argentine Republic) typical Lower Gondwana types (*Neuropteridium validum*, Feist., *Noeggerathiopsis Hislopi*, Bunb., and *Gangamopteris cyclopteroides*, Feist.) occur in beds which he regards as of Permian age; a conclusion which Prof. Zeiller confirms. The two last-named fossils are represented by closely allied types in the Newcastle Beds. Further, the flora of the Russian beds, classed by Schmalhausen[7] as Jurassic, but now regarded as Permian, has much in common

[1] See T. W. E. David, Quart. Journ. Geol. Soc. vol. xliii (1887) p. 190.
[2] See Rec. Geol. Surv. Ind. vol. xxviii (1895) p. 116 & vol. xxix (1896) p. 56.
[3] Clarke (61) p. 360.
[4] Seward (97).
[5] Rec. Geol. Surv. Ind. vol. xxix (1896) p. 57.
[6] See Zeiller (96)[2] pp. 467–68.
[7] Schmalhausen (79).

with the Newcastle Beds: at least two species, *Noeggerathiopsis Goepperti* and *Phyllotheca deliquescens*, being identical.

Prof. Zeiller[1] has recently discussed the age of the *Glossopteris*-types, and their relation to the European flora of similar age. He regards the *Glossopteris*-flora proper as made up of three types—*Gangamopteris*, exclusively Permian, and *Glossopteris* and *Phyllotheca*, appearing first in the Coal-Measures, and reaching their maximum in the Permian. As *Gangamopteris* occurs in New South Wales only in the Newcastle Beds, this is an additional point in favour of regarding these beds as Permian, rather than as Permo-Carboniferous. Such evidence as the plants in the Clarke Collection afford, would certainly seem to support Feistmantel's opinion, that the Newcastle Beds are equivalent to the Permian of Europe.

Lastly, in regard to Arowa only a few words are needed. It has been shown, as had been long suspected by Australian authors, that McCoy was mistaken in describing *Glossopteris linearis* from that locality. The identification of McCoy's *Otopteris ovata* with *Aneimites austrina*, Eth., rather than with *Rhacopteris inæquilatera* (Goepp.), in no way disagrees with Feistmantel's conclusion as to the age of these beds. On the other hand, the occurrence of *Phyllotheca* at Arowa, as asserted by McCoy, but apparently overlooked by Feistmantel, is provisionally confirmed here. So far as I am aware, this is the lowest horizon from which this genus has been described. But, as I have already explained, these specimens are of the nature of pith-casts, and as such it is practically impossible to distinguish between *Phyllotheca*, *Archæocalamites*, or even some *Calamites*. It is possible, therefore, that these specimens should be assigned rather to the genus *Archæocalamites*, a typical Lower Carboniferous European type, if an undoubted flora of that age were known from Arowa. As, however, Feistmantel[2] apparently correlated these beds with those of Port Stephens and Smith's Creek, solely on the occurrence of *Rhacopteris inæquilatera* (Goepp.), the exact horizon and age of this locality must for the present remain doubtful.

In conclusion I wish to express my great obligations to Mr. A. C. Seward, M.A., F.R.S., who has not only given me the benefit of his advice on questions of identification, but has greatly helped me in the study of a widely scattered literature.

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[1] Zeiller (96)[2] p. 482.

[2] Feistmantel (90) p. 165.

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EXPLANATION OF PLATE I.

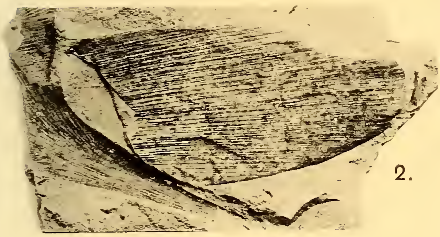
[The figures are reproduced from photographs taken by Mr. Tams, Cambridge.]
All the specimens are in the Woodwardian Museum, Cambridge.

Fig. 1. *Noeggerathiopsis Goepperti* (Schmal.). (Slightly enlarged.)
2. *Noeggerathiopsis Goepperti* (Schmal.). (Slightly reduced.)
3. *Phyllotheca deliquescens* (Goepp.). (Natural size.)
4. *Sphenopteris polymorpha*, Feist. (Slightly reduced.)
5. *Sphenopteris polymorpha*, Feist. (Slightly enlarged.)

Discussion.

Dr. Blanford expressed his satisfaction at hearing a paper read before the Society, in which the Palæozoic age of the Australian Coal-Measures was fully accepted on palæontological evidence. For many years the question had been debated, between McCoy backed by all the European palæontologists, Schimper among others, who declared that the Newcastle Beds of Australia were

1.



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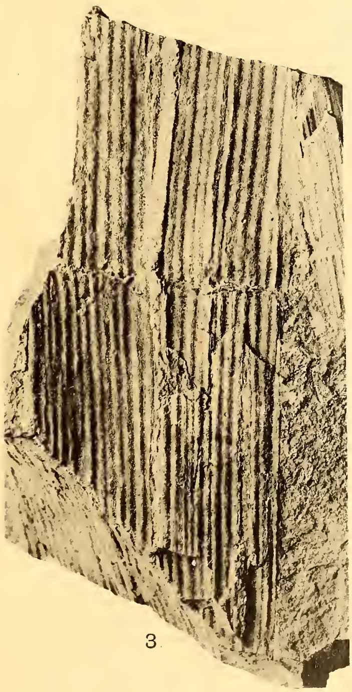

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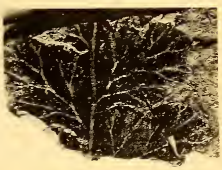

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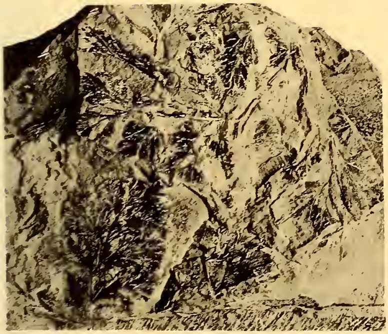


5.

Noeggerathiopsis, etc.

Tams. Photo. *Bemrose, Collo.*

Jurassic, on the one side; and on the other, by the geologists of New South Wales, among whom none did more valuable work in proving the Palæozoic age of the Coal-Measures than the Rev. W. B. Clarke, the collector of the specimens described by the Author. Clarke published sections of coal-pits, showing the actual intercalation of beds with *Glossopteris* and *Vertebraria* between others containing *Spirifer* and *Productus*. The speaker referred briefly to the distribution of the Southern Upper Palæozoic *Glossopteris*-flora, and called attention to the remarkable discovery of the same by Prof. Amalizky in Russia, in the basin of the Dwina.

Prof. Boyd Dawkins congratulated the Author on his paper based on the collection of the late Rev. W. B. Clarke, which the speaker had studied in 1874 in Sydney. Clarke—the friend of Murchison, Sedgwick, and Lyell—was regarded, and justly, as the father of Australian geology, and his work has stood the test of the more minute surveys made since. He pointed out to the speaker the association of Carboniferous plants, such as *Lepidodendron*, with the *Glossopteris*-flora; and the speaker had collected a large number of specimens of that flora from the Lower Carboniferous shales of the railway-cuttings between the Blue Mountains and Bathurst. These are in the Manchester Museum, and might form the subject-matter for a second paper on the flora from the present Author.

Dr. A. Smith Woodward said that he had studied some of the fishes obtained from these rocks. Two collections had been described, but the third collection (from St. Peter's, near Sydney), still to be described, contained the most truly typical Palæozoic fishes that he had yet seen from New South Wales, including *Pleuracanthus* and Palæoniscid fishes of undoubted Palæozoic affinities. In the Wianamatta and Hawkesbury Beds, however, there were other fish-faunas: one of the faunas was, at the earliest, Triassic, and another would certainly be described as Jurassic. Further, a fish from the so-called Mesozoic of the Clarence River-Basin proved to be generically the same as a recent freshwater fish, one now living in the Australian rivers.

The Author, in replying to Dr. Blanford, said that it now seemed clear that, towards the end of Permo-Carboniferous times, a migration into Europe of the Southern types of the *Glossopteris*-flora took place. This was shown by the discovery of *Glossopteris*, and the occurrence of *Noeggerathiopsis Goepperti* and *Phyllotheca deliquescens*, in the Permian of Russia. It was perhaps one of the most important results that had been attained by recent researches, and of which there was undoubted evidence in the plants of the Clarke Collection.

In reply to Prof. Boyd Dawkins, he said that his conclusion, that the age of the Newcastle Beds was Permian rather than Permo-Carboniferous, was based entirely on such evidence as the plants themselves afforded. He was unaware that *Lepidodendron* and *Glossopteris* had been found associated in the Newcastle Beds, as Prof. Boyd Dawkins stated, a fact which he believed had not been recorded.

2. *On an* ALTERED SILICEOUS SINTER *from* BUILTH (BRECKNOCKSHIRE). By FRANK RUTLEY, Esq., F.G.S. (Read November 6th, 1901.)

[PLATE II.]

IN a former paper some tufaceous rhyolites from Dufton Pike were described,[1] which seemed to afford evidence of solfataric action, yet they scarcely gave the convincing proof that could have been desired of the former existence of hot springs and geyser-action among the old volcanic districts of the British Isles.

Attracted as I was by the resemblance of a small specimen of a brecciated rock from Carneddau, near Builth, to a rock from Rotorua, described in a former paper,[2] it seemed desirable to examine other small chips from the Builth neighbourhood which were given to me many years ago by the late Mr. H. W. Bristow, F.R.S., my former Director on the Geological Survey. Among these specimens was one labelled 'Rock acted on by heat, Builth,' which seemed to promise more satisfactory information on the subject of old siliceous sinters than that to be derived from the microscopic examination of the generality of quartzites, the latter often showing incontrovertibly that they are sandstones which have undergone various degrees of alteration.

The rock now to be described shows no trace of original sand-grains. It is unfortunate that the label gives no indication of the precise locality at or near Builth from which the specimen was derived.[3] Apart from this drawback, however, it appears to be of sufficient interest to deserve record. If the deposit be of tolerable thickness and extent, its pale yellowish-white or pinkish-cream colour should render it easy of recognition by future investigators of the geology of the district.

The rock has an almost compact or an exceedingly fine-grained character, and a fracture which is in some parts coarsely platy, in others small-conchoidal. It is veined with quartz, sometimes distinctly crystallized where quartz was apparently attached to the walls of slightly gaping fissures. Both the rock and the veins which traverse it are too hard to be scratched by a knife-point.

Small splinters of the rock can, however, be fused on thin edges to a white, frothy glass, after long exposure to the blowpipe-flame.

Small splinters from a white siliceous sinter (H_{40}) from Rotorua[4] proved under like circumstances to be quite infusible, but in this specimen the silica was found by Mr. Philip Holland to amount to 93·59 per cent. In siliceous sinters, also from Rotorua (H_{38} and

[1] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 31.

[2] 'Additional Notes on some Eruptive Rocks from New Zealand' Quart. Journ. Geol. Soc. vol. lvi (1900) p. 493.

[3] It probably came from Carneddau or its vicinity.

[4] *Op. cit.* p. 503.

H_{39}),[1] containing many small fragments of pumice and some of felspar, fusion on the edges of thin splinters could, on the other hand, be clearly effected in the flame of the blowpipe: a circumstance easily to be accounted for by the smaller amounts of silica $= 81 \cdot 99$ and $81 \cdot 22$ per cent., which these specimens were respectively found to contain. From its slight fusibility, it is clear that if this Builth rock be a siliceous sinter, it is a more or less impure or tufaceous one, containing small fragments of fusible minerals or rocks like the specimens H_{38} and H_{39} from Rotorua.

Two other possibilities presented themselves, either that the rock was a chert or that it was a lithoidal rhyolite. The former supposition is negatived by the absence of any fragments of shells, crinoids, sponge-spicules, or foraminifera, such as one usually meets with in cherts, by the absence of rhombohedral crystals of carbonates, and also by the absence of the radial crystallizations frequently to be seen in cherty deposits. Furthermore, that this rock is not allied to any form of rhyolite seems proved by the absence of any of those microscopic structures which so commonly characterize rhyolites and their altered representatives.

Under the microscope, it is seen that the rock from Builth is decidedly tufaceous. It appears that this tufaceous matter is not entirely of one kind, since small pale greenish crystals, often with somewhat ragged boundaries, are here and there present in thin sections; but they are generally so much altered and over- or underlain by the small birefringent grains of the sinter, that it is difficult to ascertain anything definite about their optical properties. They often seem to give straight extinction, and may be epidote.

By far the greater part of the tufaceous matter is, however, seen to consist of diminutive fragments of pumice. These, at first sight, are not very evident, being usually faintly outlined in pale brown, or they often appear as almost colourless phantoms of small pumice-shreds, their concave boundaries and their occasional indications of fibrous structure alone serving to show their real character. In order to see them distinctly, it is needful to search the clearer parts of the sections in ordinary transmitted light, under a moderately high magnifying power, and to employ careful focussing.

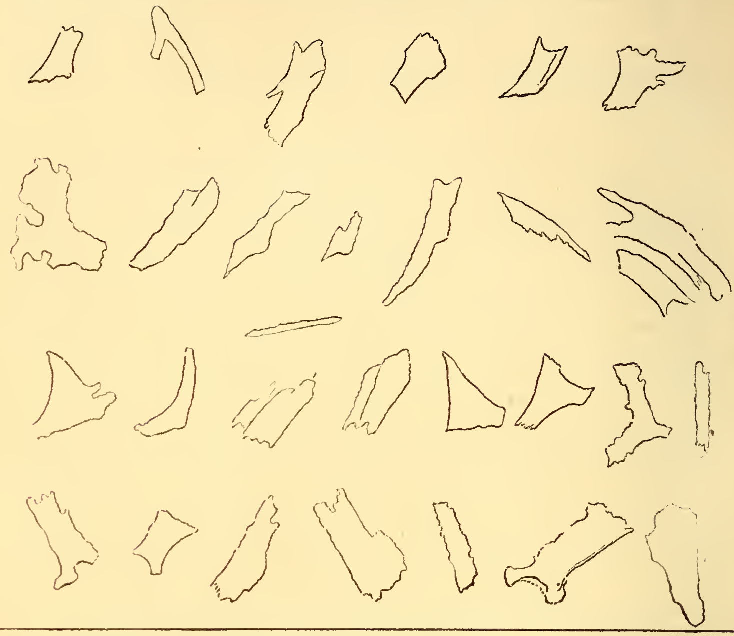
To avoid any bias from a preconceived notion regarding the nature of these small bodies, a number of drawings were made from them and from fragments of pumice occurring in the siliceous sinter (H_{39}) from Rotorua; and a comparison of a selection of these rough outlines reproduced in the accompanying figure (p. 30), will, I think, sufficiently prove that the resemblance between the fragments from the one locality to those from the other justifies the assumption that, in general form at least, there is no essential difference.

The resemblance ceases, however, when polarized light is employed. The fragments of unaltered pumice in the sinter from Rotorua are quite isotropic when viewed between crossed nicols, while the

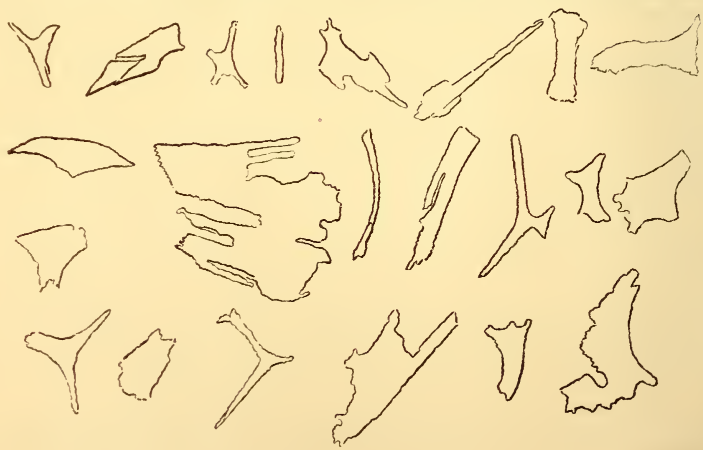
[1] Quart. Journ. Geol. Soc. vol. lvi (1900) pp. 502 & 503.

Outlines of fragments of pumice in siliceous sinters.

Pumice in siliceous sinter. Builth; South Wales. x cir. 140.



Pumice in siliceous sinter. Rotorua. H 39 x cir. 140.



fragments in the rock from Builth break up into a mosaic of birefringent grains under like examination. This is shown in Pl. II, figs. 7 & 8, the upper figure depicting a fragment of pumice in the Builth rock, as seen in ordinary transmitted light: while the lower figure represents the appearance of the same spot in the section, when viewed between crossed nicols. No trace of the fragment of pumice is any longer to be seen in the latter figure, but merely a confused mosaic of birefringent grains, the pumice being altered into the same condition as the surrounding siliceous sinter.

In Pl. II, fig. 1, is represented the general appearance of the Builth rock in ordinary transmitted light; while fig. 2 shows the same part of the section when viewed between crossed nicols. In the same Plate, part of a section of pumice-charged geyserite or siliceous sinter from Rotorua is shown for comparison, fig. 3 representing what is seen in ordinary transmitted light, while fig. 4 shows the same part of the section as it appears between crossed nicols.

The fragments of pumice in fig. 4, being in an unaltered condition, are quite dark, while no such fragments are to be seen in fig. 2, since the fragments of pumice in the Builth rock are as much altered as the sinter surrounding them. It should also be noted that the sinter in the New Zealand rock appears to be neither so dark nor so highly crystalline (between crossed nicols) as the sinter in the Welsh rock. In these figures we compare, in fact, the appearance of a young sinter with that of an extremely old one.

There yet remains another feature in these rocks about which it might be well to say as little as possible. Some of the siliceous sinters of New Zealand contain small patches of a brown substance, which in the thicker parts of a section appear very dark brown or nearly black; and in the rock from Builth, which we have been trying to describe, there are patches of what seems to be a similar substance. Mr. Frederick Chapman has kindly examined some of the sections of this rock from Builth, but, although he believes that the patches represent something of an organic origin, he has failed to detect anything which will enable him to say whether it belonged to the animal or to the vegetable kingdom.

Since Prof. Weed noted the presence of algous growths in some of the siliceous sinters of New Zealand,[1] it seems possible that this brown substance may also be of a like nature. A patch of the questionable brown substance is represented in the middle of fig. 5, Pl. II, which has been drawn from a section of the Builth rock; while fig. 6 in the same Plate shows part of a section of pumice-tuff cemented by siliceous sinter from Rotorua, in which several patches of this brown substance are represented. In this case they are clearly seen to fill up spaces between the fragments of pumice The brown substance in the Builth rock seems to occur in an equally irregular manner.

It is only right that I should mention that, in a previous paper,[2]

[1] U.S. Geol. Surv. 9th Ann. Report (1887–88).

[2] 'Notes on the Rhyolites of the Hauraki Goldfields' Quart. Journ. Geol. Soc. vol. lv (1899) p. 449.

read before this Society, I had occasion to allude to a brown substance occurring in a 'quartz-blow' from Waihi. This substance was a source of considerable perplexity to me; some of it formed spongy-looking fragments, which I doubtfully suggested might be fragments of vesicular lava and, inadvertently, it was positively so named in the description of one of the figures. In other cases the brown matter formed irregular streaks like whip-lashes. On my subsequently submitting a section of the rock to Dr. G. J. Hinde, F.R.S., he kindly examined it, and informed me that the brown bodies were doubtless of organic origin, but that he could offer no further opinion about them on account of their obscurity as regarded structure. The specimen alluded to was numbered H_{18}, and, in view of Dr. Hinde's opinion, I beg publicly to recant the statement that fig. 4, pl. xxxiii,[1] represented 'fragments of brown glassy vesicular lava,' and to say that it represented 'brown matter of organic origin in chalcedony' ('quartz-blow') ×140.

If Dr. Hinde's opinion be correct, which I do not venture to doubt, the origin of the particular 'quartz-blow' in question may have been somewhat similar to that of a geyserite or siliceous sinter; but I refrain from any further speculation about this rock, trusting that Prof. Park will work out further details concerning its mode of occurrence.

After this digression, it may be well to say a few words concerning another rock from the vicinity of Builth. It is essentially a breccia, consisting of sharply angular pinkish to greyish-white fragments, embedded in a dark grey to black cement. Both the fragments and the cement are harder than steel, the point of a penknife making no impression. This specimen, which so closely resembles a pumice-tuff or breccia from the sinter of Rotorua (H_{42}), was also given to me by the late Mr. H. W. Bristow, and was labelled as coming from Carneddau, near Builth. It and the specimen first described in this paper were doubtless collected at the same time and, I should think, probably at or near the same spot. Provisionally I merely called it a felsite-breccia, and its general appearance in thin section under the microscope warrants such a name; but, when examined more carefully in ordinary light, most of the fragments show faint and occasionally fairly distinct traces of the fibrous structure and concave outlines so characteristic of the pumice-fragments, just described as occurring both in the Builth and Rotorua sinters. The outlines of such fragments are, however, obliterated in polarized light, owing to their altered nature, in which alteration, judging from the extreme hardness of the fragments, impregnation and partial or entire replacement by silica must have played a very important part. Between crossed nicols the fragments show differences in texture, some being much more finely crystalline than others; the coarser seeming to have more the character of pumice-tuffs, while those of finer texture rather

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 463, 468.

resemble fragments of altered siliceous sinter, with little, if any, tufaceous admixture. An occasional fragment indicates that other rocks, suggestive of highly altered porphyrites, have contributed fragments to this breccia.

The cement which binds the fragments has the appearance of vitreous matter rendered turbid by brown stains and dark streaks and spots, the latter appearing in quite irregular forms when examined under an amplification of 250 diameters, and showing no approach to definite crystal-form. Under crossed nicols this cement appears more or less dark, but is filled with very minute birefringent specks. If the cement be regarded as possibly a siliceous sinter, and its hardness warrants such a supposition, it certainly has not attained the advanced stage of alteration of the sinter from Builth, previously described; and since it cements fragments of rock, most of which resemble the sinter already alluded to, it must, therefore, be of later age. Both fragments and cement are also traversed by delicate veins of quartz, the latter marking a still later stage in the history of this rock.

The specimen which it most resembles is a pumice-tuff or breccia (H_{42}) from Rotorua. The angular or subangular fragments of pumice are perfectly fresh, and the cement very slightly, if at all, exceeds in quantity that present in the breccia from Carneddau. Between crossed nicols a section of the breccia from Rotorua is practically isotropic, except for the hyalite which represents the greater part of the cement. Here the cement has a marked birefringence, and the small globules of hyalite show the usual characteristic dark crosses. There are, however, some limited areas where the siliceous sinter has not assumed the condition of hyalite, and the sinter then appears isotropic, save for some minute birefringent specks which indicate the first stage of alteration. This section also contains some brown matter, probably of organic origin, and similar to that occurring in the other sections described. That this pumice-breccia from Rotorua would, in time, pass into the condition of that from Carneddau seems by no means unlikely.

It is quite possible that further field-work may show that, in the Builth neighbourhood, conditions have existed similar to those which now exist in and around Lake Rotorua; yet, so far as I know, the recent sinters of New Zealand and the old sinters of Wales have not hitherto been compared.

In conclusion, I wish to tender my sincere thanks to Mr. Frederick Chapman, A.L.S., F.R.M.S., for the lantern-slides and photographs which he prepared in illustration of this paper.

Postscript.

[When writing this paper I was not aware that my former colleague, Mr. J. G. Goodchild, F.G.S., had found sinters, both siliceous and calcareous, in the volcanic rocks associated with the Lower Carboniferous System in and around Arthur's Seat. To these he alludes in his 'Outline of the Geological History of the Rocks around Edinburgh,' read in August 1897, and published in Proc. Geol. Assoc. vol. xv, where at p. 129 he states that

'Concurrently with the upgrowth of the volcano there arose hot springs, and perhaps also geysers. From these were deposited beds of calcareous and siliceous sinter, which were spread out in thin layers in the vicinity of their orifices.'

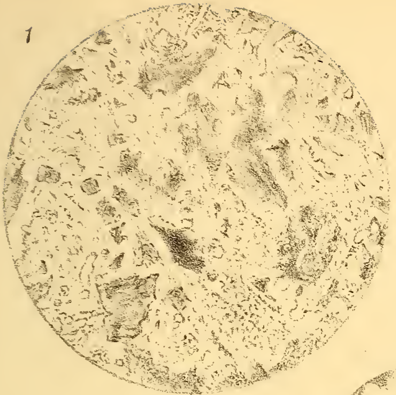
Although neither have I had an opportunity of examining this siliceous sinter, nor can I find any reference to its microscopic characters in the paper just cited, it is only right that I should give due credit to its discoverer, whose careful work has always commanded my respect.—*December 4th, 1901.*]

EXPLANATION OF PLATE II.

Fig. 1. Siliceous sinter (pumice-bearing). Builth, Brecknockshire. × 140. Ordinary transmitted light.

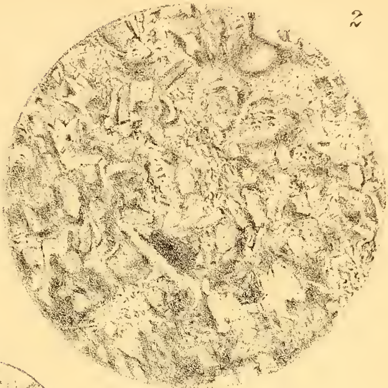
2. The same part of the section. × 140. Crossed nicols.
3. Siliceous sinter (pumice-bearing and with a few fragments of felspar). Rotorua, New Zealand (H_{39}). × 140. Ordinary transmitted light.
4. The same part of the section. × 140. Crossed nicols.
5. Siliceous sinter, showing brown matter probably of organic origin. Builth, Brecknockshire. × 140. Ordinary transmitted light.
6. Siliceous sinter (pumice-bearing), showing brown matter, probably of organic origin. Rotorua, New Zealand. × 140. Ordinary transmitted light.
7. Fragment of pumice in siliceous sinter. Builth, Brecknockshire. × 140. Ordinary transmitted light.
8. The same. × 140. Crossed nicols.

1



× 140

2



× 140

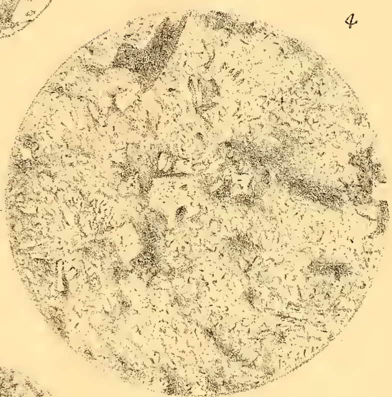
7

× 140

3

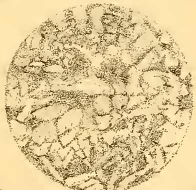
× 140

4



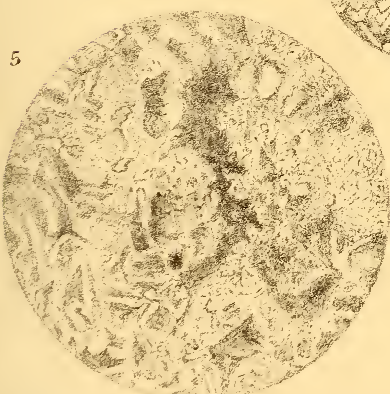
× 140

8



× 140

5



× 140

6

× 140

F. Rutley del.
M. P. Parker lith.

Parker & West imp.

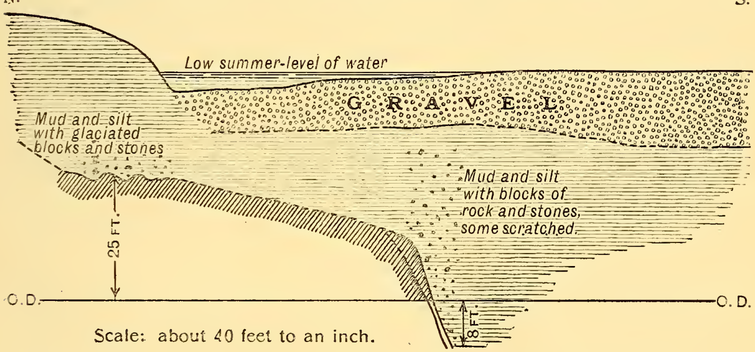
PUMICE-BEARING, SILICEOUS SINTERS
FROM BUILTH AND ROTORUA.

3. NOTE *on a* SUBMERGED *and* GLACIATED ROCK-VALLEY *recently exposed to view in* CARMARTHENSHIRE. By THOMAS CODRINGTON, Esq., M.Inst.C.E., F.G.S. (Read November 6th, 1901.)

IN a paper published in the Quarterly Journal for 1898[1] I gave particulars of submerged rock-valleys in South Wales. Further instances of the same sort have since come to light, one of which is sufficiently remarkable to deserve description. It was discovered in building a bridge across the River Towy, at Dryslwyn, 9 miles above Carmarthen (to which place the tide now flows), and about 18 miles from the mouth of the river. The sources of the Towy are some 40 miles from Dryslwyn, on the borders of Cardiganshire and Radnorshire, at about 1700 feet above the sea; but tributary streams descend from the Black Mountain, 2000 to 2600 feet above sea-level, on the south of the Towy Valley, 12 to 16 miles above Dryslwyn.

At the bridge, the valley is narrowed by a detached hill of Lower

Section in the Towy Valley at Dryslwyn.



Scale: about 40 feet to an inch.

Silurian rock rising about 180 feet above the river, which stands out into the valley and contracts the width to half a mile. The river now flows at the foot of the hill, which rises at an angle of 40° with the horizon, and is crowned by the ruins of Dryslwyn Castle.

Near the water's edge on the north of the river, the rock was laid bare, for the foundation of the abutment of the bridge, over an area of 30 by 20 feet. It sloped down gradually to 23 feet below summer water-level at the western or down-stream side, and it was glaciated in large furrows, a foot and more across, running in the direction of the river. The surface of the rock was smoothed and striated, and striated blocks of grit rested upon it. In the Boulder-Clay above, striated stones and scratched pebbles of black Carboniferous Limestone, like that of the Black Mountain already mentioned, were found.

About 60 feet farther out in the river, borings showed that beneath 10 or 11 feet of gravel a silty clay extended to a considerable depth,

[1] Vol. liv, p. 251.

and cast-iron cylinders were sunk. The rock was not met with until a depth varying between 34 and 42 feet below summer water-level was reached, or as much as 19 feet below the glaciated surface exposed on the northern bank, and it was found then to be sloping towards the south at an angle varying from 28° to 18° with a vertical line, so that to get a full bearing for cylinders 6 feet in diameter it was necessary to cut away the rock to a depth of 45 to 56 feet below summer water-level, at which depth the rock was still sloping downward at the same precipitous angle. The face of the rock presented an even surface, but the conditions under which it had to be cut away did not admit of proofs of glaciation being observed. Scratched stones and pebbles were, however, met with in the clay near the rock.

About 60 feet farther to the south the silty clay (beneath 16 feet of gravel) was penetrated to more than 30 feet below summer water-level without reaching the rock.

The low summer water-level in the river is 48 feet above Ordnance datum, so that the glaciated surface which was exposed on the northern bank is only 25 feet above that level, and 60 feet farther south the rock is sloping down at a precipitous angle at 8 feet below mean sea-level, at a distance of 18 miles from the mouth of the river. There is here, as in the instances given in the paper above referred to, evidence of a very considerable elevation of the land during the Glacial Period, with a corresponding greater distance to the sea.

It was my intention to have exposed to view in the new bridge a well striated block of gritstone from the foundation, but the glaciated surface began to flake off, and so the block was sent to Carmarthen for preservation. Some smaller glaciated and scratched stones and pebbles have also been preserved.

Discussion.

Prof. Boyd Dawkins pointed out that the Author's observations, as to the pre-Glacial valleys on the Welsh seaboard having been excavated when the land stood at a higher level than it does now, were amply confirmed by the examination of the whole of the area reaching from Wales to Cumberland. In this area all the lower portions of the valleys are filled with Boulder-drift. In some cases—as, for example, in the Lancashire and Cheshire plain—they have been completely filled up. The observations made for the purposes of the Manchester Ship Canal prove that the rock-valley of the pre-Glacial Mersey exists at a depth of about 160 feet below Ordnance datum to the north-west of Runcorn, and the barrier of Red Sandstone reaching across from Liverpool to Birkenhead proves that the outlet seaward was not in that direction: it was in the Drift-covered region to the north of Liverpool. When these valleys were being cut by the pre-Glacial rivers, the 100-fathom line was probably the Atlantic seaboard.

The Author, in connexion with Prof. Boyd Dawkins's remarks, called attention to the specimens of pebbles exhibited, which were perfectly rounded before they were scratched.

4. *On the* Meteorological Conditions *of the* Pleistocene Epoch.

By Dr. Nils Ekholm, Meteorologiska Central-Anstalten, Stockholm. (Communicated by Prof. W. W. Watts, M.A., F.G.S. Read November 20th, 1901.)

In his interesting paper entitled 'The Influence of the Winds upon Climate during the Pleistocene Epoch,' Mr. F. W. Harmer[1] has endeavoured to describe the meteorological conditions of that epoch by means of the theories and facts of modern meteorological science. The subject is no doubt one of great interest, but also of great difficulty. We still know too little concerning the nature, origin, and development of the great atmospheric eddies, the cyclones and anticyclones, to be able to reconstruct their average positions and tracks on the globe during a past geological epoch. Furthermore, it is very difficult to estimate the influence of those eddies on climate. As my opinion on this matter differs in some important respects from that expressed in Mr. Harmer's paper, I crave permission to discuss the question briefly. It may be conveniently divided under the following heads :—

(1) What are the meteorological conditions necessary and sufficient to produce a permanent ice-sheet, or glaciation such as that of the Great Ice-Age?

(2) What will be the influence of such a glaciation on the meteorological conditions, especially on the cyclones and anticyclones, over the ice-covered land and its neighbourhood ?

In order to answer these questions we must consider the present climatic conditions of the earth, and draw our inferences therefrom.

(1) We know that a land must lie above the snow-line in order that it may be glaciated. At first sight, we might be inclined to assume that this snow-line coincides approximately with the mean annual isotherm of 32° Fahr. But this holds good only in the vicinity of the Equator, where the yearly variation of the temperature of the air is insignificant. The farther we recede from the Equator, and the nearer we approach the Poles, the more, as a general rule, does the mean annual temperature of the snow-line sink below 32° Fahr. This temperature, however, will not vary with latitude only, for the quantity, quality, and annual period of precipitation [rainfall], and the summer temperature have a very marked influence. Thus the centre of cold near Verkhoyansk in Siberia, with a mean annual temperature of about 0° Fahr., is not glaciated, whereas the southern point of Greenland, with an annual mean of about 32° Fahr., is covered with a permanent ice-cap. Now Eastern Siberia is covered during the whole winter by a great anticyclone, the sky is nearly always clear, little or no snow falls, and that which does fall is very quickly thawed

[1] Quart. Journ. Geol. Soc. vol. lvii (1901) pp. 405–76.

at the beginning of the hot season. This season is short, but relatively warm with frequent rainfall. In Southern Greenland, on the contrary, a great deal of snow falls during the whole winter, owing to frequent cyclones passing across or south of that area during that season. Moreover, this cyclonic state of weather persists in summer as well: the sky is generally cloudy, and the effect of the summer sun is counteracted thereby, and by the cold and damp winds coming in from the ice-filled sea surrounding the Greenland coast. Of course, the height above sea-level and the thick ice-sheet already covering that land also contribute to maintain its state of glaciation; and it is possible that the present climatic conditions of this region are such that, if the ice-sheet were now removed, it would not return. It is remarkable, more-over, that the northernmost part of Greenland and the surrounding islands are not completely ice-covered, despite the much lower mean annual temperature, a fact which is explained by the insignificance of the snowfall there.

Such instances might be multiplied, and from all of them the conclusion may be drawn that a region where a permanent anticyclone prevails during the winter, cannot be covered with a permanent ice-sheet, however low the winter-temperature may fall, unless possibly the summer is not only cold but accompanied by an abundant snowfall, so that more snow falls in that season than is thawed away. This latter state of weather might perhaps be found somewhere in the unexplored Polar regions—the South Polar cap for instance—but certainly not in any known country.

The most favourable climate for land-glaciation is to be found in the great Southern Ocean. In Cape Horn and Kerguelen Island the glaciers come down to the sea, and the snow-line is comparatively very low, so that it probably coincides nearly with the isotherm of 32° Fahr., despite the high latitude (49° to 55° S.). Moreover, the cyclonic state of weather prevails there all the year round, and the summer is relatively very cool.

If we now consider the area of glaciation in North America and Europe during the Great Ice-Age, we find that it nearly coincides with the area now crossed by the most regularly frequented tracks of storms or cyclones. More strictly speaking, those regions are the site of moving or temporary cyclones and anticyclones, which alternate. Regions occupied by stationary anticyclones during the greater part of the year have little or no permanent ice-sheet, even though the mean annual temperature be much below the freezing-point. Such are several great plains and highlands in Asia and America.

We find also that the difference between the mean annual temperatures at the same latitude in Europe and North America probably was nearly the same during the Great Ice-Age as it is now, for the southern limit of the ice-sheet coincides approximately with the mean annual isotherm of 55° Fahr. in both continents (or 50° Fahr., if only the glaciation of the low land is considered). Then, too, most geologists agree in considering that a lowering of the present snow-line to the extent of about 3300 feet, corresponding to a lowering of the mean annual temperature of the earth's surface by 7° or 9° Fahr., was the general cause of the Great Ice-Age.

But it must be borne in mind that glaciation, when once begun, deteriorates the climate, as it increases the snowfall and lowers the summer-temperature; and that the ice-sheet at the edges is maintained by the ice-streams coming from the central parts, and not by the snow falling at the edges, where much more ice is thawing than is falling in the form of snow. In this manner the glaciation of the British Isles may be explained: it was probably due merely to the circumstance that the centre of glaciation in Scandinavia sent its ice-streams across the North Sea, and thereby modified the climate of the British Isles.

The hypothesis that all this glaciation was caused by an upheaval of the ice-covered districts from 3000 to 5000 feet, is in itself very improbable, as the phenomenon of increased glaciation took place nearly all over the earth's surface. Such an hypothesis is certainly not established by means of geological facts, but imagined only in order to explain a glaciation for which no other sufficient cause could be found. If this explanation were true, the melting-away of the ice must also be explained in a similar way, that is, by an equally great subsidence. Now this melting-away, according to Baron Gerard De Geer, went on very rapidly in the centre of Eastern Sweden (plain of Upland), namely, at a rate of 300 feet or more every year horizontally (along the ground), whereas no simultaneous subsidence of corresponding dimensions took place. By this I do not mean to deny that great alterations in level took place before, during, and after the Great Ice-Age, but I do affirm that the phenomenon of glaciation as a whole was not controlled by them.

The hypothesis that a glaciation of North America would raise the temperature of Europe, and *vice versâ*, by means of an alteration of the great centres of action of atmospheric circulation seems to me to be physically untenable. For the influence of the Atlantic continuation of the Gulf-Stream, and the south-westerly winds generated by it, on the climate of Europe, would be powerless to prevent an ice-age, if a general lowering of the mean temperature of the earth's surface amounting to 7° or 9° Fahr. took place. In fact, that influence has rather a cooling effect during the summer, because the temperature of the European continent, and also that of the British Isles, is then higher than that of the Atlantic. Moreover, the temperature of those Isles is, in July, somewhat lower than the average for the corresponding parallel. Only during the winter has the Atlantic any very considerable influence in warming North-western Europe. But as only the warmth of the summer can prevent glaciation, it is evident that, so soon as snow falls in the winter, an increase of the oceanic influence on the European weather will tend to increase also the probability of an ice-age, under the supposition, of course, that the above-named general lowering of the mean temperature of the earth's surface has taken place. In any case the influence of the winds alone will be but feeble, as the summer-temperature is only slightly influenced by them.

Still feebler, and indeed quite insensible, would be the influence of a glaciation of Europe on the climate of North America. For the influence of an ocean on the climate of the continent on its western side is in every case very small in our latitudes, as the general air-currents come from the west. Moreover, the cold Labrador current flowing past the American coast would prevent the Gulf-Stream from warming this coast, even if north-easterly winds were so common in the Northern Atlantic that they could deviate the Gulf-Stream so that it should flow from east to west. This deviation is, however, impossible, as the general direction of winds and ocean-currents is determined by the rotation of the earth, and by the decrease of temperature from the Equator to the Poles.

It must be borne in mind that the general atmospheric and oceanic circulation depends primarily on the state of the earth's surface as a whole, and that the influence of the hot zone is preponderating. In fact, let the Northern Hemisphere be divided into three zones, the first from the Equator to 40° lat. N., the second from 40° to 70° lat. N., and the third from 70° lat. N. to the Pole; and let us calculate the areas of those zones and the quantities of heat received by them from the sun, in percentages of that of the whole hemisphere. We find

Zone.	*Area.*	*Quantity of heat received in a year.*
	per cent.	per cent.
0° to 40° N.	64	73
40° to 70° N.	30	24
70° to 90° N.	6	3

Thus the first zone receives nearly three quarters of the whole heat, the second scarcely one quarter, and the third or Polar zone only 3 per cent. The difference of area is not quite so great, but it is still considerable. Hence we conclude that the first zone must play the principal part in all great and secular climatic changes. Now, the area of the Northern Hemisphere covered by a permanent ice-sheet during the Great Ice-Age was only about 9 or 10 per cent. of the area of the hemisphere; and therefore its influence on the general atmospheric circulation could not be very marked.

Furthermore, the positions and movements of anticyclones are not generally determined by the temperature of the ground in our latitudes. In most cases they seem to be eddies formed by the great circulation going on between the tropical and temperate zones, and sometimes they persist during several weeks over Europe or North America in a hot summer month. As a rule, the great cooled continents attract them during the winter, but they are not regularly formed over the Polar regions, where the weather is nearly as variable as in our latitudes, with moving cyclones and anticyclones. Thus we have no reason to believe that permanent anticyclones were formed over the ice-sheets of the Great Ice-Age. And, in fact, as remarked above, the ice would have disappeared relatively soon during such a state of weather, as it would not then have been maintained by snowfall.

(2) It remains to determine the influence of the ice-cap on the glaciated land and its neighbourhood.

We know that the amount of rain or snowfall generally increases with the height of the ground above sea-level, and proportionately more so if the ground is covered with snow. This is verified both by theory and by observation. Thus, the observations recently made by Dr. Axel Hamberg in Lapland have given a yearly precipitation of 80 to 120 inches of water at a height of 6500 feet above sea-level, whereas the amount in the neighbouring meteorological stations at heights of 650 to 1000 feet is only about 15 inches.

The formation of an ice-sheet one or more miles thick will, therefore, increase the snowfall enormously and tend to reinforce itself, so long as the temperature remains sufficiently low. Moreover, the height of the upper surface of the ice and the thermal properties of snow and ice will lower the temperature considerably. In this way the enormous extension of the ice-sheets may be explained.

As to atmospheric circulation, the effect on it during the winter was probably similar to that observed in a cold winter nowadays. Such a winter begins with frequent snow-storms caused by cyclones, which are deviated into a more and more southerly track as the winter advances, whereas an anticyclone is often formed in the north over the cooled area. Such an anticyclone, however, is not stationary, for it generally moves eastward just as the cyclones do, though as a rule more slowly and irregularly. Owing to the great contrasts of temperature and copious condensation of water, snow-storms in the Ice-Age were probably much more violent and frequent than at the present time. Also the summer must have been generally cool and stormy, with frequent fogs. The present climate of Cape Horn or Kerguelen Island will probably give some faint idea of the weather prevailing in Europe and North America during the Great Ice-Age.

As in our present cold and stormy winters the cyclonic tracks are much more southerly than in the mild winters, I conclude—in agreement with Mr. Harmer—that the southern part of North America and Europe, as well as the northernmost part of Africa, were much more rainy than now. The great anticyclones now situated between 20° and 40° lat. N. were also probably displaced southward, and the thermal equator of the earth, which now is to be found at about 10° N. in the longitudes of Europe and

America, may have approximately coincided with the geographical equator.

As to the influence of this state of weather on the climate of the great Asiatic continent, I do not venture to express an opinion, and must leave that point for future consideration.

Finally, I may add the following brief remarks.

Trees grow now farther north in Siberia than in Scandinavia, as the summer is warmer in the first-named region. As shown by Dr. Gunnar Andersson, no trees can grow if the mean temperature of July does not amount to at least 50° Fahr., but if this condition is realized, excessive severity of the winter does not prevent their growth.

With regard to my paper on the variations of the climate of the geological and historical past and their causes,[1] I tried to prove, in agreement with Prof. Sv. Arrhenius, that the principal cause of these variations is to be found in the variations in the quantity of carbon-dioxide present in the atmosphere. I remarked[2] also that the principal cause of the gradual rise of temperature about the end of the Great Ice-Age must be attributed to a slow increase of the quantity of carbonic acid in the air. But as the changes in the obliquity of the ecliptic also cause noticeable variations in the summer-temperature of every country north of 45° lat. N., those variations must be taken into account as well. Now, considering the geological fact that the Swedish palæobotanists have found after the end of the Great Ice-Age only one marked period of a type of vegetation richer and more southerly than the present one, namely, that which occurred 9000 years ago, we must assume that 48,000 years ago the ice that covered Sweden during the Great Ice-Age had not thawed away completely, or at least had so lately thawed that a richer flora had not had sufficient time to establish itself. Thus the end of the Great Ice-Age cannot have occurred more than about 50,000 years ago. It may possibly have occurred later, but it seems not improbable that the exceptionally intense insolation which, according to the formula of Stockwell, must have taken place during the summers of the northern countries from 50,000 to 46,000 years ago contributed materially to the melting away of the ice-cap. With regard to this conclusion of mine, Mr. Harmer remarks[3]:

'It seems to me improbable that the close of the Glacial Period took place at so remote a date.'

Thus he considers the 50,000 years as a maximum value, which is just what I said in the words printed above. On the other hand, nearly all those Swedish geologists and palæobotanists who have carefully studied the Quaternary Epoch in Sweden, believe that a date of 50,000 years ago is not too remote for the end of the Glacial Period in that country, and some of their evaluations,

[1] Quart. Journ. Roy. Met. Soc. vol. xxvii (1901) p. 1.
[2] *Op. cit.* p. 45.
[3] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 474, footnote 1.

founded on purely geological and palæobotanical grounds, amount to 70,000 and even 100,000 years. Thus my estimate, founded on astronomical and physical grounds, seems to give a fairly average value between the highest and lowest estimates of the geologists.

To conclude with a general observation on Mr. Harmer's paper, I cannot but think that he underrates the thermal effect of insolation, and overrates that of the winds. In order to appreciate the exact value of every cause, it is necessary to make quantitative calculations and measurements. If we do this, we find that the effect of insolation during summer far exceeds that of the winds during the same season. The temperature of the summer only is essential for the phenomenon of glaciation.

Discussion.

Mr. Harmer thanked the Author for his paper, as being likely to arouse an interest in the study and discussion of palæometeorology. He still adhered, however, to the opinion which he had expressed, that the influence of the winds must have been a very important factor in the determination of climatal zones during the Pleistocene Epoch, as it undoubtedly is at the present day. If the distribution of pressure and the consequent direction of the prevalent winds which then obtained could be ascertained by the joint efforts of geologists and meteorologists, it would throw much light on the history of the Glacial Period.

He could not admit that there was the same difference between the winter-temperature of North America and Western Europe as that which now exists. At present the winter-isotherm of 32° Fahr. extends 30° of latitude farther northward in the latter than its southernmost limit in the former. It is true that the ice-sheets are supposed to have reached farther to the south in America, but the principal centre of ice-accumulation in Europe was situated many hundred miles farther north than that of the Laurentian region. The gathering-ground of the ice was, moreover, more extensive in the latter case. Had the mountain-region of Scandinavia extended over France and the plains of Northern Germany to the Alps and the Pyrenees, the European ice-sheet would no doubt have assumed much larger proportions. No important ice-centres are recorded in North America farther south than the latitude of Switzerland, to which the influence of Glacial cold certainly extended, and there seems no valid reason for supposing that the winter-climate of New England was much more severe at the climax of the Ice-Age than that of the last-named country. If this was so, it seemed in favour of the hypothesis that the maximum glaciation of the Eastern and Western Hemispheres may not have been contemporaneous. He had shown that during the winter of 1898–99 excessive cold (reaching −60° Fahr.) lasted for many weeks in North America, coincidently with an abnormally mild season in Europe, a maximum temperature of 70° Fahr. being recorded at Liége, 134° above the American minimum of the preceding day: and both these phenomena were due to the existence of strongly marked cyclonic conditions in the Atlantic. There does not seem anything unreasonable in the idea that under similar conditions, but of a more permanent character, such a state of things might have persisted in Glacial times for a lengthened period.

The view that there was one period of greatest cold, which gradually approached and gradually passed away, with local variations in climate, if it could be established, would remove a great and at present unexplained geological difficulty. It seemed *a priori* improbable that the annual isotherms of the Northern Hemisphere then coincided more nearly with the parallels of latitude than they do now.

He suggested that the Author should construct hypothetical charts, showing what would probably have been the distribution of pressure and of temperature during the Pleistocene Epoch, on the theory that the maximum glaciation of North America and of Europe took place at the same time.

Prof. Sollas remarked that, since Mr. Harmer's contribution to this subject, the study of Glacial phenomena had been distinguished by a remarkable advance; the homology which had been traced between the extension of the ice in the Old and New Worlds seemed now to be extended from the Northern into the Southern Hemisphere. Prof. Edgeworth David and his colleagues had confirmed the observations of Lendenfeld and Stirling in the Kosciusko district of the Australian Alps; and Prof. Penck, after analysing the phenomena as presented in Australia, Tasmania, and New Zealand, and comparing them with those of Europe, had shown that the snow-line in the Southern Hemisphere had been brought nearer the sea-level during the Glacial Period by at least 1000 feet more than in corresponding parallels of the Northern Hemisphere. But it is just this difference which distinguishes the height of the snow-line in these two cases at the present day, and the conclusion is thus naturally suggested that the Southern and Northern Hemispheres were simultaneously affected by the conditions of the Glacial Period and to a like degree. The proved extension of the ice in Kerguelen, Patagonia, and the Bolivian Andes, as well as over Kenya and Ruwenzori, was in harmony with this conclusion; and it would thus seem that the meteorological conditions to be considered were of no mere local character, but general and affecting the whole planet. The incompetence of such geographical changes as seemed likely to have occurred, to account for a Glacial Period, was clearly shown by the now established glaciation of the Southern Hemisphere. For, although the two hemispheres presented an almost perfect contrast in geological conditions, yet each had passed through a Glacial climate, which was certainly not less severe in the Southern than in the Northern Hemisphere. Mr. Dickson had lately shown that a change in the temperature-gradient from the Equator to the Poles would bring about a change in meteorological conditions of just such a nature as was required to account either for genial or glacial climates, according as the gradient became more or less steeply inclined; an increase of the gradient would bring the mean path of cyclones over a line extending from the English Channel to the Kara Sea, and as one result of this an excessive precipitation of snow would take place on the eastern side of Scandinavia. Both the Author and Mr. Dickson seemed inclined to look for the cause of the change of gradient in variations of the obliquity of the ecliptic, or in the composition of the atmosphere. The speaker was inclined to think that a change in the rate of solar radiation might indirectly affect the gradient. The methods of Buchan were, by themselves, inadequate for a complete discussion of the subject, and the general circulation of the atmosphere, concerning which we are now beginning to attain a clearer understanding, must be taken into account, as it had been by Mr. Dickson and the Author. The co-operation of geologists in the Northern and Southern Hemispheres, and of meteorologists and geologists, was already leading to unexpected progress, and it might be hoped that we were now on the eve of important discoveries.

Mr. A. E. Salter said that he had come to the conclusion, from his observations in Central and Eastern England, that the data upon which 'Ice-Sheets' and 'Interglacial Periods' were based could be better explained in other ways. The phenomena due to earth-movements, and those due to chemical and other denuding agents acting upon the calcareous and soft argillaceous strata of the Midlands, had not been sufficiently appreciated. The highest point in Central England (Arbury Hill, above 800 feet O.D.) consisted of Lias, and it was reasonable to suppose that when younger formations, up to and including the Chalk, covered that area, the ground was sufficiently high to affect the climate very considerably.

Dr. Du Riche Preller remarked that, while the Author had stated the annual rainfall at altitudes of 2000 metres to be 2 metres, and in lowlands 0·4 metre, it was a fact that in the Alps, on the north side, the rainfall of 2 metres was the average at much lower altitudes, namely, of 1000 metres, and even in the Swiss lowlands (Zurich, Bâle, etc.) it was 1 metre. On the south side of the Alps both averages were even higher. Again, the Author's statement that trees required for their growth a mean temperature of 50° Fahr. hardly agreed with experience in the Alps, where, for instance in the Engadin, trees existed in lower average temperatures. These facts had an important bearing on the conditions under which glaciation might take place, and hence the data on which the Author based his conclusions might apply to Scandinavia, but they could not apply to the Alps.

5. *On the* ORIGIN *of* CERTAIN CONCRETIONS *in the* LOWER COAL-MEASURES. By HERBERT BIRTWHISTLE STOCKS, Esq., F.I.C., F.C.S. (Communicated by Prof. W. W. WATTS, M.A., F.G.S. Read November 20th, 1901.)

IN certain restricted areas of the Lower Coal-Measures at Halifax in Yorkshire and at Oldham in Lancashire, and in a seam of coal called the 'hard-bed coal,' peculiar nodules or concretions occur.

These concretions, termed locally 'coal-balls,' are disseminated throughout the coal, not in particular lines but quite indiscriminately. They are spherical or ovoid, sometimes slightly flattened, and externally—by contact with the coal—they have been blackened; though when broken open they are found to be pale or dark brown internally, and often streaked with veins of iron-pyrites.

Some years ago I made analyses of two of these concretions,[1] and the results are tabulated below:—

	I. Per cent.	II. Per cent.
Ferrous oxide	3·21	0·16
Manganous oxide	trace	—
Alumina	0·33	trace
Lime	36·17	46·10
Magnesia	0·88	0·30
Silica	1·16	1·21
Sulphuric acid	0·15	0·01
Chlorine	trace	—
Carbonic acid	29·00	35·28
Phosphoric acid	trace	trace
Iron-pyrites	21·58	12·16
Water	0·31	3·01
Organic matter and undetermined	7·21	1·77

From these figures the constituents of the coal-balls are calculated to be:—

	I. Per cent.	II. Per cent.
Ferrous carbonate	6·00	0·30
Calcium-carbonate	64·41	82·32
Magnesium-carbonate	1·82	0·61
Calcium-sulphate	0·32	0·03
Iron-pyrites	21·58	12·16
Alumina	0·33	trace
Silica	1·16	1·20
Hygroscopic water	0·25	3·00
Organic matter, etc. undetermined.		

The nodules or 'coal-balls' are of great interest, because they contain extremely well preserved vegetable remains, sections of the concretions revealing the internal structure of Coal-Measure plants in a very remarkable manner, and it is from such sections that our knowledge of the structure of the Carboniferous flora has been largely increased.

[1] Proc. Yorks. Geol. & Polytechn. Soc. n. s. vol. viii (1884) p. 394.

In many cases it is easy to detach large pieces of fossil wood from these concretions. Several samples of this fossil wood have been analysed by me with the following results[1]:—

	I. Per cent.	II. Per cent.	III. Per cent.	IV. Per cent.
Ferrous oxide	0·79	3·14	0·60	1·91
Ferric oxide	—	1·60	0·59	2·77
Alumina	0·01	—	—	—
Lime	48·32	18·05	49·61	30·49
Magnesia	1·73	0·71	1·52	2·96
Sulphuric acid	trace	6·70	0·60	4·32
Carbonic acid	not estimated	11·80	39·09	26·80
Silica	do.	0·30	·01	·08
Iron-pyrites	do.	48·63	4·75	24·25
Organic matter	do.	4·03	3·43	4·79
Water and matter volatilizing at 110° C.	do.	4·25	0·25	1·61
		99·21	100·45	99·98

The constituents of the samples of fossil wood may be calculated as follows:—

	I. Per cent.	II. Per cent.	III. Per cent.	IV. Per cent.
Ferrous carbonate	1·44	5·77	1·12	3·57
Ferric oxide	—	1·60	0·59	2·77
Calcium-carbonate	86·30	23·88	87·01	49·05
Magnesium-carbonate	3·63	1·49	3·19	6·21
Calcium-sulphate	not estimated	14·40	1·29	9·28
Silica	do.	0·30	0·01	0·80
Iron-pyrites	do.	48·63	4·75	24·25
Organic matter	do.	4·03	3·43	4·79
Hygroscopic water	do.	1·37	—	—

From the foregoing analyses it is apparent that the fossil wood and also the concretions themselves are made up very largely of two constituents—calcium-carbonate and iron-pyrites; and that there is great variation in their relative amounts.

Since the first analyses of these concretions were made, it has been my wish to arrive at some knowledge of their genesis and mode of formation, and seeing that very little but speculation has hitherto been accomplished in this department of geology, it was necessary to perform a large number of experiments, which happily led to an understanding of the conditions under which such concretions may have been produced.

These experiments will be described in the present paper, but before they are detailed it will be interesting to recapitulate the little that geologists have had to say about concretions.

The late E. W. Binney, who devoted much of his leisure to the preparation and examination of sections of 'coal-balls,'[2] stated that

[1] Proc. Roy. Soc. Edin. vol. xx (1893) p. 71.
[2] Proc. Manch. Lit. & Phil. Soc. vol. v (1865) pp. 61, 62.

these concretions are always associated with shells in the shale or roof of the coal, and therefore he attributed their formation to calcium-carbonate being dissolved away from these shells by percolating water, and the precipitation or aggregation of it in certain centres of the vegetable matter now forming the coal below.

Sir Archibald Geikie[1] says that the concretionary structure

'may be part of the original sedimentation, or may be due to subsequent segregation from decomposition round a centre.'

David Page[2] observed that concretions are formed by a molecular aggregation distinct from crystallization.

Dana[3] gives the following details:—

'Percolating waters, aided by the carbonic or humus acids which such waters are likely to contain, dissolve the grains and deposit the material, in a drying time, around grains, or any small object, as a nucleus. In like manner, concretions of limonite and iron-carbonate are made, if any ferruginous grains or any decomposable iron-bearing mineral is present. Occasionally other materials make disseminated concretions.

'The form of the concretion is not owing to any central control of the molecular disposition, but to the regular progress of the superficial accretion, and to the rate of supply of the mineral solution in vertical and horizontal directions, together with the shapes of the nuclei.'

The search that I have made for information upon this subject has not been further rewarded than by the extracts just quoted. With reference to the formation of calcium-carbonate, we shall recollect that this mineral is deposited by several processes which need not be enumerated, so well known are they; but it is necessary to bear in mind that calcium-carbonate in solution in water containing carbonic acid is rarely deposited in a rock, except in caverns or veins where the carbonic acid can escape. Indeed, it can be abundantly demonstrated that percolating water has almost invariably the opposite tendency, that is, to dissolve the calcium-carbonate out of rocks through which it is percolating. As the coal-balls are not found in caverns or in veins, percolating water may be dismissed from any suspicion of being the cause of their formation.

Then, again, we cannot assume that the whole of the vegetation composing this bed of coal was swept down by one flood, and thereupon covered immediately after by mud containing shells. We must take it that a bed of coal even only 1 foot thick required an appreciable time to form, and during that interval the plants would be so badly decayed that the vegetable tissues would be to a large extent destroyed, or at any rate much deformed. The fossil wood shows very little evidence of such destruction or deformation; and it is far more probable that these concretions were forming upon the plants as they were deposited in still water, and before any accumulation of other material upon them had taken place. The spherical, or nearly spherical, form of these concretions is also, to my mind, conclusive evidence that they were not produced under the pressure of superincumbent strata.

[1] 'Textbook of Geology' 1st ed. (1882) p. 487.
[2] 'Textbook of Advanced Geology' 5th ed. (1872) p. 454.
[3] 'Manual of Geology' 4th ed. (1896) p. 139.

One or two points may now be taken into account. First, that the calcium-carbonate was introduced in the state of solution, and by osmosis passed through the cell-walls, and was deposited within the cell-walls before their decay. (As a matter of fact, the cell-walls are still largely organic, as may be seen by treating the material with hydrochloric acid and examining the residue under the microscope.) Secondly, that the calcium-carbonate must have been produced in small quantity and deposited slowly, as shown by the isolation of the nodules and by their comparative rarity. Thirdly, that certain conditions were favourable, as the concretions are not found in every seam of coal.

We have to consider in the first place why calcium-carbonate was produced in this coal, and also, in the second place, why it separated out in the spherical form.

Coal appears to have been formed by the slow decay of vegetable matter either in the delta at a river's mouth or on a sea-shore. There is no formation being produced at the present day which exactly represents the conditions that existed in Carboniferous times; hence it is difficult to trace out exactly what did take place so long ago. There is, however, sufficient evidence in the Coal-Measures to show that coal was produced by the decay of a very luxuriant vegetation upon swampy ground, which at certain periods was covered by inundations both of brackish and of salt water. The freedom of the coal-seams from all but the finest mud, shows that the vegetable matter was clotted together so closely as to exclude all but the very finest mineral impurities in suspension, while allowing the free circulation of the water with its matters in solution. Brackish water being simply diluted sea-water, the salts in solution would be those present in sea-water.

The late Prof. Dittmar[1] and others have made numerous exhaustive analyses of sea-water collected during the *Challenger* Expedition, and the following figures represent the average proportion of ̀e different salts:—

	Per cent.
Sodium-chloride	77·758
Magnesium-chloride	10·878
Magnesium-sulphate	4·737
Calcium-sulphate	3·600
Potassium-sulphate	2·465
Magnesium-bromide	0·217
Calcium-carbonate	0·345
	100·000

Sea-water contains 3·5 per cent. of total salts, hence the amount of calcium-carbonate in the sea-water is ·012 per cent., and that of calcium-sulphate ·126 per cent. According to T. E. Thorpe & E. H. Morton,[2] 1000 grammes of sea-water contain ·04754 gramme of calcium-carbonate, and ·00503 gramme of ferrous carbonate.

Returning to the formation of coal, we may picture to ourselves

[1] *Challenger* Reports: Physics & Chemistry, vol. i (1884) p. 204.
[2] Journ. Chem. Soc. vol. xxiv (1871) p. 507.

the conditions under which it was produced in a delta or on a sea-shore. Huge forests grew out into the shallow water with roots in the mud, and a mass of decaying vegetable matter formed a swamp or morass. It is probable also that a certain amount of animal matter was present, derived from decaying fish and other sources: the result would be the solution of some of the organic matter in the water, and consequent absorption of the oxygen in solution, so that further decay must have taken place under anaërobic conditions. That decay can take place under anaërobic conditions has been abundantly proved by the action of the so-called 'septic' tank, which is a part of the modern method of sewage-treatment. In a closed tank, by the action of anaërobic organisms, not only are albuminous and other easily decomposable organic matters destroyed, but such stable materials as paper and other forms of cellulose are likewise broken down, with the production of carbonic acid, hydrogen, and marsh-gas in large quantities, together with a humus-like substance. These products are the same as those that accompany coal; and therefore it is reasonable to suppose that coal was produced in a similar way, though not so rapidly, as the conditions were not so favourable.

As practically all natural organic decay is brought about by the agency of bacteria, coal may be said to have been produced by bacteria. Whether this assumption be correct or not, it is hardly to be doubted that bacteria were at work during the Carboniferous Period, and that they brought about then changes similar to those effected through their agency at the present time. The magnitude of these changes has not been fully realized as yet by geologists.

The action of anaërobic organisms is a very peculiar one, and results in some rather unexpected changes. In sewage, the action of these bacteria may be studied very clearly. Two of the almost constant accompaniments of sewage are a foul smell and a black mud: the smell is due to sulphuretted hydrogen and volatile organic matter, and the mud is black, owing to the presence of ferrous sulphide; these are produced by anaërobic organisms. Such organisms are not only to be found in sewage, but they are present everywhere.

Sir John Murray & Mr. Robert Irvine, in a very interesting paper on oceanic deposits, give a full account of the blue mud which exists on all coasts beyond the 100-fathom line, and state that the colour of the mud is due to organic matter and ferrous sulphide, the latter being produced by the destruction of organic matter by bacteria, and the reduction of the sulphates in the sea-water.[1]

The changes which take place are shown in the following equations:—

$$(1)\ RSO_4+2C=2CO_2+RS,$$

where R is an earthy metal.

$$(2)\ RS+2CO_2+H_2O=H_2S+RCO_3.CO_2.$$
$$(3)\ RS+RCO_3.CO_2+H_2O=2RCO_3+H_2S.$$

[1] Proc. Roy. Soc. Edin. vol. xvii (1889-90) p. 93, & *Challenger* Rep. 'Deep-Sea Deposits' (1891) pp. 254, 255.

On the sulphuretted hydrogen meeting with the ferric oxide present in the surface-layer of the blue muds, the following reaction occurs:—

$$(4)\ Fe_2O_3 + 3H_2S = 2FeS + S + 3H_2O.$$

By subsequent pressure these muds may become shales, and at the same time the ferrous sulphide and sulphur become iron-pyrites, the other product being calcium-carbonate. This reaction was shown not to take place if the material was boiled or sterilized.

The authors just quoted also mention that Prof. Andrussow, after exploring the Black Sea, found much sulphide of iron and sulphuretted hydrogen beyond the 100-fathom line, the muds at greater depths consisting principally of calcium-carbonate.

M. J. M. van Bemmelen, in a paper on 'The Composition of the Acid Soils in Dutch Alluvial Districts,'[1] gives an account of the changes which take place in clay-soil under the influence of brackish or sea-water and decomposing vegetable matter. The ground is first covered with reeds, and saturated with water containing calcium-sulphate; after a time air becomes excluded from the soil, when calcium-sulphate disappears and ferrous sulphide, free sulphur, and perhaps a trace of ferrous sulphate, replace it; when air again gains access the quantity of ferrous sulphate increases, while ferrous sulphide and sulphur decrease, and after aëration and drainage basic sulphates are produced. In the earlier stages of this action we have a close parallel to the formation of the sulphides in the Coal-Measures.

I have found several instances of stagnant ponds in which were lying decaying fishes or other animal substances, and the mud surrounding them was completely blackened on account of the formation of sulphide of iron from the sulphates in the water and the oxide of iron in the mud.

Bischof[2] placed a mineral water containing iron and sulphates along with a small quantity of sugar in sealed bottles. After about 13 months black flocks had separated. After 3½ years the bottles were opened, and smelt of sulphuretted hydrogen. The black powder had nearly the composition of iron-pyrites. There was very little sulphate left in the water.

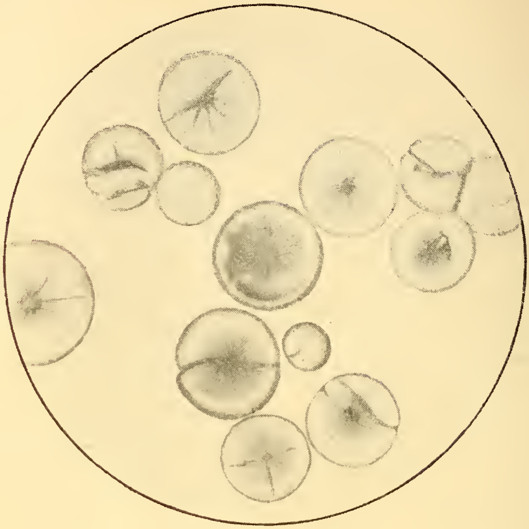
These instances are sufficient to show that anaërobic organisms are capable of decomposing sulphates, taking the oxygen from them to oxidize organic matter, and at the same time producing calcium-carbonate and ferrous sulphide which may ultimately become iron-pyrites.

I have performed a considerable number of experiments, in order to arrive at a conclusion as to how the nodules in the Coal-Measures were formed, and as it would be tedious to enumerate

[1] Recueil des Trav. Chimiques des Pays-Bas, vol. v (1886) no. 4, p. 199.

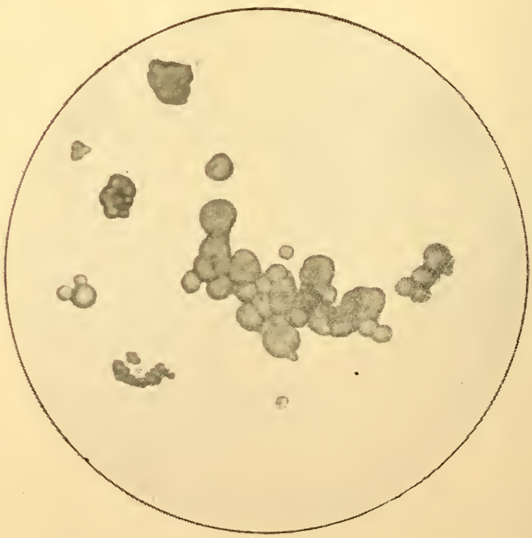
[2] 'Elements of Chemical & Physical Geology' Engl. transl. vol. i (1854) p. 163.

Fig. 1.—*Spheres of calcium-carbonate, produced by slow mixing of calcium-chloride and sodium-carbonate in presence of gum-solution.*



[× about 160 diam.]

Fig. 2.—*Botryoidal groups of calcium-carbonate, produced in presence of glue.*



[× 170 diam.]

all of them, it will be more convenient to divide them into classes and discuss the salient points:—

(1) On the precipitation of calcium-carbonate under varying conditions.
(2) On the action of salts of lime and of iron upon wood, etc.
(3) On the action of bacteria upon solutions containing calcium-sulphate in solution and ferric oxide in the deposit.

(1) On the Precipitation of Calcium-Carbonate under Varying Conditions.

It was found that calcium-carbonate precipitated from pure solutions in the cold by whatever means was almost always crystalline, the crystals being various forms of calcite; in a few cases only it was flocculent, showing no structure. At the boiling temperature crystals of aragonite were formed.

When calcium-carbonate was precipitated from solution in presence of organic matter the results were quite different, and the substance considerably modified; in certain cases it was quite flocculent, but as a rule it separated in dumbbell-shaped crystals, or more or less perfect spheres, twinned spheres, or botryoidal groupings. Colloids such as glue, gum, dextrin, and albumen have the most marked effect, but urine and peaty matter also influence it considerably.

The best results were obtained by the slow mixing of solutions of calcium-chloride and sodium-carbonate in strong gum-water. (See figs. 1 & 2, p. 52.)

The first to point out this remarkable fact was Mr. George Rainey.[1] He used for the purpose of the experiments two solutions—one a solution of calcium-chloride in gum-water, the other sodium-carbonate in the same fluid; and they were brought into a bottle in such a way that the one solution floated upon the other without mixture taking place: by slow diffusion through the liquid, spheres of calcium-carbonate were produced.

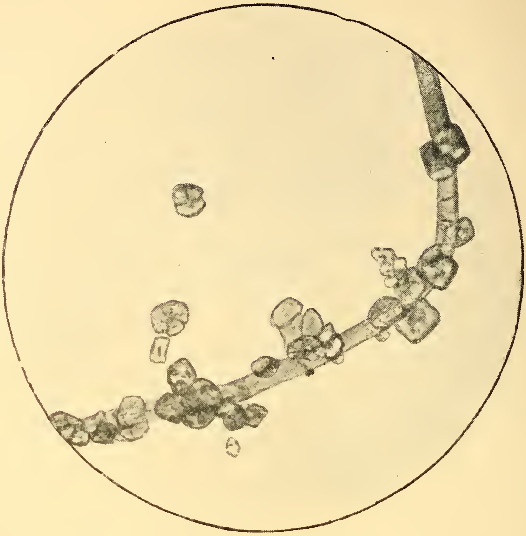
This line of enquiry was also followed by Prof. Harting, of Utrecht, who used the hollow of a porcelain plate which was filled up with the colloid solution, and the solids were placed on opposite sides of the raised portion of the plate just in contact with the solution. The plate was covered with a sheet of glass, and left for a few weeks, when the diffusion of the two substances caused the precipitation of calcium-carbonate in the colloid. Dr. W. M. Ord has extended the experiments in connection with the formation of urinary and other calculi, which are really concretions of calcium-carbonate and phosphate, etc. produced in the organic fluids of the body.

Calcium-carbonate very often separates in perfect spheres from alkaline urines.[2] Organic matter and especially colloidal substances

[1] See Hogg 'On the Microscope' 4th ed. (1859) p. 606; also W. B. Carpenter 'The Microscope & its Revelations' 7th ed. (1891) p. 1021.

[2] A fine photograph of this is reproduced in R. W. Lucas's 'Practical Pharmacy.'

Fig. 3.—*Modified crystals of calcium-carbonate, growing upon a cotton-fibre.*



[× about 160 diam.]

Fig. 4.—*Nodules of calcium-carbonate, growing upon wood treated alternately with sodium-carbonate and calcium-chloride solutions.*

[× 170 diam.]

have therefore the property of modifying calcium-carbonate as it is formed, and converting it into spheroids or rounded crystals. Any solid substance suspended in the liquid during the deposition acts as a nucleus, and this may be seen in the photograph of a cotton-fibre upon which nodules of carbonate of lime are forming (fig. 3, p. 54).

As peaty matter produces a result similar to that obtained with the colloids, it is fair to assume that the nodules from the Coal-Measures may have been produced in stagnant water containing a large quantity of organic matter in solution. But there is reason to believe that these nodules were the centres of bacterial activity, and that they grew in a true colloid—the bacterial jelly—which was attached to portions of the undecayed vegetable matter now found perfectly preserved in the fossilized condition.

(2) On the Action of Salts of Lime and of Iron upon Wood, etc.

The experiments on the action of salts of iron and of lime proved that soluble iron-salts are preservatives, arresting decay in vegetable matter and even in putrescent animal matter; whereas lime-salts did not prevent decay, moulds growing rapidly, and very soon woody tissues, etc. were destroyed. In no case, however, was there any approach to fossilization or the deposition of calcium-carbonate.

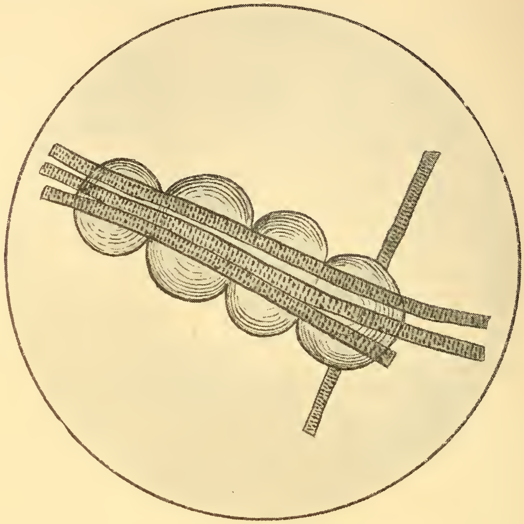
When iron-salts and sodium-carbonate were applied many times alternately, the wood became gradually harder and penetrated by ferric hydrate. When calcium-salts and sodium-carbonate were applied many times alternately, the cells became filled with crystalline calcium-carbonate, and small nodules were formed on the exterior (see fig. 4, p. 54).

Though interesting, this experiment reveals nothing as to the natural process of fossilization, for we know of no such alternations in the crust of the globe.

(3) On the Action of Bacteria upon Solutions containing Calcium-Sulphate, etc.

In the third series of experiments, a solution containing sewage was mixed with calcium-sulphate solution and left for a few days; it quickly became black, and contained an immense number of bacteria. A solution of calcium-sulphate containing ferric hydrate in suspension (representing the calcium-sulphate of sea-water and the iron in the mud) was kept in a closed bottle with both fresh and decayed woody tissue and some decayed fish: the whole representing on a small scale the conditions present in local areas during the formation of coal. After a year, the bottle was opened and examined. It was quite black throughout, and smelt strongly of

Fig. 5.—*Composite concretion of calcium-carbonate, produced by the action of reducing bacteria upon calcium-sulphate, growing upon scalariform vegetable cells.*



[× about 38 diam.]

Fig. 6.—*Concretion of calcium-carbonate, produced by the action of bacteria upon calcium-sulphate, growing in the bacterial jelly.*

[× about 38 diam.]

sulphuretted hydrogen and decayed organic matter. The animal matter and a large part of the vegetable matter had disappeared. Upon the surface of the fluid was a clotted gelatinous mass of fungi and bacteria in which were disseminated very fine spheres of calcium-carbonate, and also some of the harder vegetable tissue thoroughly impregnated or fossilized by the same mineral. The black material was ferrous sulphide.

This experiment has been repeated several times by me, and I have found that the action could be started almost immediately by introducing a small quantity of sewage which contains the reducing or anaërobic bacteria in large numbers. The blackening was then noticed after the first three days, and after a few weeks all the softer vegetable tissues were dissolved out, leaving the harder parts often with adhering nodules of carbonate of lime. (See fig. 5, p. 56, showing scalariform cells of carrot with nodules upon them.) Many spheres and modified crystals were also found embedded in the bacterial jelly (fig. 6, p. 56): these show that the centre of activity is in this jelly, and their rounded form is a direct result of the medium in which they have been formed, the bacterial jelly behaving in a similar way to gum, glue, and other colloids.

The solutions tested contained little or no calcium-sulphate after this action: hence all the calcium-sulphate is converted into calcium-carbonate if the conditions are favourable.

When sewage was introduced into a nutrient medium containing calcium-sulphate and ferric hydrate, but without solid vegetable or animal matter, the same result was obtained, the whole mass becoming black, owing to the formation of sulphide of iron, in a few days. But if, after such introduction of sewage, the material was sterilized by heat no blackening ever took place, and this was sufficient to show that the changes described above were due entirely to bacteria.

I have made several endeavours to cultivate these reducing organisms upon ordinary solid media such as sugar, but so far without success, and it has therefore not been possible to isolate and further examine them.

The reactions brought about by these anaërobic organisms are represented by the following equations:—

$$(1)\ CaSo_4+2\,C=2\,CO_2+CaS.$$
$$(2)\ CaS+CO_2+H_2O=CaCO_3+H_2S.$$
$$(3)\ Fe_2(HO)_6+3\,H_2S=2\,FeS+6\,H_2O+S.$$

Many minor reactions, however, appear to take place. In one experiment a large quantity of crystalline sulphur was found on the stopper of the bottle where limited oxidation could take place. This may have been produced as shown in the following equation:

$$H_2S+O=H_2O+S.$$

The deposit also contains sulphur, and sometimes radiating needles very like calcium-oxalate.

Conclusion.

We may summarize the foregoing particulars shortly as follows:— Coal was formed in stagnant sea-water by anaërobic decay brought about by bacteria; the calcium-sulphate in the sea-water was reduced and ultimately converted into carbonate, which first separated in the cells of water-logged vegetable matter and then around it, forming a concretion which grew in the bacterial jelly and hence acquired its rounded shape. At the same time sulphide of iron was formed from the iron in the fine mud and became part of the concretion thus formed, being subsequently converted into iron-pyrites by pressure or some other agency.

6. Notes on the Genus *Lichas*. By Frederick Richard Cowper Reed, Esq., M.A., F.G.S. (Read November 20th, 1901.)

I. Introductory Remarks.

Various attempts have been made to separate the species of the genus *Lichas* into subgeneric groups; but the results arrived at have not been altogether satisfactory, and emphasize the difficulty of deciding as to what are the important structural features which should determine the classification. The fragmentary state of the material available has considerably increased the difficulty, for very few species are known completely; and in the majority of cases we have to be content with the evidence of isolated head-shields and pygidia. For this very reason the system of classification employed by Barrande[1] is not capable of general application, because it is based on the characters of the thoracic pleuræ. The majority of European species would (by Barrande's system) fall into his third group, which contains a heterogeneous mixture of forms that are only known by their pygidia or head-shields. Apart from the general rarity of the preservation of those very parts which Barrande's classification demands, there is a narrowness in the system which fails to commend it to a palæontologist who attaches importance to the combination of structural characters, rather than to the presence of a single feature irrespective of other differences. A consequence of Barrande's method is seen in his Group 1, in which there are species associated together that possess head-shields showing most fundamental differences.

The basis of a natural and phylogenetic classification of the Trilobita, as opposed to an artificial one, has been found in the structural characters of the head-shield; and the principle has been shown to be safely applicable in all the minor subdivisions and groups, as far down as genera and subgenera.

The variations in the form and lobation of the glabella in the Lichadidæ evidently indicate, as Dr. Beecher[2] has truly remarked, 'differences in the relative development of the appendages and organs of the head, and therefore are of considerable morphological importance.'

II. Generic and Subgeneric Subdivisions.

There has been no general agreement among palæontologists as to the number of the subgenera. Prof. Zittel[3] in 1885 gave two forms, *Lichas* and *Terataspis*, as of generic value in his family Lichadæ, and mentioned *Platymetopus*, *Hoplolichas*, and *Conolichas* as subgenera of *Lichas*, while the following names are enumerated as synonyms of *Lichas*:—*Platynotus*, *Arges*, *Metopias*, *Archinurus* [sic],

[1] 'Syst. Sil. Boh.' vol. i (1852) p. 595.
[2] Amer. Journ. Sci. ser. 4, vol. iii (1897) p. 197.
[3] 'Handbuch der Paläontologie' vol. ii (1885) pp. 623, 624.

Nuttaina [sic], *Corydocephalus*, *Dicranopeltis*, *Acanthopyge*, and *Dicranogmus*.

In the same year M. Schmidt[1] recognized the following groups among the Ordovician species of *Lichas* in the Baltic Provinces of Russia:—*Arges*, *Leiolichas*, *Platymetopus*, *Metopias*, *Hoplolichas*, *Conolichas*, *Homolichas*, *Oncholichas*, and a miscellaneous group.

Dr. Beecher[2] in 1897 quoted the following genera and subgenera as belonging to the family Lichadidæ:—*Lichas*, *Arctinurus*, *Arges*, *Ceratolichas*, *Conolichas*, *Dicranogmus*, *Homolichas*, *Hoplolichas*, *Leiolichas*, *Metopias*, *Oncholichas*, *Platymetopus*, *Terataspis*, *Trochurus*, and *Uralichas*.

In Beecher's chapter on trilobites in the English edition (1900) of Zittel's 'Text-book of Palæontology' (vol. i, p. 632), *Lichas* alone is given as the type-genus of the family Lichadidæ, with the following subgenera:—*Arges*, *Dicranogmus*, *Conolichas*, and *Ceratolichas*.

[Lastly, Dr. Gürich[3] has recently published his views on the subdivisions of *Lichas*, and has recognized the following subgenera:—*Metopolichas* (= *Metopias*), *Platylichas*, *Platopolichas*, *Leoilichas*, *Homolichas*, *Hoplolichas*, *Conolichas*, *Platymetopus*, *Trachylichas*, *Pterolichas*, *Oncholichas*, *Echinolichas*, *Ceratolichas*, *Hemiarges*, *Plusiarges*, *Euarges*, *Liparges*, *Cerataryes*, and *Craspedarges*.]

III. Historical Summary of the Nomenclature.

Acanthopyge, Corda, 1847 ('Prodr. Böhm. Trilob.' p. 144 & pl. i, figs. 5–7). Type, *A. Leuchtenbergii*, Corda = *Lichas Haueri*, Barrande, 1846 ('Not. Prélim. Syst. Silur.' p. 73). [Dr. Gürich (Neues. Jahrb. Beilage-Band xiv, 1901, p. 527) proposes the subgeneric name *Euarges* for this type.] The young of this species Corda included in his genus *Dicranopeltis* as *D. parva* ('Prodr. Böhm. Trilob.' p. 143).—The name *Acanthopyga* was used by J. E. Gray in 1838 (Ann. Nat. Hist. vol. i, p. 278) for a genus of Lacertilia.

Arctinurus, Castelnau, 1843 ('Essai Syst. Silur. Amér. septentr.' p. 21 & pl. iii, fig. 2). Type, *L. Boltoni* (Bigsby) 1825 (*Paradoxides Boltoni*). Conrad in 1838 (Rep. Geol. Surv. N.Y. pp. 113, 118) had proposed the name *Platynotus* for the same species. Schmidt in 1885 ('Rev. Ostbalt. Silur. Trilob.' pt. ii, p. 31) chose this species as the type of a new group which he termed *Oncholichas*, but the Russian species which he associated with it differ in some important particulars (see p. 76) from the type.

Arges, Goldfuss, 1839 (Nova Acta Acad. Cæs. Leop.-Carol. vol. xix, pt. i, p. 355 & pl. xxxiii. figs. 1 *a–c*). Type, *A. armatus*, Goldfuss, 1839.—The name *Arges* had, however, previously been given in 1835 by De Haan ('Faun. Jap.' vol. v, p. 21) to a subgenus of *Brachyura*, and cannot therefore be used for a trilobite.

[Ceratarges, Gürich, 1901 (Neues Jahrb. Beilage-Band xiv, p. 531). Type, *Arges armatus*, Goldf.]

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[1] 'Rev. Ostbalt. Silur. Trilob.' pt. ii, Mém. Acad. Imp. Sci. St. Pétersb. vol. xxxiii, no. 1 (1885) pp. 27–40.

[2] Amer. Journ. Sci. ser. 4, vol. iii (1897) p. 196.

[3] Neues Jahrb. Beilage-Band xiv (1901) p. 519. [It has been impossible for me to do full justice to Gürich's article, as it only reached me to-day, after the proofs of the present paper had been received.—*December 18th, 1901.*]

CERATOLICHAS, Hall & Clarke, 1888 (Pal. N.Y. vol. vii, p. 84 & pl. xix *b*, figs. 7–13). Type, *C. gryps*, Hall, 1888.

CONOLICHAS, Dames, 1877 (Zeitschr. Deutsch. Geol. Gesellsch. vol. xxix, p. 806 & pl. xiii, fig. 5). Type, *C. æquiloba* (Steinhardt) 1874 ('Die in preuss. Geschieb. gefund. Trilob.' p. 30 & pl. iii, fig. 6).

CORYDOCEPHALUS, Corda, 1847 ('Prodr. Böhm. Trilob.' p. 139 & pl. vii, fig. 74). Type, *C. flabellatus*, Corda = *Lichas palmata*, Barrande, 1846 ('Not. Prélim. Syst. Silur.' p. 54) = *Trochurus speciosus*, Beyrich, 1845 *pars* (pygidium, not head), 'Ueb. Böhm. Trilob.' p. 31, fig. 14, and Barr. 'Syst. Sil. Boh.' vol. i, p. 599. [Owing to the uncertainty attaching to Corda's types, Dr. Gürich (Neues Jahrb. Beilage-Band xiv, 1901, p. 526) would substitute the name *Plusiarges* for *Corydocephalus*, type *Pl. palmatus* (Barr.).]

[CRASPEDARGES, Gürich, 1901 (Neues Jahrb. Beilage-Band xiv, p. 532 & pl. xviii, fig. 1). Type, *Cr. Wilcanniæ*, Gürich.]

DICRANOGMUS, Corda, 1847 ('Prodr. Böhm. Trilob.' p. 145 & pl. vii, fig. 77). Type, *D. pustulatus*, Corda = *L. (!) simplex*, Barrande, 1846 ('Not. Prélim. Syst. Silur.' p. 55). Hall (Pal. N.Y. 1888, vol. vii, p. 86) proposed to revive Corda's name for subgeneric use. [Dr. Gürich (Neues Jahrb. Beilage-Band xiv, 1901, pp. 528–29) would substitute the name *Liparges* for Corda's *Dicranogmus*.]

DICRANOPELTIS, Corda, 1847 ('Prodr. Böhm. Trilob.' p. 141 & pl. vii, fig. 75). Type, *D. scabra*, Beyrich, 1845 (*Lichas scabra*, 'Ueb. Böhm. Trilob.' p. 28 & fig. 16). [Dr. Gürich (Neues Jahrb. Beilage-Band xiv, 1901, p. 525) proposes the name *Trachylichas* in place of Corda's *Dicranopeltis*.]

[ECHINOLICHAS, Gürich, 1901 (Neues Jahrb. Beilage-Band xiv, p. 530). Type, *L. Eriopis*, Hall (Pal. N.Y. 1888, vol. vii, p. 78 & pl. xix *a*, figs. 2–13, 15, 16).

[EUARGES, Gürich, 1901 (*op. cit.* p. 527) = *Acanthopyge*, Corda. Type, *L. Haueri*, Barr.]

[HEMIARGES, Gürich, 1901 (*op. cit.* p. 526). Type, *L. wesenbergensis*, Schmidt ('Rev. Ostbalt. Silur. Trilob.' pt. ii, 1885, p. 44 & pl. vi, figs. 1–4).]

HOMOLICHAS, Schmidt, 1885 (*op. cit.* pp. 31, 94). Type, *L. depressus*, Angelin 1854 ('Palæont. Scand.' p. 70 & pl. xxxvi, figs. 4, 4 *a*).

HOPLOLICHAS, Dames, 1877 (Zeitschr. Deutsch. Geol. Gesellsch. vol. xxix, p. 794, pl. xii, figs. 1–3, & pl. xiii, fig. 1). Type, *H. tricuspidata* (Beyrich) 1846 (*Lichas tricuspidata*, 'Untersuch. üb. Trilob.' p. 7 & pl. i, fig 7 head.)

LEIOLICHAS, Schmidt, 1885 ('Rev. Ostbalt. Silur. Trilob.' Mém. Acad. Imp. Sci. St. Pétersb. vol. xxxiii, no. 1, pp. 29–30, 46 & pl. iii, figs. 27–31). Type, *L. illænoides* (Nieszkowski) 1857 ('Mon. Trilob. Ostseeprov.' Archiv f. Naturk. Liv-, Ehst-Kurlands, ser. 1, vol. i, p. 622 & pl. iii, figs. 3–5).

LICHAS, Dalman, 1826 ('Ueber die Palæaden' 1828, pp. 53, 71, 72 & pl. vi, fig. 1). Type, *L. laciniatus* (Wahlenberg) 1821 (Nov. Acta Soc. Reg. Sci. Upsala, vol. viii, p. 34 & pl. ii, fig. 2. *Entomostracites laciniatus*).

[LIPARGES, Gürich, 1901 (Neues Jahrb. Beilage-Band xiv, pp. 528–29) = *Dicranogmus*, Corda. Type, *L. simplex* (Barr.).]

METOPIAS, Eichwald, 1842 ('Urw. Russl.' pt. ii, p. 60 & pl. iii). Type, *M. Hübneri*, Eichwald (*op. cit.* p. 62 & pl. iii, figs. 21, 22). Owing, however, to the application of the name *Metopias* to a genus of Coleoptera in 1832 by Gory (Guérin's Mag. Zool. vol. ii, pl. 42), it has to be relinquished here. [Dr. Gürich (Neues Jahrb. Beilage-Band xiv, 1901, p. 521) proposes the name *Metopolichas* for this subgenus.]

[METOPOLICHAS, Gürich, 1901 (Neues Jahrb. Beilage-Band xiv, p. 521)=*Metopias*, Eichwald. Type, *M. Hübneri*, Eichwald.]

NUTTAINIA, Eaton, 1832 ('Geol. Textbook' 2nd ed. pp. 33, 34). The name was applied by Eaton to two specimens of trilobites which are now assigned to the genera *Trinucleus* and *Homalonotus* respectively, and therefore it falls to the ground. Portlock, however, in 1843 ('Rep. Geol. Londond.' p. 274, pl. iv, fig. 1 & pl. v, figs. 1–3) revived it as a generic designation for the species *Lichas hibernicus* (Portlock). M. Schmidt (1885, 'Rev. Ostbalt. Silur. Trilob.' pt. ii, p. 29) places this species, as represented by the head-shield, in the group *Platymetopus*, to which it undoubtedly belongs. The pygidium which is generally attributed to this species is believed by M. Schmidt to belong to another group or subgenus.

ONCHOLICHAS, Schmidt, 1885 ('Rev. Ostbalt. Silur. Trilob,' pt. ii, Mém. Acad. Imp. Sci. St. Pétersb. vol. xxxiii, no. 1, p. 31). The type-species chosen by M. Schmidt unfortunately is *L. Boltoni* (Bigsby), which had previously been selected as the type of *Arctinurus* by Castelnau in 1843 and of *Platynotus* by Conrad in 1838. This species, moreover, does not possess the glabellar characters of the Russian species which M. Schmidt associates with it, and therefore the type of *Oncholichas* must be considered to be the species *L. ornatus*, Angelin, 1854 ('Pal. Scand.' p. 72 & pl. xxxvii, figs. 7, 7*a*), which Schmidt takes as the second and European example of the group.

[PLATOPOLICHAS, Gürich, 1901 (Neues Jahrb. Beilage-Band xiv, p. 522). Type, *L. avus*, Barr. ('Syst. Sil. Boh.' Suppl. vol. i, pp. 12–19 & pl. x).]

[PLATYLICHAS, Gürich, 1901 (*op. cit.* p. 522). Type, *Pl. margaritifera* (Nieszkowski) in 'Mon. Trilob. Ostseeprov.' Archiv f. Naturk. Liv-, Ehst-Kurlands, ser. 1, vol. i (1857) p. 568 & pl. i, fig. 15.]

PLATYMETOPUS, Angelin, 1854 ('Pal. Scand.' p. 73 & pl. xxxviii, fig. 3). Type, *Pl. planifrons*, Angelin (*pars*). M. Schmidt ('Rev. Ostbalt. Silur. Trilob.' pt. ii, 1885, pp. 28–29) considers *Pl. lineatus*, Angelin ('Pal. Scand.' p. 75 & pl. xxxviii, fig. 12 head-shield, *non* fig. 13 pygidium), to be the type, because *Pl. planifrons* has been shown to be a composite type, the pygidium (fig. 3) being closely allied to that of *L.* (*Dicranopeltis*) *scaber*, Beyrich, while the hypostome alone (fig. 3*a*) belongs to the group of which *Pl. lineatus* (fig. 12, head-shield) is a member. [Dr. Gürich (Neues Jahrb. Beilage-Band xiv, 1901, p. 524) takes *Pl. Holmi*, Schmidt ('Rev. Ostbalt. Silur. Trilob.' pt. ii, 1885, p. 548 & pl. vi, figs. 14–17) as the type.]—The name *Platymetopus*, however, must be abandoned for this group, since it was given previously in 1829 by Dejean to a genus of insects ('Spéc. gén. Coléopt.' vol. v, p. 815).

PLATYNOTUS, Conrad, 1838 (Rep. Geol. Surv. N.Y. pp. 113, 118). Type, *Pl. Boltoni* (Bigsby).—The name *Platynotus* was employed by J. C. Fabricius in 1801 for a genus of Coleoptera ('Syst. Eleutherat.' vol. i, p. 138), and must therefore be discarded for a group of trilobites.

[PLUSIARGES, Gürich, 1901 (Neues Jahrb. Beilage-Band xiv, p. 526)=*Corydocephalus*, Corda. Type, *L. palmata*, Barr.]

[PTEROLICHAS, Gürich, 1901 (*op. cit.* p. 528)=*Arctinurus*, Castelnau. Type, *L. Boltoni* (Bigsby).]

TERATASPIS, Hall, 1863 (16th Ann. Rep. N.Y. State Cab. Nat. Hist. p. 223). Type, *T. grandis* (Hall) 1861 ('Descrip. New Species of Fossils, etc.' 15th Ann. Rep. N.Y. State Cab. Nat. Hist. p. 82). [For figures, see Hall & Clarke, Pal. N.Y. vol. vii, p. 73 & pls. xvii–xix.]

[TRACHYLICHAS, Gürich, 1901 (Neues Jahrb. Beilage-Band xiv, p. 525)=*Dicranopeltis*, Corda. Type, *L. scabra*, Beyrich.]

TROCHURUS, Beyrich, 1845 ('Ueb. Böhm. Trilob.' p. 31). This name was originally applied to a composite and artificial species consisting of the head of *Staurocephalus Murchisoni* and the pygidium of *Lichas*. This heterodox species was called *Tr. speciosus*, Beyrich (*loc. cit.*). But in 1846 Beyrich recognized his error ('Untersuch. üb. Trilob.' p. 10) and declared that the genus did not exist. It seems therefore desirable to drop the name altogether; but Lindström has recently (Öfv. K. Svensk. Vet.-Akad. Förhandl. 1885, No. 6, p. 60; and 'List Foss. Up. Silur. Gotland' 1885, p. 3) revived it in a wider and slightly different sense, giving *L. Salteri*, Fletcher and *L. Bucklandi*, M.-Edw. (=*L. anglicus*, Beyr.) as examples.

URALICHAS, Delgado, 1892 (Comm. d. Trab. Geol. Portugal, 'Fauna Silurica de Portugal' p. 5). Type, *U. Ribeiroi*, Delgado, 1892.

The palæontological value of the above groups as subgenera or genera is examined in a later portion of this paper; but it may here be remarked that several well-known and more or less widely accepted names must be dropped, because of their pre-occupation or for other reasons given above. Such are *Arges*, *Metopias*, *Nuttainia*, *Platymetopus*, *Platynotus*, and *Trochurus*. The advisability of substituting new names in the place of those chosen by Corda is open to question, since Barrande revised Corda's species, and the change might lead to confusion.

The characters of the original type-species on which each group was founded have so frequently been lost sight of in assigning other or subsequently discovered species to a subgenus or genus, that it is well to give a list of these type-forms for reference in all cases. As an example of the expansive interpretation of the characters of a group and the gradual enlargement of its boundaries so as to include very diverse species, the group *Arges* may be mentioned, of which the original species is *Arges armatus*, Goldfuss,[1] with highly specialized characters which are found in scarcely any of the other forms commonly attributed to this subgenus.

The following is a list of the type-species, the old subgeneric names (excluding only synonyms) being retained for the present:—

Acanthopyge Haueri (Barrande).
Arctinurus Boltoni (Bigsby).
Arges armatus, Goldfuss.
Ceratolichas gryps, Hall.
Conolichas æquiloba (Steinhardt).
Corydocephalus palmatus (Barrande).
Craspedarges Wilcanniæ, Gürich.
Dicranogmus simplex (Barrande).
Dicranopeltis scabra (Beyrich).
Echinolichas Eriopis (Hall).
Hemiarges wesenbergensis (Schmidt).
Homolichas depressus (Angelin).
Hoplolichas tricuspidatus (Beyrich).
Leiolichas illænoides (Nieszkowski).
Lichas laciniatus (Wahlenberg).
Metopias Hübneri, Eichwald.
Oncholichas ornatus (Angelin).
Platopolichas avus (Barr.).
Platylichas margaritifer (Nieszk.).
Platymetopus lineatus, Angelin.
Terataspis grandis, Hall.
Uralichas Ribeiroi, Delgado.

The references to the original and most important descriptions of the above species have already been given.

[1] Nova Acta Acad. Cæs. Leop.-Carol. vol. xix, pt. i (1839) p. 355 & pl. xxxiii, figs. 1 *a*, 1 *b*, 1 *c* (*non* 1 *d*, 1 *e*).

IV. The Structure of the Head-Shield.

Homology of the Lobes and Furrows of the Glabella.

It is doubtful whether the commonly-accepted nomenclature of the parts of the glabella in *Lichas* is based on a true conception of their homologous parts in other trilobites. It is essential to look into this question, in order to obtain a clear view of their morphological equivalents before proceeding to attempt a natural grouping of the members of the family.

In the first place, the disproportionate size of the so-called 'first' lateral lobes of the glabella is remarkable. The occasional presence of a more or less distinct furrow across these lobes, or of a notch on their inner side in various non-allied species, *L. Pahleni*, *L. ornatus*, *L. gotlandicus*, *L. scutalis*, etc., representing several of the above-mentioned subgenera or genera, suggests that these so-called 'first' lobes are in reality of a composite nature and consist of two fused lateral lobes. According to this hypothesis, the so-called 'second' lateral furrow is homologous with what is termed the 'third' lateral furrow of other less-modified genera, and the so-called 'second' lateral lobes correspond to the 'third' lateral lobes. On this hypothesis the segmentation of the glabella of *Lichas* is brought into correspondence with that of other trilobites. Dr. Beecher[1] has arrived at the conclusion that the trilobite-head consists of several fused somites, of which the first or anterior segment is represented by the hypostome; the second by the paired eyes, free cheeks, and epistome; the third by the anterior lobe of the glabella and first antennæ or antennules; the fourth by the second lobe of the glabella and the second pair of antennæ; the fifth by the third lobe of the glabella and the mandibles; the sixth by the fourth lobe of the glabella and the first maxillæ; and the seventh by the neck-lobe (=occipital lobe or ring) and the second pair of maxillæ.

'The five annulations, or lobes, of the axis of the cranidium [=head-shield] since they primarily carry fulcra for the attachment of muscles supporting or moving the appendages, could thus be interpreted in terms of the ventral structure, making the first lobe the antennulary, the second the antennary, the third the mandibular, the fourth the first maxillary, and the fifth the second maxillary.' [Beecher, *loc. cit.*]

Following Beecher's scheme, we must regard the anterior lateral portions of the so-called median or frontal lobe of the glabella in *Lichas* as corresponding to the antennulary or true first lobe of the glabella. The so-called 'first' lateral lobes of *Lichas* would correspond to the fused antennary and mandibular lobes, the true second and third lobes of the glabella. The lateral lobes which are usually termed the 'middle' or 'second' lateral lobes become homologous with the fourth or first maxillary; and the neck- or

[1] Amer. Journ. Sci. ser. 4, vol. iii (1897) pp. 95–97; see also Bernard, Quart. Journ. Geol. Soc. vol. li (1895) p. 352.

occipital lobe or ring falls into its right place as the second maxillary lobe.

But the objection may reasonably be urged that this correlation leaves out of account the so-called 'basal' lobes which are found in many members of the Lichadidæ. Their presence, however, does not upset the above conclusions, because there is considerable evidence that these 'basal' lobes are genetically of the nature of occipital lobes, and belong to the occipital or second maxillary segment of the cranidium. They have usually been regarded as belonging to the glabella, and as true third lateral or basal lobes: but, if this be the case, it is difficult to see the cause of the peculiar course of the occipital furrow in the majority of those species which possess them. The course of this furrow closely resembles that of the same furrow in the species of *Proetus*, *Cyphaspis*, etc., which possess unquestioned occipital lobes that have been cut out of the sides of the neck-ring by the formation of new oblique furrows. The regular course of the occipital furrow, in those species of *Lichas* which do not possess these lobes, is with difficulty explicable on the supposition that they are true 'third lateral' glabellar lobes. The narrowness of the neck-ring behind these lobes and its much greater width in the centre, the bending-forward of the lateral portions of the occipital furrow in front of them, and the non-continuation of this furrow into that which marks off the occipital segment on the cheeks, find their counterpart in species of *Proetus* (as, for example, *Pr. bohemicus*, Cord.) in which occipital lobes occur.

The simplest and least modified condition of the neck-ring, in which it is very plain that these so-called 'basal' lobes really belong to the occipital segment and have been cut out of it, is found in those members of the Lichadidæ in which the median portion of the occipital furrow and the so-called 'third lateral' or 'basal' furrows are in the same straight line and make practically one simple transverse furrow (as, for example, *Lichas verrucosus*, *Hoplolichas tricuspidatus*, etc.). In many species (*Platylichas margaritifer*, *Lichas St.-Matthiæ*, *L. triconicus*, *L. furcifer*, etc.) the idea of regarding these lobes as belonging to the glabella would never have arisen, if the more highly modified examples of them in other species had not been at first so interpreted. In the case of *Proetus* there are some species that possess occipital lobes, and others that do not; while in other respects these species may be closely allied. We may, therefore, not unreasonably be prepared to find similar instances in the Lichadidæ.

With the foregoing principles of homology in our mind, we may now attempt to discover the principal lines of modification along which the evolution of the head-shields of the Lichadidæ has proceeded.

The archetype of the family may be conceived as having a glabella with the normal five annulations, as in other trilobites. There must have been, therefore, four pairs of lateral lobes and a neck-segment, and three pairs of lateral furrows and a neck-furrow. From this archetype all the members of the family may be derived, by various classes and degrees of modification proceeding along two main lines.

I.—At a very early period in the initiation of the family, the first pair of lateral furrows was prolonged backward in a curved manner, so as to meet the second pair of lateral furrows[1] at nearly a right-angle. Of this stage there has been so far no representative discovered, and we may probably regard it as never having been of a sufficiently lasting or permanent character to have left representatives behind, or to have formed the starting-point of a side-branch of the family. Owing to acceleration in the early stages of the ontogeny, this stage has not been found in young forms. The backward growth of the first lateral furrows seems in fact to have continued without cessation, till the third pair of lateral furrows was met; and on attaining this level a definite point in the phylogeny appears to have been reached, so that from this stage important offshoots developed. The growth of the first lateral furrows backward was here checked, at least for a time, until a strong and numerous group of forms arose possessing the essential features of this stage. The union of the first and third lateral furrows was complete; and thus there resulted, with the help of the axial furrow, the enclosure of the second and third lateral lobes of the glabella.

The second lateral furrows had meanwhile almost or completely disappeared, and now but faint and rare traces of their presence are found, as before mentioned. The second and third lobes thus became completely merged into one lobe on each side, and compose what is commonly termed the 'first' lateral lobes of the glabella. These lobes are thus seen to be bi-composite, and the occasional vestigial or reversionary occurrence of the second lateral furrows and the outward kink in the course of the prolonged first lateral furrows remind us of this fact.

There are various subsidiary or secondary modifications at this stage.

1. The Furrows.—(*a*) The anterior portions of the first lateral furrows may become very faint or disappear (as, for example, in *Dicranogmus simplex*).

(*b*) The third lateral furrows may become weak or obsolete, so that the bi-composite lateral lobes are ill-defined posteriorly. This is a very common modification, and the extent to which it takes place varies even in the same species (as, for example, in *Lichas celorrhin*). The outwardly-bent termination of the first furrow usually ends in a deep pit, when the third furrow is relatively weak or absent. Examples are *Lichas laciniatus*, *Metopias Hübneri*, and

[1] The new nomenclature of the furrows and lobes, as above explained, is employed from this point onward in the present paper.

Uralichas Ribeiroi. As one result, the fourth lateral lobes (the so-called second or middle) are more or less poorly defined.

(*c*) The axial furrows may become obsolete posteriorly, and the posterior portion of the glabella comprising the fourth or first maxillary segment becomes fused with the fixed cheeks. The early stages are represented by a weakening of the posterior part of the axial furrows (as, for example, in *Lichas scutalis*, *Hemiarges wesenbergensis*, and *Arges armatus*); and the final stage by their complete disappearance behind the third lateral furrows (as, for example, in *Acanthopyge Haueri*, *Dicranogmus simplex*, *Platylichas margaritifer*, and *Lichas anglicus*).

(*d*) The first lateral furrows may become connected with the occipital furrow by an additional furrow (as, for example, in *Lichas conicotuberculatus*, *Platylichas margaritifer*, and *Lichas ambiguus*). This modification foreshadows the second great stage in the development of the glabella of the Lichadidæ, but seems not to be in the direct line of descent. In *Dicranopeltis scabra* the first lateral furrows are directly continued back to the occipital furrow.

(*e*) A transverse furrow may be formed across the base of the median lobe, thus connecting the third lateral furrows (as, for example, in *Lichas anglicus*, *Acanthopyge Haueri*, *Corydocephalus palmatus*, and *Dicranopeltis scabra*).

2. The Lobes.—With regard to the lobes, there are several modifications more or less dependent on those of the furrows just described. Thus:—

(i) The bi-composite lateral lobes may become undefined anteriorly or posteriorly by modifications (*a*) or (*b*) of the furrows.

(ii) The fourth lateral lobes may become undefined or weakly marked off in front by modification (*b*); or may become laterally confluent with the fixed cheeks by modification (*c*); or may become marked off from the middle portion of the glabella by modification (*d*); or may unite to form a continuous ring by modification (*e*) without (*d*).

(iii) The anterior part of the median lobe may become swollen, as in *Lichas celorrhin*.

The development of occipital lobes at this stage may, or may not, take place; and in otherwise closely allied species this difference may be noticeable. In *Acanthopyge Haueri*, *Lichas anglicus*, etc. they are absent; but in *Dicranogmus simplex* they are present. On the other hand, species which show considerable differences in respect to the glabellar furrows may agree in possessing them, as, for example, *Platylichas margaritifer* and *Dicranogmus simplex*.

In most members, however, of this stage exhibiting the bi-composite lateral lobes of the glabella, occipital lobes are present, as, for instance, *Metopias Hübneri*, *Corydocephalus palmatus*, *Dicranogmus simplex*, *Dicranopeltis scabra*, *Lichas laciniatus*, and *Uralichas Ribeiroi*. In a few cases, as in *Arctinurus Boltoni*, they are obsolescent. The shape and relative size of these occipital lobes vary slightly; in some cases they are small and obviously cut out of the neck-ring (as in *Lichas verrucosus*); in others they are comparatively large and triangular (as in *L. pachyrhina*) and have encroached upon the glabella.

It is possible that in some cases in which occipital lobes are now absent, they may have disappeared owing to a secondary fusion with the fourth lateral lobes. This may have happened in *Lichas anglicus, L. hirsutus, Acanthopyge Haueri*, etc., and may be regarded as another mark of the wide departure from the ancestral type which these and allied species have made.

Spinose processes, generally paired, may be developed on the glabella, as, for example, in *Arges armatus*.

There are a few species in which the bi-composite lateral lobes appear to extend for practically the whole length of the glabella; and the cause appears to be that the fourth lateral lobes have been squeezed out and obliterated by a shortening and condensation of the head-shield at their expense. Such are the species *Oncholichas ornatus* and *Lichas gotlandicus*, in which the single pair of lateral lobes appears not to be due to an incorporation and fusion of the fourth lateral lobes with the bi-composite pair, or to a prolongation backward of the first lateral furrows to the occipital furrow. The traces of the second lateral furrows across these lobes are fairly distinct. We shall see that the pygidial characters of these species support the conclusion that they belong to this first stage, and not to the second one which is now to be described.

II.—The second stage in the evolution of the glabella is marked by the first lateral furrows not ending their backward prolongation at the third lateral furrows, but continuing to the occipital furrow in a regular course which may be almost straight or concave outward. A single long median lobe to the glabella is thus formed, extending from its anterior end to the neck-ring, and it is bounded on each side by a single long lateral lobe composed of the fused second, third, and fourth lateral lobes. The presence of this pair of tri-composite lobes is the distinguishing feature of this second stage.

The intermediate or transitional condition between the first and second stages is indicated in a few species (such as *Hoplolichas tricuspidatus, Lichas conicotuberculatus*), in which there is a slight deflexion in the course of the first lateral furrows opposite the third lateral furrows, and behind the latter they are less deeply impressed. The occasional persistence of the third lateral furrows across the single tri-composite lateral lobes indicates also a transitional state, but it is doubtful whether we possess any examples on the direct line of descent of the second from the first stage, and it is possible that the second line of modification proceeded parallel to the first from a common stock. In the most completely developed members of this stage the course of the first lateral furrows is a regular curve or continuous straight line of uniform strength, and the third lateral furrows have completely disappeared (as in *Lichas hibernicus*).

There are various subsidiary modifications.

1. The Furrows.—(*a*) The posterior part of the first lateral furrows may become weak (as, for example, in *Lichas lævis* and *Leiolichas illænoides*).

(*b*) Traces of the third lateral furrows may persist, as above-mentioned. This is not a secondary modification, but rather the persistence of a primitive character.

(*c*) The axial furrows may become partially or completely obsolete (as in *Ceratolichas gryps* and *Terataspis grandis*).

2. The Lobes.—(i) The tri-composite lobes may be incompletely defined on their inner side by modification (*a*) of the furrows;

(ii) the regular convexity of their surface may be interrupted by modification (*b*);

(iii) by modification (*c*) they may lose their separate existence by fusion with the fixed cheeks (as in *Ceratolichas gryps*).

(iv) The anterior portion of the median lobe may become swollen into a conical protuberance (*Conolichas*), and the posterior part may become depressed and constricted (*Terataspis*).

The development of occipital lobes is usual at this stage, and they are always present in the groups *Homolichas*, *Hoplolichas*, *Conolichas*, and *Leiolichas*, as defined by M. Schmidt: of which the type-species are *Homolichas depressus*, *Hoplolichas tricuspidatus*, *Conolichas æquiloba*, and *Leiolichas illænoides*. In *Platymetopus lineatus* and the other allied species (*Lichas hibernicus*, *L. Holmi*, etc.) they are absent, and the first lateral furrows meet the occipital furrow at right-angles.

These occipital lobes, as at the first stage, vary somewhat in size and shape. They may be relatively large and subtriangular (as in the transitional form *Lichas furcifer*), or they may be small and nodular (as in *L. Eichwaldi* and *Conolichas æquiloba*), or nearly obsolete (as in *Ceratolichas gryps*).

Modifications of the neck-ring and the development on it of spines or processes are seen in *Hoplolichas* and *Terataspis*. Spines, often of great length, are found on the lobes of the glabella in these two groups and in *Ceratolichas*. The spinosity of the highly modified and aberrant forms, *Terataspis* and *Ceratolichas*, belonging to this stage, is comparable to that which exists in *Arges armatus* [and to a less extent in *Craspedarges Wilcanniæ*] of the first stage.

Dr. Beecher[1] has pointed out that spinose forms must be regarded as derived phylogenetically from non-spinose ancestors, and that spinosity represents a limit to morphological and physiological variation. Evidence also proves that highly spinose organisms are the end-terms of lines of evolution, and leave no descendants. The extreme divergence of these members of the Lichadidæ from the normal types and their late geological appearance, just before the extinction of the family, support these conclusions.

[1] Amer. Journ. Sci. ser. 4, vol. vi (1898) p. 356.

V. Classification of the Lichadidæ.

From the foregoing considerations we see that, on the evidence of the head-shield and lobation of the glabella, the members of the Lichadidæ fall into two great groups corresponding to the two stages above described. There is (1) the group with a pair of bi-composite lateral lobes to the glabella, and a more or less definite fourth pair of lateral lobes; and (2) a group with a pair of tri-composite lateral lobes, originating by the fusion of the fourth pair with the bi-composite pair of the preceding group.

The types of the subgenera or genera previously given are distributed as follows between these two groups, in so far as their cranidial characters are concerned:—

Group I.

Acanthopyge Haueri.	*Hemiarges wesenbergensis.*
Arctinurus Boltoni.	*Lichas laciniatus.*
Arges armatus.	*Metopias Hübneri.*
Corydocephalus palmatus.	*Oncholichas ornatus.*
Craspedarges Wilcanniæ.	*Platopolichas avus.*
Dicranogmus simplex.	*Platylichas margaritifer.*
Dicranopeltis scabra.	*Uralichas Ribeiroi.*

Group II.

Ceratolichas gryps.	*Hoplolichas tricuspidatus.*
Conolichas æquiloba.	*Leiolichas illænoides.*
Echinolichas Eriopis.	*Platymetopus lineatus.*
Homolichas depressus.	*Terataspis grandis.*

These two groups, in which the original and usual subgeneric names applied to different species have been used in order to show their proper place in this scheme, can be further subdivided.

Group I.

Section A. (Fig. 1, p. 71.)

It has been pointed out that closely allied forms can have the furrows and lobes of the glabella in either of these groups modified to a considerable extent within the limits of the group-characters; and the pygidia may retain certain common features in spite of all. Thus *Acanthopyge Haueri* and *Dicranogmus simplex* have closely similar head-shields, though in the latter the anterior portion of the first lateral furrows is wanting, a condition which we see commencing to develop in *Lichas anglicus*, where these furrows are weak anteriorly. In *A. Haueri* and *L. anglicus* and in the American species of *Dicranogmus* we find a precisely similar type of pygidium, consisting of two complete pleuræ on the lateral lobes, two distinct rings on the axis followed by several indistinct annulations, and a narrow post-axial ridge. The rest of the lateral lobes behind the second pair of pleuræ is not traversed by any furrow. Three principal pairs of spines represent the free ends of the pleuræ. *Corydocephalus palmatus* has a similar pygidium, and from the head-shield of this species, with its well-developed lobes and furrows, it may easily be seen how the other species above-mentioned are derived by the suppression of certain furrows and the fusion of certain lobes.

Modifications in the pygidium may also set in, such as the loss of the lateral spines; but the important features of (1) the possession of two complete pleuræ, each well marked out and with pleural furrow; (2) the non-furrowed surface of the posterior portion of the lateral lobes; and (3) a definitely circumscribed axis and no broad post-axial piece, are retained.

Fig. 1.—Lichas palmatus, *Barr.* *(After Barrande.)*

[*a* from 'Syst. Silur. Boh.' pl. xxviii, fig. 7; *b* from pl. xxviii, fig. 9.]

A large number of species fall into this Section A of Group I, nearly all of which seem to be of Silurian age. The type-species of *Acanthopyge* [= *Euarges*, Gürich], *Corydocephalus* [= *Plusiarges*, Gürich], *Dicranogmus* [= *Liparges*, Gürich], and *Hemiarges* belong here, as well as many others which have been wrongly ascribed to *Arges*.[1]

Section A.

L. (Corydocephalus) palmatus, Barr.
L. (Acanthopyge) Haueri, Barr.
L. (Dicranogmus) simplex, Barr.
L. anglicus, Beyr.
L. hirsutus, Fletch.
L. scutalis, Salt.
L. ambiguus, Barr.
L. heteroclytus, Barr.
L. (Hemiarges) wesenbergensis, Schm.

Lichas palmatus may be regarded as the type of this group, as it possesses the most complete development of the head-shield, lobes, and furrows, and all the important sectional features of the pygidium. [The four above-mentioned subgenera recognized by Dr. Gürich *(Euarges, Plusiarges, Liparges*, and *Hemiarges)* which are associated together in this section may be regarded as subsections, though hardly of subgeneric value. *Craspedarges Wilcanniæ* is closely allied to *Euarges* and *Hemiarges* in its cranidial characters, but on account of its peculiar yet imperfectly known pygidium it must for the present be put doubtfully in another subsection by itself.]

Section B. (Fig. 2, p. 72.)

Of this next section which may be recognized in Group I, we appear to know only one complete example, *Dicranopeltis* [= *Trachylichas*, Gürich] *scabra*, and the characters of its head-shield may be regarded as typical of the section. But, from the resemblance of certain other

[1] Only a few examples are given in each section, and no complete list of the species is attempted.

species, of which we know only the pygidium or head-shield, we can associate them with it. The pygidial characters are :—(1) the possession of two rings on the axis; (2) a broad post-axial piece; and (3) three pairs of pleuræ on the lateral lobes, each with free

Fig. 2.—Lichas scaber, *Beyr.* *(After Barrande.)*

[*a* from 'Syst. Silur. Boh.' pl. xxviii, fig. 24; *b* from pl. xxviii, fig. 22.]

point and pleural furrow. The first two pairs are complete, but the third pair is not completely marked off posteriorly from the post-axial piece.

Section B.

L. (Dicranopeltis) scaber, Beyr.
L. Barrandei, Fletch.
L. Woodwardi, Reed MS.
? L. Salteri, Fletch.

Section C. (Fig. 3.)

In this section the axial furrows of the head-shield are more or less obsolete posteriorly, occipital lobes are present, the pygidium

Fig. 3.—Lichas margaritifer, *Nieszk.* *(After Schmidt.)*

[*a* from 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. v, fig. 17; *b* from pl. v, fig. 23. Fig. 3*b* does not show properly the incurving of the pleural furrows in the third pair.]

has three rings on the axis and a post-axial piece, with the lateral lobes composed of three pairs of pleuræ. Of these the first two pairs are complete, with pleural furrows and free points; but the third pair is incompletely marked off from the post-axial piece, and the pleural furrow curves inward towards the axial furrow, so as more or less to enclose a small oval area. The free points of this pair of pleuræ are closely placed together.

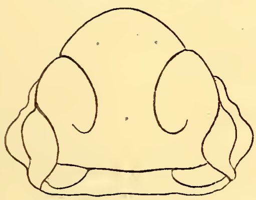
SECTION C.

L. (Platylichas) margaritifer, Nieszk.
L. docens, Schm.
L. bifurcatus, Reed.
? *L. Grayi*, Fletch.

SECTION D. (Figs. 4 & 5.)

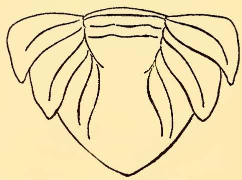
In all the head-shields of this section we notice the presence of complete axial furrows and of occipital lobes, but a strong tendency exists for the third lateral furrows to become obsolete. In the pygidium of *Lichas affinis* and some allied species, which appear to belong here, the third pair of pleuræ have lost their free points. The species *L. celorrhin* and *L. pachyrhina* are closely allied; the pygidium ascribed to the latter shows two rings on the axis,

Fig. 4.—Lichas verrucosus, *Eichw.* (*After Schmidt.*)



[From 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. ii, fig. 1 *a*.]

Fig. 5.—Lichas affinis, *Ang.* (*After Angelin.*)



[From 'Pal. Scandinav.' pl. xxxviii, fig. 4 *b*.]

a broad post-axial piece, and three pairs of pleuræ, of which the first two are completely defined and have each free points and pleural furrows. The third pleuræ have also simple pleural furrows and free points, but are incompletely marked off from the post-axial piece posteriorly.[1] [To this section belong Dr. Gürich's *Metopolichas* (=*Metopias*) and *Pterolichas* (=*Arctinurus*). The latter may mark a subsection, and probably his subgenus *Platopolichas* also belongs here and likewise designates a subsection, the third pleuræ of the pygidium possessing free points, but not pleural furrows.]

SECTION D.

L. (Metopias) Hübneri, Eichw.
L. verrucosus, Eichw.
L. laciniatus, Dalm.
L. bulbiceps, Phill.
L. conformis, Ang.
L. affinis, Ang.
L. celorrhin, Ang.
L. pachyrhina, Dalm.
? *L. kuckersianus*, Schm.
? *L. (Arctinurus) Boltoni*, Bigsby.
? *L. (Platopolichas) avus*, Barr.
? *L. (Platopolichas) incola*, Barr.

SECTION E. (Figs. 6 & 7, p. 74.)

The species attributed to *Lichas cicatricosus*, Lovén[2] by M. Schmidt[3] does not show the pygidial characters of the type according to

[1] The accuracy of the association of some of the pygidia with head-shields belonging to this section is rather doubtful.
[2] Öfv. K. Svensk. Vet.-Akad. Förhandl. vol. ii (1845) no. 3, p. 56 & pl. i, fig. 8.
[3] 'Rev. d. Ostbalt. Silur. Trilob.' pt. ii, Mém. Acad. Imp. Sci. St. Pétersb. ser. 7, vol. xxxiii (1885) no. 1, p. 122 & pl. v, figs. 25, 26.

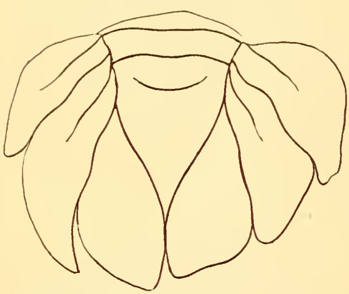
Lovén's figure. The pygidium of the type appears to resemble that of *L. deflexus* which belongs to the second group. M. Schmidt, on the strength of the similarity of ornamentation, associates with the head-shield (*op. cit.* fig. 25) attributed by him to *L. cicatricosus*, Lov. a peculiar pygidium (fig. 26). The head-shield shows a pair of well circumscribed bi-composite lobes, and the essential features of

Fig. 6.—Lichas cicatricosus, *Schmidt* non *Lovén*. *(After Schmidt.)*

[*a* from 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. v, fig. 25 *a*; *b* from pl. v, fig. 26.]

Section C. The axial furrows are incomplete, being quite obsolete behind the bi-composite lobes; the fourth lateral lobes are absent; the first lateral furrows are continued back to the neck-furrow by short additional furrows; and occipital lobes are present. The pygidium possesses two rings on the axis, a triangular post-axial piece, completely defined and pointed posteriorly, and three pairs of complete pleuræ on the lateral lobes with free obtuse ends; the first two pairs have pleural furrows, and the third pair are in contact in the middle line behind the post-axial piece.

Fig. 7.—Lichas hibernicus, *Portl.* pars. *(After Portlock.)*



[From 'Rep. Geol. Londonderry' pl. iv, fig. 1 *c*.]

The pygidium of *L. hibernicus*, Portl.[1] is closely similar, as M. Schmidt[2] has remarked, but the head-shields attributed by Portlock (*op. cit.* pl. v, figs. 1–3) to this species appear to belong to another species, for their ornamentation is different from that of the pygidium, as an examination of the type-specimens confirmed. Accordingly it seems necessary (1) to separate Schmidt's *L. cicatricosus* from Lovén's species bearing the same name; and (2) to give a new specific name to the head-shields usually called *L. hibernicus*. If the above conclusions are adopted *L. kildarensis* is suggested for the latter, which belongs to the second group of Lichadidæ.

[1] 'Rep. Geol. Lond.' 1843, p. 274 & pl. iv, figs. 1 *a–d*.
[2] 'Rev. Ostbalt. Silur. Trilob.' pt. ii (1885) p. 29.

Fig. 8.—Lichas Ribeiroi, *Delg. (After Delgado.)*

[From 'Faun. Silur. Portug.']

Section E will accordingly have *L. cicatricosus*, Schmidt (*non* Lovén) as its type; and the following examples may be mentioned:—

Section E.

L. cicatricosus, Schmidt *non* Lovén.
L. hibernicus, Portl. (*pars*).
L. æqualis, Törnq.
?*L. St.-Matthiæ*, Schmidt.

Section F. (Fig. 8.)

The form *Uralichas Ribeiroi* is marked off from all the other members of the Lichadidæ by the peculiar nature of its pygidium, with its long caudal spine of the pair of partly fused and enrolled third pleuræ. The characters of its head-shield are almost identical with those of Section D, of which it may perhaps be considered a special offshoot.

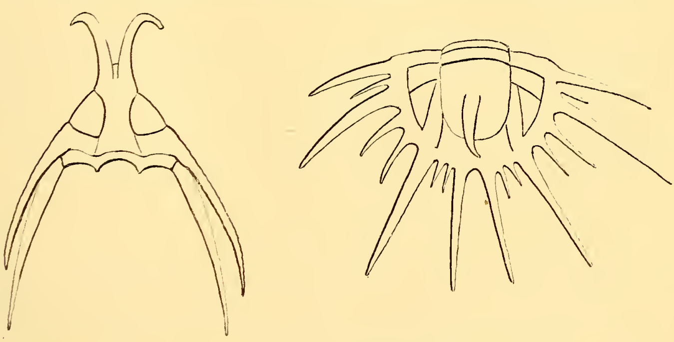
Section F.

L. (Uralichas) Ribeiroi, Delg.

Section G. (Fig. 9.)

To this section belongs the most modified form of the first group, *Lichas (Arges) armatus*. The bi-composite lobes are circumscribed, but the fourth lateral pair is fused with the fixed cheeks.

Fig. 9.—Lichas armatus, *Goldfuss. (After Goldfuss.)*



[From Nova Acta Acad. Cæs. Leop.-Carol. vol. xix, pt. i, pl. xxxiii, figs. 1 *a* & 1 *c*.]

The pair of curved spines near the front end of the glabella, the long spines of the fixed cheeks, the long genal spines, and the remarkably spinose pygidium are among the remarkable features of this species. [Dr. Gürich, Neues Jahrb. Beilage-Band xiv (1901) p. 531, puts it by itself in a new subgenus, *Ceratarges*.]

SECTION G.
L. (Arges) armatus, Goldf.

SECTION H. (Fig. 10.)

The last section of this group comprises those few species in which the fourth lateral lobes appear to have been squeezed out, so that the glabella has, as lateral lobes, only the one pair of bi-composite lobes. Occipital lobes are absent; and in the species

Fig. 10.—Lichas ornatus, *Ang*. *(After Schmidt.)*

[*a* from 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. vi, fig. 18 *a*; *b* from pl. vi, fig. 20.]

(Lichas ornatus) of which the pygidium is known, there is in the latter part one axial ring, a broad post-axial piece, and three pairs of complete pleuræ, each with pleural furrow and the two first also with free points.

SECTION H.

L. (Oncholichas) ornatus, Ang. | *L. gotlandicus*, Ang.

Note.—There is the well-known British species *L. laxatus*, McCoy, for which a place does not seem naturally to exist in the above scheme. The head-shield has its essential points agreeing with those of Section C [in which Dr. Gürich places it], and the pygidium agrees in the number and course of its furrows; but there are four rings on the axis, and a strong rounded margin. It seems, on the whole, desirable at present to put this species in a subsection of Section C.

Of *L. Geikiei*,[1] which belongs to Group I, we do not know sufficient to be able to decide its true affinities or sectional position.

GROUP II.

The second stage in the modification of the glabellar lobes of the Lichadidæ marks out likewise a natural group characterized by the possession of a single pair of tri-composite glabellar lateral

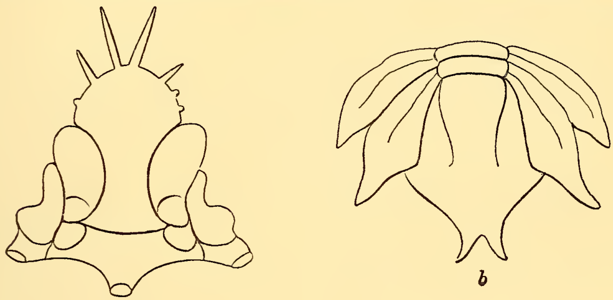
[1] Etheridge & Nicholson, 'Monogr. Silur. Foss. Girvan' fasc. ii (1879) p. 137 & pl. x, fig. 1.

lobes composed of the fused second, third, and fourth lateral lobes. Occipital lobes are present in nearly all the sections.

Section A. (Fig. 11.)

In this section occipital lobes are present, and occasionally traces of the third lateral furrows are found crossing the tri-composite lobes. The posterior portion of the first lateral furrows may also be weak, and not form a regular continuation of the anterior portion.

Fig. 11.—Lichas tricuspidatus, *Beyr*. *(After Dames & Schmidt.)*



[*a* from Zeitschr. Deutsch. Geol. Gesellsch. vol. xxix (1877) pl. xii, fig. 1; *b* from 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. ii, fig. 13.]

The neck-ring is furnished with a posterior simple or bifurcated spine. The pygidium has an axis with two rings, and a broad post-axial piece. There are two complete pairs of pleuræ on the lateral lobes, each with a pleural furrow and free point. The third pair of pleuræ is incompletely marked off from the post-axial piece, and has no pleural furrows; the two free points of this pair may exist, or a single median point may replace them.

Section A.

L. (Hoplolichas) tricuspidatus, Beyr.
L. Plautini, Schm.
L. longispinus, Schm.
L. conicotuberculatus, Nieszk.
L. furcifer, Schm.

Section B. (Fig. 12, p. 78.)

This section contains those forms in which the tri-composite lobes are complete, and marked out on their inner side by a regularly curved furrow. Occipital lobes are present. The pygidium has an axis with two rings, and a post-axial piece not defined by furrows posteriorly as in the last section. There are three pairs of pleuræ on the lateral lobes, each with a pleural furrow, but only the first two pairs of pleuræ are complete and have free points, the third pair not being marked off from the post-axial piece posteriorly, nor making any projection beyond the rounded posterior margin.

Fig. 12.—Lichas depressus, *Ang.* (*After Schmidt.*)

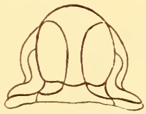
[*a* from 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. iv, figs. 1 *a*, 2, & 3 *a*; *b* from pl. iv, fig. 4.]

SECTION B.

L. (Homolichas) depressus, Ang.	*L. Eichwaldi*, Nieszk.
L. Pahleni, Schm.	

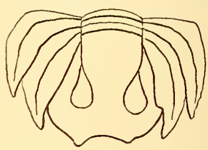
The species *L. Schmidti*, with the free points of the third pair of pleuræ projecting, may be allied to the above, and seems to lead to a subsection comprising those species which possess similar characters in the head-shield and, for the most part also, in the pygidium; but

Fig. 13.—Lichas angustus, *Beyr.* (*After Schmidt.*)



[From 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. iv, fig. 18 *a*.]

Fig. 14.—Lichas deflexus, *Sjögr.* (*After Schmidt.*)



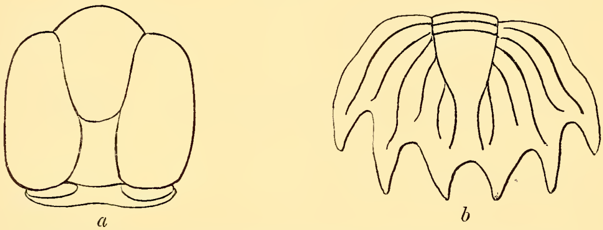
[*Op. cit.* pl. iv, fig. 35.]

the pleural furrow of the incomplete third pleuræ curves round to meet the axial furrow and to enclose a small oval area, and the ends of this pair of pleuræ form blunt projections on the margin of the pygidium. The following species are included:—*L. deflexus*, Sjögr., *L. angustus*, Beyr., and ?*L. cicatricosus*, Lovén & Angelin *non* Schmidt.

SECTION C (Fig. 15, p. 79.)

The group of species in this section shows many points of affinity with the preceding. The anterior portion of the median lobe of the glabella is elevated or even swollen into a conical protuberance, while the posterior part is depressed. Occipital lobes are present. The pygidium has two rings on the axis, a post-axial piece not defined posteriorly, and three pairs of pleuræ, each with a free

Fig. 15.—Lichas æquiloba, *Steinh.* *(After Schmidt.)*



[*a* from 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. v, fig. 8 *a*; *b* from pl. v, fig. 10.]

point and pleural furrow; but the third pleuræ are incompletely defined, and their pleural furrow tends to curve inward to the axial.

SECTION C.

L. (Conolichas) æquiloba, Steinh. | *L. triconicus*, Dames.

SECTION D.

A peculiar American species, *L. Eriopis*, Hall, appears to demand a section to itself, but it is imperfectly known. Hall put it with *Conolichas*, to which it is undoubtedly allied by the swollen anterior portion of the glabella, but in some other respects it shows resemblances to *Terataspis*. [Dr. Gürich, Neues Jahrb. Beilage-Band xiv (1901) p. 530, forms the subgenus *Echinolichas* for its reception.]

SECTION D.

L. (Echinolichas) Eriopis, Hall. | *?L. Bigsbyi*, Hall.

SECTION E. (Fig. 16, p. 80.)

A single species, *L. illænoides*, characterizes this section, its peculiarities of a smooth surface, a pygidium with anterior facets and rounded margin, and the absence of all indications of pleuræ (except in the cast) on the lateral lobes, being quite sufficient to separate it from all others in Group II.

SECTION E.

L. (Leiolichas) illænoides, Nieszk.

Fig. 16.—Lichas illænoides, *Nieszk.* *(After Schmidt.)*

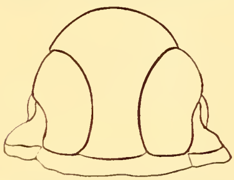
a *b*

[*a* from 'Rev. Ostbalt. Silur. Trilob.' pt. ii, pl. iii, fig. 27 *a*; *b* from pl. iii, fig. 29.]

Section F. (Figs. 17 & 18.)

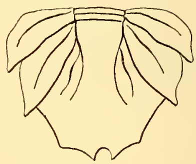
In this section the occipital lobes are absent, and the neck-ring forms a regular band. The pygidium has two rings on the axis, a post-axial piece not defined posteriorly, and three pairs of pleuræ,

Fig. 17.—Lichas dalecarlicus, *Ang.* *(After Schmidt.)*



[From 'Rev. Ostbalt. Silur. Trilob. pt. ii, pl. vi, fig. 12 *a*.]

Fig. 18.—Lichas lævis, *Eichw.* *(After Schmidt.)*



[*Op. cit.* pl. vi, fig. 10.]

each with a pleural furrow and free point, but the third pair is incompletely defined from the post-axial piece, and its free points are short and blunt.

Section F.

L. (Platymetopus) lævis, Eichw.
L. dalecarlicus, Ang.
L. Holmi, Schm.
L. kildarensis nom. prop. (=*L. hibernicus*, Portl. *pars.* Head-shield, *non* pygidium or thorax.)

Section G.

The species *Terataspis grandis* marks another section, of which the characters are those of this species. So far no members of this section appear to have been found in Europe. The kind of modification is similar to that of *Arges* in Group I, and it appears to be an instance of heterogenetic homœomorphy.

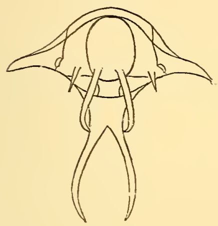
Section G.

L. (Terataspis) grandis, Hall.

SECTION H. (Fig. 19.)

The aberrant form *Ceratolichas gryps* likewise heads an independent section, the characters of which are those of the type-species. This section also seems limited to America.

Fig. 19.—Lichas gryps, *Hall.*



[See Zittel's 'Textbook of Palæont.' transl. Eastman, 1900, p. 632, fig. 1315.]

SECTION H.

L. (Ceratolichas) gryps, Hall.
L. dracon, Hall.

VI. CONCLUSION.

In the foregoing sections of the two main groups all the known members of the Lichadidæ can be naturally included.

It is questionable to what extent it is advisable to employ subgeneric or generic names in an extended or restricted sense. The original conception of the subgenus or genus is lost by so doing, and its definiteness may be obscured, but the existence of newly-recognized transitional forms renders it difficult to draw up a permanent and invariable rule. The types of several different subgenera occasionally fall into the same section; and in such a case it seems desirable to apply to the section the name of the most typical and comprehensive form. For example, in Section A, Group I, *Corydocephalus* may be used as the title of the section.

The sections probably may be regarded as of subgeneric rank, though some are not so isolated as others, and all are not of equal value; and only the two groups can be considered as generically separable.

Names for the two groups seem necessary, and therefore for Group I the name *Protolichas* is proposed, and for Group II the name *Deuterolichas.* In spite of my reluctance to add to an already overburdened nomenclature, it does not seem possible to avoid giving distinctive designations to these two main divisions.

In the case of the sections of these groups the majority already have names attached to them, which have been employed by various writers as of subgeneric value. The names *Metopias*, *Arges*, and *Platymetopus* must be dropped because of their preoccupation, and for them may be substituted respectively *Metopolichas*, Gürich, *Ceratarges*, Gürich, and *Paralichas*, nom. prop. The two Sections C & E of Group I may be termed respectively *Platylichas*, Gürich, and *Metalichas*, nom. prop., and Section D of Group II *Echinolichas*, Gürich, in order to complete the series of sectional names, which will then run as follows :—

Group I.—*Protolichas*, nom. prop.	Group II.—*Deuterolichas*, nom. prop.
Section A. *Corydocephalus.*	Section A. *Hoplolichas.*
,, B. *Dicranopeltis.*	,, B. *Homolichas.*
,, C. *Platylichas.*	,, C. *Conolichas.*
,, D. *Metopolichas.*	,, D. *Echinolichas.*
,, E. *Metalichas*, nom. prop.	,, E. *Leiolichas.*
,, F. *Uralichas.*	,, F. *Paralichas*, nom. prop.
,, G. *Ceratarges.*	,, G. *Terataspis.*
,, H. *Oncholichas.*	,, H. *Ceratolichas.*

The British members of the family of the Lichadidæ are distributed among the sections as follows:—

Group I. (*Protolichas.*)

Sect. A. (*Corydocephalus.*)
L. anglicus, Beyr.
L. hirsutus, Fletch.
L. scutalis, Salt.
L. devonianus, Whidb.
? *L. nodulosus*, Salt.

B. (*Dicranopeltis.*)
L. Barrandei, Fletch.
L. Woodwardi, Reed MS.
? *L. Salteri*, Fletch.

C. (*Platylichas.*)
L. margaritifer, Nieszk. (? British).
L. bifurcatus, Reed.
? *L. Grayi*, Fletch.
? *L. laxatus*, McCoy.

Sect. D. (*Metopolichas.*)
L. laciniatus, Dalm.
L. patriarchus, Wyatt Edgell.
L. affinis, Ang.
L. conformis, Ang., var. *keisleyensis*, Reed.
L. bulbiceps, Phill.
L. verrucosus, Eichw. (? British).

E. (*Metalichas.*)
L. hibernicus, Portl. (*pars*).

Group II. (*Deuterolichas.*)

Sect. B. (*Homolichas.*)
L. angustus, Beyr. (? British).

Sect. F. (*Paralichas.*)
L. kildarensis nom. prop. (= *L. hibernicus* Portl. *pars.*)
L. lævis, Eichw. (? British).

The small number of British species belonging to Group II is noticeable.

With regard to their distribution in the British Isles, Sections A & B of Group I appear to be entirely Silurian or Devonian, while the great majority of the members of the other sections are Ordovician.

7. *On* POLYPHYMA, *a* NEW GENUS *belonging to the* LEPERDITIADÆ, *from the* CAMBRIAN SHALES *of* MALVERN. By Prof. THEODORE GROOM, M.A., D.Sc., F.G.S. (Read December 4th, 1901.)

[PLATE III.]

I. OCCURRENCE.

THE number of lobulated ostracoda at present recorded from the Cambrian formation is very small, and the species are still very imperfectly known. Forms referred to *Beyrichia* have long been known from the Cambrian beds of Scandinavia,[1] Stockingford,[2] and South Wales.[3] The writer some time since detected in the lowest portion of the Malvern Black Shales a species identical with the Stockingford form, which latter had been provisionally identified with the Swedish *Beyrichia Angelini*, Barr. The specimens obtained from the Stockingford Shales were few and imperfect; the Malvern examples are far more abundant and, though for the most part imperfect, are better preserved. They present characters which serve to separate the species from those now placed under the genus *Beyrichia*. Many of the specimens have been submitted to Prof. T. Rupert Jones, who (after an examination kindly made of much of the material) considers it impossible to refer the form to any known g-nus, and recommends the establishment of a new genus and species. I would propose to describe the species under the name of *Polyphyma Lapworthi*.

The specimens were obtained from the Black Shales (M 257) at the northern extremity of Chase End Hill, in the Southern Malverns, where they were associated with *Acrotreta* sp., *Kutorgina pusilla*, Sars, *Protospongia fenestrata*, Salter, and other fossils. The shales are nowhere actually exposed, and can be reached only by excavation. Some two days' work with the pick and spade produced perhaps a hundredweight of the shale in small pieces. *Polyphyma* is very abundant in certain bands of the shale, and altogether over 300 recognizable individuals were obtained, in addition to many fragments. The shales have been subjected to considerable pressure, consequently the specimens are frequently crushed and indented, and present differences in their appearance so extraordinary that Prof. Rupert Jones and myself at first thought that we might be dealing with several distinct species. In many examples the shell presents a beautifully reticulate appearance; but closer

[1] J. Barrande, 'Syst. Silur. du Centre de la Bohême' vol. i, Suppl. (1872) p. 485.

[2] C. Lapworth, Geol. Mag. 1886, p. 321.

[3] T. Rupert Jones, *ibid.* 1881, p. 343. *Beyrichia Hollii*, Jones, is here recorded from the Menevian, and regarded as an ally of *B. intermedia*, Jones (a form since referred to the genus *Klœdenia*); see Jones & Holl, Ann. & Mag. Nat. Hist. ser. 5, vol. xvii (1886) p. 362.

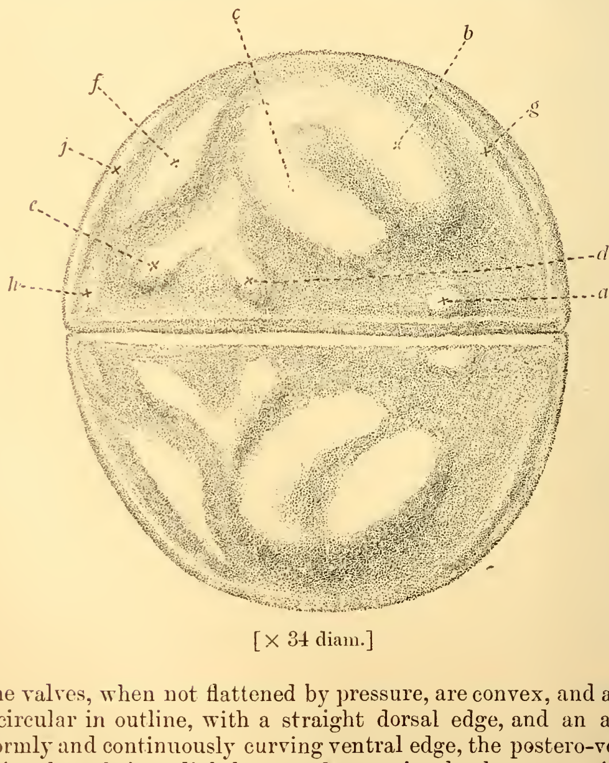
examination shows that the reticulate individuals differ from the rest in no other particular, and, moreover, reveals the fact that the reticulation is due to the presence of a meshwork of intersecting cracks which are clearly of secondary origin. A similar reticulation is seen in some individuals of the associated *Acrotreta*.

With the aid of the more perfect specimens I have now been able to reduce all the individuals, with the exception of one or two of the poorest specimens, to the single type, now to be described.

II. Description.

The chief characteristics of *Polyphyma Lapworthi* are:—A subcentral, obliquely-directed reniform elevation; three tubercles near the dorsal margin; and an anterior subtriangular lobe (see the accompanying text-figure).

Restoration of Polyphyma Lapworthi, gen. et sp. nov.



[× 34 diam.]

The valves, when not flattened by pressure, are convex, and almost semicircular in outline, with a straight dorsal edge, and an almost uniformly and continuously curving ventral edge, the postero-ventral margin alone being slightly protuberant in the larger specimens. The dorsal and ventral margins meet in a well-defined angle. The ventral border is strongly convex, except along the posterior margin and near the angles; it is marked off from the rest of the valve by a gentle depression, and thus forms a marginal ridge (*j*).[1] Along the posterior margin, in the best-preserved examples, the narrow rim is raised only slightly above the level of the adjacent part of the shell. The dorsal margin, too, is as a rule slightly raised above the general level to form a narrow ridge, and is thence sharply bevelled off towards the hinge-line.

The centre of the valve is occupied by a well-defined, broad reniform elevation, the concavity of which is directed obliquely upward and backward. The ventral limb (*b*) of this is more prominent than the dorsal (*c*), and at or near its free extremity is generally raised up to form a prominent rounded tubercle. Prof. Rupert Jones has suggested to me that this limb represents the 'gigot-lobe' of *Beyrichia*. It is on this supposition that the orientation adopted here is based.

In the antero-dorsal part of the valve are situated two tubercles. Of these, one (*d*), placed in a line with the free ends of the lobes *b* and *c*, is nearly hemispherical; the second (*e*), situated in front, in the best examples is spindle-shaped, the axis of the spindle being directed obliquely upward and forward. These two tubercles, though sometimes apparently isolated, are usually more or less completely connected with the lobe *c* by a low forked ridge. Towards the posterior end of the dorsal margin is a third smaller tubercle (*a*), sometimes very small and hemispherical, but usually elongated in a direction more or less parallel to the dorsal margin of the valve, with the bevelled edge of which it is, as a rule, nearly continuous at one point.

Starting from a point close to the antero-ventral margin is a well-marked lobe (*f*) which, diverging from the margin, runs forward and upward, and ends near the lobe *e*. In the smaller examples it frequently appears to be spindle-shaped, but in larger and better specimens it is subtriangular. From a second point, on the postero-ventral margin, a more slender and less elevated ridge (*g*) runs upward and backward, and at the same time diverges from the edge and becomes submarginal. I have been unable to make certain that this ridge represents a feature originally present, for it is often poorly developed, and seems to occur at variable distances from the margin, sometimes indeed quite close to the latter; but its repetition with identical features in several of the best specimens favours the view that it is not of secondary origin. Indications of a small triangular lobe (*h*) are sometimes seen at the anterior angle in good specimens.

The lobes just described rise up from the adjacent areas with tolerable distinctness, and where close together are separated by well-defined channels with rounded floors. The lobe *c*, however, often subsides gently into a flattened area characteristic of the hinder part of the valve. The two valves of the shell appear to be perfectly similar, and are sometimes preserved in juxtaposition. The dorsal and ventral edges appear to lie wholly in a plane, and

[1] The letters *a–j* in parentheses refer to the text-figure, p. 84.

it is therefore to be presumed that, unless this is due to pressure, the valves when closed did not gape at any point along the ventral margin. No differences between different individuals which could be attributed to sex were observed.

The substance of the valves is thin, black, and shining, and evidently consisted originally of chitinous material.

The length of the valves generally varies from 1 to 3 millimetres, and the height from 0·5 to 1·8 mm. The most abundant individuals measured a little under 2 mm. by a little over 1 mm. Measurements of a number of selected individuals gave the following dimensions (in millimetres):—1·0 × 0·5; 1·24 × 0·66; 1·6 × 0·8; 1·75 × 1·0; 1·9 × 1·1; 2·0 × 1·1; 2·26 × 1·32; 2·4 × 1·3; 2·6 × 1·56; 2·8 × 1·65; and 2·9 × 1·8 (the biggest complete individual seen). A few specimens showed indications of greater size; the largest of these, an imperfect specimen measuring 2·6 mm. in height, must have been some 4 or 4·5 mm. in length. The average lengths and heights of sixteen specimens less than 2 mm. in length were 1·6 and 0·9 mm. respectively; the corresponding measurements of ten larger individuals were 2·5 and 1·4 mm. The relative height thus appears to increase with age.

III. Relation to Allied Genera.

The genus *Beyrichia* was instituted by McCoy.[1] In subsequent years many new species were referred to this genus by different observers. Latterly, however, certain of these have been separated off to form distinct genera, and other genera having been added, the Leperditiadæ now include a number of lobulate forms. Among the lobulate genera recognized are the following:—*Beyrichia*,[2] *Ctenobolbina*,[3] *Tetradella*,[4] *Bollia*,[5] *Strepula*,[6] *Polyzygia*,[7] *Poloniella*,[8] *Jonesella*,[9] and *Drepanella*.[10] The mutual relations between many of these forms is very obscure, and it appears doubtful whether all of them are entitled to rank as genera. The genera to which *Polyphyma* appears to be most nearly related are those provided with broad lobes, such as *Klœdenia*, *Beyrichia*, *Ctenobolbina*, and *Tetradella*. The arrangement of the lobes, however, is more complex than that seen in *Klœdenia* or in the simpler forms of *Beyrichia* and *Ctenobolbina*; moreover, it does not seem possible to regard *Polyphyma* as having originated, like the more complex forms of *Beyrichia*, from the simple three-lobed type. On the other hand,

1 'Synops. Silur. Foss. Irel.' 1846, p. 57.

2 See T. Rupert Jones, Ann. & Mag. Nat. Hist. ser. 2, vol. xvi (1855) pp. 81, 163; & G. Reuter, Zeitschr. Deutsch. Geol. Gesellsch. vol. xxxvii (1885) p. 621.

3 E. O. Ulrich, Journ. Cincinnati Soc. Nat. Hist. vol. xiii (1891) p. 108.

4 *Ibid.* p. 112.

5 T. Rupert Jones & H. B. Holl, Ann. & Mag. Nat. Hist. ser. 5, vol. xvii (1886) p. 360.

6 *Ibid.* p. 403.

7 G. Gürich, Verh. Russ. Kaiserl. Mineralog. Gesellsch. St. Petersb. vol. xxxii (1896) p. 387.

8 *Ibid.* p. 388.

9 E. O. Ulrich, Journ. Cincinnati Soc. Nat. Hist. vol. xiii (1891) p. 121.

10 *Ibid.* p. 117.

it is conceivable that the lobes *b*, *c*, *d*, and *e* (perhaps together with the lobe *a*, which may belong either to lobe *b* or to lobe *c*) correspond with the four lobes seen in *Tetradella* (and in some forms referred to *Ctenobolbina*).[1] If this comparison be just, the lobes *f* and *g* may be extra lobes, not seen in *Klœdenia*, *Beyrichia*, *Ctenobolbina*, or *Tetradella*, and perhaps comparable with the submarginal lobes seen in *Strepula* and *Polyzygia*, though these differ greatly in form from the broad lobe *f*. But whatever be the interpretation, it appears that *Polyphyma* presents a combination of characters not seen in any other genus. Considering our ignorance of the homologies of the lobes in the majority of the genera, it appears hardly worth while to discuss the question further; the true systematic position of *Polyphyma* will be first understood when, by means of transitional stages between this form and other genera, it has been ascertained what parts correspond in each case.

IV. Occurrence in other Districts.

Owing to the kindness of Prof. Lapworth, I have been enabled to examine specimens of '*Beyrichia*' obtained by him from the Oldbury Shales, and I find that the best example among these is referable to *Polyphyma Lapworthi*. In the Oldbury district, as in the Malverns, this species is found in shales beneath the zone of *Sphærophthalmus alatus*, Boeckh. It seems probable that at Malvern the horizon is that of the uppermost part of the Paradoxidian; it is, however, possible that it corresponds with the zone of *Beyrichia Angelini*, Barr., which in Sweden is situated above that of *Agnostus pisiformis*, Linn.

'*Beyrichia*' *Angelini*, originally figured without description by Angelin, and shortly afterwards briefly described by Barrande,[2] was later redescribed by Linnarsson.[3] The last-mentioned observer remarks that, among the variety of forms described under the name *Beyrichia*, none approach '*Beyrichia*' *Angelini*, and he regarded the generic position of the latter as quite uncertain.

From Linnarsson's description, '*Beyrichia*' *Angelini* appears to present some resemblance to *Polyphyma Lapworthi*; this is seen in the chitinous nature, the size, the semicircular form, the flattening at one end, and the subcentral position of the main tubercle, and perhaps in other respects. But the description is hardly full enough to warrant the inclusion at present of Barrande's species in the genus *Polyphyma*. In reply to a request of mine to be furnished

[1] A. Krause, Zeitschr. Deutsch. Geol. Gesellsch. vol. xliv (1892) pp. 389, 395 & pl. xxi, fig. 2, pl. xxii, fig. 9.

[2] Angelin's figure (pl. A, figs. 36 *a* & *b*) was apparently intended to appear in a supplement to the 'Palæontologia Scandinavica,' but was never published, as might be inferred from Barrande's statement, 'Syst. Silur. du Centre de la Bohême' vol. i, Suppl. (1872) pp. 485 & 495, though proofs of the plate containing it were privately circulated. I may add that the late Dr. Gustav Lindström informed me that Angelin's original specimen was lost before 1876.

[3] Öfvers. Kongl. Vetensk.-Akad. Förhandl. vol. xxxii (1875) no. 5, p. 45, & pl. v, fig. 11.

with a large drawing of '*Beyrichia*' *Angelini*, the late Dr. Lindström informed me that Linnarsson's original specimen is the only one now possessed by the Riksmuseum at Stockholm, and that it is well delineated in Linnarsson's paper. Under these circumstances there can be little doubt that the English and Swedish species are different.

V. Diagnosis of *Polyphyma Lapworthi.*

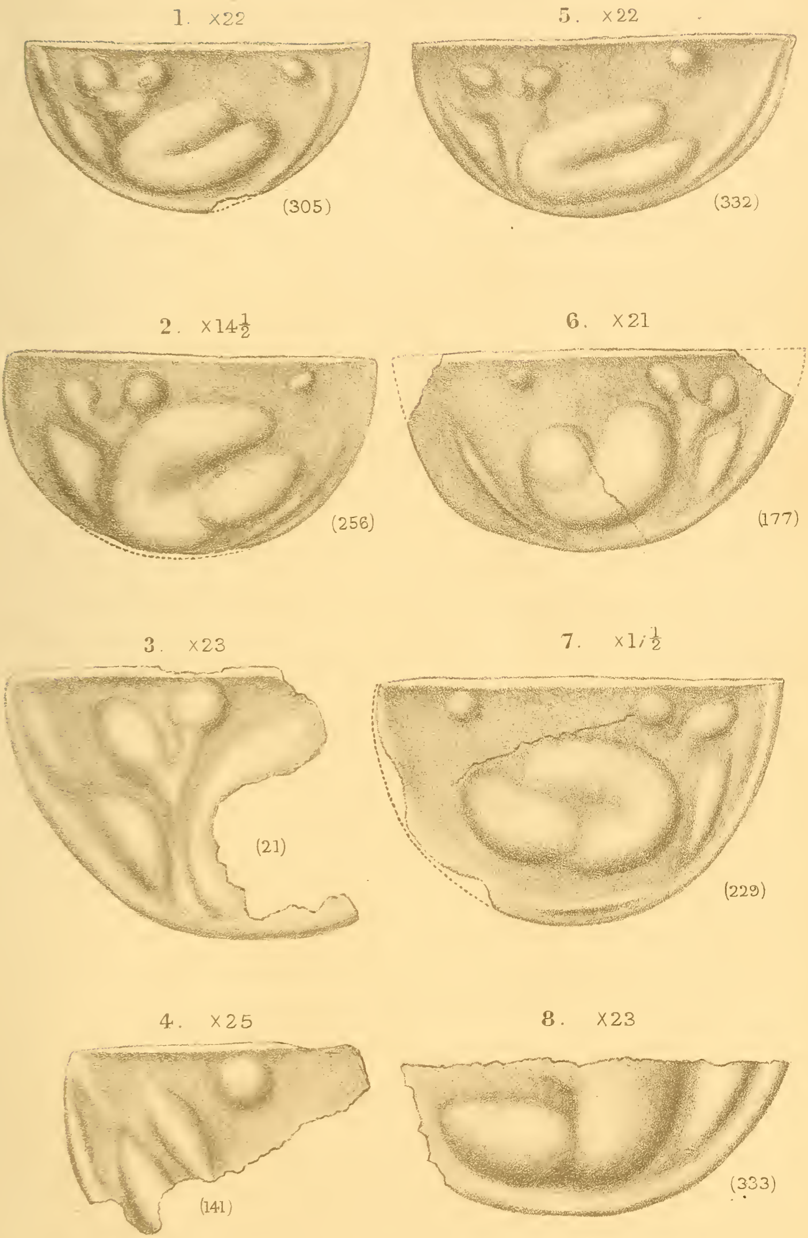
Shell thin and chitinous; convex, semicircular, with straight hinge-line and well-defined angles. Ventral border raised into a marginal rim, which narrows posteriorly. Valves, each flat behind, furnished with a large, subcentral, obliquely-directed reniform lobe, the ventral limb of which is commonly provided with a prominent tubercle; a small, elongated, postero-dorsal submarginal lobe; two antero-dorsal lobes, usually connected with the reniform lobe by a low forked ridge: the one hemispherical, the other more anteriorly situated, spindle-shaped, directed towards the anterior angle; a subtriangular anterior submarginal lobe, and probably a slender submarginal posterior ridge. Dorsal margin slightly raised, and sharply bevelled off towards the hinge-line. Valves when closed probably not gaping at any point. Prevailing size: about 2 millimetres by 1.

Horizon.—Lowest Black Shales (Cambrian), Southern Malverns.

EXPLANATION OF PLATE III.

Fig. 1. Left valve of *Polyphyma Lapworthi*, gen. et sp. nov. (No. 305.) ×22.
2. Do. (No. 256.) × 14½.
3. Part of do. (No. 21.) × 23.
4. Do. (No. 141.) × 25.
5. Left valve. (No. 332.) × 22.
6. Right valve. (No. 177.) × 21.
7. Do (No. 229.) × 17½.
8. Part of do. (No. 333.) × 23.

[The numbers in parentheses are those of the original specimens, which are now in the Museum of the Birmingham University.]



[illegible] del.
A. H. Searle lith.

Mintern Bros imp.

POLYPHYMA LAPWORTHI.
GEN. ET SP. NOV.

8. *The* SEQUENCE *of the* CAMBRIAN *and* ASSOCIATED BEDS *of the* MALVERN HILLS. By Prof. THEODORE GROOM, M.A., D.Sc., F.G.S. *With an* APPENDIX *on the* BRACHIOPODA by CHARLES ALFRED MATLEY, Esq., B.Sc., F.G.S. (Read December 4th, 1901.)

CONTENTS.

I. INTRODUCTION.

IN a former communication [1] the disposition of the older Palæozoic beds in the Southern Malverns was described, but few stratigraphical details were given. It is proposed on the present occasion to complete the description of these rocks, with the exception of the lithology. Further research has strengthened the conclusions formerly drawn, and has afforded some additional evidence as to the succession; while diligent collecting, and examination of the specimens previously collected, has added many fossils to the small stock hitherto known. A number of these are new; they have already been described in part by Mr. Frederick Chapman,[2] and by the author,[3] and descriptions of the remainder by Mr. C. A. Matley and the present writer will be found towards, or at the close of this paper, together with some notes on certain trilobites for which Mr. Philip Lake and myself are jointly responsible.

The following subdivisions of the strata may now be recognized:—

4. Bronsil Shales (Grey Shales).
3. White-Leaved-Oak Shales (Black Shales).
2. Hollybush Sandstone.
1. Malvern Quartzite.[4]

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[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 129 *et seqq.*

[2] *Ibid.* vol. lvi (1900) pp. 257 *et seqq.*

[3] Geol. Mag. 1902, p. 70.

[4] [This name is intended to replace that of Hollybush Quartzite and Conglomerate used in my first memoir on the district. The change has been made in accordance with a suggestion put forward by Prof. Lapworth at the reading of the paper.—*December 5th*, 1901.]

II. The Malvern Quartzite.

(*a*) Distribution and Stratigraphical Relations.

The conglomeratic beds of the Malvern Quartzite were apparently first seen in the Gullet Pass by Leonard Horner.[1] Murchison later spoke of a very felspathic grit on the flank of Midsummer Hill.[2] John Phillips described the same conglomerate as wrapping round the northern end of Raggedstone Hill, and descending towards the Hollybush Pass on the north.[3] It was observed too by Holl at the foot of the western spur of this hill, and also in the Gullet Pass, but the rock in the last-mentioned locality was referred by him to the Llandovery Series.[4] Symonds mentions the occurrence of the conglomerate on the western slopes both of the Raggedstone and Midsummer Hill, and on the northern side of the former, between the eastern and western spurs, and also at the top of the quarry at the southern end of Swinyard Hill.[5]

The distribution of the Malvern Quartzite, as ascertained by the present writer, has already been described,[6] and it will be sufficient to point out that it occurs in the Abberley Hills (near Martley, and in Cowley Park); immediately south of the Gullet Pass (M 109, M 170, M 265, and M 366)[7]; on the western sides of Midsummer Hill (M 173 *a*) and of Raggedstone Hill (M 244); and in the central depression traversing Midsummer Hill (M 169) and Raggedstone Hill (M 164 & M 177); another small patch at White-Leaved Oak is mentioned below (p. 91).

Holl and Symonds both placed the 'Conglomerate' in what is evidently its true position, namely, at the base of the Hollybush Sandstone. A close relation between the two formations is suggested by the presence of glauconitic grains in some samples of the quartzite, and by the occasional assumption by the conglomerate of a matrix much resembling the green Hollybush Sandstone; moreover, one variety of the grey Hollybush Sandstone is indistinguishable lithologically from the yellowish-grey type of quartzite (see p. 96). Rarely hand-specimens may be obtained from débris, in which green and grey quartzite alternate in thin bands. Symonds states that

> 'excavations for stone on the western slope of the Raggedstone exposed this old beach [the Malvern Quartzite] dipping at a high angle underneath the greenish Hollybush sandstones.' (*Op. cit.* p. 24.)

It is not, however, sufficiently clear whether the conglomerate was actually seen to underlie the sandstones, or merely to dip towards them. The excavations are now filled up, and the relations between

[1] Trans. Geol. Soc. vol. i (1811) p. 302.

[2] 'Silurian System' 1839, pp. 415 & 416.

[3] Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 52.

[4] Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 87 & 100; and Symonds in Purchas & Ley's 'Flora of Herefordshire' 1889, pp. xiii–xiv.

[5] 'Old Stones' 2nd ed. (1884) p. 24.

[6] Quart. Journ. Geol. Soc. vol. lv (1899) fig. 1, p. 132 & pl. xiii facing p. 167; and *ibid.* vol. lvi (1900) pl. xv facing p. 168.

[7] Throughout this paper M, followed by a numeral in parentheses, refers to the maps which accompany the author's previous papers on the Malverns, Quart. Journ. Geol. Soc. vol. lv (1899) pl. xiii & vol. lvi (1900) pl. viii.

the two rocks are obscure. But, judging from the distribution of the débris of the Quartzite, it would appear to crop out along a line running in a south-westerly direction obliquely down the slope, and parallel to the probable direction of outcrop of the sandstone [1]; this circumstance lends support to Symonds's view. Other considerations, however, suggest that the Quartzite and Sandstone at this spot are separated by a fault (see pp. 96 & 97).

The view that the Malvern Quartzite directly underlies the Hollybush Sandstone is further borne out by the close analogy between the Malvern and Shropshire districts; in the latter the sequence is clearer, and the glauconitic Comley (or Hollybush) Sandstone is immediately underlain by the Wrekin Quartzite.[2] The frequently conglomeratic character of the Malvern Quartzite also points in the same direction. At one spot there appears to be direct evidence of the infra-position of the Quartzite. At the northern end of the big quarry at White-Leaved Oak, the lowest portion of certain flaggy beds of the Hollybush Sandstone (which were evidently regarded as the base of that formation by Prof. Lapworth) is seen to consist chiefly of grey and greyish-white quartzite precisely like certain varieties of the Malvern Quartzite, and unlike any seen in the Hollybush Sandstone. These contain, in addition to doubtful fragments of *Kutorgina Phillipsii* (Holl), which occurs in both formations, *Obolella (?) Groomii*, sp. nov., a fossil hitherto found only in the Malvern Quartzite. This quartzite passes up by alternation into the green flaggy Hollybush Sandstone. We have here, then, beds which represent either the summit of the Quartzite, or the passage-beds between the formations and the Hollybush Sandstone.

The junction of the Malvern Quartzite series with the Archæan complex being probably everywhere a fault,[3] it is impossible to say on what rocks the former originally rested. It may have passed down into a pre-Cambrian sedimentary series, or into a volcanic series analogous to the Caldecote Series of Warwickshire,[4] possibly into the Warren House Series of the Malverns.[5] But it seems more probable that the Quartzite rested unconformably on both of the Malvern Archæan series; for the inclusion in the conglomeratic beds of fragments bearing a general resemblance to certain rocks of the present Malvern Hills proves the denudation of a land containing rocks of both Malvernian and Uriconian type situated not far from the site of the present Malvern chain.[6]

(*b*) Lithology and Thickness.

Lithologically the rocks of this series vary from a compact quartzite to a rather coarse conglomerate, every transition between

[1] Quart. Journ. Geol. Soc. vol. lv (1899) fig. 1, p. 132.

[2] Callaway, Quart. Journ. Geol. Soc. vol. xxxiv (1878) pp. 754 *et seqq.*, and Lapworth & Watts, Proc. Geol. Assoc. vol. xiii (1894) p. 309.

[3] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 137, 139, & 145.

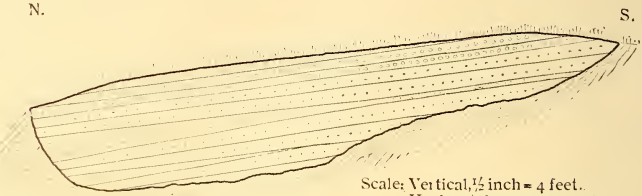
[4] Lapworth, Proc. Geol. Assoc. vol. xv (1898) pp. 330–32.

[5] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 140.

[6] Rep. Brit. Assoc. 1900 (Bradford) p. 739.

these two types being found. In Winter Combe, on Raggedstone Hill,[1] the prevailing rock is a coarse greyish-white quartzite, or grit, with some finer-grained quartzite. At the northern end of Midsummer Hill (see fig. 1) layers of quartzite and conglomerate

Fig. 1.—*Diagrammatic sketch of the small quarry in the Malvern Quartzite and Conglomerate, at the north-western corner of Midsummer Hill (M 170).*



[Impersistent layers of conglomerate are interbedded with grey quartzite (dotted in the figure). The fossils are most abundant in the uppermost band of quartzite, especially near the junction with the overlying band of conglomerate.]

alternate. The prevailing type is a fine-grained quartzite with tiny flakes of white mica, and often containing minute fragments of horny brachiopoda, chiefly referable to *Kutorgina Phillipsii*. In places, especially where the rock becomes a little coarser in grain, there are clear indications of lamination, and not uncommonly of false-bedding. Occasionally the rock passes into a sandstone of a chocolate-brown colour. Very commonly the grain of the quartzite or sandstone becomes coarser, and the rock then passes into a grit. The colour of the quartzite varies considerably: the commonest type is grey; but greyish-white, or greyish-black, bluish-, greenish-, yellowish-, brownish-, pinkish-, or reddish-grey tints are frequently assumed. By the gradual or fairly sudden appearance of pebbles or subangular fragments, the rock passes into a pebbly quartzite, sandstone, or grit, and into somewhat coarse conglomerate, the pebbles of which may attain a diameter of 2 inches.

A description of the materials of the Malvern Quartzite is reserved for a future occasion; for the present, it may suffice to state that the fragments consist largely of grey or white quartz and metamorphic quartzite; variously tinted felsites, bearing much resemblance to rocks in the Herefordshire Beacon which have been regarded as rhyolites; and reddish binary granites and granophyres; as also of minerals which may have been derived from such rocks.

It may be remarked that while all the varieties of quartzite or conglomerate found in the different localities can be more or less closely paralleled in the chief outcrop at the northern end of

[1] Quart. Journ. Geol. Soc. vol. lv (1899) fig. 14, p. 146.

Midsummer Hill, the development of the series in the several localities is usually somewhat different in one or more respects, such as the prevailing nature of the matrix, the variety of pebbles, or the relative proportions of quartzite and conglomerate. Thus in Winter Combe, on Raggedstone Hill, the prevailing rock is a pebbly grit, of tolerably uniform character, the pebbles of which are of less varied character than those seen at the northern end of Midsummer Hill. On the western side of Raggedstone Hill quartzites of a light colour, and containing *Hyolithus*, are found. At the southern end of the same hill, greyish-white quartzites are interbedded with Hollybush Sandstone. These facts are of importance, inasmuch as they either point to rapid horizontal change, or more probably suggest that we are dealing with dislocated fragments of a series originally of considerable thickness.

It is difficult to say what the original thickness may have been. The little patch on Winter Combe consisting chiefly of grit can hardly be less than 50, and is probably more than 65 feet thick.[1] The thickness of that portion of the series of quartzites, grits, and conglomerates which crops out at the northern extremity of Midsummer Hill may be as great as 200 or 300 feet; but the difficulty of ascertaining the exact disposition of the beds, makes this estimate very uncertain. It seems probable, however, that the formation was originally comparable in development with the quartzite at the base of the Cambrian Series in Shropshire, or possibly even with the still thicker Lower Quartzites of the Nuneaton district.

(*c*) Palæontology.

Fossils are not common in the series in most places. Symonds speaks of an *Obolella*,[2] and Murchison records the following:—*Obolella Salteri*, *Orthis lenticularis*, *Ctenodonta* sp., *Theca* sp., *Serpulites fistula*, and *Scolithus* sp.[3]

No specimens recorded as from the 'Conglomerate' appear to occur in the existing collections, but a few labelled as from the 'Hollybush Sandstone' may be seen at Oxford, Cambridge, South Kensington, and Worcester. They include *Kutorgina cingulata* var. *Phillipsii* nov., and *Obolella (?) Groomii*, sp. nov. These specimens, however, are embedded in a quartzite which is precisely like that of Raggedstone Hill (M 244) or Midsummer Hill (M 170) The same may be said of a specimen of *Hyolithus (Serpulites) fistula* (Holl)? preserved in the Woodwardian Museum. The subject has been thrown into confusion, apparently owing to the circumstance that, although Holl distinguished between the Hollybush Sandstone and the basal Conglomerate (=Malvern Quartzite), collectors have referred indiscriminately all the fossils collected to the former. Moreover, Holl, I believe, included under the name 'felspathic sandstones' rocks belonging in part to the

[1] See Quart. Journ. Geol. Soc. vol. lv (1899) fig. 14, p. 146.
[2] 'Old Stones' 2nd ed. (1884) p. 24.
[3] 'Siluria' 4th ed. (1867) App. p. 541.

Hollybush Sandstone and in part to the Malvern Quartzite. I think it advisable, therefore, to disregard the lists given by Holl and Murchison, and to rely solely on the specimens preserved in museums, or collected by myself.

On the western slopes of the Raggedstone (M 244) fossils are abundant, in pieces of quartzite and quartzose grit. These include, in large numbers, *Kutorgina cingulata* var. *Phillipsii* nov., and less frequently *Obolella (?) Groomii*, sp. nov., and *Hyolithus primævus*, sp. nov., and rarely *H. fistula* (Holl). In the more conglomeratic quartzites at the northern end of Midsummer Hill (M 170), I obtained *Kutorgina Phillipsii* in the greatest abundance, though frequently in a fragmentary condition. With these were associated a much smaller number of specimens of *Obolella (?) Groomii*. The foregoing are the only fossils (with the exception of glauconitic casts of foraminifera) that it appears safe to attribute to the Malvern Quartzite.

III. The Hollybush Sandstone.

(a) Succession and Thickness.

The Hollybush Sandstone was first observed by Murchison on the western flanks of the Raggedstone. He described the formation as composed of a pale-green, fine-grained, slightly micaceous, earthy sandstone, passing up above into hard flag-like and highly micaceous layers.[1] The sandstone, he states,

'might be termed greensand with as much propriety as any rock in the geological series.'

De la Beche speaks of the same beds as

'greenish sandstones, in thick and thin beds, often of a trappean aspect.'[2]

It was John Phillips, however, who gave the first detailed description of the series, and applied to it its present name.[3] Holl in later years carefully studied the character of the sandstones, and obtained fossil remains from them.[4] He attempted also to establish a general succession of strata within the series, and distinguished on the northern slopes of the Raggedstone (in descending order) the following:—

Beds with *Trachyderma antiquissima*.
Greenish sandstones with *Serpulites fistula*.
Contemporaneous lava.
Light-coloured felspathic sandstones and speckled sandstones with fossils, and rather massive olive-green unfossiliferous sandstone.
Basal conglomerate (= Malvern Quartzite).

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[1] 'Silurian System' 1839, p. 416.
[2] Mem. Geol. Surv. Gt. Brit. vol. i (1846) p. 21.
[3] *Ibid.* vol. ii, pt. i (1848) pp. 51–54.
[4] Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 87–89.

At the southern end of the Raggedstone he described, in descending order, the following succession:—

Olive-green massive beds.
Thinly-laminated micaceous sandstone.
Light-blue calcareous sandstone, with a thin bed of limestone.
Dark-purple and purplish-black sandstone.
Sandy shales, with worm-tracks.

These beds Holl placed below the horizon of the lava of the more northerly exposures, but above the lowest beds. Both on the northern and southern parts of the hill, the beds appear to be less satisfactorily exposed than when Holl examined them; but careful examination of the ground shows that, at any rate in part, Holl's succession will not hold good. He does not seem to have detected the fault crossing the series at White-Leaved Oak,[1] and in the northern part of the hill the supposed lava has been shown by the present writer to be a dyke crossing the bedding.[2]

The formation in Raggedstone Hill exhibits a difference in development in three or four different areas. There is, firstly, a series consisting chiefly of thin flaggy sandstones, interstratified with sandy shales: these are seen only on the western side of the big quarry at White-Leaved Oak.[3] Secondly, a set of more massive green sandstones, interstratified with dark-green or black sandstones: these are exposed immediately west of the flaggy sandstones, from which they are separated by a fault.[4] Thirdly, a set of dark-grey and grey sandstones or quartzites, with green sandstones, seen to the north of the big quarry. And lastly, a thick series of green sandstones, apparently including in the middle a band of fine-grained, dark-green or grey sandstone, overlain by variously-tinted light-grey sandstones[5]; this series occupies the north-western corner of Raggedstone Hill. The mutual stratigraphical relations between these portions of the formation are not clear; but the available evidence suggests that they constitute, on the whole, series following each other in the order just given, but possibly with some overlapping[6] of the members in some or all cases.

The flaggy beds consist chiefly of thin flags of green sandstone, separated by equally thin shaly seams. In places the beds become calcareous, and at one spot small lenticular patches of impure light-green limestone are seen, and in two others a very hard, compact, impure, brown or grey limestone, 2 or 3 feet thick.[7] Towards the upper part of the series thin beds of dark-grey sandstone come in; and the uppermost beds seen consist of more massive green, dark-green, or dark-grey sandstone separated by shaly beds.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) fig. 2, p. 134.
[2] *Ibid.* fig. 1, p. 132. [3] *Ibid.* fig. 2, p. 134.
[4] *Ibid.* pp. 135 & 137.
[5] *Ibid.* fig. 1, p. 132. The outcrop of this band, which is marked *Hb.S'*, should probably be extended somewhat in width towards the south.
[6] This term is not used in a stratigraphical sense.
[7] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 133–35. The limestone is represented in black, in the map and sections on pp. 134 & 136 there.

At the northern end of the quarry, the flaggy beds are separated from the Archæan by 1 or 2 feet of grey and whitish-grey quartzite, in thin seams separated by bands of sandy shale; into this series they pass by alternation. This quartzite appears to be the summit of the Malvern Quartzite (see p. 91), the greater part of which is faulted out. A calcareous layer in the flaggy series yielded to Prof. Lapworth *Kutorgina cingulata*, *Obolella Salteri*, *Linnarssonia sagittalis*, and *Hyolithus* sp.[1] From what is possibly the same layer I obtained *Kutorgina cingulata* var. *Phillipsii* and *Hyolithus* sp. Other portions of the flaggy series yielded *Scolecoderma antiquissima* (Salter) and *Hyolithus (?)* sp.

The second series includes a band of impure, greenish-grey, glauconitic, sandy limestone a few inches thick. The only fossil detected was *Scolecoderma antiquissima*. The resemblance of this series to the uppermost part of the flaggy beds suggests that the fault separating them is not of great importance.

The third series is poorly exposed, but appears to occupy a considerable area on the western side of the Raggedstone. Judging from the débris and from the few exposures seen, it consists chiefly of grey, dark-grey, and black sandstones and quartzites; green and dark-green sandstones, with subordinate conglomerate and coarse conglomeratic grit[2]; the pebbles of the conglomerate, which are sometimes nearly 1 inch long, are set in a dark-grey, dark-green, or green matrix. These beds, which may be over 200 feet thick, have furnished no fossils.

Of the fourth series the upper beds only are exposed, though judging from débris the lower beds resemble these. They consist chiefly of green flaggy sandstones with *Scolecoderma antiquissima*. The dark zone in the middle of the series includes a thin conglomeratic band (M 158). The concealed grey sandstones are of grey, or greenish-, brownish-, yellowish-, pinkish-, or reddish-grey colour. A yellowish-grey variety is lithologically indistinguishable from a variety of the Malvern Quartzite seen in Winter Combe. These grey beds appear to correspond in part with Holl's 'light-coloured felspathic sandstones.'[3] They are characterized by the great abundance of *Hyolithus fistula* (Holl); with this are associated *H. primævus*, sp. nov. and *H. malvernensis*, sp. nov., and probably other species of the same genus, together with *Coleoloides (?)* sp., *Kutorgina Phillipsii*, a minute species of *Modiolopsis (?)*, and *Scolecoderma antiquissima*. The light-grey sandstones are probably overlain by a very compact dark-grey platy sandstone, which forms a little tump near the road in the Hollybush Pass. The higher beds consist of green sandstones, with *Scolecoderma antiquissima*. The beds on the northern side of the Pass and those in Winter Combe seem to belong chiefly to this fourth class.

1 Proc. Geol. Assoc. vol. xv (1898) p. 338.

2 The conglomerate was seen only in the form of débris at the foot of the hill.

3 Quart. Journ. Geol. Soc. vol. xxi (1865) p. 87.

Owing to the difficulty in ascertaining the precise succession of the beds, and to the disturbances and faulting which the formation has undergone, any estimate of the original thickness of the Hollybush Sandstone must be very uncertain. The combined thickness of the visible portion of the flaggy beds, and of the sandstones west of them at White-Leaved Oak, is probably about 225 feet: this estimate agrees closely with that of Holl, who says that the beds here are not much more than 200 feet thick.[1] The thickness of the flaggy beds alone is not less than 75 feet. The inclination of the third set of beds can be seen only at two places. In one of these green sandstones dip north-eastward at a considerable angle[2]; in the other, situated towards the northern end of the large quarry at White-Leaved-Oak, black quartzites show a north-easterly dip of 60°.[3] If this dip is maintained throughout the strip, the beds may be as much as 300 feet thick. The thickness of the beds of the uppermost series on the northern side of the Hollybush Pass, west of the fault traversing the sandstone, is about 550 feet; the corresponding series in the north-western part of the Raggedstone is probably about 650 feet, an estimate which is near that of 600 feet given by Phillips for the whole formation.[4] But if, as may be suspected from the absence of débris of the supposed lower subdivisions, these are faulted out, and the series here consequently includes only the upper part of the formation, the thicknesses already suggested for the lower portions must be added to this value; this will give a maximum thickness of nearly 1200 feet for the whole formation. If, however, as seems probable, certain beds are repeated in the second and third series, and others in the third and fourth, some deduction must be made, though not, I think, a great one. I would suggest, therefore, an estimate of 1000 or 1100 feet, and do not think that the series can be much less than 900 feet thick.

The following succession may be tentatively suggested:—

(*b*) Massive Sandstones.

3. Green sandstones containing *Scolecoderma antiquissima*, with a zone of dark-green sandstones (with a thin conglomeratic layer), dark-grey quartzite, and light-grey sandstones containing *Scolecoderma antiquissima*, *Kutorgina Phillipsii*, *Hyolithus fistula*, *H. primævus*, *H. malvernensis*, and probably other species of *Hyolithus*, together with *Modiolopsis (?)* sp. Thickness probably not less than 650 feet.
2. Grey, dark-grey, or black sandstones and quartzites, alternating with green and dark-green sandstones (with subordinate conglomerate), and with a thin impure limestone towards the base. *Scolecoderma antiquissima* also occurs in these. Thickness 400 feet (?).

(*a*) Flaggy and Shaly Sandstones.

1. Flaggy and shaly green sandstones, with one or two thin calcareous layers and a thin impure limestone; passing up into more massive green, dark-green, or dark-grey sandstones, and down into

[1] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 89.

[2] See dip-arrow a little north of the *d* in 'White-Leaved-Oak,' Quart. Journ. Geol. Soc. vol. lv (1899) map, pl. xiii.

[3] *Ibid.* fig. 2, p. 134.

[4] Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 53.

greyish-white quartzite (Malvern Quartzite). Fossils: *Kutorgina Phillipsii*, *Linnarssonia sagittalis*, *Obolella (?) Salteri*,[1] *Hyolithus* sp., and *Scolecoderma antiquissima*. Fossils in the white quartzite: *Obolella (?) Groomii* and *Kutorgina Phillipsii (?)*. Thickness not less than 75 feet.

(*b*) Palæontology.

The fossils recorded from the Hollybush Sandstone by Holl[2] are the following:—*Scolithus*, *Scolecoderma (Trachyderma) antiquissima*, *Serpulites fistula*, *Lingula squamosa*, *Lingula* sp., *Kutorgina (Obolella) Phillipsii*, *Obolella* 2 spp., and a small bivalve. Murchison[3] records also the following:—*Lituites* sp., *Theca* sp., *Obolella Salteri*, and annelid-tubes. It is unfortunate that scarcely any of the foregoing specimens appear to have found their way into the large public collections. The only fossils from the Hollybush Sandstone that I have been able to find in these collections are *Hyolithus (Serpulites) fistula* and *Scolecoderma (Trachyderma) antiquissima*.

It appears very doubtful whether many of the specimens recorded were obtained from the Sandstone (see p. 93), and the generic value of most of the unnamed species is very uncertain. The only forms which it seems safe to refer to the Hollybush Sandstone are the following:—

Kutorgina cingulata, var. *Phillipsii* (Holl).
Hyolithus (Orthotheca) fistula (Holl).
H. primævus, sp. nov.
H. malvernensis, sp. nov.
Hyolithus, 2 or more spp.
Modiolopsis (?) sp.
Scolecoderma antiquissima (Salter).
Casts of foraminifera.[4]

IV. The White-Leaved-Oak Shales.

(*a*) Palæontology and Thickness.

The Malvern Black Shales appear to have been first detected by Conybeare.[5] They were subsequently recognized by Murchison, and doubtfully correlated by him with the Llandeilo Beds.[6] A year or two later John Phillips[7] detected *Agnostus* and other trilobites in the shales, a discovery which induced Barrande to place the shales on the horizon of the *Lingula*-Flags and of his 'primordial fauna.'[8] The further discovery by Symonds of *Dictyonema sociale*, Salter, in the immediately overlying Grey Shales tended to confirm the antiquity

[1] The specimens of *Linnarssonia sagittalis* and *Obolella (?) Salteri*, recorded from the Hollybush Sandstone, have not undergone revision by Mr. Matley.

[2] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 89.

[3] 'Siluria' 4th ed. (1867) App. p. 541.

[4] Mr. Frederick Chapman has carefully examined the glauconitic casts of foraminifera in the Malvern Quartzite and Hollybush Sandstone, and in the grits of the White-Leaved-Oak Shales, but has failed to identify any of the genera.

[5] Annals of Philosophy, n. s. vol. iv (1822) p. 337.

[6] 'Silurian System' 1839, p. 416.

[7] Lond. Edin. & Dubl. Phil. Mag. & Journ. Sci. vol. xxii (1843) p. 384; and Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 55.

[8] Bull. Soc. Géol. France, ser. 2, vol. viii (1851) pp. 211–12.

of the series.[1] Still later this was followed by the researches of Belt in the *Lingula*-Flags of North Wales[2]; while the subsequent investigations of English and Scandinavian geologists have assisted in further defining the age of the Black Shales, and have shown that they include beds which must be correlated with the Upper Dolgelly Beds or upper part of the *Lingula*-Flags, and represent the zone of *Sphærophthalmus alatus*, Bœck, and its associates.

The Black Shales are found chiefly in the neighbourhood of the village of White-Leaved-Oak, and may be termed the White-Leaved-Oak Shales. They have been subdivided into the following:—

(4) Upper Black Shales;[3]
(3) Upper White-Leaved-Oak Igneous Band;
(2) Lower Black Shales; and
(1) Lower White-Leaved-Oak Igneous Band.

The lowest beds previously recognized are the Lower Black Shales. Many years ago a shaft was sunk at the southern end of Raggedstone Hill in beds low down in this series.[4] Symonds, regarding these shales as situated on the eastern side of the crystalline axis of the hills, stated that they dip steeply away from the axis[5]; this must mean that they have an easterly dip, and are therefore presumably inverted, as elsewhere along the line of junction with the older rocks of Raggedstone Hill. In débris (on the southern side of the road) which, I am informed by an inhabitant, was thrown out of this pit, I failed to find any fossils, but '*Oleni*' were obtained from the débris thrown out, together with an *Agnostus* discovered by Strickland.[6] The latter trilobite, at first identified by Salter as *Agnostus pisiformis*, was afterwards separated by him under the name of *Agnostus princeps*, and regarded as a new species allied to the former.[7] This supposed species, as Mr. Lake and myself endeavour to show on p. 119 of this paper, has apparently resulted from a confusion by Salter of *Agnostus pisiformis* with *A. trisectus*. All the Malvern examples of *Agnostus* from the Black Shales preserved in the collections known to us, including an '*Agnostus pisiformis*' in the Strickland Collection at Cambridge, appear to be typical specimens of *A. trisectus*. The shales in question, long supposed to form part of the zone of *A. pisiformis*, therefore belong to the zone of *A. trisectus* (to which *Peltura scarabæoides*, *Sphærophthalmus alatus*, and *Ctenopyge* are also limited), and, like the overlying portion of the Black Shales, must be correlated with the Upper Dolgelly Beds, and not with the Lower *Lingula*-Flags.

I have, however, detected at another spot beds belonging

[1] 'Old Stones' 2nd ed. (1884) p. 27.
[2] Geol. Mag. 1867, p. 536.
[3] Quart. Journ. Geol. Soc. vol. lv (1899) p. 159.
[4] 'Old Stones' 2nd ed. (1884) p. 27; see also [G. H. Piper] Trans. Woolhope Nat. Field Club, 1893–94, p. 22.
[5] 'Old Stones' 2nd ed. (1884) p. 27.
[6] See Murchison's 'Siluria' 1st ed. (1854) p. 92.
[7] Mem. Geol. Surv. U. K. dec. xi (1864) p. 1.

horizon evidently below that of *Peltura*. Suspecting the presence of shales at the north-western corner of Chase-End Hill, I caused excavations to be made which resulted in the discovery of Black Shales (M 257) interbedded with thin bands of coarse, very dark-grey quartzose grit and invaded by one or two sills of igneous rock (M 117). The series constitutes the Lower Igneous Band. The grits vary from seams a fraction of an inch thick to bands 8 inches thick. Like the Hollybush Sandstone, they contain glauconite, but are generally appreciably coarser than the black and dark-grey varieties of that formation. The shales at this point are in contact with the Hollybush Sandstone, but the actual junction is obscured by the decay of the rocks on either side. The dip of the shales is uniformly high, and varies about 10° on either side of the vertical. Lithologically the shales are indistinguishable from other portions of the White-Leaved-Oak Series. The thickness of the series, exclusive of the sill M 117, is about 30 feet (fig. 2); but it is possible that higher shales belonging to the same series occur south-west of this sill. A complete lack of exposures, however, precludes an examination of the beds for some distance in this direction.

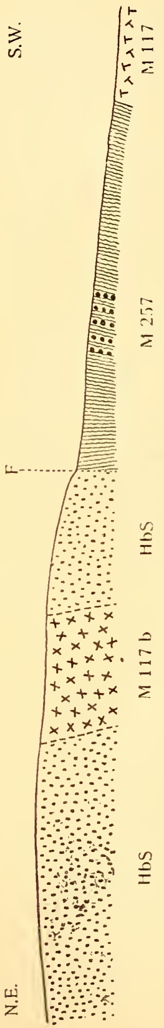


Fig. 2.—*Section of Hollybush Sandstone and Black Shales at the northern extremity of Chase-End Hill.*

[Scale: 1 inch = 16 feet.]

Hb.S = Hollybush Sandstone with M 117 *b* (olivine-basalt); M 257 = Black Shales and grits, with *Polyphyma Lapworthi*; M 117 = Hornblende-camptonite. F = Supposed fault. The dip of the sandstone is doubtfully south-westerly.

Excavations over the whole outcrop carried on for several days, with the aid of a man and boys, resulted in the discovery of perhaps a thousand fossiliferous fragments, many of which showed a number of fossils. The prevailing fossil is *Polyphyma Lapworthi*, Groom,[1] a fossil which is probably allied to '*Beyrichia*' *Angelini*, Barrande, and of which several hundreds of recognizable individuals were obtained. These were associated with a much smaller number of a small ostracod somewhat resembling *Leperditia*. Some of the layers are very rich in the remains of hexactinellid sponges, most or all of

[1] Quart. Journ. Geol. Soc. vol. lviii (1902) p. 83.

which are referable to *Protospongia fenestrata*, Salt. These are accompanied by numerous flat, and sometimes striated, carbonaceous markings, possibly of vegetable origin; a single imperfect specimen of a finely-striated species of *Agnostus* was also obtained. Brachiopoda are fairly abundant, and the following have been identified by Mr. C. A. Matley:—Many examples of *Acrotreta (?) Sabrinæ*, var. *malvernensis* nov. (figs. 11–14, p. 143); a few specimens of *Kutorgina cingulata*, var. *pusilla*, Lnrs. (figs. 19 & 20, p. 147); and a single example very doubtfully referred to *Lingulella Nicholsoni*, Call.

These shales and grits may be regarded as constituting the zone of *Polyphyma*. The fossils are most abundant towards the middle of the zone, above, below, and between the grits; and very few have been obtained in the upper layers.

The Lower Black Shales are actually exposed only in the village of White-Leaved Oak and in the fields immediately to the north-west, where they have served for many years as the chief hunting-ground for collectors. They are well exposed along the footpath leading from the village to Fowlet Farm (M 222); here they commonly dip north-eastward at a high angle. No interbedded igneous rocks are seen in the shales near the village, which are of a deep bluish-black colour. Bands in these shales have afforded almost uniformly in abundance the following:—*Sphærophthalmus alatus*, Bœck,[1] and *Ctenopyge bisulcata*, Phill.; less common are *Peltura scarabæoides*, Wahlenberg[2]; *Ctenopyge pecten*, Salt., and *Ct. flagellifer*, Ang.? Still more rare are *Lingula (?) pygmæa*, Holl, and *Obolella (?) Salteri*, Holl. In the field to the north-east, close to the junction of the Black Shales with the Hollybush Sandstone, further exposures (M 222*j*) have afforded many specimens of *Sphærophthalmus alatus* and *Ctenopyge bisulcata*; also a few of *Peltura scarabæoides*, together with *Ctenopyge flagellifera* or *Ct. pecten*. The fauna is thus similar to that seen along the footpath below; and if these beds, together with those of the old pit be included, the Lower Black Shales must be some 250 feet thick.

The Upper White-Leaved-Oak Igneous Band consists largely of olivine-basalts interbanded with dark shales, which are often bleached white, or indurated by the action of the igneous rocks. The shales of the series are best exposed in the road at White-Leaved Oak, in the lane leading southward from the village, and along the footpath to Fowlet Farm at some distance from the village. Trilobites are mentioned by Symonds as occurring in the baked shales of the last-mentioned locality[3]; and I have obtained an abundance of *Sphærophthalmus alatus*, together with *Ctenopyge* sp., from the débris of Black Shales (M 218) on the ridge constituting the north-eastern boundary of the 'Valley of White-Leaved Oak.' The fragments here include pieces of a remarkable dark-grey shelly limestone

[1] *Olenus humilis*, Phillips, is a synonym of this species.
[2] *Conocephalus malvernianus*, Phillips, is a synonym of this species.
[3] 'Old Stones' 2nd ed. (1884) p. 30.

with a conchoidal fracture. Excavations made in the plantation (numbered 125*m* on the 25-inch Ordnance Survey-map), where alone the fragments have been found, failed to reach the rock, owing to the thick covering of débris of basalt and Black Shale, and to the dense undergrowth and numerous roots. The limestone may possibly occur in the form of discontinuous nodules. The fossils obtained from it included *Obolella (?) Salteri ?*,[1] *Murchisonia (?)* sp., *Glyptarca primæva*, Hicks ?, and numerous smaller organisms. Microscopic examination revealed to Mr. Frederick Chapman a number of species of foraminifera, together with ostracoda, echinoderm-spines, and sponge-spicules (?).[2] When the parent rock has been reached the above list will probably be augmented, for the fragments of limestone obtained were crowded with fossils, large and small. The total thickness of the Upper White-Leaved-Oak Igneous Band is about 300 feet, of which the basalts probably constitute the greater part.

The Upper Black Shales are exposed at the foot of the small escarpment, formed by the igneous band that traverses the north-eastern portion of Pendock's Grove; also in the road leading south-westward from White-Leaved Oak; but the best exposure is seen in the lane leading southward from the village. I obtained here (M 270) *Sphærophthalmus alatus* (abundant), *Ctenopyge bisulcata*, and *Agnostus trisectus*. The total thickness of the Upper Black Shales may be estimated at about 150 feet.

The Lower and Upper Black Shales, and the included Upper White-Leaved-Oak Igneous Band, accordingly all belong to the zone of *Sphærophthalmus* and the associated forms. But it must be added that no fossils have been obtained from the uppermost layers of the Upper Black Shales.

Apart from the localities mentioned in the foregoing pages, the only place at which I have succeeded in finding traces of organic remains is in the small faulted patch of Black Shale in Pendock's Grove (M 223 *a*), where a doubtful specimen of *Linnarssonia Belti* occurred. But it may be noted that in the well-sinking at West Malvern the Black Shales reached afforded '*Olenus*,' '*Conocoryphe*,' and '*Lingulella*.'[3] It should be remarked also that in most places the shale appears to be nearly or quite unfossiliferous, the fossils being largely confined to certain bands. Examples of most of the species mentioned above may be seen in the Museums at Oxford, Cambridge, Malvern, and Worcester. The Malvern collection includes also a doubtful crushed orthoceratite.

Among the fossils previously recorded from the Black Shales, the following are enumerated by Holl[4] :—Fragments of a large trilobite,

[1] This species is very doubtfully referred by Mr. Matley (see Appendix, p. 140) to *Obolella (?) Salteri*, Holl; I am disposed to regard it as distinguished from the latter by its greater obesity and by the larger size attained.

[2] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 257.

[3] 'Midland Naturalist' vol. x (1887) p. 198.

[4] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 91.

a minute bivalve, *Cytheropsis* sp. nov., and *Spondylobolus (?)* sp. No descriptions of these fossils have appeared, and none of them, if represented at all in the large collections, are labelled. Their identification is therefore a matter of impossibility. A specimen of '*Spondylobolus*' is figured by Phillips[1]; this is possibly one of the species of *Acrotreta* described in the Appendix to this paper by Mr. C. A. Matley (pp. 142 *et seqq.*). Phillips also recorded and figured *Olenus pauper*, sp. nov., but gave no description of the fossil (*loc. cit.*). The specimen is still in the Museum at Oxford: it is evidently a member of the *Sphærophthalmus*-group, and is too imperfect for certain determination, but I think that in all probability it is an immature *Sphærophthalmus flagellifer*.[2]

The identification of the Llandeilo species *Agnostus Maccoyi*, Salt., by Phillips (*loc. cit.*) is in the highest degree uncertain. In all probability the species is *Agnostus trisectus*, which has been confused with *A. pisiformis*, which in its turn was at first confused with *A. Maccoyi*. Great doubt, moreover, attaches to *Olenus micrurus* and *O. serratus*, both recorded by the Rev. G. E. Mackie.[3] Murchison records also *Kutorgina cingulata* from the Black Shales.[4] In all probability this name has been accidentally interchanged with that of *Obolella Salteri*, which, though known at the time to occur in the Black Shales, does not appear in the list; while the reverse is the case with *Kutorgina cingulata*.[5] It appears, therefore, advisable to omit altogether from the list the species enumerated above, especially since the precise horizon to which they belong is uncertain, owing to the fact that the White-Leaved-Oak Shales and the Bronsil Shales have both been included under the name 'Black Shales.' The list of fossils, thus amended, obtained from the zone of *Sphærophthalmus* and its associates may for the present stand as shown on pp. 109, 110.

The total thickness of the White-Leaved-Oak Shales is probably somewhat over 800 feet, of which the olivine-basalts constitute perhaps some 300 feet. The zone of *Sphærophthalmus alatus*, with some 500 feet of shale, and with 200 feet of basalt, makes up the greater part of this thickness.

[1] 'Geology of Oxford & the Valley of the Thames' 1871, p. 68.

[2] So far as can be seen, it agrees with this form in the free cheek and cheek-spines; the glabella, with very good illumination, is seen to be divided by furrows arranged much as in this species; the pleuræ, with their short deflexed spines, also resemble those of *Sph. flagellifer*, and the last body-segment seen is provided with a dorsal spine; but the number of segments visible in this apparently complete specimen is 7, or possibly 8, the first being perhaps obscured.

[3] 'Malvern Field Handbook' 1886.

[4] 'Siluria' 4th ed. (1867) App. p. 541: *sub nom. Obolella Phillipsii.*

[5] The variety of *Kutorgina cingulata* recognized as *K. Phillipsii* must have been meant. A different variety, *K. pusilla*, has recently been obtained by me from the Lowest Black Shales (see p. 101).

(*b*) Lithology.

Except where bleached or indurated by igneous action, the beds of the zone of *Sphærophthalmus alatus* are almost always soft, very fine-grained, minutely micaceous, fissile, black or coal-black, or very dark-grey shales, so closely jointed as to break at the slightest tap into small tabular pieces. It is, in fact, almost impossible to obtain a durable specimen of even moderate size.

The grits of the zone of *Polyphyma* vary from medium to coarse grain; they are practically in the condition of quartzite, often with concealed joints. The fragments consist chiefly of quartz, metamorphic quartzite, and decomposed felsites. Glauconitic casts of foraminifera are present in fair quantity. The finer-grained varieties closely resemble the dark quartzites of the Hollybush Sandstone.

In the village of White-Leaved Oak an almost identically similar rock was used, evidently many years ago, for road-metal. It differs from the grits described above in the prevailingly somewhat finer grain, and could hardly have been obtained from the locality in which these are found, inasmuch as they can be reached only by excavation in an old pathway and are not present in sufficient quantity to furnish road-metal. But I failed, after assiduous search and inquiry, to trace the road-metal to its source. At first, it seemed possible that the rock belonged to the Hollybush Sandstone Series, in which there is much dark-grey and black sandstone; but no sample of the sandstone precisely resembling this black grit could be found, and I finally obtained from the road-metal pieces of grit with Black Shale still clinging to the bedding-surface—a clear proof that the grit belongs to the White-Leaved-Oak Shales. In all likelihood the road-metal came from the shales of the village-road itself, and I think it possible that it is *in situ*. We have, then, some evidence either that a patch belonging to the zone of *Polyphyma* has been faulted-up into the overlying shales near White-Leaved Oak, or that grits similar to those of that zone occur also in the zone of *Peltura*.

(*c*) Relation to Underlying and Overlying Formations.

The striking contrast between the Hollybush Sandstone and the White-Leaved-Oak Shales seen everywhere, even along the line of contact, and the circumstance that along the greater part of this junction the Hollybush Sandstone is of the dark type supposed to characterize a low horizon in the formation (see p. 96), suggests that beds are missing along the line of contact, owing either to unconformity or to faulting. The recent discovery at the northern extremity of Chase-End Hill of the grits of the *Polyphyma*-zone (see p. 100) appeared to suggest that the beds containing them might be near the base of the Black Shale Series; but the possible occurrence of similar grits in the overlying shales (see p. 104) takes away some of the force of this argument. The relations at Chase-End Hill between the two formations at the actual junction (fig. 2, p. 100) are compatible with the existence, either of an unconformity or of a fault. The circumstance that the grits contain no fragments of Hollybush Sandstone or of Malvern Quartzite favours the view that the base of the White-Leaved-Oak Shales is faulted out; and this view seems to be further strengthened by the similarity of the fine grits to the black varieties of the Hollybush Sandstone.

The junction of the Black Shales with the overlying Grey Bronsil Shales and their sills of basalt is well defined, and probably rather abrupt, but is nowhere actually exposed.[1] The occurrence of a band of rather dark-grey shale in the Coal-Hill belt tends to diminish the contrast between the two series, and there seems no reason to believe that the upper series follows the lower otherwise than conformably.

(*d*) Summary.

To summarize the results set forth in the foregoing pages, the White-Leaved-Oak Shales may be divided into

(*a*) A lower series of Black Shales with dark glauconitic grits, not less than 30 feet thick—the zone of *Polyphyma*—characterized by the abundance of *Polyphyma Lapworthi*, together with *Protospongia fenestrata*, and the brachiopods *Acrotreta (?) Sabrinæ* var. *malvernensis*, *Kutorgina cingulata* var. *pusilla*, and by a dearth of trilobites.

(*b*) An upper series of Black Shales, including a foraminiferal limestone (? in the form of nodules) at one horizon, and possibly dark grits at another. This series—the zone of *Sphærophthalmus alatus*, etc.—is characterized by the presence of *Sph. alatus*, *Ctenopyge bisulcata*, *Ct. pecten*, *Peltura scarabæoides*, *Agnostus trisectus*, *Obolella (?) Salteri*, and *Lingula (?) pygmæa* in the Black Shales, and by *Obolella (?) Salteri* and *Spirillina Groomiana* and other foraminifera, etc., in the limestone.

V. The Bronsil Shales.

The Grey Shales, to which I would propose to apply the name Bronsil Shales, occupy a relatively considerable area west of the Southern Malverns, and are by no means limited to the small triangular area spoken of by Holl.[2] They are usually of a light-blue, light-green, or yellowish tint: rather dark shales occur in some places, and are difficult to distinguish from similarly coloured

[1] Compare map in Quart. Journ. Geol. Soc. vol. lv (1899) pl. xiii.
[2] *Ibid.* vol. xxi (1865) p. 92.

varieties of the White-Leaved-Oak Shales; but, on the whole, the distinction in colour between the two series is very marked.

The Bronsil Shales have already been divided into[1]:—

(4) Upper Grey Shales;
(3) Coal-Hill Igneous Band;
(2) Lower Grey Shales; and
(1) Middle Igneous Band.

The shales of the lowest band are nowhere actually exposed, the intercalated basalts alone being visible; but plenty of shale-débris is associated with the latter along the north-eastern border of Pendock's Grove, and more is seen on the ridge lying north-east of Coal Hill. Fossils appear to be rare, and are obtainable only with great difficulty in the small pieces of shale available. The only kind found was a small imperfect *Lingulella*, from the north-eastern corner of Pendock's Grove (M 231). The total thickness of the series is about 300 feet.

The overlying Lower Grey Shales, some 250 feet thick, are also very imperfectly exposed. They may be seen at the corner of a cottage-garden towards the foot of Chase-End Hill, but no fossils were detected here. In the débris (M 252) south of the garden two imperfect lingulelliform brachiopods were obtained, and at another spot to the north-east a species of *Lingulella* was found. In both places many examples of *Tomaculum problematicum*, gen. et sp. nov. (figs. 32–35, p. 126) were collected.

The sedimentary beds of the Coal-Hill Band consist chiefly of Grey Shales, frequently baked yellowish-white, or much indurated. A good exposure of these may be seen in the garden of Coal-Hill Cottage (M 182), at the north-western end of Coal Hill.[2] Other exposures are seen along the path immediately above the cottage, and along the same path at the south-eastern end of Coal Hill. Sections of some of the upper beds are also to be seen in a cottage-garden by the roadside south of Coal Hill, and at a point on the road a little farther south (M 261). In all these exposures the shales are interbanded with thin sills of diabase. Fossils are rare; but in the dark-grey shales at the spot last mentioned, and in the débris from the upper light-coloured beds of the band along the path skirting the south-western border of Coal Hill, *Dictyonema sociale*, Salt., was obtained. The spot last-mentioned also yielded to the Rev. G. E. Mackie a specimen of *Linnarssonia Belti* (Dav.) and numerous examples of *Tomaculum problematicum*. In the shales which accompany one of the Bronsil igneous bosses (M 248), and probably immediately underlie the basalt, numerous specimens of *Dictyonema sociale*,[3]

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 159.
[2] *Ibid.* pp. 158 etc.
[3] These and other specimens have been kindly examined for me by Miss E. M. R. Wood, who has provisionally identified them with Salter's species.

Salt., have been obtained. The thickness of the Coal-Hill Band in the southern part of the district is about 250 feet, the shales alone being perhaps 100 feet thick.

The Upper Grey Shales are well exposed in two spots: namely, in the bed of the stream, south of Bronsil (M 159), and at the south-eastern corner of Chase-End Hill (M 275). In the first-mentioned locality the only fossil obtained was the rib of a trilobite; the Chase-End exposure yielded a specimen containing an Asaphid trilobite (pygidium and part of thorax) agreeing, so far as can be seen, with *Platypeltis Croftii*, Call., together with what seems to be a portion of the head of *Parabolinella (?) triarthrus*, Call.; but *Dictyonema sociale,* Salt., is the most abundant fossil. This small section has long been known as a locality for *Dictyonema*, which was first discovered here by Symonds. The thickness of the Upper Grey Shales in the southern part of the district may be estimated at about 500 feet.

Shales probably belonging to this horizon were revealed in excavations made by me, on either side of the path half way between Fowlet Farm and Martins; and others are sometimes imperfectly exposed in the ditch along the main road, close to Bronsil Lodge. Loose fragments obtained close to Martins (M 156) yielded in abundance *Lingulella Nicholsoni*, Call., and *Acrotreta Sabrinæ*, Call.; and grey shales (M 155) from the roadside due north of Fowlet Farm yielded a fine specimen of *Obolella (?) Salteri.*

Besides the fossils recorded above from the Bronsil Shales, additional species have been obtained by the prolonged researches of Grindrod and others, and are to be seen in the Museums at Oxford, Jermyn Street (London), Malvern, and Worcester. In the Grindrod Collection at Oxford a number of specimens are preserved, which (as I am informed by the present Dr. Grindrod) were obtained from the well-known small exposure of *Dictyonema*-shales at Chase-End Hill (M 275),[1] to which allusion has just been made. These include some fragments of Asaphids, probably referable to *Platypeltis Croftii*, Call.[2] (fig. 29, p. 122), *Niobe Homfrayi*, Salt. (fig. 31, p. 125), and *Asaphellus affinis*, McCoy (or *A. Homfrayi*, Salter), *Acanthopleurella Grindrodi*, Groom[3]; an Olenid, probably referable to *Olenus (Parabolinella ?) triarthrus*, Call.; *Lingula (?)* sp. (fig. 9, p. 142); and *Acrotreta* sp. cf. *A. Nicholsoni* (fig. 10, p. 142). A specimen of dark shale labelled 'Malvern,' and probably collected from the Bronsil Shales, contains *Niobe (?)* sp., near '*Ogygia*' *peltata* (fig. 30, p. 123). In dark-grey, minutely micaceous pieces of shale

[1] See map in Quart. Journ. Geol. Soc. vol. lv (1899) pl. xiii.
[2] *Ibid.* vol. xxxiii (1877) p. 660.
[3] Geol. Mag. 1902, p. 70.

labelled 'Upper Black Shale'[1] Mr. Matley recognizes the following:—*Acrotreta* sp., cf. *A. socialis* (figs. 15 & 16, p. 144); *Lingulella* sp., cf. *L. petalon* (figs. 7 & 8, p. 141), and *Linnarssonia Belti (?)*. In precisely similar pieces of shale in the Worcester Museum, labelled 'Black Shale,' Mr. Matley finds *Acrotreta* sp., cf. *A. socialis*, and *Lingulella (?)* sp. The same collection contains an imperfect Olenid and *Hyolithus assulatus*, sp. nov. (fig. 26, p. 119), which probably came from a dark band in the Bronsil Shales. In the Museum of Practical Geology, Jermyn Street, specimens labelled '*Dictyonema*-shale' include *Obolella (?) Salteri*, *Lingulella* sp., cf. *L. petalon*, and *Linnarssonia Belti* (figs. 17 & 18, p. 145). In the collection belonging to the Malvern Field Naturalists' Club at Malvern College are fragments of Grey Shale containing the following:—*Cheirurus Frederici* (figs. 27 & 28, p. 120); an *Agnostus* indistinguishable from *A. dux*, Call.; an Asaphid (*Platypeltis Croftii?*); and an imperfect Olenid. Dr. Callaway is stated[2] to have recognized *Macrocystella Mariæ*, Call., in a piece of grey shale in the collection of the late Dr. Piper; but no specimens referable to this form appeared to exist when I examined the collection shortly before Dr. Piper's death, and Dr. Callaway informs me that he has no recollection of ever seeing the specimen in question.

The fauna of the Bronsil Shales may, for the present, stand as shown in the table on p. 110.

With regard to their lithology, the shales are of a light bluish-, greenish-, or yellowish-grey colour, micaceous, and very fissile, but apparently of somewhat coarser grain than the Black Shales, and at the same time firmer and less closely jointed. Some dark-grey shales occur in the Coal-Hill igneous band.

The total thickness of the Bronsil Shales and diabases may be put down at about 1300 feet (it is possibly even greater at the extreme southern end of the district); and if, out of the 550 feet representing the combined thickness of the two igneous bands, 250 feet be attributed to the shales, the total thickness of the Bronsil Shales alone will amount to 1000 feet, and that of the diabases and basalts to 300 feet. It is, however, necessary to note that higher beds of the original series have almost certainly been removed by the denudation which preceded the deposition of the May-Hill Sandstone; so that the Tremadoc Series may have been originally more than 1000 feet thick. It is possible, indeed, that some of these upper beds still remain uncovered by the May-Hill Sandstone at the southern end of this district, though not exposed, and that the Upper Grey Shales may be more than 500 feet thick.

[1] The term 'Upper Black Shale' refers to the Bronsil Shales (Grey Shales). I have not succeeded in finding a rock that quite agrees in character with these pieces, either in the Black or Grey Shales; but, apart from their rather dark colour, the fragments resemble the Grey rather than the Black Shales.

[2] Geol. Assoc. Rec. of Excurs. 1860–1890 (1891) p. 412.

VI. Table of Fossils found in the Malvern Quartzite, Hollybush Sandstone, White-Leaved-Oak Shales, and Bronsil Shales.

	Malvern Quartzite.	Shaly Hollybush Sandstone.	Massive Hollybush Sandstone	White-Leaved-Oak Shales. Zone of *Polyphyma*.	White-Leaved-Oak Shales. Zone of *Sphærophthalmus*.	Bronsil Shales.
Malvern Quartzite.						
Kutorgina Phillipsii (Holl)	*	*	*			
Obolella (?) Groomii, sp. nov.	*					
Hyolithus primævus, sp. nov.	*	?	*			
Orthotheca fistula (Holl)	*	...	*			
Foraminifera (glauconitic casts)	*	*	*	*		
Hollybush Sandstone.						
Kutorgina Phillipsii (Holl)	*	*	*			
Linnarssonia sagittalis, Salter?	...	*				
Orthotheca fistula (Holl)	*	...	*			
Hyolithus primævus, sp. nov.	*	?	*			
H. malvernensis, sp. nov.	...	...	*			
Hyolithus, 2 or more spp.	...	...	*			
Coleoloides (?) sp.	...	...	*			
Scolecoderma antiquissima (Salter)	...	*	*			
Modiolopsis (?) sp.	...	...	*			
Foraminifera (glauconitic casts)	...	*	*	*		
Zone of *Polyphyma*.						
Polyphyma Lapworthi, gen. et sp. nov.	...	...	...	*		
Small ostracod	...	...	...	*		
Protospongia fenestrata, Salter	...	...	...	*		
Agnostus sp.	...	...	...	*		
Acrotreta (?) Sabrinæ, var. *malvernensis*, nov.	...	...	...	*		
Kutorgina cingulata, var. *pusilla*, Linrs.	...	...	...	*		
Lingulella Nicholsoni, Callaway?	...	...	...	*		
Plant-remains (?)	...	...	...	*		
Zone of *Sphærophthalmus alatus*, etc.						
Sphærophthalmus alatus, Bœck	...	...	...	...	*	
Ctenopyge bisulcata, Phill.	...	...	...	...	*	
Ct. pecten, Salt.	...	...	...	...	*	
Peltura scarabæoides, Wahl.	...	...	...	...	*	
Agnostus trisectus, Salt.	...	...	...	...	*	
Obolella (?) Salteri, Holl	...	*	...	...	*	*
Lingulella pygmea, Holl	...	...	...	...	*	
Lingulella sp.	...	...	...	...	*	
Linnarssonia Belti (Dav. ?)	...	...	...	...	?	
Hyolithus assulatus, sp. nov.	...	...	...	...	?	
Orthoceras (?) sp.	...	...	...	...	?	

	Malvern Quartzite.	Shaly Hollybush Sandstone.	Massive Hollybush Sandstone.	White-Leaved-Oak Shales.		Bronsil Shales.
				Zone of *Polyphyma.*	Zone of *Sphærophthalmus.*	
LIMESTONE-NODULES FROM THE ZONE OF *SPHÆROPHTHALMUS ALATUS.*						
Obolella (?) Salteri, Holl	...	?	...	...	*	*
Murchisonia (?) sp.	...	...	...	...	*	
Glyptarca primæva, Hicks?	...	...	...	...	*	
Ostracoda	...	...	...	...	*	
Echinoderm-spines	..	...	...	...	*	
Sponge-spicules	...	...	..	...	*	
Spirillina Groomiana, Chapman	...	...	. .	...	*	
Cristellaria sp., cf. *Cr. acutiauricularis*, Fichtel & Moll	...	...	...	...	*	
Marginulina sp., cf. *M. soluta*, Reuss	...	...	...	...	*	
Dentalina sp., cf. *D. abnormis*, Reuss	...	...	...	...	*	
Glandulina (?) sp., cf. *Gl. pygmæa*, Terq.	...	...	...	...	*	
Lagena lævis, Montagu	...	...	...	...	*	
L. apiculata, Reuss	...	...	...	...	*	
L. ovum, Ehrenberg	...	. .	...	...	*	
BRONSIL SHALES.						
Dictyonema sociale, Salter	...	...	...	...	...	*
Tomaculum problematicum, gen. et sp. nov.	. .	...	...	...	...	*
Lingulella Nicholsoni, Callaway	...	...	...	?	...	*
Acrotreta (?) Sabrinæ, Callaway	...	...	...	...	...	*
Acrotreta sp., cf. *A. socialis*, von Seebach.	...	...	...	...	...	*
Acrotreta sp., cf. *A. Nicholsoni*, Dav.	...	...	...	...	...	*
Linnarssonia Belti, Dav.	...	...	...	...	?	*
Obolella (?) Salteri, Holl	...	?	...	...	*	*
Lingulella (?) sp.	...	...	...	...	...	*
Lingula (?) sp.	...	...	...	...	...	*
Hyolithus assulatus, sp. nov.[1]	...	...	...	...	...	*
Agnostus dux, Callaway	...	...	...	...	...	*
Cheirurus Frederici, Salter	...	...	...	...	...	*
Platypeltis Croftii, Call.?	...	...	...	...	...	*
Asaphellus affinis, McCoy?	...	...	...	...	...	*
Parabolinella (?) triarthrus, Call.?	...	...	...	...	...	*
Acanthopleurella Grindrodi, Groom	...	...	...	...	...	*
Niobe (?) sp., near *O. peltata*, Salt.[1]	...	...	...	...	...	*
Niobe Homfrayi, Salt.?	...	...	...	...	...	*

[1] It is possible, but hardly probable, that this form belongs to the zone of *Sphærophthalmus.*

VII. Description of the Hyolithidæ, Trilobita, etc.

(a) Hyolithidæ.

Theca (or *Hyolithus*) was recorded by Murchison from the Hollybush Sandstone and Malvern Quartzite many years ago,[1] and again from the Hollybush Sandstone by Prof. Lapworth.[2] But with the single exception of *Serpulites fistula*, Holl, hitherto not recognized as one of the Hyolithidæ, no specimens of *Hyolithus* from these beds appear to exist in the collections known to me. In the field specimens are very difficult to obtain, those collected being nearly all from débris in two localities where the rock is not exposed. They are, moreover, commonly in the condition of fragmentary casts. Had it been likely that further material would be forthcoming, it would have been preferable to await the discovery of better specimens than those obtained; but since, owing to the practical exhaustion of the proper débris, this is not likely to occur for a long time to come, it has been thought advisable to describe the material already collected.

Hyolithus (Orthotheca) fistula (Holl). (Figs. 1–9, pp. 112–13.)

The original specimens from which *Serpulites fistula* was described appear to have been lost, but examples presented by Holl may be seen in the Worcester Museum. The species is thus described by Holl[3] :—

'Cylindrical, straight, tapering very gradually to a point; shell thin, smooth. Length 1 inch to 1½ inch; diameter about 1 line.'

The fossil has all the appearance of being a *Hyolithus*. A large number of specimens collected in the field enable me to give more precision to the foregoing definition. Transverse sections vary from nearly circular to very broadly oval; occasionally, a slightly greater flattening on one side appears to indicate the dorsal surface. The largest specimens seen measure 2·5 mm. in diameter, and the smallest about 0·25 mm. Taking the smaller diameter as unity, the larger diameter varies from 1·05 to 1·28, the average of twelve examples giving 1·137 mm. The angle of divergence of the sides commonly varies from 3° to 5°, but occasionally sinks below 1°. Fragments with a diameter of less than 0·5 mm., and possibly not belonging to *Hyolithus fistula*, show scarcely any taper[4]: thus a fragment 16 mm. in length (the longest seen) varies little from 0·25 mm. in diameter. The shell is thin. The internal cast appears to be quite smooth, but the exterior of the shell is marked by closely-set, fine, transverse striæ of growth.

The operculum is probably represented by four incomplete

[1] 'Siluria' 4th ed. (1867) App. p. 541.
[2] Proc. Geol. Assoc. vol. xv (1898) p. 338.
[3] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 102.
[4] It is possible that some of these very slender fragments belong, either to *Coleoloides* or to *Hyolithellus*.

Figs. 1–6.—Hyolithus (Orthotheca) fistula (*Holl*). *From the grey Hollybush Sandstone of Raggedstone Hill.*

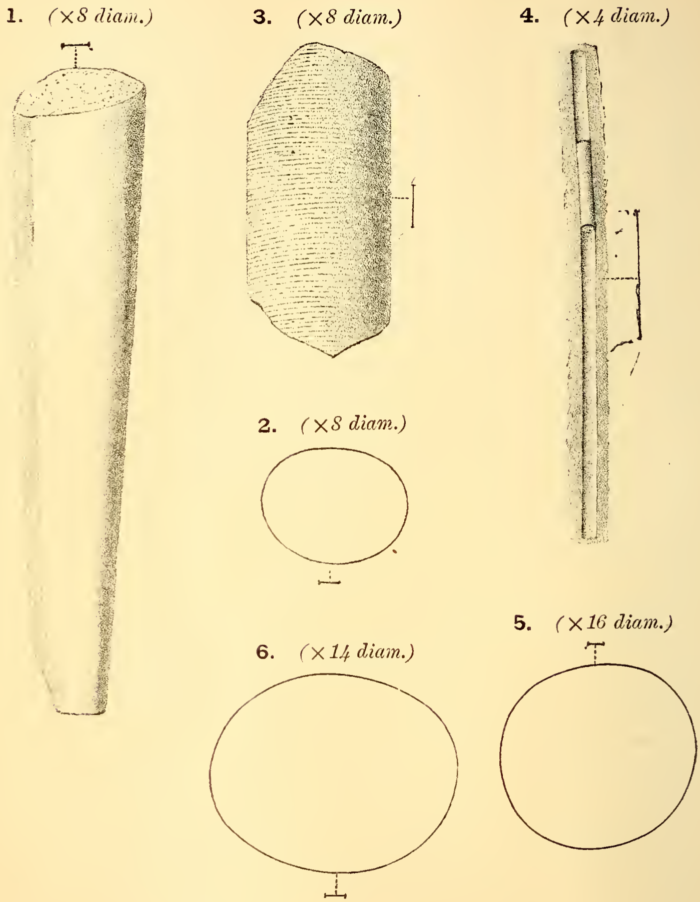


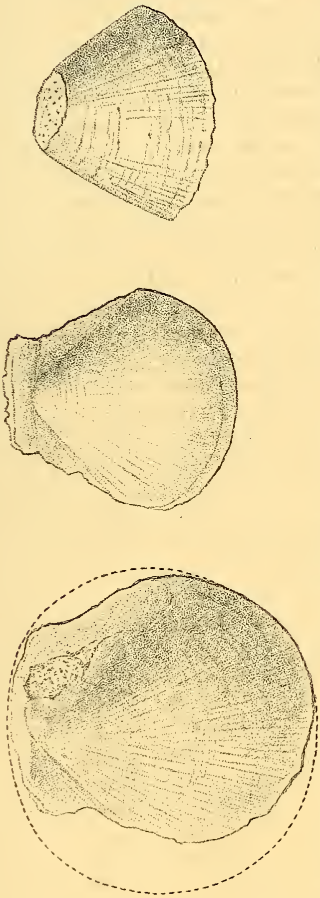
Fig. 1.—Fragment of tube measuring 2 mm. in diameter; fig. 2, transverse section of the same.

3.—Fragment of a gently tapering tube, showing transverse striæ.

4.—Fragment of a slender tube, the greater part of which is represented by an external cast. Doubtfully referred to *Hyolithus fistula*, possibly belonging to *Hyolithellus* or to *Coleoloides*.

Figs. 5 & 6.—Transverse sections of two tubes of *H. fistula*, to show the variation in shape.

specimens, the most perfect of which (fig. 7) is an internal cast showing a large well-defined oblique cone, marked by very fine radial striæ, and apparently also by indistinct traces of concentric lines of growth. The cone is situated on an apparently subcircular platform, from which the somewhat overhanging apex rises sharply. The apex of the cone does not extend to the edge of the platform. The transverse and dorso-ventral diameters of the operculum probably measured about 1·72 and 1·65 mm. respectively, the relative proportions being 1·40 : 1. The measurements thus agree with those made on the tube itself. The rather thick shell itself is seen in the counterpart of the specimen.



9. 8. 7.

Figs. 7–9.—*Opercula of* Hyolithus fistula. (×24 *diam.*)

The internal cast of a second specimen (fig. 8) is essentially similar in shape, but the cone is less sharply marked off from the platform. In a third specimen (fig. 9) the conical part of the shell itself is preserved, and shows closely-set, fine, radial lines, and less regular concentric lines of growth.

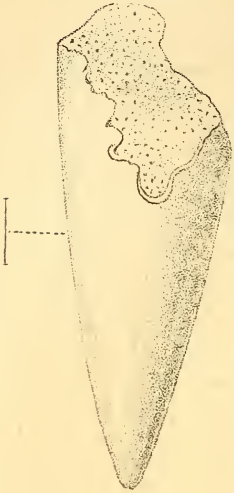
Occurrence: Common in the Grey Hollybush Sandstone of Raggedstone Hill (M 439, 443), associated with *Hyolithus malvernensis*, *H. primævus*, *Kutorgina Phillipsii*, etc. Two specimens were also obtained from the débris of the Malvern Quartzite (M 244 *c*). The species has been, moreover, recorded by Dr. Callaway from the Hollybush Sandstone of Shropshire,[1] and by Prof. Lapworth from the Lower Stockingford Shales.[2]

Hyolithus fistula appears to belong to Holm's subdivision 'Teretes' (Lower and Middle Cambrian) of the subgenus *Orthotheca*. It seems to be intermediate, to a certain extent, between *Orthotheca corneolus*, Holm, on the one hand, and the remaining 'Teretes' (*O. Hermilini*, Holm, *O. teretiusculus*, Linnarsson, and *O. stylus*, Holm) on the other. From the forms last mentioned it is dis-

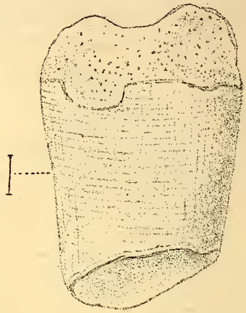
[1] Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 759.
[2] Geol. Mag. 1886, p. 548.

Figs. 10–15.—Hyolithus malvernensis, *sp. nov.*

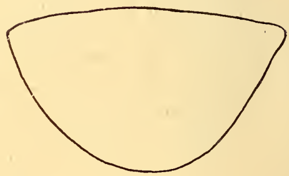
10. (×*8 diam.*)



12. (×*7 diam.*)

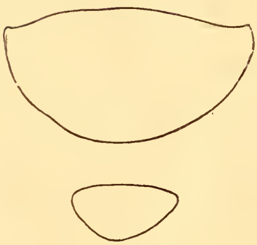


13.



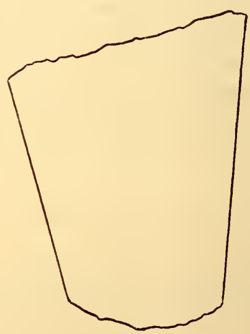
11.

a



b

14. (×*12 diam.*)



15.

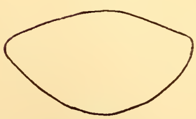


Fig. 10.—Ventral view; fig. 11, *a* & *b*, sections of the same specimen, taken towards the mouth and apex respectively.

12.—Ventral view of another specimen; fig. 13, transverse section of the same.

14.—Dorsal view of a specimen, measuring 2·5 millimetres at its broadest part; fig. 15, transverse section (towards the smaller end) of the same.

tinguished by its smaller diameter; and from *O. corneolus* by its greater length. The angle of divergence is smaller than in any of these forms, but not so small as in the American *Hyolithellus*.

Hyolithus malvernensis, sp. nov. (Figs. 10–15, p. 114.)

Type-specimen (fig. 10).—Shell straight; length seen, 8 mm.; breadth indicated, 3 mm.; angle of divergence of the sides near the apex = about 43°, decreasing to about 17° towards the mouth, average angle = about 22°. Ventral side uniformly convex, semicircular in section; dorsal side gently convex, but becoming slightly flattened at the sides; towards the apex uniformly convex; lateral angles well-marked. Surface apparently showing faint traces of longitudinal and transverse lines on the dorsal side. Taking the dorso-ventral diameter as unity, the remaining diameter is 1·69, or near the apex 1·9 mm. Mouth not preserved. Operculum unknown.

In a second fragment (fig. 14), measuring 2·5 mm. across at the broader end, the angle of divergence is also about 22°; and in a third about 15½°. In a fourth specimen (fig. 12) the width towards the mouth (3·75 mm.) is greater, the angle of divergence (about 14°) is somewhat less, the convexity of the ventral side is more pronounced, and the transverse and longitudinal lines are distinct, both on the dorsal and ventral sides. [A fragment of a fifth specimen (M 470), previously overlooked, is 5 mm. in length; the dorsal side alone is exposed. It measures 5 mm. in breadth towards the mouth, and the angle of divergence is 13°. A portion of the external cast of this specimen clearly shows a series of closely-set, strongly-curving lines of growth, which indicate that the oral margin formed a prominent arch. A less distinct system of closely-set longitudinal lines is visible over the whole breadth of the shell.—*January 11th, 1902.*]

The transverse sections vary somewhat in the different specimens, and in different parts of the same specimen. Taking the shorter diameter as unity, the longer measures 1·08 mm. and 1·68 respectively (in the second and fourth specimens to which reference has been made).

The species is characterized among the Cambrian forms of *Hyolithus* by its large angle of divergence, but more particularly by its shape as seen in transverse section. It belongs evidently to Holm's section 'Dorsi-lineati' (*H. Nathorsti*, Holm) of the subgenus *Hyolithus*, but differs from *H. Nathorsti* of the Lower Cambrian in the flattening of the lateral margins, and obviously also in the greater development of the longitudinal lines in the middle of the dorsal side. The curvature of the lines of growth on the dorsal side is about as great as in *H. Nathorsti*.[1]

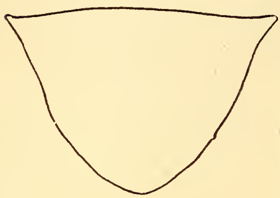
All the specimens were obtained from the Grey Hollybush Sandstone of Raggedstone Hill (M 439, 443, & 470).

[1] Holm, Sveriges Geol. Undersökn. ser. C, no. 112 (1893).

Hyolithus, sp. *a*. (Fig. 16.)

A large imperfect specimen (now lost) has the ventral side raised into a blunt keel, which becomes less marked towards the mouth. The transverse section somewhat resembles that of *H. malvernensis*, but the depth is greater, the proportions of the vertical and horizontal diameters being 1 to 1·4. Indications of longitudinal and transverse striation are seen, as in that species, but the angle of divergence (6°?) appears to be much less. Length seen, 16 mm.; breadth towards the mouth, 4·7 mm.

Fig. 16.—Hyolithus *sp.* a. *Transverse section at the smaller end.*



Occurrence: In the grey Hollybush Sandstone of Raggedstone Hill (M 439).

Hyolithus, sp. *b*.

A large imperfect example. Length preserved, 9 mm.; breadth towards the mouth, not less than 5 mm. Dorsal side (alone exposed) showing, in addition to indistinct traces of longitudinal striation, five or six shallow longitudinal grooves, with intervening gentle ridges, impressed upon the internal cast. Angle of divergence, apparently 13° or 14°.

Occurrence: In the grey Hollybush Sandstone of Raggedstone Hill (M 443).

Hyolithus primævus, sp. nov. (Figs. 17–24, p. 117.)

Type-specimen (figs. 17 & 18).—Ventral side semicircular in section; dorsal side flat; lateral angles well-rounded. Breadth towards the mouth, 3 mm.; length preserved, $6\frac{1}{2}$ mm.: proportion of vertical to horizontal diameter of the cross-section, 1 : 1·4; angle of divergence, about 10° or 11°; surface apparently nearly smooth.

In a second specimen (fig. 20) the angle of divergence is 11°; the ventral side is raised into a median blunt keel; proportion of width to depth, 1 : 1·4.

In a third specimen (fig. 19), measuring about 3·25 mm. in breadth towards the mouth, the ventral side is more convex than in the two foregoing specimens, the proportion of depth to width being 1 : 1·4; and the dorsal side shows a very shallow median depression.

The ventral, and perhaps also the dorsal, side of the shell in this specimen exhibits faint indications of longitudinal and transverse striation, seen also in several other imperfect specimens apparently belonging to the species under consideration.

The foregoing specimens were all obtained from the grey Hollybush Sandstone (M 439, 443). Others, agreeing in form, were found in the Malvern Quartzite (M 244 *c*). In one (figs. 21–23), an internal

Figs. 17–24.—Hyolithus primævus, *sp. nov.*

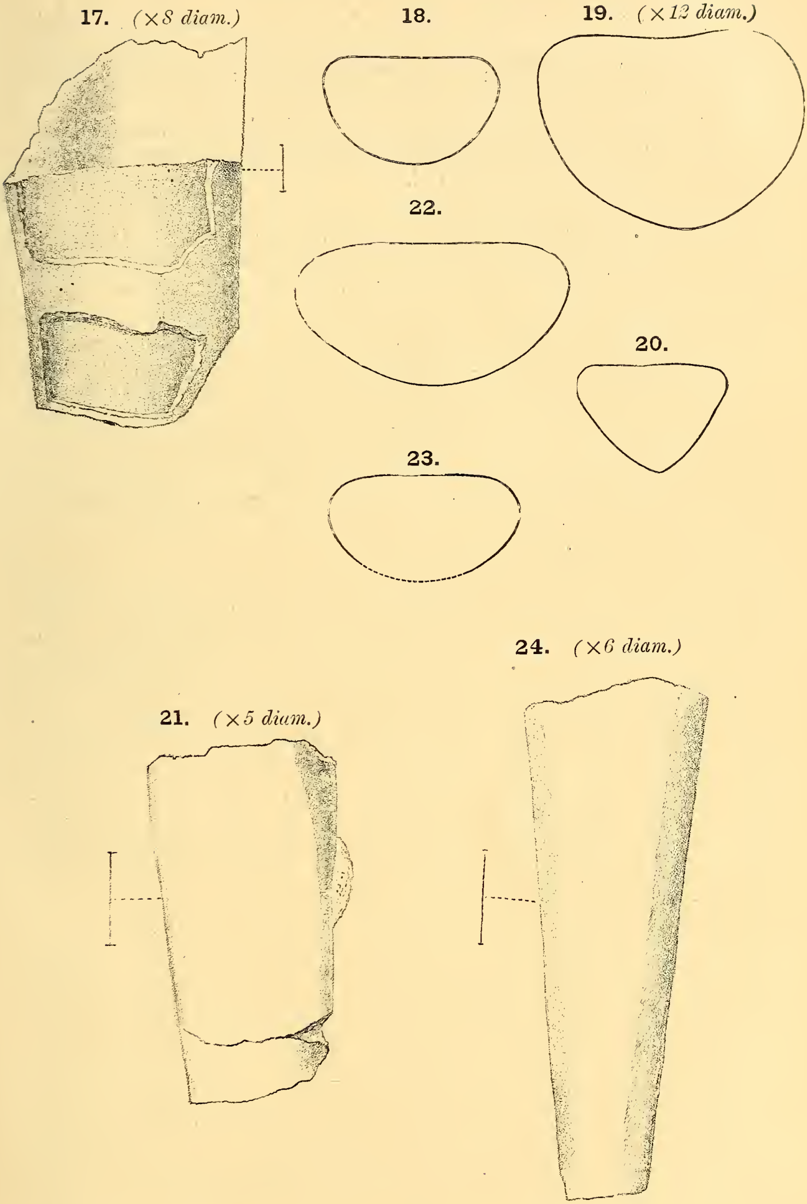


Fig. 17.—Dorsal view of a specimen, part of the shell of which is preserved. From the Hollybush Sandstone (M 443).

18.—Transverse section of the same.

Figs. 19 & 20.—Cross-sections of two other individuals from the same locality.

Fig. 21.—Dorsal view of an internal cast. From the Malvern Quartzite (M 244 *c*); figs. 22 & 23, transverse sections of the same, taken at the broad and narrow ends respectively.

24.—A second internal cast from the same locality.

cast, having a length of 12 mm., and a breadth of 6·5 mm. towards the mouth and of 4 mm. towards the apex, the relative proportion of depth to breadth is 1 : 2 at the larger, and 1 : 1·8 at the smaller end, and the angle of divergence is 11°.

In a second internal cast, 12·5 mm. in length (fig. 24), the breadths towards the mouth and apex respectively are 4 and 2 mm., and the angle of divergence 12°.

A third internal cast, with the same angle of taper, gives a length of 5·5 mm., and a breadth of 3 mm. towards the mouth.

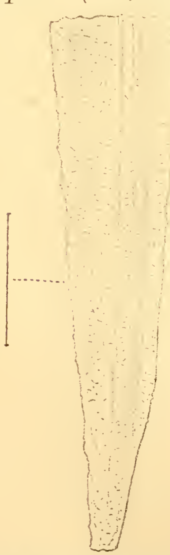
Any markings originally present are not preserved on external casts of specimens from the Malvern Quartzite, several of which were obtained. The maximum length of this species was evidently not less than 3 cm., or $1\frac{1}{5}$ inches.

The species probably belongs, either to Holm's section 'Dorsilineati' of the subgenus *Hyolithus*, or to the 'Complanati' in the subgenus *Orthotheca*, among which it seems to present considerable resemblance to *O. communis*, Billings, of the Lower Cambrian. The very flat dorsal side, the well-rounded angles, the uniform taper of 11° or 12°, and the size, together seem to define the species.

Hyolithus (?) sp. *c*.

A fragment of a large species, apparently of *Hyolithus*. Length preserved, 11 mm.; breadth towards the mouth, not less than 6 mm. Section elongated, lenticular (crushed); lateral angles rounded. Surface exposed (apparently dorsal) gently arched, showing transverse striations of growth, which follow the slightly curved oral margin, part of which is preserved. Obtained from the grey Hollybush Sandstone of Raggedstone Hill (M 443).

Fig. 25.—Hyolithus *(?) sp*. d. *(× 4 diam.)*



[From the greenish-grey Hollybush Sandstone of Raggedstone Hill (M 443).]

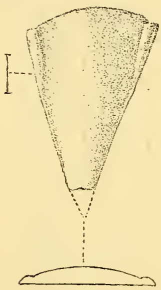
Hyolithus (?) sp. *d*. (Fig. 25.)

Represented by a single internal cast. Length seen, 17 mm.; breadth towards the mouth, not less than 4 mm. The surface exposed (dorsal ?) is marked by a broad longitudinal ridge, which is apparently median, and is marked by one prominent raised line, and by traces of others. One lateral margin, apparently complete, is convex, and shows a rounded angle.

Hyolithus assulatus,[1] sp. nov. (Fig. 26.)

An apparently nearly complete individual, the dorsal side of which alone is exposed. Shell straight: length indicated, 4·5 mm.; breadth at the oral end, 3·25 mm.; angle of divergence, about 40°. Ventral surface slightly arched, apparently quite smooth. Oral margin gently curved. Sides, for about two-fifths of their length, furnished with a strong conical bar. Occurrence, probably in the dark shales of the *Dictyonema*-beds, but possibly from the Black Shales (zone of *Sphærophthalmus*). The only specimen is in the Worcester Museum.

Fig. 26.—Hyolithus assulatus, *sp. nov.* (× 6 *diam.*)



[From the Upper Cambrian Shales of Malvern.]

The small size, the rapid attenuation, and the lateral bars, conjointly distinguish this species from any hitherto described. It appears to approach most nearly to *H. tardus*, Barr., from the Lower Devonian of Bohemia,[2] but differs in the smaller size and larger angle of divergence. It also resembles *H. expansus*, Holm, from the Silurian of Sweden,[3] but is much smaller and more obtuse.

(*b*) Trilobites etc. from the Black and Grey Shales.

(*a*) Black Shales.

No new trilobites have been certainly detected in the Black Shales, but in connection with the species *Agnostus trisectus*, Salt., *A. princeps*, Salt., has been subjected to a revision by Mr. Philip Lake, M.A., F.G.S., and myself.

Agnostus trisectus, Salter.

1864. *A. trisectus*, Salter, Mem. Geol. Surv. dec. xi, p. 10 & pl. i, fig. 11.
1864. *A. princeps* (pars), Salter, *ibid.* p. 1, pl. i, figs. 1–5.
18—. *A. Turneri*, Salter MS. Cat. Cambr. & Sil. Foss. Mus. Pract. Geol. p. 12.
1880. *A. trisectus*, Tullberg, '*Agnostus*-Arterna,' Sver. Geol. Undersökn. ser. C, no. 42, p. 24 & pl. i, fig. 13.

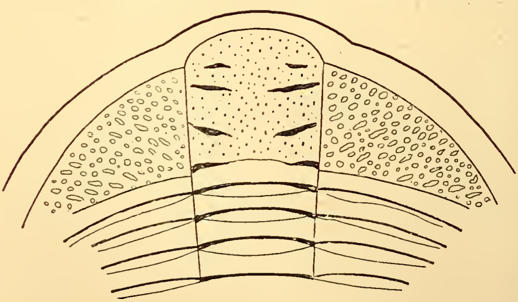
After having examined all the specimens of *Agnostus* from the Malvern Black Shales in the Woodwardian Museum, Cambridge, the Museum of Practical Geology, Jermyn Street, and the University Museum, Oxford, we have come to the conclusion that all, or at least all that are identifiable, must be referred to the species described

[1] Lat. *assula* = splint.
[2] Novák, Abhandl. d. k. Böhm. Gesellsch. d. Wissenschaften, ser. 7, vol. iv (1891) p. 27.
[3] Sveriges Geol. Undersökn. ser. C, no. 112 (1893) p. 76.

Fig. 27.—Cheirurus Frederici, *Salter*. ($\times 5\frac{3}{4}$ *diam.*)

[External cast of part of head and thorax. From the Bronsil Shales, Southern Malverns. The specimen is to be seen in the Museum at Malvern.]

Fig. 28.—Cheirurus Frederici. ($\times 4\frac{1}{2}$ *diam.*)



[Head and part of thorax restored, by means of tracings from a *camera-lucida* drawing, of the specimen illustrated in fig. 27.]

by Salter as *A. trisectus*. The species *A. princeps* appears to have been founded upon imperfect specimens of *A. trisectus* from the Upper *Lingula*-Flags of Malvern, etc., and of another form (probably *A. pisiformis*) from the Lower *Lingula*-Flags of other districts.

The foregoing paragraph was written some years ago, and since that time Prof. W. C. Brögger has referred to *Agnostus princeps* in the following terms:—

'*Agnostus princeps*, Salter, is a species which is supposed to occur both in the "Upper *Lingula*-Flags" and in the (Lower and Upper) Tremadoc. But it seems probable that different species have here been included under one name.' [1]

It will be seen that this conclusion is in harmony with that drawn by Mr. Lake and the present writer. It follows that *Agnostus princeps*, which has long occupied a prominent position in our list of Cambrian fossils, must disappear.

(*b*) Grey Shales.

Apart from the characteristic *Dictyonema sociale*, fossils are rare, and no trilobites or other organisms have hitherto been recognized from the Bronsil Shales, with the exception of *Platypeltis Croftii*, Call., and *Shumardia salopiensis*, Call., both recorded by Dr. Callaway. I have recently recognized in the form referred to the last-mentioned species the type of a new genus and species—*Acanthopleurella Grindrodi*.[2] A few other trilobites, for the most part fragmentary, are preserved in the collections at Oxford, Jermyn Street (London), Malvern, and Worcester; and others have been obtained by me. Some of these, to which allusion has been made in the text of the paper, are too imperfect for description; of the rest, two have been submitted to Mr. P. Lake, who is jointly responsible with myself for the following notes on *Cheirurus Frederici* and *Platypeltis Croftii*.

In the Malvern Collection is a good fragment of the head of the imperfectly-known *Cheirurus Frederici*, Salter (fig. 27), the length of which is 5 mm., and the original width probably 16 mm. The specimen is found in Grey Shale.

Cheirurus Frederici, Salter. (Figs. 27 & 28, p. 120.)

1862. Salter, 'Brit. Trilob.' Monogr. Palæont. Soc. p. 74 & pl. v, figs. 18–21: 1866. Mem. Geol. Surv. vol. iii, p. 322, pl. viii, figs. 1–3 & text-fig. 10, p. 323.

Head depressed, crescentic, marginate. Glabella quadrate, much narrower than the cheeks, reaching to the front margin; axial furrows almost parallel; three pairs of nearly transverse lateral furrows. Cheeks wide, scrobiculate. Eyes and facial suture apparently placed very far forward; consequently the free cheeks are extremely small.

Thoracic axis narrow, about two-thirds the width of the pleuræ. Pleuræ convex, deeply grooved.

The specimen here described is evidently from the Malvern Grey

[1] Nyt Mag. for Naturvidensk. vol. xxxvi (1898) p. 201.
[2] Geol. Mag. 1902, p. 70.

Shales, and is now in the Malvern Museum. It agrees closely with Salter's description, but is much smaller, and differs also in the arrangement of the glabellar furrows, which according to Salter are radiate. Salter's specimens, however, are much compressed, and but little confidence, therefore, can be placed in this character.

Fig. 29.—Platypeltis *sp. cf.* Croftii, *Call.*

[Part of right-hand side and front of head, with labrum, × 8 diam. From a specimen in the Grindrod Collection, labelled '*Dictyonema*-shales, Malvern.']

Platypeltis sp. *cf.* Croftii, Call. (Fig. 29.)

Represented in the Grindrod Collection, University Museum, Oxford, by a free cheek, together with a portion of the rest of the head, including one eye and part of the labrum. The margin of the head is broad and was evidently prolonged behind into a genal spine. The eye is large, crescentic, and facetted, and is situated near the front of the head. Externally to the eye, and separated from it by a well-marked groove, is a rounded ridge, narrow in front, but broadening out behind.

If, as Brögger suggests,[1] the name *Platypeltis*, Call., be reserved for a subgenus of *Symphysurus*, distinguished by the possession of genal horns, the form under consideration probably belongs to this subgenus. The Malvern specimen is closely allied to, if not identical with, *Platypeltis Croftii*, Call. It is, however, larger than any of the examples of the latter species seen by either of us.

The specimen is labelled '*Dictyonema*-shales (=Bronsil Shales), White-Leaved Oak.'

Niobe (Ptychocheilus)? sp. (Fig. 30.)

Head unknown.

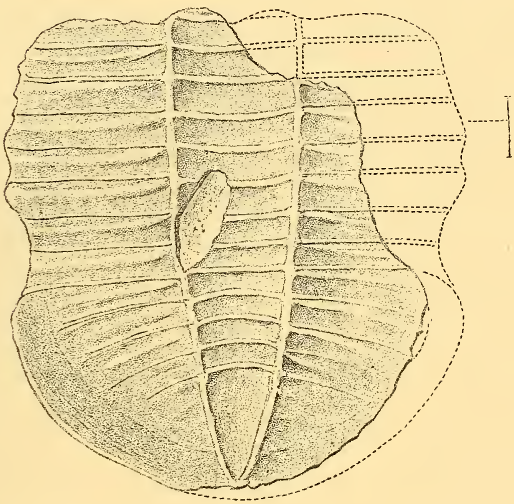
Thorax.— Probable length and breadth, 4 and 7·5 mm. respectively. Portion of eight rings preserved. Axis well-defined, fairly convex, narrow, occupying about one-quarter of the total breadth, narrowing slightly behind. Pleuræ narrow, straight for the

[1] Nyt Mag. for Naturvidensk. vol. xxxvi (1898) pp. 220 & 221.

whole of the length seen, flat; with grooves starting at the axis and running straight towards the ends of the pleuræ, which are not preserved.

Pygidium.—Relatively large, semi-elliptical, shorter than the thorax; probable length and breadth, 3·5 and 6·7 mm. respectively;

Fig. 30.—Niobe *(?) sp. External cast of part of the pygidium and thorax. (×8 diam.)*



[From a specimen in dark-grey shale, labelled 'Malvern,' in the University Museum at Oxford. Probably obtained from the Bronsil Shales, Southern Malverns.]

composed of more than five segments. Axis well-defined, fairly convex, narrow, tapering towards the posterior margin, which probably it nearly reaches: anterior part of axis clearly segmented into four rings: posterior part segmented indistinctly in front, but not behind. Limb gently convex; margin fairly broad, faintly striated, marked off from the rest of the limb by a faint depression. Five ribs present in front, the most anterior of which are the strongest, and just reach the marginal rim; hinder part of limb not distinctly segmented.

This small fossil is represented in the Oxford Collection by a single external cast in dark shale, labelled 'Malvern'; it probably came from a dark band in the *Dictyonema*-shales.[1]

The general characters are those of the species of '*Ogygia*' found in the Arenig and Tremadoc Beds of Wales, such as *Ogygia peltata*,

[1] This specimen, after being drawn, was unfortunately broken in two during transit, and one portion was lost.

Salt.,[1] *O. Selwynii*, Salt.,[2] and *O. marginata*, Crosfield & Skeat.[3] It also approaches such forms as '*Ogygia*' *producta*, Hall & Whitfield, of the Quebec Group,[4] and '*Asaphus*' *Wirthi*, Barr. (pygidium), from the Tremadoc of Hof.[5] The Bronsil form differs, however, from all of these in several respects. It comes nearest, perhaps, to '*Ogygia*' *peltata*. From this species it differs in the small size and imperfect segmentation of the pygidium, and in the axis being narrower, and apparently prolonged farther towards the hinder margin of the pygidium.

According to Brögger, *O. peltata* is not an *Ogygia*, but probably a true *Niobe*; and the same may probably be said of '*Ogygia*' *Lignieresi*,[6] '*Ogygia*' *producta*,[7] and *Asaphus Wirthi*.[8] The same author throws doubt on the possession of genal horns by '*Ogygia*' *peltata*. They are, however, shown with sufficient clearness in the original specimen from which Salter's fig. 8, pl. xvii ('Monograph of British Trilobites') is taken, and which is still preserved in the Museum of Practical Geology, Jermyn Street. The figure, though condemned by Salter himself, is sufficiently good in this respect. The labrum agrees even more closely with that of such forms as *Niobe insignis*, Lnrs. than would appear from Salter's figure (*op. cit.* pl. xxv*, fig. 3), or from Novák's figure.[9] If, therefore, Brögger's suggestion,[10] that the name *Ptychocheilus* should be applied to horned species of *Niobe* with the typical labrum of that genus, be adopted, Novák's reference of '*Ogygia*' *peltata* to *Ptychocheilus* would appear to be justified.

NIOBE HOMFRAYI, Salter (?). (Fig. 31, p. 125.)

Niobe Homfrayi, Salt., is probably represented, in the Grindrod Collection at Oxford, by two imperfect specimens from the Bronsil Shales of the Southern Malverns. In one of these (fig. 31) the characters seen agree with those of this species. It is only perhaps in the labrum that the Malvern species may differ from *N. Homfrayi*. This structure, though imperfectly preserved, shows much the same form and dimensions as those described by Salter in the latter species, but the anterior lobe appears to be raised up in front into an oval eminence, which, however, is not improbably adventitious. The form shown by the labrum approaches that seen in the oldest Scandinavian species of *Niobe* and *Ogygia*,[11] especially that of the last-mentioned genus; but it appears to be a little more elongated, and

[1] J. W. Salter 'Brit. Trilob.' Monogr. Palæont. Soc. (1864–83), pp. 135-36, 177–78. [2] *Ibid.* pp. 136–37.

[3] Quart. Journ. Geol. Soc. vol. lii (1896) p. 538.

[4] 'U.S. Geol. Explor. 40th Parallel' vol. iv (1877) p. 244 & pl. ii, figs. 31–34.

[5] Neues Jahrb. 1868, p. 680.

[6] Nyt Mag. for Naturvidensk. vol. xxxvi (1898) pp. 170 & 171.

[7] *Ibid.* p. 228. [8] *Ibid.* p. 212.

[9] Beiträge zur Palæont. Oesterreich-Ungarns u. des Orients, vol. iii (1884) p. 33.

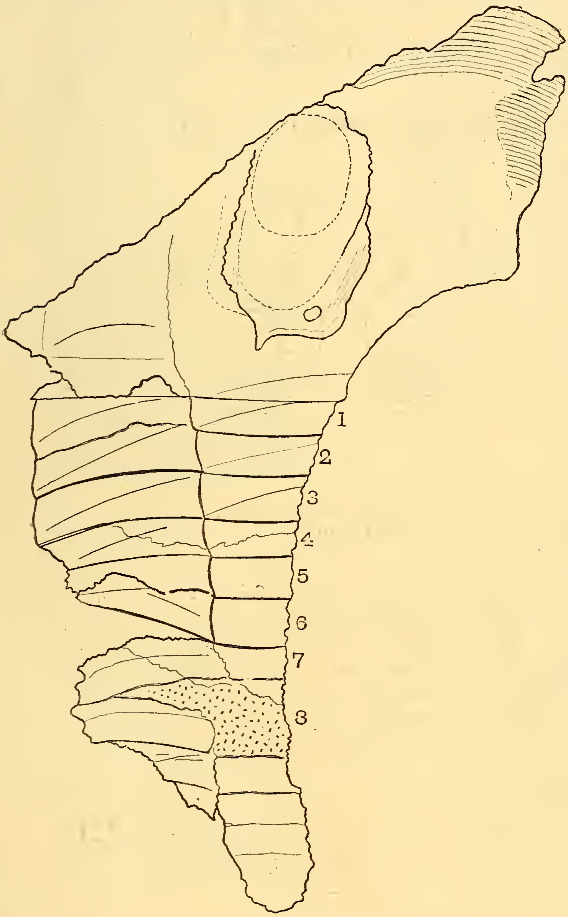
[10] Nyt Mag. for Naturvidensk. vol. xxxvi (1898) p. 219.

[11] Brögger, Bihang t. Kongl. Svenska Vet.-Akad. Handl. vol. xi (1886) no. 3, pp. 46 *et seqq.*

seems almost as acutely pointed behind as in *Megalaspis rotundata*, Ang., or *M. grandis*, Sars.[1]

Novák, relying on Salter's figure, has classed *Niobe Homfrayi*, Salter, as an *Ogygia*. Brögger, however, suggests that Salter's figure is imperfect, and that the labrum may in reality agree with that of *Niobe insignis*, Lnrs., a species which *N. Homfrayi* much resembles in general appearance. I have examined the only labrum of *N. Homfrayi* that I have been able to find (Museum of Practical Geology, Jermyn Street): it is probably that figured by Salter himself. It much resembles the labrum of *Ogygia dilatata*, but is more ovate, and has a much more prominent median tooth, apparently either truncated at the end, or with a pointed tooth like that of the Malvern specimen, now broken off. The anterior lobe is large and ovate; the lateral margins are apparently narrow; and the maculæ are connected by a transversely oval, prominent posterior tubercle, well-defined by furrows both in front and behind. The anterior wings appear to be short. The labrum much resembles that of *Ogygia*.

Fig. 31.—Niobe Homfrayi, *Salter*. (×5 *diam.*)
From the Bronsil Shales, Southern Malverns.



It follows that so far from being 'kaum specifisch verschieden'

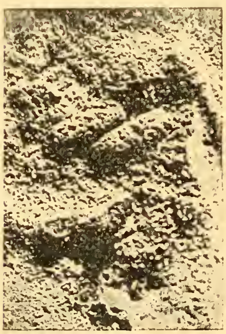
[1] Brögger, Bihang t. Kongl. Svenska Vet.-Akad. Handl. vol. xi (1886) no. 3, pl. ii, figs. 26 & 27.

Figs. 32–35.—Tomaculum problematicum, *gen. et sp. nov. from the Bronsil Shales, Southern Malverns. Reproductions of photographs.*

33. *(×7 diam.)*

32. *(×7 diam.)*

35. *(×10 diam.)*



34. *(×10 diam.)*

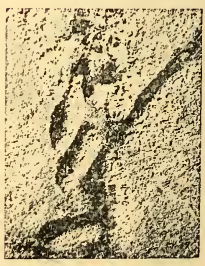


Fig. 32.—Two small patches of individuals in relief.
33.—A portion of a string of individuals, partly in relief and partly in the form of external casts.
34.—A portion of the same figure, illuminated differently and more highly magnified.
35.—A group of three individuals in relief (internal casts).

from *Niobe insignis*, Lnrs. as Brögger suggests, *Niobe Homfrayi*, Salter, differs essentially in the form of the labrum. The remaining characters are, however, as Brögger points out, those of a *Niobe*.[1]

TOMACULUM PROBLEMATICUM, gen. et sp. nov. (Figs. 32–35, p. 126.)

In the Malvern *Dictyonema*-shales a number of small sausage-shaped bodies have been detected at several spots by me, and many additional examples have been collected and kindly placed at my disposal by the Rev. G. E. Mackie. They are found in a grey, minutely micaceous shale. The constancy in size and shape of these bodies points, with a certain amount of definiteness, to their organic nature. They are occasionally isolated, or in groups of two or three (fig. 35), but are usually collected together in elongated patches, or in short, broad, or narrow, more or less irregularly curved or bent strings, which are flattened in the plane of bedding. The longest fragment of such a string seen is about 15 mm. in length, and must contain at least 40 or 50 of the bodies; in other fragments, part of one of which is shown in fig. 33, a length of 10 to 15 mm. is visible, and in this length some 25 bodies can be counted. In these strings and patches the bodies are orientated in all directions: in some cases they are closely packed together, and piled up one over the other; in others the texture is looser, and the bodies appear to be disposed in a single layer.

The individuals are cylindrical in shape, with circular section, and broadly rounded and equal ends; the breadth is about one-third of the length. The average length of 14 of the most perfect examples measured was 1·50 mm., and the average breadth of 13 of these 0·53 mm.; the smallest among them measured 1·23 and 0·45 mm. in length and breadth respectively; the corresponding measurements of the longest individual were 1·72 and 0·52 mm.: four, however, were somewhat broader, the breadth of three of these being about 0·67 mm.: these, however, are possibly a little flattened by pressure. One individual, larger than any of these 14 or than any others seen, measured 2·03 by 0·75 mm. The many remaining examples do not appear to depart greatly from the average size. The external surface appears to have been smooth, although the internal cast sometimes shows faint indications of longitudinal and transverse striation. The test was apparently thin, but does not seem to be preserved in any case.

The nature of these bodies is very problematical; their small size and shape suggest that they are either the excreta or the eggs of some animal. The frequently excellent preservation of the form indicates that the body was provided with a resistant covering, and this, as well as the fairly constant size, and perhaps the arrangement in clusters, favours the latter of the two alternatives.

Very similar bodies, occurring in a similar manner, have been described by Barrande, who has regarded them as the eggs of

[1] Bihang t. Kongl. Svenska Vet.-Akad. Handl. vol. xi (1886) no. 3, pp. 57 & 58.

trilobites.[1] The chief reasons for this view are, the nearly constant size and shape, the delicate, opaque, external black pellicle, and their frequent association with trilobites; one kind, indeed, is constantly associated with *Phacops fecundus*, Barr. Moreover, one group of these bodies was found in a head of *Barrandia crassa*, Barr.

Barrande distinguishes eggs of three sizes: firstly, those measuring 4 to 5 millimetres; secondly, those measuring 2 mm.; and thirdly, those not more than $\frac{2}{3}$ mm. in diameter. The Malvern examples agree in size with those of the third group.

In most cases the bodies described by Barrande were spherical, but in many instances they were ovoid or cylindrical. The examples found at horizon d^5 near Leiskov and at horizon d^1 at Wosek are stated to be constantly cylindrical. The Malvern specimens agree closely in form with those in Barrande's pl. xviii, figs. 31-33.

The trilobites found in the Malvern *Dictyonema*-shales are enumerated in the table on p. 110.

Despite the uncertainty of the systematic position of the egg-like bodies described above, it seems desirable for the present to recognize them as distinct forms; and I would propose for them the name of *Tomaculum problematicum*.

VIII. Correlation of the Beds described with those of other Areas.

(*a*) The Bronsil Shales.

The Bronsil Shales have long been correlated with the '*Dictyonema*-beds' of North Wales and other districts; their resemblance to the Shineton Shales, in particular, has been pointed out by Dr. Callaway.[2] Concerning the fossils other than *Dictyonema* which serve for comparison with other areas, the following remarks may be made:—*Linnarssonia Belti* appears to be confined in Wales to the Lower Tremadoc.[3] *Niobe Homfrayi* is apparently found only in the Lower Tremadoc, and in the passage-beds between this and the Upper Tremadoc.[4] *Lingulella Nicholsoni*, *Acrotreta Sabrinæ* (typical variety), *Parabolinella triarthrus*, *Agnostus dux*, *Platypeltis Croftii*, and *Asaphellus affinis* are found in the Shineton Shales. Of these, the four last mentioned either resemble, or are identical with, species occurring in the *Ceratopyge*-beds of Norway, which are the recognized equivalents of the British Tremadoc.[5] *Asaphellus affinis* is found also in the Tremadoc and Arenig of North Wales; and *Cheirurus Frederici* is chiefly characteristic of the Upper Tremadoc of Wales, but also occurs in the passage-beds between this and the

[1] 'Système Sil. du Centre de la Bohême' pt. i, vol. i (1852) pp. 276 *et seqq.*, and vol. i, suppl. (1872) pp. 429 *et seqq.*

[2] Quart. Journ. Geol. Soc. vol. xxxiii (1877) pp. 660, 661.

[3] T. Davidson, 'Brit. Foss. Brachiop.' Monogr. Palæont. Soc. vol. iii (1871) p. 341.

[4] Mem. Geol. Surv. Gt. Brit. vol. iii, 2nd ed. (1881) p. 359.

[5] W. C. Brögger, Nyt Mag. for Naturvidensk. vol. xxxvi (1898) p. 194.

Lower Tremadoc, and in the Arenig.[1] This form, moreover, is represented by an allied species (*Cheirurus foveolatus*, Ang.) in the Upper *Ceratopyge*-bed of Norway.[2] *Niobe (Ptychocheilus) peltata*, Salter, of the Tremadoc and Arenig of Wales, is also represented in the Bronsil Shales by an allied or identical species. These facts leave no doubt that the Bronsil Shales contain a typical *Euloma-Niobe* fauna, and that, at all events in the main, they correspond to the Lower Tremadoc of North Wales. The occurrence of *Cheirurus Frederici* may, however, indicate that a zone as high up as the passage-beds between the Lower and Upper Tremadoc is represented. Furthermore, it is possible that the highest Bronsil Shales, which are largely concealed, and have hitherto yielded no recognizable species, may belong to the Upper Tremadoc.

The occurrence of *Dictyonema sociale*, Salter, in company with a definite Tremadoc fauna is paralleled elsewhere. The *Dictyonema*-shales of North Wales were grouped in 1867 by Belt,[3] and in 1881 by Prof. Lapworth, with the Lower Tremadoc, rather than with Dolgelly Beds, or Upper *Lingula*-Flags.[4] It is true that some of the beds containing *Dictyonema sociale* have been placed by Salter & Etheridge in the Upper *Lingula*-Flags[5]; but it would appear that, with one doubtful exception,[6] the fossils recorded as accompanying *Dictyonema sociale* are of Tremadoc type. They include *Lingulella lepis*, Salt.,[7] *Symphysurus (Psilocephalus) innotatus*, Salt., *Niobe Homfrayi*, Salt., and '*Ogygia*' sp.[8]; and in such instances the beds have been referred to the Tremadoc. On the other hand, *Dictyonema sociale* is recorded from dark slates which have been termed 'Upper *Lingula*-Flags.' The characteristic 'Upper *Lingula*-Flag' fossils, such as *Sphærophthalmus alatus* and *Peltura scarabæoides*, however, appear to occur in the lower part of the dark band; and it is expressly stated that *Dictyonema sociale* is found only in the uppermost beds, at the point where the black slates of the 'Upper *Lingula*-Flags' give place to the greyer overlying beds.[9] Mr. P. Lake & Prof. S. H. Reynolds, moreover, find in the neighbourhood of Dolgelly the zone of *Dictyonema sociale* in dark slates well above the widely-spread band of black and dark slates ('Upper *Lingula*-Flags') which contain the Dolgelly fauna; they have obtained from the black slates themselves *Acrotreta Sabrinæ*, Call., a characteristic Shineton and Malvern form. The evidence, then, appears to be in favour of including all the slates of North Wales

[1] Mem. Geol. Surv. Gt. Brit. vol. iii, 2nd ed. (1881) pp. 359 & 521.
[2] Nyt Mag. for Naturvidensk. vol. xxxvi (1898) p. 233.
[3] Geol. Mag. 1867, p. 542.
[4] *Ibid.* 1881, p. 320.
[5] Mem. Geol. Surv. Gt. Brit. vol. iii, 2nd ed. (1881) pp. 86, 344, 349, 350, 354, & 536.
[6] *Ibid.* p. 343.
[7] Lake & Reynolds, Quart. Journ. Geol. Soc. vol. lii (1896) p. 514.
[8] Mem. Geol. Surv. Gt. Brit. vol. iii, 2nd ed. (1881) pp. 86 & 358; see also pp. 91, 344, 354, & 356.
[9] *Ibid.* pp. 86, 349, & 536. It may be seen, too, in the list (*op. cit.* p. 350) of localities for fossils of the 'Upper *Lingula*-Flags' that when *Dictyonema sociale* is recorded, it does not appear in association with the remaining fossils.

from which *Dictyonema sociale* has been recorded, in the Tremadoc, in spite of the darker colour of the lower beds.

It may be pointed out further that, in Shropshire and in Northern Herefordshire, the shales containing *Dictyonema sociale* lithologically resemble the Tremadoc Beds of Shropshire which do not contain this fossil. The *Dictyonema*-bearing shales of Malvern [1] are for the most part of the same type, though some of the beds show a rather dark-grey colour.

On the Continent most writers have followed Angelin, who placed the beds containing *Dictyonema flabelliforme*, Eichw., in his 'Regio Olenorum' [2]—the *Olenus*-shales of later authors. Linnarsson, who first recognized the *Dictyonema*-shales as a distinct division,[3] regarded them as constituting the uppermost division of the 'primordial fauna'; and most other Scandinavian geologists have adopted the same classification. Brögger, however, while sharing this view, admitted that the *Dictyonema*-shales might quite well have been grouped with the *Ceratopyge*-shales.[4] This course was, later, definitely advocated by Moberg,[5] who has, moreover, recently offered fresh evidence in support of it.[6] I understand that Senhor Delgado and Dr. Törnquist [7] have also expressed themselves in favour of the same view. The latter, indeed, adds that

> 'This proposition . . . will, possibly, prove practicable in foreign countries too.'

This suggestion appears to be borne out by the evidence adduced above from the British areas.[8]

A few words with reference to the classification of the rest of the Tremadoc Beds may not be out of place here. In Britain the line between the Cambrian and Ordovician (or Lower Silurian) has commonly been drawn either between the Lower and Upper Tremadoc, or at the base of the Arenig. Mr. J. E. Marr, however, stated in 1883 [9] that

> 'if a break is to be drawn at all on palæontological grounds, it should be drawn at the base of the Tremadoc, and not of the Arenig Series.'

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[1] Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 660.

[2] 'Palæontologia Scandinavica' p. iii (publ. 1854), 1878.

[3] Geol. Fören. Stockh. Förhandl. vol. ii (1874–75) pp. 273, 274, & 282.

[4] 'Die Silur. Etag. 2 & 3' 1882, p. 156.

[5] Sveriges Geol. Undersökn. ser. C, no. 109 (1890) pp. 1–9.

[6] Geol. Fören. Stockh. Förhandl. vol. xxii (1901) p. 523.

[7] Lunds Universitets Årsskrift, vol. xxxvii (1901) sect. ii, no. 5, p. 8.

[8] It may be remarked that *Dictyonema sociale*, Salt. is commonly regarded abroad as identical with *D. flabelliforme*, Eichw. It is further to be noted that in New Brunswick, while *D. flabelliforme* is found at what is apparently the same horizon as *D. sociale* and *D. flabelliforme* in Europe (that is, immediately above the zone of *Peltura* and its associates), a variety also occurs in the *Peltura*-zone, and possibly as low down as the zone of *Parabolina spinulosa*. See G. F. Matthew, Canad. Rec. of Sci. vol. iv (1890–91) pp. 342 & 343.

[9] 'Classif. Cambr. & Silur. Rocks.' Sedgw. Prize Essay for 1882 (publ. 1883) p. 23.

Continental geologists, following the lead of Linnarsson in 1869, have also grouped the foreign equivalents of the Tremadoc Series with the Ordovician rather than with the Cambrian. Prof. Brögger has strongly advocated this view.[1] He points out that while the *Euloma-Niobe* fauna (Tremadoc) has marked peculiarities which entitle it to rank independently of the Arenig, it nevertheless presents a prevailingly Ordovician facies, due to the appearance of many of the characteristic Ordovician genera. Much may be said in favour of this view. The Malvern area, it is true, does not throw much new light on the question, but the somewhat fragmentary fauna of the Bronsil Shales shows the same peculiarities as those that characterize the *Euloma-Niobe* fauna elsewhere, and thus permits the extension of Brögger's generalizations to an additional area. I am, accordingly, inclined to endorse cordially the view held by Prof. Brögger and others, and to group the Tremadoc Series with the Ordovician, but with the reservation made by Moberg, that in so far as the *Dictyonema*-beds may be regarded as forming a definite zone, they should be grouped with the Tremadoc, and that the line between the Cambrian and the Ordovician should therefore be drawn below, instead of above these beds.

(*b*) The White-Leaved-Oak Shales.

The upper, and by far the greater part of the Malvern Black Shales belong to the zone of *Sphærophthalmus alatus*, *Peltura scarabœoides*, *Ctenopyge pecten*, and *Agnostus trisectus*.

The underlying shales with *Polyphyma Lapworthi* evidently correspond to the lower part of the Oldbury Shales of Warwickshire, in which Prof. Lapworth speaks of this form [?'*Beyrichia*'] as perhaps the most abundant fossil.[2] They may also possibly be the equivalents of the Swedish zone of '*Beyrichia*' *Angelini* (a species probably congeneric with *Polyphyma Lapworthi*[3]), which is situated below that of *Peltura scarabœoides*. This would be in harmony with the apparent absence of the zones of *Agnostus socialis* and *A. pisiformis* from the Malvern area, which may be faulted out. On the other hand, *Polyphyma Lapworthi* appears to be specifically distinct from '*Beyrichia*' *Angelini*, and it is, moreover, possible that *Agnostus pisiformis* may occur in the concealed shales which overlie those containing *Polyphyma*. The occurrence of the mainly Menevian (and Lower *Lingula*-Flag) genus *Protospongia*, and of *Kutorgina pusilla*, in the zone of *Polyphyma* also supports the view that this zone underlies that of *Agnostus pisiformis*; for *K. pusilla*, in Sweden, is characteristic of the zones of *Paradoxides Forchhammeri* and *Agnostus lævigatus*. It seems most probable, therefore, that the lowest black shales seen in the

[1] Nyt Mag. for Naturvidensk. vol. xxxvi (1898) pp. 236 *et seqq.*
[2] Proc. Geol. Assoc. vol. xv (1898) p. 347.
[3] Quart. Journ. Geol. Soc. vol. lviii (1902) p. 83.

Malverns belong to the uppermost part of the Paradoxidian. Further light on this question may be expected from the Nuneaton area, in which *Polyphyma Lapworthi* and *Agnostus pisiformis* both occur.

(*c*) The Hollybush Sandstone.

The fossils obtained from the Hollybush Sandstone do not afford much aid in determining the precise horizon of this formation. Dr. Callaway long ago regarded it as the equivalent of the very similar Hollybush or Comley Sandstone of Shropshire.[1] The passage in each area down into an underlying quartzite tends to support this view. In Shropshire the basal beds of the sandstone have yielded to Prof. Lapworth *Olenellus* and *Paradoxides*.[2] The somewhat similar basal flaggy, shaly, and calcareous sandstones of Malvern have not yielded either of these forms, but contain the associated Lower and Middle Cambrian form *Kutorgina cingulata*, and other fossils. The probabilities are, therefore, that the base of the Cambrian is represented also at Malvern. The overlying sandstones contain *Kutorgina cingulata* var. *Phillipsii*, and *Hyolithus fistula* (which also occurs in Shropshire), together with other Hyolithidæ, all of which are apparently new: three of the fossils also occur in the Hollybush Quartzite. Moreover, *Hyolithus fistula*, *H. malvernensis*, *H. primævus*, and perhaps other species of the same genus, appear to be most closely related to forms which characterize the Lower and Middle Cambrian beds of other countries (see pp. 111 *et seqq.*). These facts, together with those mentioned on pp. 104 & 131, indicate that much or the whole of the Hollybush Sandstone belongs to the zone of *Paradoxides*, rather than to the *Lingula*-Flags, with which it has generally been correlated.

Prof. Lapworth was disposed to correlate both the Hollybush Sandstone and the Comley Sandstone with the Camp-Hill Quartzite, or upper division of the Hartshill Quartzite of Nuneaton.[3] The occurrence of shaly beds at the base, and their passage down into the underlying quartzite, is in harmony with this view, but no fossils have been obtained from the Camp-Hill Quartzite itself. The lower portions of the two formations in the Malvern and Nuneaton districts are comparable in thickness, the 50 or 60 feet, chiefly shales, in the last-mentioned locality being represented by 75 feet or more of thin flags and sandy shales. The differences seem to consist mainly in the greater thickness, and more arenaceous and glauconitic (but less calcareous) character of the Malvern beds. Considering the lithological differences, the poverty of the Malvern beds in fossils, as compared with the richer fauna of the Hyolite-limestone, is, perhaps, not surprising.[4] In the upper portions of the two series compared, some of these differences are in the same direction, but

[1] Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 652.
[2] Geol. Mag. 1891, p. 529.
[3] Proc. Geol. Assoc. vol. xv (1898) p. 344.
[4] *Ibid.* p. 343.

are immensely exaggerated: the upper, like the lower, Hollybush Sandstones are very glauconitic, and they include conglomerates; moreover, a thickness of about 50 feet of quartzite at Nuneaton is replaced in the Malverns by possibly twenty times that amount of sandstones and quartzites. Considering this great difference, together with the absence in the Malverns and in Shropshire of shales resembling the Purley Beds or lowest division of the Stockingford Shales (which rest directly on the Camp-Hill Quartzite), it seems possible that these shales are in part represented by the upper portion of the Hollybush Sandstone and of the Comley Sandstone. This hypothesis would be in harmony with the behaviour of the associated beds, in so far that the sandy material of the Malvern district would be replaced by shales in the Nuneaton district. The upper part of the Hollybush Sandstone, however, contains no shales such as might possibly on this hypothesis be expected to occur. Here again, perhaps owing to the great difference in facies, palæontology fails to throw much light on the question; but it may be noted that *Hyolithus fistula*, which is the most abundant species in the Hollybush Sandstone, has also been detected in the Stockingford Shales by Prof. Lapworth.[1] The view suggested here is, I think, rather strongly supported by the fact that the lowest black shales in the Malverns include bands of dark glauconitic grit, the finer examples of which greatly resemble some of the darker varieties of the Hollybush Sandstone; this not improbably indicates that the Malvern Black Shales originally passed down by alternation into the Hollybush Sandstone. The circumstance that *Polyphyma* is found in the oldest black shales both at Malvern and Nuneaton, taken together with this presumed passage in the Malverns, seems further to indicate that only a small portion of the sequence at the northern extremity of Chase-End Hill is faulted-out.

(*d*) The Malvern Quartzite.

The Malvern Quartzite agrees in position with the Wrekin Quartzite, and probably with the Lower Quartzites of Nuneaton, and all three are lithologically very similar. In each area there is probably a passage upward into the overlying Cambrian beds. The Malvern Quartzite has the distinction, among British quartzites of this age, in alone presenting fossils other than worm-tubes. It contains in places abundantly, *Kutorgina cingulata* var. *Phillipsii*, together with *Hyolithus primævus*, sp. nov., *H. fistula*, and *Obolella Groomii*, sp. nov.; all of which also occur in the Hollybush Sandstone, with the exception of the last-mentioned, which hitherto has not been detected above the passage-beds into the Sandstone. It must be noted, however, that *Kutorgina Phillipsii*, which is very common in the Quartzite, becomes much rarer in the Hollybush Sandstone, and that the reverse is true of *Hyolithus fistula*. The Quartzite appears to be intimately united to the Hollybush Sandstone stratigraphically, lithologically,

[1] Geol. Mag. 1886, p. 548.

and palæontologically; but whether the formation is best regarded as the natural base of the Cambrian, or as a separate pre-Cambrian formation, such as the Etcheminian may be,[1] the evidence appears as yet insufficient to show.

IX. Conclusions.

The Cambrian and lowest Ordovician sediments attain a considerable development in the Malverns. The maximum thickness may be estimated as over 3000 feet, while the minimum can hardly be much less than 2500 feet. To these estimates must be added a thickness of some 600 feet of intrusive igneous rocks.

The series (exclusive of igneous rocks) consists of the following, in descending order:—

(4) The Bronsil Shales, 1000 feet thick; grey shales containing *Dictyonema sociale*, and many Tremadoc brachiopods and trilobites.

(3) The White-Leaved-Oak Shales; black shales including:—
- (*b*) The zone of *Peltura scarabæoides*, *Sphærophthalmus alatus*, *Ctenopyge pecten*, *Ct. bisulcata*, *Agnostus trisectus*, etc.; thickness 500 feet.
- (*a*) The zone of *Polyphyma Lapworthi*, containing *Acrotreta malvernensis*, *Kutorgina pusilla*, *Protospongia fenestrata*, etc.; thickness not less than 30 feet.

(2) The Hollybush Sandstone, comprising:—
- (*b*) Massive sandstones (glauconitic), probably not less than 1000 feet thick, and containing:—*Hyolithus fistula*, *H. malvernensis*, *H. primævus*, *Scolecoderma antiquissima*, *Kutorgina Phillipsii*, etc.
- (*a*) Flaggy and shaly sandstones (glauconitic), not less than 75 feet thick, with *Kutorgina Phillipsii*, *Scolecoderma antiquissima*, *Hyolithus* sp., etc.

(1) The Malvern Quartzite, consisting chiefly of grey quartzites and conglomerates, seldom slightly glauconitic; probably several hundred feet thick; containing *Kutorgina Phillipsii*, *Obolella (?) Groomii*, and *Hyolithus primævus*.

The Malvern Quartzite probably at one time rested unconformably upon both of the Malvern series recognized as pre-Cambrian, since it contains angular fragments and rounded pebbles of Uriconian and Malvernian type, but it appears now to be separated from the older rocks by faults. It is to be compared with the Wrekin Quartzite, and probably with the greater part of the Hartshill Quartzite, and with quartzites which in other parts of the world immediately underlie the *Olenellus*-beds.

The shaly basal beds of the Hollybush Sandstone possibly correspond with the *Olenellus*-beds, and with the zone of *Paradoxides Groomii*, Lapworth, in the Comley Sandstone of Shropshire.

The bulk of the Hollybush Sandstone probably represents the greater part of the Paradoxidian of other localities, and not improbably corresponds with the Camp-Hill Quartzite (exclusive of the

[1] G. F. Matthew, Ann. N.Y. Acad. Sci. vol. xii (1899) p. 41, & Bull. Nat. Hist. Soc. New Brunsw. vol. iv (1899) pp. 189, 198.

basal shales) together with the Purley Beds, or lowest division of the Stockingford Shales. Otherwise no representatives of these shales exist in the Malverns.

The shales with *Polyphyma Lapworthi* in the southern part of the district, like the shales with *Sphærophthalmus* farther north, are probably faulted against the older rocks. They may represent the Swedish zone of '*Beyrichia*' *Angelini*, and, perhaps at the same time, the Ffestiniog Beds of North Wales. It is, however, equally, or more, probable that they represent the uppermost part of the Paradoxidian, since they contain the Swedish fossil *Kutorgina pusilla.* The zone of *Agnostus pisiformis* has so far not been detected in the Malvern area, the fossils attributed to this species being referable to *A. trisectus.*

The greater part of the Malvern Black Shales belongs to the zone of *Sphærophthalmus alatus* and its associates. It is possible, however, that other zones, both immediately above and immediately below this, may be represented in the district, but no fossils characteristic of the zones of *Parabolina spinulosa*, *Leptoplastus* and *Eurycare*, or *Cyclognathus,* have been detected hitherto.

The lowest part of the Bronsil Shales has furnished only a few minute fossils, but the middle part has yielded many Tremadoc and Shineton forms, including Asaphids and Olenids, in association with *Dictyonema sociale.* The *Dictyonema*-beds of Malvern, and probably of North Wales and other parts of Britain, are to be classed with the Tremadoc Series (*Euloma - Niobe* fauna), and may conveniently be taken as marking the base of the Ordovician.

It remains for me to tender my best thanks to Sir Archibald Geikie, Prof. T. McKenny Hughes, Prof. Charles Lapworth, the Rev. G. E. Mackie, Prof. W. J. Sollas, the officers of the Malvern Field Naturalists' Club, and the authorities in charge of the Museum at Worcester, who have kindly facilitated my work by the loan or gift of fossils.

Appendix.

On the Cambrian Brachiopoda *of the* Malvern Hills.

By Charles Alfred Matley, Esq., B.Sc., F.G.S.

(i) Introductory.

Before entering upon a description of the Malvern Cambrian brachiopoda which I have had the opportunity of examining, it may be well to make a few brief remarks as to our present knowledge of these fossils.

Although the Cambrian rocks of the Malvern district have been patiently hammered over by more than one generation of geologists (among whom, of those now passed away, may be mentioned Prof. Phillips, Dr. Grindrod, Dr. Holl, the Rev. W. S. Symonds, and

Mr. Hugh Strickland), the collection of brachiopoda which their labours have made known has been disappointingly meagre, both as regards individuals and species.

In 1871 the full list, according to Phillips,[1] was as follows:—

Hollybush Sandstone.	Malvern Shales.
Lingula squamosa, Holl.	*Lingula pygmæa*, Salter.
,, another species.	*Obolella Salteri*, Holl.
Obolella Phillipsii, Holl.	*Spondylobolus*.
,, two other species.	A minute bivalve.
A small unascertained bivalve.	

Diagnoses of some of the above were given in Holl's paper of 1865,[2] but the descriptions were scanty and the figures not very satisfactory; moreover, the species were in some cases admittedly founded on very imperfect material. It is unfortunate, too, that the present whereabouts of his type-specimens is unknown. Prof. Groom has endeavoured to trace them, but without success. Davidson, in his monograph, redescribed the then known species, treating, however, Holl's *Obolella Phillipsii* as a synonym of Billings's *Kutorgina cingulata*; but it is clear that, excepting the *Kutorgina* of the Malvern Quartzite, he had very little material to help him.

Of the species in the above list, *Lingula squamosa* is obscure and of doubtful value: it may have been founded on fragments of *Kutorgina*. I have not found any specimen to agree with Davidson's figure of this species (see the description of *Obolella Groomii*, sp. nov., p. 137). Phillips figured in a woodcut his so-called *Spondylobolus* (*op. cit.* p. 68), but stated no dimensions and gave no description. The figure suggests that the fossil may have been an *Acrotreta*.

There is also a list of Malvern Cambrian fossils in the Appendix to Murchison's 'Siluria' 4th ed. (1867) p. 541. It will be seen from p. 507 that the list originally drawn up by Salter was emended by Etheridge, Morris, and Jones. The list apparently contains some errors. Thus *Obolella Phillipsii* is given for the Black Shales, and *O. Salteri* for the Conglomerate and Sandstone, in which deposits they probably do not occur. *Orthis lenticularis* is also stated to occur in the Conglomerate; this statement too requires verification, as *Kutorgina* may easily have been mistaken for an *Orthis*.

The following notes and descriptions are mainly based on the examination of a number of specimens which Prof. Groom has forwarded to me for identification. The majority have been collected by himself in the course of his geological researches in the Malvern district; the remainder have been lent to him by the Museums at Oxford, Worcester, and Malvern. Some specimens have also been kindly lent to me from the collection of the Geological Survey. In studying these forms I have had the advantage of seeing Prof. Groom's own notes and sketches.

Many of the fossils are fragmentary or imperfectly preserved,

[1] 'Geol. of Oxford & the Valley of the Thames' 1871 pp. 66–68.
[2] Quart. Journ. Geol. Soc. vol. xxi, p. 72.

but several are in a fairly good condition of preservation. The identification of some small circular brachial valves found in the shales has been a matter of difficulty, because species in close agreement with respect to that valve may differ widely, even generically, as regards the pedicle-valve.

(ii) Description of the Species.

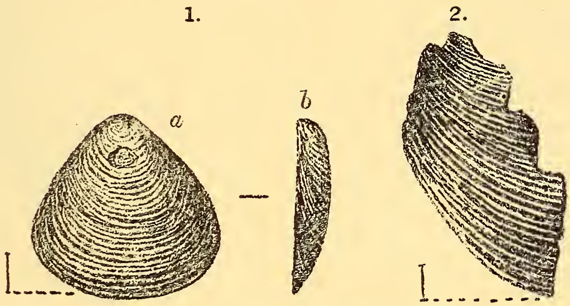
Order ATREMATA, Beecher.

Family OBOLIDÆ, King.

OBOLELLA (?) GROOMII, sp. nov. (Figs. 1 *a*, 1 *b*, & 2.)

Shell oval, moderately convex, about as long as wide, widest towards the front, which is moderately to well rounded. Lateral

Figs. 1 & 2.—Obolella (?) Groomii, *sp. nov.*, *from the Malvern Quartzite. (Prof. Groom's Collection.)*



[Fig. 1 *b* is a side-view; fig. 2 represents part of the exterior of the shell enlarged.]

margins straight or slightly convex, converging posteriorly to form a rounded beak. Hinge-area absent, or not well defined. Sides usually somewhat deflected. Surface covered by about 30 small but well-marked, concentric, rugose ridges. No radial striæ. Casts of the interior show nothing but very faint traces of markings.

Dimensions of type-specimen.—About $4\frac{1}{2}$ mm. long by 5 mm. wide. Type in Prof. Groom's collection. Other specimens measure:—

Length.	Width.
7 mm.	$5\frac{1}{2}$ mm.
$5\frac{1}{2}$	5
$4\frac{1}{2}$	$4\frac{3}{4}$

Horizon.—Malvern Quartzite (M 170, 244 *c*, & 476) associated with *Kutorgina cingulata*, var. *Phillipsii*.

Observations.—Several examples of this shell have been collected by Prof. Groom, in honour of whom the specific name is

Figs. 3-6.—Obolella (?) Salteri, *Holl.*

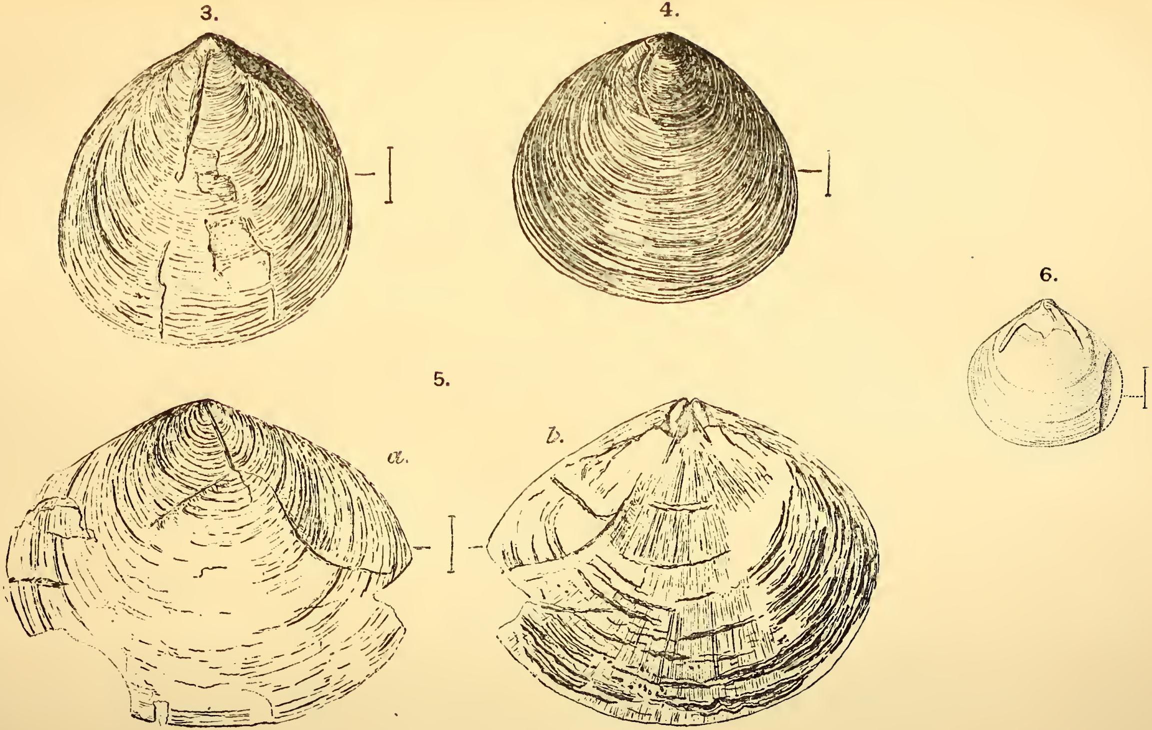


Fig. 3=Pedicle-valve from the Black Shales of White-Leaved Oak (Worcester Museum).
4=External cast of brachial valve, from the Black Shales of Malvern (Museum of Practical Geology, Jermyn Street).
5=Broad variety: (*a*) external, and (*b*) internal, cast of brachial valve, from the Grey Shales (Prof. Groom's Collection).
6=Internal cast of a valve doubtfully referred to this species; from the Grey Shales (Museum of Practical Geology, Jermyn Street).

given. With no knowledge of its internal characters, the generic reference is necessarily provisional, but the species approaches in outline and external characters some American forms of the genus *Obolella*, especially the type-species of the genus, *O. chromatica*, Bill., of the *Olenellus*-zone of Canada, from which, however, it appears to be separated by the form of the beak and the shape of the umbonal region. In any case it seems better, until the two forms can be directly compared, to keep them distinct. I have been unable to differentiate satisfactorily between the pedicle- and brachial valves, but the valve figured is probably brachial, while the pedicle-valve seems to be rather more pointed. The ornamentation is not unlike that of the associated *Kutorgina*.

I had at first some doubt whether this species might not be the imperfectly known *Lingula squamosa* of Holl, a form from the Hollybush Sandstone described (but without a figure, owing to the fragmentary nature of the specimens) in Quart. Journ. Geol. Soc. vol. xxi (1865). But Holl described his species as having imbricating growth-lines, an acute beak, and a truncated front; moreover, the figure given by Davidson,[1] which was an attempted restoration of some of Holl's fragments, shows a quite differently shaped shell.

Obolella (?) Salteri, Holl. (Figs. 3–6, p. 138.)

1865. *Obolella Salteri,* Holl, Quart. Journ. Geol. Soc. vol. xxi, pp. 101 & 102, fig. 9.

1866. *? Obolella Salteri,* Davidson, 'Brit. Silur. Brach.' Monogr. Palæont. Soc. p. 61 & pl. iv, figs. 28 & 29.

1871. *Obolella Salteri,* Phillips, 'Geol. of Oxford & the Valley of the Thames' p. 68, diagram xvii, fig. 11.

Cf. 1882. *Obolus Salteri,* Brögger, 'Die Silur. Etagen 2 u. 3 im Kristiania-gebiet u. auf Eker' p. 44 & pl. x, figs. 10 & 11; also figs. 12 & 13 (as *Lingula* sp.).

Description.—Valves slightly convex, subcircular to broadly ovate in contour, some examples about as long as wide, others rather wider than long. Sides and front well rounded. Beak of pedicle-valve marginal and more pointed than that of the brachial valve. Shell thin; surface covered with numerous fine concentric lines of growth, which at intervals are more strongly marked.

Internal casts reveal little respecting the muscular impressions. Two internal casts of brachial valves from the Grey Shales exhibit a triangular elevation beneath the umbo, bisected by a median depression, and show the impression of a hinge-area (?). These casts are also covered with very fine and inconspicuous radial striations, a feature which does not appear on corresponding external casts (compare fig. 5 *a* with 5 *b*), and is therefore an internal character only. Another internal cast (fig. 6, from the Grey Shales), which I refer to this species with much hesitation, shows a pair of elongate lateral scars and a central muscular area—in these features resembling species of the genera *Lingulella*, *Lingulepis*, and *Obolella*.

[1] 'Brit. Silur. Brach.' Monogr. Palæont. Soc. (1866) pl. ii, fig. 7.

Dimensions.—Three specimens measured:—

Length.	Width.
9 mm.	11 mm.
7	8½
5½	5½

Horizon.—The specimens have been most abundantly obtained from the Black Shales and (?) from a band of foraminiferal limestone (M 218) included in them, but they occur also in the overlying Grey Shales. I have seen no examples from any horizon lower than the Black Shales.

Observations.—Undoubted members of the genus *Obolella*, to which genus it is very doubtful that Holl's species can be assigned, are not known to occur above the Lower Cambrian; but, until the generic position of this form can be fully established, its nomenclature may as well be left undisturbed. As will be seen from the figures, the specimens vary much in the proportion of length to breadth, but there are sufficient intermediate forms between the broad and narrow varieties to warrant the belief that we are dealing with a single species. All the specimens from the foraminiferal limestone-band are exclusively of the broad type and are of large size,[1] but the broad form is also found with those of less width in both the Black and the Grey Shales.

Davidson saw only one example of this shell, which reminded him very strongly of *Obolella? (or Obolus?) plumbea*, Salter, and he seemed uncertain whether the two forms were distinct. The last-mentioned shell may, however, be readily distinguished by its numerous radial striæ, which are absent from the exterior of *O. Salteri*.

Holl's figure (also reproduced by Davidson) shows a median line extending from the umbo for about two-fifths the length of the valve, suggesting a median septum or the impression of a pedicle-slit. The examples which I have been able to examine show that this is an adventitious feature, the result of the splitting of the shell under compression. Nearly all the shells from the shales show a splitting of the valves at the umbo, and in almost every case the crack is more or less oblique to the middle line, and sometimes extends to the front of the shell.

According to Linnarsson,[2] *Obolella Salteri* forms in Sweden a zone above the *Dictyonema*-beds, and Prof. Brögger records the same species from the *Ceratopyge*-shales, *Ceratopyge*-limestone, and *Phyllograptus*-shales; but it seems very doubtful whether the Scandinavian fossil is identical with Holl's species,[3] and moreover the Malvern species appears to be found most plentifully below the *Dictyonema*-horizon.

[1] There is some doubt about the identity of these limestone-specimens, on account of their large size and greater convexity. While most of them are no bigger than large examples from the Shales, there is one (incomplete) example, to which Prof. Groom has drawn my attention, which must have measured 30 mm. across. As regards difference of convexity, the valves found in the Shales have probably been somewhat flattened by compression.

[2] See Lapworth, 'Life & Work of Linnarsson' Geol. Mag. 1882, p. 75.

[3] See the figures in Brögger's 'Die Silur. Etag. 2 u. 3 im Kristianiagebiet' 882, p. 44, pl. x.

Family LINGULELLIDÆ, Schuchert.

LINGULELLA NICHOLSONI, Callaway ?

1877. *Lingulella Nicholsoni*, Callaway, Quart. Journ. Geol. Soc. vol. xxxiii, p. 668 & pl. xxiv, figs. 11, 11 *a*, 11 *b*.
1883. *Lingulella Nicholsoni*, Davidson, 'Brit. Silur. Brach. Suppl.' Monogr. Palæont. Soc. p. 208, pl. xvii, figs. 31 & 32.

Two examples from the *Dictyonema*-beds (Grey Shales) appear to be identical with the Shropshire fossil. A fragmentary valve, too imperfect for precise identification, from the Lowest Black Shales, is possibly a small example of the same species.

LINGULELLA (?) sp. (Figs. 7 & 8.)

A cast of a tiny valve, barely a millimetre in length, occurs on a tablet (LP809) in the University Museum, Oxford, from 'Upper Black Shales, Coal Hill' (probably, according to Prof. Groom, a dark zone in the Grey Shales).[1] It shows a muscular region near the apex, and a fold of very slight elevation widening towards the front (fig. 7).

Figs. 7 & 8.—Lingulella (?) *sp.*

7. 8.

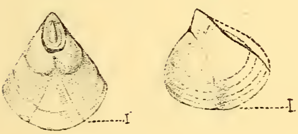


Fig. 7 = Internal cast, from the Upper Black Shales of Coal Hill (probably = Grey Shales). University Museum, Oxford.
Fig. 8 = Specimen in light-grey shale. Prof. Groom's Collection.

Another minute valve (fig. 8), of somewhat similar outline, has been found by Prof. Groom in light-grey shale (M 262). It has much the shape of *Lingula petalon*, Hicks (Davidson), a much larger form found in the Arenig.

Family LINGULIDÆ, Gray.

LINGULA PYGMÆA, Salter.

1865. *Lingula pygmæa*, Salter (Holl), Quart. Journ. Geol. Soc. vol. xxi, p. 102, figs. 8 *a* & 8 *b*.
1866. *Lingula pygmæa*, Davidson, 'Brit. Silur. Brach. Monogr. Palæont. Soc. p. 53 & pl. ii, fig. 8.
1871. *Lingula pygmæa*, Phillips, 'Geol. of Oxford & the Valley of the Thames' p. 68, diagram xvii, fig. 13.

I have seen only one specimen, an internal cast, of this obscure species, collected by Prof. Groom from the Black Shales. In size and shape it agrees fairly well with the description and figure in Holl's paper.

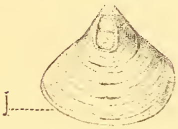
[1] Formerly all the Cambrian shales of the Malvern district were included under the term of 'Black Shales.'

Family Lingulasmatidæ, Winchell & Schuchert.

Lingula (?) sp. (Fig. 9.)

There is in the Grindrod Collection, University Museum, Oxford, an internal cast, about $2\frac{3}{4}$ mm. in length, of a small, convex, ovate shell, dilated in front and tapering posteriorly to an acuminate beak. A special feature of the fossil is a median depression on the posterior third of the cast, which appears to denote that the shell possessed a small solid 'platform.' This is of interest because, with the exception of the remarkable *Lakhmina linguloides*, from the Salt Range (Cambrian) Beds of India, platform-bearing brachiopoda have not hitherto been found in rocks older than the Ordovician. The species, which appears to be new, belongs in all probability to the Lingulasmatidæ, Winchell & Schuchert, a family which connects the Lingulidæ with the Trimerellidæ, but the characters are hardly those of the known genera (*Lingulops* and *Lingulasma*) of that family. It is to be hoped that further specimens will be discovered, which will enable the genus and species to be defined. The present reference of this form to the well-known genus *Lingula* is, of course, purely provisional; the species can scarcely belong to that genus, if the name is used in its modern restricted sense. The specimen is from the *Dictyonema*-beds, White-Leaved Oak.

Fig. 9.—Lingula (?) *sp.*



[Internal cast, from the *Dictyonema*-beds of White-Leaved Oak. University Museum, Oxford.]

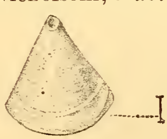
Order NEOTREMATA, Beecher.

Family Acrotretidæ, Schuchert.

Acrotreta sp. (Fig. 10.)

On the same tablet in the Oxford University Museum as the shell last described, and from the same locality, there is another fossil. It appears to be an *Acrotreta*, though unfortunately the side on which the cardinal area should be found is embedded in the matrix. The shell is $2\frac{1}{2}$ mm. in length by 2 mm. in width; it is larger than, and, I should say, of a different species from, any of those described below. It reminds me very much of the Llandeilo species *A. Nicholsoni*, Dav.

Fig. 10.—Acrotreta *sp.* *cf.* Nicholsoni, *Dav.*



[Internal cast, from the *Dictyonema*-beds of White-Leaved Oak. University Museum, Oxford.]

ACROTRETA (?) SABRINÆ (Callaway).

1877. *Obolella Sabrinæ*, Callaway, Quart. Journ. Geol. Soc. vol. xxxiii, p. 669 & pl. xxiv, fig. 12.
1883. *Obolella Sabrinæ*, Davidson, 'Brit. Silur. Brach. Suppl.' Monogr. Palæont. Soc. p. 211 & pl. xvi, figs. 27 & 28.

Several specimens found in Grey Shale, in company with *Lingulella Nicholsoni*, are in close agreement with examples from the Shineton Shales. It has been suggested[1] that this species, previously described as an *Obolella*, is an *Acrotreta*, though the pedicle-valve is much less elevated than in typical members of the genus, nor has the pedicle-furrow been observed.

ACROTRETA (?) SABRINÆ, var. MALVERNENSIS nov. (Figs. 11–14.)

Shell small, rather wider than long, or as long as wide, in outline subcircular, but somewhat truncated posteriorly by a straight hinge-line, whose width is about two-thirds of the greatest width of the valve.

Figs. 11–14.—Acrotreta (?) Sabrinæ, *var.* malvernensis *nov.*
(From the Lowest Black Shales. Prof. Groom's Collection.)

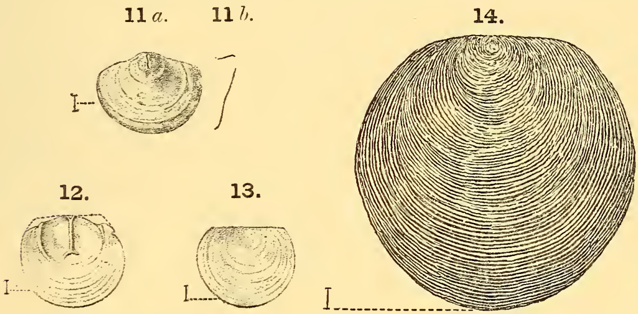


Fig. 11 *a* = Internal cast of pedicle-valve; *b* = profile of the same.
12 = Interior of brachial valve.
13 = External cast of brachial valve, slightly concave.
14 = Exterior of brachial valve, somewhat restored.

Brachial valve slightly convex for about half the distance from the umbo to the curved margin, remainder of valve flat. Umbo slightly elevated and marginal. In the interior of the brachial valve the most conspicuous feature is a rounded median septum, which extends from the hinge-line for rather more than one-third of the length of the valve, and lies within the circular depression formed by the slightly convex part of the valve. This septum thickens slightly at the hinge-line, where it terminates bluntly, and in one example it has two short processes at its anterior end (see fig. 12). A pair of muscular scars are visible near the posterior extremity of the septum.

Pedicle-valve convex, most elevated at the umbo, height about one-third the length of the valve. Umbo small, marginal,

[1] See Hall & Clarke, Pal. N. Y. vol. viii, pt. i (1892) p. 103.

projecting very slightly over the area, and pierced by a minute foramen (?). Internal casts show a short longitudinal groove at the umbo, towards the posterior end of which is a minute tubercle. The latter may be the cast of the pedicle-foramen. The 'false area' is traversed from apex to hinge-line by a pedicle-groove, and is crossed by the lines of growth. Two narrow muscular impressions diverge from near the apex of the valve, and terminate about half way towards the antero-lateral margins.

Shell-substance tenuous, consisting of a few thin laminæ. Surface of valves ornamented with very numerous, close, fine, concentric lines of growth, which at intervals are strongly marked. In well-preserved examples the finer growth-lines are little more than ·01 mm. apart.

Two specimens measured in length 2 and $1\frac{1}{4}$ mm. respectively, and in width 2·5 and 1·5 mm. respectively.

Horizon.—This is the characteristic brachiopod of the Lowest Black Shales. More than two dozen examples of the brachial valve and one dozen of the pedicle-valve were obtained by Prof. Groom from this horizon [M 257].

Observations.—Owing to the small elevation of the pedicle-valve, the reference to the genus *Acrotreta* is somewhat doubtful, but there is no question that it belongs to the family Acrotretidæ, Schuchert. In general aspect it is much like *Linnarssonia sagittalis*, Salter, but its brachial valve is flatter and its internal characters are different. It is closely allied to *Obolella (Acrotreta?) Sabrinæ*, Callaway, of the Shineton Shales, and, I think, is only a variety of that shell occurring at a lower horizon. The variety has a longer hinge-line, the ornamentation is bolder, and the internal characters are rather different from those of the typical form.

ACROTRETA sp. (cf. *A. socialis*, von Seebach). (Figs. 15 & 16.)

The pedicle-valve of an undoubted species of *Acrotreta* appears on a tablet (LP 809) in the University Museum, Oxford, marked 'Upper Black Shales, Coal Hill'; Prof. Groom thinks that the specimen comes from a dark zone in the Grey Shales. It is an internal cast, very minute, being not more than 1 mm. in length, and it shows the pedicle-groove plainly. There is a very similar valve from the Black Shales, Malvern, on a tablet in the Worcester Museum, and with it is a brachial valve of equal minuteness, which probably belongs to the same species, though it would be difficult to separate it from the corresponding valve of *Linnarssonia Belti* (Dav.).

Figs. 15 & 16.—Acrotreta *sp. cf.* A. socialis, *von Seebach.*

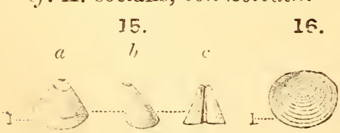


Fig. 15 *a* = Internal cast of pedicle-valve; *b* = side-view; *c* = view of the cardinal area. University Museum, Oxford.
Fig. 16 = Brachial valve, probably of this species. Worcester Museum.

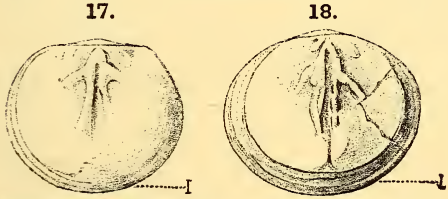
The Malvern fossil has a general resemblance to *Acrotreta* *socialis* of the *Paradoxides*-beds of Sweden, but the apex of the latter is more central and it occurs on a different horizon. A form found in the Stockingford Shales at Purley Park near Nuneaton is very similar, but possesses in addition to the concentric markings very close radiating striæ.

LINNARSSONIA BELTI (Davidson). (Figs. 17 & 18.)

1868. *Obolella Belti*, Davidson, Geol. Mag. p. 310 & pl. xv, figs. 25–27.
1871. *Obolella Belti*, Davidson, 'Brit. Silur. Brach.' Monogr. Palæont. Soc. p. 340 & pl. l, figs. 15–17. (In the explanation of the plate it is called *Obolella sagittalis*, var. *Belti*.)

There are three brachial valves of this species in the Museum of Practical Geology, Jermyn Street, from the Grey Shales, White-Leaved Oak. They are separated from *L. sagittalis*, Salter, which they much resemble, on account of their smaller size. Two of the examples are internal casts which show the characteristic features of the genus, but it is difficult to distinguish the exterior of the brachial valve from corresponding valves of the genus *Acrotreta*.

Figs. 17 & 18.—Linnarssonia Belti (*Dav.*).



[Internal casts of brachial valves, from the Grey Shales. Museum of Practical Geology, Jermyn Street.]

Order PROTREMATA, Beecher.

Family KUTORGINIDÆ, Schuchert.

KUTORGINA CINGULATA, var. PHILLIPSII (Holl).

1865. *Obolella Phillipsii*, Holl, Quart. Journ. Geol. Soc. vol. xxi, pp. 101, 102 & figs. 10 *a*, *b* & *c*.
1866. *Obolella (?) Phillipsii*, Davidson, 'Brit. Silur. Brach.' Monogr. Palæont. Soc. p. 62 & pl. iv, figs. 17–19.
1868. *Kutorgina cingulata*, Davidson, Geol. Mag. p. 312 & pl. xvi, fig. 10.
1871. *Kutorgina cingulata*, Davidson, 'Brit. Silur. Brach. Appx.' Monogr. Palæont. Soc. p. 342 & pl. l, fig. 25.
1871. *Obolella Phillipsii*, Phillips, 'Geol. of Oxford & the Valley of the Thames' p. 68, diagram xvii, fig. 12.
1883. *Kutorgina cingulata*, Davidson, 'Brit. Silur. Brach. Suppl.' Monogr. Palæont. Soc. p. 212.
Cf. 1861. *Obolella cingulata*, Billings, in Hitchcock & Hager's 'Geol. of Vermont' vol. ii, p. 948, figs. 347 & 349.
Cf. 1865. *Obolella (Kutorgina) cingulata*, Billings, Geol. Surv. Canad. 'Pal. Foss.' vol. i, p. 8, figs. 8–10.
Cf. 1876. *Kutorgina cingulata*, var. *pusilla*, Linnarsson, 'Brach. *Paradoxides*-Beds of Sweden' Bihang till k. Svensk. Vet.-Akad. Handl. vol. iii, no. 12, p. 25 & pl. iv, figs. 53–54.
Cf. 1886. *Kutorgina cingulata*, Walcott, Bull. U. S. Geol. Surv. vol. iv (no. 30) pp. 102–104 & pl. ix, figs. 1, 1 *a–h*.

The following may be added to Davidson's description of the British form :—

The shell-substance is corneous or calcareo-corneous, and composed of several layers, the inner of which are ornamented by numerous, very fine, slightly-raised, rounded radial striæ. Some examples show a triangular, deltidium-like, slightly convex bulging of the middle part of the area below the umbo, suggesting an approach to the deltidium of the genus *Iphidea.* This appears to be a new feature of the genus.[1] The breaking away or resorption of this portion of the shell would leave a triangular fissure, such as that figured for *K. latourensis*, Matthew, in Pal. N. Y. vol. viii, pt. i, pl. iv, fig. 20.

There is no doubt that the Malvern shell is very closely allied to the American *K. cingulata*, yet there seems sufficient reason for retaining Holl's designation of *Phillipsii* as a varietal name. The Malvern shells are much smaller than the maximum size of the American form. The average dimensions of those forwarded to me by Prof. Groom are about 4½ mm. long by 6½ mm. wide, the largest measuring 7 by 10 mm. Davidson figured a large example, which when complete must have been about 11 mm. long by 16 wide, but even this has only half the dimensions of an example from America figured by Walcott.[2] The American species appears to be more convex than the British, especially in the neighbourhood of the umbo, and the shell-substance of the former is calcareous, according to Walcott, while in the Malvern examples it is phosphatic.

Prof. Groom's specimens are from the Malvern Quartzite (M 170, M 244, M 244 *c*) and Hollybush Sandstone (M 323 b^{iv}, M 443). Species of the genus *Kutorgina* are mainly characteristic of the *Olenellus*-fauna, but in America *K. stissingensis* is found at a rather higher horizon. In Sweden, *K. cingulata*, var. *pusilla*, Linrs. (see below) occurs in the zone of *Paradoxides Forchhammeri* and in strata with *Agnostus lævigatus*, while one species, *K. minutissima*, is found in the Secret Cañon Shales (Middle Cambrian) and the Hamburg Shales (Upper Cambrian) of North America.[3]

KUTORGINA CINGULATA, var. PUSILLA, Linrs. (Figs. 19 & 20, p. 147.)

1876. *Kutorgina cingulata*, var. *pusilla*, Linnarsson, 'On the Brachiopoda of the *Paradoxides*-Beds of Sweden' Bihang till k. Svenska Vet.-Akad. Handl. vol. iii, no. 12, p. 25 & pl. iv, figs. 53–54.

The Lowest Black Shales (M 257) have yielded several fragments and one complete valve of a *Kutorgina* which differs from that found in the Hollybush Conglomerate and Sandstone mainly in its smaller size. The valve just mentioned is a brachial valve, and measures about 1·75 mm. in length by 2 mm. in breadth; an incomplete pedicle-valve of a rather smaller individual has also been found (fig. 19), and the fragments belong to rather larger specimens, probably about 4 mm. wide. They appear to be identical with the

[1] Since writing the above, I find that the presence of a deltidium has been observed in the American *K. cingulata*; see Beecher, Amer. Journ. Sci. ser. 3, vol. xliv (1892) p. 138, quoted and remarked upon by Hall & Clarke, Pal. N. Y. vol. viii, pt. ii (1894) p. 327.

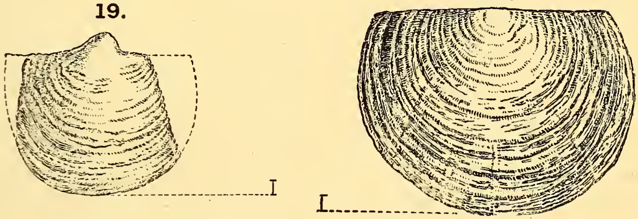
[2] 'Fauna of the *Olenellus*-zone' Tenth Ann. Rep. U.S. Geol. Surv. 1888–89 [1890] pl. lxix, figs. 1 & 1 *a–b*.

[3] Frech, 'Lethæa palæozoica' vol. ii, pt. i (1897) pp. 44 & 45.

Swedish variety *pusilla*, a form which Linnarsson found as a rare fossil in the highest *Paradoxides*-zones of Sweden—that is to say, in the zones of *P. Forchhammeri* and of *Agnostus lævigatus*. Linnarsson's specimens measured 3 mm. in length by 4 mm. in breadth. The brachial valve shows some radial plications not described in the Swedish variety.

Figs. 19 & 20.—Kutorgina cingulata, *var.* pusilla, *from the Lowest Black Shales. (Prof. Groom's Collection.)*

19. 20.



[Fig. 19 = Pedicle-valve; fig. 20 = Brachial valve.]

In Europe, up to the present, no species of *Kutorgina* has been detected above the *Agnostus-lævigatus* zone; but in North America, as stated on p. 146, *K. minutissima* is said to occur in the Secret Cañon Shales of Middle Cambrian age and in the Hamburg Shales of Upper Cambrian age.

(iii) Summary of the Species and their Distribution in the Malvern Cambrians.

Names of the Species.	Malvern Quartzite.	Hollybush Sandstone.	Lowest Black Shales.	Black Shales.	Foraminiferal Limestone in Black Shales.	Grey Shales.
Obolella (?) Groomii, sp. nov. ...	*					
O. (?) Salteri, Holl	...	...	...	*	?	*
Lingulella Nicholsoni, Call. (?) ...	...	...	?	...	...	*
L. sp.	...	...	...	...	...	*
L. sp. (cf. *L. petalon*, Hicks) ...	...	...	...	...	...	*
Lingula pygmæa, Salt.	...	...	...	*		
L. (?) sp.	...	...	...	...	...	*
Acrotreta sp.	...	...	...	...	...	*
A. (?) Sabrinæ (Call.)	...	...	...	...	...	*
A. Sabrinæ var. *malvernensis* nov.	...	...	*			
A. sp. (cf. *A. socialis*, von Seeb.)	...	...	...	...	...	*
Linnarssonia Belti (Dav.)	...	...	...	...	...	*
Kutorgina cingulata,						
var. *Phillipsii* (Holl)	*	*				
var. *pusilla*, Linrs.	...	...	*			

Discussion.

Prof. Lapworth spoke of the excellent work done by the Author in unravelling the complicated geology of the Malvern Hills, and congratulated him and the Society upon the interest and importance of the present communication.

With regard to the Hollybush Quartzite, it seemed desirable that some alternative name should be suggested for the sake of distinction. He agreed with the Author in his reference of the Hollybush Group as a whole (including the Quartzite) to the general geological period embracing the so-called Etcheminian, the *Olenellus*-zone, and the Paradoxidian. We ought, however, carefully to bear in mind that as yet the *Olenellus*-zones marked by forms similar to *Olenellus Thompsoni* and those marked by forms of the type of *Holmia* (*Olenellus*) *Kjerulfi* have not yet been demonstrated to be contemporaneous; and also that the Etcheminian fauna, claimed as pre-Cambrian by some, is as strenuously claimed as Cambrian by others. It is certainly safest in the meantime to refer all these pre-Paradoxidian fossil-bearing beds to the Lower Cambrian.

It is not unlikely, as the Author has suggested, that the higher parts of the Malvern Hollybush Sandstone Series answer to the much thinner and less arenaceous beds of the Purley Shales of Nuneaton. This correlation would harmonize with the known thinning of the Cambrians when followed eastward into Europe, and also with their thickening and the coming-in of more arenaceous deposits when followed in the contrary direction, as for example into the Harlech district, where Dr. Stacey Wilson and himself, in mapping that country, had found that the Lower Cambrians were represented by several massive arenaceous formations separated by shaly zones.

As respects the carrying downward of the systematic base of the Ordovician System from the bottom of the Upper Tremadoc (Lower Arenig of Hicks), where it was originally drawn, to the bottom of the Lower Tremadoc as proposed by the Scandinavian geologists, there could be no question that, as the term 'Ordovician' was suggested as a title for the rock-formations containing the second Lower Palæozoic fauna, the geological horizon which most naturally and conveniently divided the first from the second fauna must, in the nature of things, be the base-line of the Ordovician System. The credit of showing that such was the most natural line of division between the Cambrian and the Ordovician in Europe belonged solely to Linnarsson and Brögger. Linnarsson selected this line as the base of the Scandinavian Ordovician many years ago; and Prof. Brögger, in his recent brilliant paper on the '*Euloma-Niobe* Fauna,' has shown that it appears to be the most natural basement-line all over the world. Moberg's further proposal to include also the Scandinavian *Dictyonema-flabelliforme* zone in the Ordovician is quite justifiable, and has been already adopted by some. But to what extent the *Dictyonema*-zones of other regions answer to the *Dictyonema*-zone of the Baltic basin, we have yet to discover; and graptolithologists await with keen interest the results of Holm's revision of Eichwald's typical *Dictyonema flabelliforme,* so that they may separate out satisfactorily the various forms which, on both sides of the Atlantic, have hitherto been provisionally grouped under that name and that of *Dictyonema sociale.* So gradually do the typical Cambrian and Ordovician faunas shade one into the other in most regions, and so convenient is it for mapping purposes to select a lithological break as the dividing-line, that it will probably be found that for some years to come we must content ourselves in many districts with drawing an approximate boundary-line between the two.

Mr. Philip Lake remarked that the trilobites which had been found in the White-Leaved-Oak Shales belonged to the Upper *Lingula*-Flags; but it appeared from the Author's correlation with the Warwickshire sequence, that the Lower *Lingula*-Flags might also be represented. There seemed, however, to be an entire absence of Middle *Lingula*-Flag forms; and he asked whether this apparent absence was due to an unconformity, or to a fault, or merely to the fact that no fossils had yet been found in the intervening beds.

With regard to the limits of the Cambrian and the Ordovician, the Tremadoc Slates were undoubtedly passage-beds, and the selection of any particular horizon as the boundary was largely a matter of convenience. Palæontologically, at least so far as the trilobites are concerned, the Tremadoc Series, as a whole, appears to be more closely related to the Ordovician than to the Cambrian.

The Author said that he was glad that his work had led him to conclusions so closely in agreement with the views of Prof. Lapworth. With reference to the term '*Olenellus*-zone,' he might say that it had been used in a wide sense employed by many geologists. He added that since the similarity of the names 'Hollybush Sandstone' and 'Hollybush Quartzite' might lead to confusion, he was quite prepared to adopt Prof. Lapworth's suggestion, and proposed to employ a new term in place of the latter. He had not entered into the specific differences between the *Dictyonemas* of the *Dictyonema*-shales, but had simply regarded them either as forming or as not forming a definite zone, which might be simple in character, or complex like that of *Sphærophthalmus.*

In reply to Mr. Lake, he said that beds representing the Middle *Lingula*-Flags might be present, though concealed, in the Malvern district.

9. Coal- *and* Petroleum-Deposits *in* European Turkey. By Lieut.-Colonel Thomas English, F.G.S. (Read December 18th, 1901.)

[Plate IV—Map.]

In the following paper I have attempted to give an account of the general succession, so far as at present known, of the formations which include some recently-discovered coal-seams and naphtha-bearing sands of Tertiary age, in the little-visited stretch of country lying to the north of the Gulf of Xeros in the Mediterranean and of the western portion of the Sea of Marmora.

The absence of any map sufficiently detailed for geological purposes renders it somewhat difficult to interpret various interesting features, and I feel that apology is due beforehand for many errors and omissions arising from this cause.

By far the best map is that compiled by the Russian military staff, on the scale of about half an inch to a mile, and the geological sketch-map which accompanies my paper is reduced from this. The Russian map is furnished with approximate contour-lines, apparently 10 sagenes (=70 feet) apart; but these are only sketched in, and though amply sufficient for military purposes, do not give much geological information in so broken a country. I have therefore only transferred sufficient heights in feet to the sketch-map to give a general idea of the relief.

There is but little written description accessible of the geological features of the district. The only original information that I have been able to find is contained in Ami Boué's 'La Turquie d'Europe,'[1] 1840, and in Viquesnel's 'Voyage dans la Turquie d'Europe,' 1868. The former[2] gives a short general summary of the composition of the Tertiary formation in Thrace. Viquesnel, in the atlas accompanying his book, shows a traverse-sketch of his itinerary, and also furnishes short descriptions of the rocks and fossils met with on the road. Some of the fossils were subsequently identified by Vicomte d'Archiac, and are described in an appendix to Viquesnel's second volume.

There is also a paper by F. von Hochstetter in the Jahrbuch der k.-k. Geologischen Reichsanstalt, 1870,[3] but he states definitely (on p. 387) that he is dependent for his information, as to the district here dealt with, on Viquesnel, and that he had not himself visited the neighbourhood. Probably as a consequence, dependence cannot be placed in all points upon the geological map which accompanies his paper, so far as it relates to the localities which I propose to describe.

[1] Paris 1840, 4 vols. 8vo, with map.

[2] *Op. cit.* vol. i, pp. 319 *et seqq.*

[3] 'Die geologischen Verhältnisse des östlichen Theiles der europäischen Türkei' pp. 365–461 & pl. xviii (geological map).

These are included in a tract of country about 24 miles wide in a north-and-south direction, bounded on the west by the alluvial valley of the River Maritza, and on the south by the northern shore of the Gulf of Xeros; and in a littoral strip about 4 miles wide skirting the northern coast of the Sea of Marmora for about 32 miles, from abreast the head of the Gulf of Xeros to Ganos, opposite the western end of Marmora Island.

Hochstetter remarks (*op. cit.* p. 387) that

'this much, at any rate, can safely be derived from Viquesnel's account, that the core of this coastal chain of mountains is formed of old crystalline rocks (Viquesnel indeed generally mentions "terrain de transition") and chiefly of rocks of the "phyllite-zone" which are enveloped and overlain by Eocene Nummulitic limestones and sandstones, and by late Tertiary sandstones, limestones, clays, and marls.'

His map accordingly shows a large extent of 'pro-zoic' clay-slate (phyllite) which, so far as I can ascertain, has no existence, the area being occupied by Eocene strata and contemporaneous or younger volcanic rocks. It is true that Viquesnel often suggests 'terrains de transition,' but always with considerable reserve, and Vicomte d'Archiac, at the commencement of the description of fossils ('Voyage dans la Turquie d'Europe' vol. ii, 1868, p. 450) says:—

'We have not found, in the collection made by Viquesnel of fossils from Thrace, a single specimen belonging to transitional or even to old Secondary faunas. The only ones that denote the existence of late Secondary rocks are very few in number and come from two different localities.'

The lowest beds that I have seen are thinly-bedded hard blue coralline and softer brown Nummulitic limestones of Lutetian age. These crop out at the village of Vernitza (about 9 miles north-east of Ibridji on the Gulf of Xeros), where they show a north-westerly dip of about 15°, and are overlain conformably by blue shales. The junction-beds are one mass of nummulites, closely allied to *Nummulites complanata* and *N. biarritzensis*, of all sizes up to 2 inches in diameter, weathering into a gravel entirely composed of these fossils.

The outcrops of Eocene strata apparently form a belt stretching in an easterly-and-westerly direction for about 40 miles, as Viquesnel notes similar fossils at Margarice, 3 miles south of Vernitza; and Vicomte d'Archiac identifies *Nummulites Ramondi* and *Orbitoides sub-media* in yellowish compact limestone, subcrystalline, with splintery fracture, from Bournar Oren near Examil, on the isthmus between the Gulf of Xeros and the Sea of Marmora.[1] He also notes *Nummulites biarritzensis* and *N. Ramondi* in brownish-grey limestone from Mount Serian, 2 leagues north-east of Kavak, and again *N. Ramondi* in yellowish-grey compact limestone with waxy fracture from Mount St. Elias, near Sterna.[2]

At the last-named locality, the conical summit of the mountain, 2300 feet above the sea, is a mass of coarse marble dipping 20° south-eastward, with seams of calcite weathering into distinct crystals about a quarter of an inch along their edges. The eastern and

[1] *Op. cit.* pp. 324, 466, 467. [2] *Ibid.* p. 457.

south-western slopes of Mount St. Elias are also formed of thickly-bedded limestone.

At Vernitza, the blue shales overlying the Nummulitic limestone, which are about 70 feet thick, are covered conformably by brownish-grey calcareous sandstones with rectangular partings. These strata, with occasional volcanic interruptions, form the principal features of the country, and apparently stretch continuously nearly 50 miles to the eastward, to Ganos and Combos on the Marmora coast.

A fault, or series of faults, running north-east and south-west, with a south-easterly downthrow, marks out the course of the Deli Osman River for about 5 miles north-east of Mount St. Elias, and no Eocene limestones or sandstones are visible south-east of this line. North-west of it, the sandstones, with a northerly and north-westerly dip of 20° to 30°, form a continuous ridge from near Mount St. Elias for 10 miles, until they reach the sea at Ganos. Eastward from this point they form high cliffs along the coast, dipping 30° inland, and rise quickly into the mountain-mass of the Tekfur Dagh (Holy Mountain) about 3000 feet high, 3 miles inland from Ganos, which is the highest ground in the district.

The sandstones are generally fine-grained, grey or greenish in fresh fractures, weathering to a dark brown, and breaking into rectangular fragments, often with calcite-partings; they contain thin subordinate beds of clay and shale, and few, if any, recognizable fossils. With occasional interruptions of basalt and rhyolite, they extend over a large area, perhaps three-quarters of the whole extent of country described, and form a belt with several parallel folds and a general east-north-easterly and west-south-westerly strike. They skirt both sides of the upper portion of the Gulf of Xeros, and probably extend across its bed.

Like all the other formations seen, they are concealed at intervals under a mantle of reddish, unstratified, sandy clay unconformably overlying them, and containing small angular fragments of sandstone which generally do not exceed a few cubic inches in volume.

The sandstones and associated beds are at least 3000 feet thick, both on the coast-section east of Ganos and in the western portion, along a south-easterly and north-westerly section following the road from Examil to the town of Keshan, a distance of 24 miles, approximately at right angles to the line of strike.

On this section, at the southernmost point exposed, near the village of Examil, the strata dip 30° to 15° northward for 2 miles. The head of the Gulf of Xeros, 6 miles wide, is covered by alluvium and stony clay, through which some small basaltic knolls appear. Near the village of Kodja-chesme the sandstones reappear with a south-easterly dip of 60° to 30°; and the ground rises rapidly to a well-marked anticlinal 3 miles beyond this point, with a north-easterly and south-westerly strike, which forms the ridge of the Kuru Dagh range of hills, about 1400 feet high, skirting the northern shore of the Gulf of Xeros.

North-west of this point the dip is generally north-north-westerly 10° to 30° where it can be seen, for about 3 miles, when the sequence of the sandstones is interrupted for 2 miles by a mass of scoriaceous olivine-basalt with palagonite. The sandstones are then covered by stony clay and alluvium for 4 miles, as far as the village of Teke-keui (about 4 miles from Keshan), where they reappear dipping 20° northward, and the road skirts another large mass of basaltic rock (melaphyre) as far as Keshan.

I have not been able to determine satisfactorily whether these masses of basalt are intrusive or interbedded with the sandstones, but the general dip of the strata does not seem to be affected by them. Several similar basaltic masses appear among the sandstones and higher strata to the south-west in a chain stretching eastward from the large volcanic mass forming the Enos mountain.

Beyond Keshan to the north-west and north, the sandstones continue to dip in a northerly direction at moderate angles into a synclinal basin, 8 miles across from south to north, along the edges of which the outcrops of several seams of coal have been traced.

One seam in particular crops out for a distance of at least 3 miles along the southern edge of the basin, at about 400 to 500 feet above sea-level, from a point 1 mile north-east of Keshan; and the same seam, to all appearance, occurs again at Boztepe, 6 miles west of Keshan. Along the north-western edge of the basin, following a curved line passing through the villages of Boztepe, Beyendikeui, and Mousali, the sandstone-strata generally dip steeply south-eastward.

A considerable fault, with a downthrow to the north of at least 90 feet, dislocates the coal-seam at Boztepe; but the general features of the basin are so much concealed by stony clay, that the extent of this, and of other probable faults can only be ascertained by future underground workings.

The coal is now being worked near Keshan, where it is from 3 to 3½ feet thick, and consists of a bituminous hard coal with the characteristic features of cannel, burning with a long flame and little smoke. The coal is non-coking, does not soil the fingers, and breaks with a cubical, occasionally a conchoidal fracture. The specific gravity is about 1·37, and good samples yield about 2 per cent. of grey ash. Near the outcrop, so far as the workings have as yet gone, the coal is deposited directly on the sandstone and has a hard clay-roof about 2 feet thick, in which many impressions of dicotyledonous leaves occur.

A remarkable feature in connection with this deposit is the occurrence above the coal, and generally separated from it by about 40 feet of shales, clays, and sandstones, of a thick layer (usually 40 to 50 feet) of brecciated rhyolite. This layer is very persistent, and has possibly had some influence in the conversion of lignite into true coal. Overlying the coal near Mousali, on the northern edge of the basin, there is a layer of decomposed andesite, with much biotite. Near the centre of the basin, 4 miles north of Bulgarkeui, is an outcrop of augite-syenite forming a large knoll; and outside the basin, at Kurujekeui on the north-west, there is a considerable outcrop of mica-basalt, with biotite and augite.

A section of a trial-boring, striking the coal at 122 feet from the surface, is appended; and I consider that this may be taken as a fair sample of the average formation immediately above the coal, so far as yet known :—

Section of borehole above the coal between Keshan and Bulgarkeui.

Dip N. 25° E. at 33°.	Vertical thickness. Feet.	Inches.
Red stony clay	34	0
Volcanic ash and conglomerate (Rhyolite)	48	7
Sandstone with black layers	6	7
Coaly mixture	1	6
Shale and clay	5	4
Sandstone	1	6
Shale and clay	5	4
Coaly mixture	0	11
Shale and clay	11	4
Sandstone	0	6
Shale and clay	5	6
Chocolate-coloured ground	0	10
COAL	3	4
Sandstone	1	6

There are many indistinct leaf-impressions in the sandstone-beds above and below the coal, but no other fossils have yet been discovered in the sandstones, which in this neighbourhood, especially below the coal, are very thickly-bedded and free from joints, greenish-grey in colour, and form admirable building-stones. Some of the cores produced by diamond-drilling have been brought to the surface in lengths of 4 or 5 feet, and some of the beds are sufficiently tenacious and gritty to be worked for grindstones.

A boring 225 feet deep, immediately below the coal, yielded the following section :—

Section of borehole below the coal between Keshan and Bulgarkeui.

Dip N. 25° E. at 15°.	Vertical thickness. Feet.	Inches.
Grey sandstone	7	6
Blue shale	5	0
Grey sandstone	5	6
Blue shale	20	0
Grey sandstones intermixed with blue shales	17	0
Grey sandstone	12	0
Grey sandstone with shale	4	0
Grey sandstone	3	0
Dark blue shale (rough-grained)	20	0
Blue shale (lower 3 in. clay)	16	3
Blue shale intermixed with grey sandstone	14	9
Grey sandstone, with layers of blue shale	27	6
Blue shale, with layers of sandstone	45	0
Grey sandstone, with layers of shale	8	6
Blue shale, with layers of sandstone	22	0

As I have not been able to find a complete section of the sandstones free from interruption by basalt or stony clay, I cannot say definitely whereabouts in the series the coal occurs, but I am inclined to place it not far from the middle; there are more shale-beds interstratified with the sandstones near the coal-horizon than far above or below it.

A seam of coal of similar quality, also interbedded with these sandstones, and 2 feet 4 inches thick, crops out at Capoudjidere, 3 miles north-east of Examil, at the head of the Gulf of Xeros. The sandstones and coal are here dipping 50° south-eastward, directly into the hill which forms the southern slope of the Kavak river-valley, at about 400 feet above sea-level.

A layer of brecciated rhyolite is interstratified with the sandstone-beds between the villages of Kiskapan and Grabuna, and may probably be the same as that at Keshan, but no coal has yet been found in connection with it.

Much-disturbed beds of doubtful age occur to the south-west of this, apparently overlying the sandstones. Among them are several outcrops of palagonite-tuff, interstratified with thinly-bedded shales, which come to the surface near the village of Geltic. In one specimen microscopic foraminifera (*Globigerina*) are included in the tuff. A sample of fragmental, possibly reconstructed limestone from near Bekeui contains a few small *Nummulites biarritzensis* and other foraminifera:—*Carpenteria*, *Operculina complanata*, *Orbitoides papyracea*, and *O. sumatrensis*; also angular quartz-granules, pieces of dolomite, and probably palagonite.

In apparent connection with these beds is a series of variegated clays and sands. Similar clays appear to the east of Mount St. Elias, where they are tilted to very steep angles, and are of considerable thickness, perhaps 500 feet. The upper tributaries of the Deli Osman River have cut deep gorges through these beds, in which mineral springs occur.

A large expanse of hard limestones overlying the above-mentioned tuffs includes the sea-cliffs near Ibridji, on the Gulf of Xeros. These strata are generally grey, very hard, semi-crystalline, and sometimes thickly-bedded. A specimen from Ibridji was largely composed of foraminifera, *Lithothamnion*, polyzoa, and ostracoda. The recognizable foraminifera belong to the genera *Spiroloculina*, *Planispirina*, *Textularia*, *Anomalina*, and *Heterostegina*. Another specimen from about 3 miles north of Ibridji, of fragmental limestone with much calcitic cement, was also composed largely of foraminifera, *Lithothamnion*, and polyzoa, containing *Miliolina*, *Globigerina*, *Pulvinulina*, *Amphistegina*, and *Heterostegina*.

Near Erekli, on the coast 4 miles west of Ibridji, and at Fakirma village north of this, a capping of soft friable limestone-beds of Miocene (Helvetian) age occurs, containing *Pecten subbenedictus*, *Ostrea*, and *Cardium*. These Miocene rocks apparently extend westward along the coast as far as Cape Gremia at the mouth of the Gulf of Xeros, occupying all the country to the south of the Enos Mountain.

In the north and north-west the Eocene sandstones are occasionally overlain by soft sandy strata, probably Pliocene, containing *Melanopsis* allied to *M. Martiniana*, at a point $1\frac{1}{2}$ miles north of Boztepe, and numerous casts of *Corbula Saulcyi*, *Cardium*, and *Dreissensia* near Ghonue and Malgara; also *Cardium Paulini* and *Corbula Saulcyi* at Maltepe.

In the district south-east of the fault which stretches from Mount St. Elias to Ganos a series of sands, marls, and clays occur, with which naphtha-bearing beds are interstratified. The lowest beds visible are clays containing indeterminate Unioniform shell-remains, probably Pliocene; the beds above are generally light-coloured and very variable in composition.

From the junction of the Deli Osman River with the Milos Brook, 320 feet above the sea, the river runs 3 miles eastward to the village of Hora, where it falls into the Sea of Marmora. At this junction naphtha in fair quantity, and under considerable gas-pressure, has been obtained from borings about 300 feet deep. Appended is the section of a borehole, $1\frac{1}{2}$ inches in diameter, which has yielded at the rate of 2 tons in 24 hours.

Section of naphtha-borehole, at the junction of the Deli Osman River and the Milos Brook.

	Feet.	Inches.
Yellow loam and boulders	35	6
Grey marls	4	6
Grey sandy limestone	1	0
Blue and red marls	12	0
Hard grey limestone	0	6
Grey marls	4	6
Limestone (chalky)	0	6
Clay	0	6
Limestone	0	6
Marls	11	6
Soft calcareous conglomerate	2	0
Marls	18	0
Sandy marls	4	0
Hard limestone	0	4
Sandy marls	11	8
Blue and red marls	32	0
Running sand with brackish water	3	0
Yellow clay	4	0
Blue, red, and yellow marls	30	3
Cream-coloured limestone	0	3
Blue and yellow marls	47	0
NAPHTHA.		
Limestone	0	6
Marls	15	6
Hard limestone	0	9
Marls	15	0
Sandy marls	28	0
NAPHTHA.		
Yellow clays	0	6
Grey marls.		

The naphtha has a specific gravity of about 0·825, and contains about 10 per cent. of paraffin; it is accompanied as usual by a flow of bitter-salt water.

The naphtha-sands and marls, with a thickness of perhaps 1000 feet, occupy the surface from Sarkeui eastward as far as Ganos, for a length of about 15 miles along the coast, and extend inland for an average breadth of about 3 miles. The strata are very much disturbed over the whole area, and are nearly vertical in places. The only fossil that I have seen from them is a specimen of a small variety of *Melanopsis*. West of Sarkeui the naphtha-sands are hidden by red stony clay, but show in many of the gorges.

Indications of naphtha, in the shape of sands with a strong smell of petroleum and surface-oozings of bitumen, occur at many points between Ganos and Sarkeui. Several beds of lignite, 12 to 18 inches thick, are intercalated. North-eastward from the naphtha-borings, these sands and marls can be traced for about $1\frac{1}{2}$ miles, nearly as far as the village of Milos, where they have a conglomerate-capping containing *Planorbis* and *Cyrena*, and dipping 30° northward.

It has hitherto proved impracticable to determine from the surface whether the Eocene sandstones and limestones exist under the Pliocene strata; but a deep boring now proposed will probably settle this point, and also the presence or absence of the coal-horizon in this part of the country.

The stony clay, which has several times been referred to, is spread unconformably over all the formations already described. In general it occupies the lower grounds, but has no apparent connection with the present drainage-system. At Ibridji it covers a limestone-saddle about 420 feet above the sea-level. In many places it is of considerable thickness, and a shaft sunk in it to a depth of 170 feet near Boztepe has not reached the bottom. At the eastern end of the district, it abuts against the flanks of the sandstone-mountains of the Tekfur Dagh to a height of about 1000 feet, and forms a considerable mass, covering a saddleback which forms the water-parting of the Ganos and Milos Brooks, and stretching down both valleys towards the sea, with a thickness, where exposed in a ravine leading to the Ganos Brook, of at least 100 feet, and a surface-slope of about 4° from the mountain.

Many scratched and striated sandstone-boulders (see figure, p. 158) occur in the clay near Milos village, at 900 to 1000 feet above the sea-level. Lower down the Milos Valley near the naphtha-borings, the mass changes in character, and becomes much more stony and full of subangular and facetted sandstone-boulders, which fill up the valleys through which the Deli Osman River and Milos Brook run. The existing streams have cut their way through this deposit, rearranging the boulders and carrying them down the valley towards the beach at Hora. Neither the upper nor the under surface of the stony mass agrees at all in slope with the existing river. One of the borings for naphtha, starting from the river-level, passed through 60 feet of clay and boulders; while half a mile above the naphtha-borings, in the Deli Osman Valley, there is a cliff-section

Scratched sandstone-boulder, Milos. (Length=about 2 feet.)

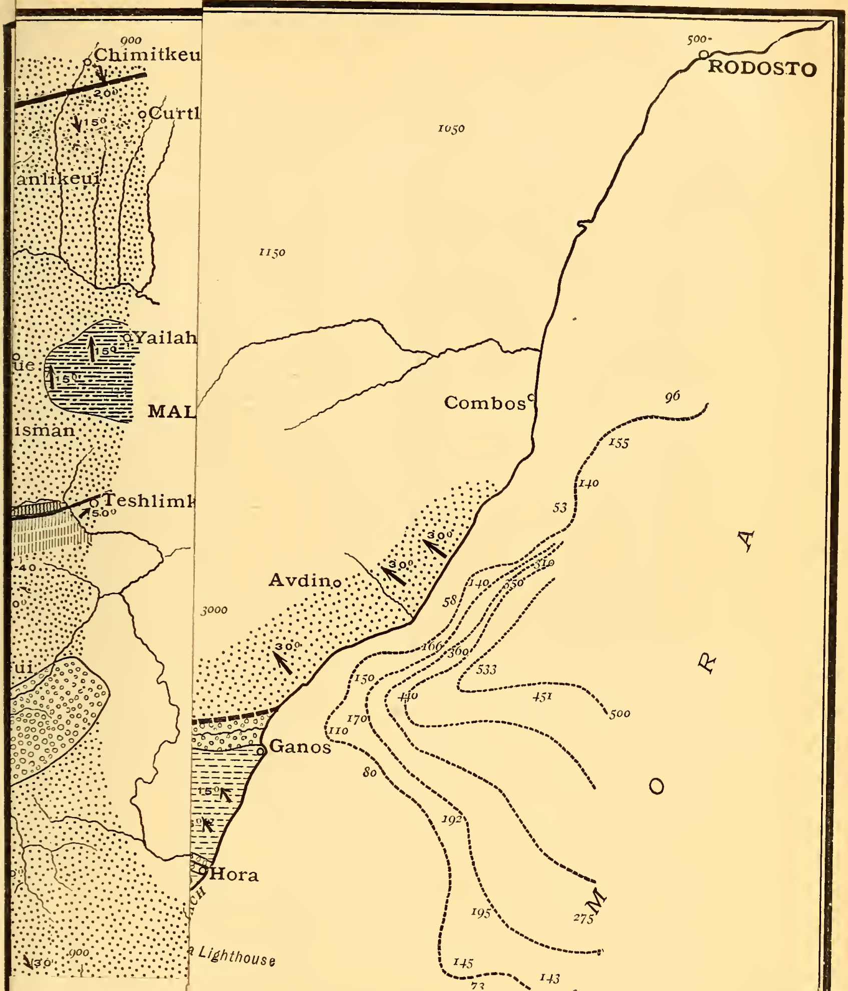
[From a photograph.]

60 feet high from the river-level, composed of 40 feet of boulders and clay, with a capping of sand slipped down from the naphtha-bearing strata.

At the naphtha-borings, the upper surface of the stones is about 12 to 17 feet above the river-level, and presents a series of parallel ridges, about 5 feet high, curving diagonally, with a downstream convexity, across the Milos Valley. These ridges are full of boulders up to 3 tons in weight, and have a general surface-slope down the valley of 3°. The river-slope is 1°, and no boulders of more than 5 cwt. are visible in the channel.

The stony clay merges similarly into a mass of stones in the Ganos Valley, as the sea is approached. This valley is prolonged into the Sea of Marmora to a very remarkable depth, rivalling the deepest fiords of Norway: soundings of 533 fathoms being shown on the Admiralty Chart about 4 miles east-north-east of Ganos and within $1\frac{1}{2}$ miles of the coast, which at this point is formed by the steep sandstone-cliffs of the Tekfur Dagh, dipping 30° inland. Farther west there are scarcely any soundings of 50 fathoms for more than 100 miles towards and through the Dardanelles.

At the Hora Lighthouse, about 1 mile to the south-west of the river-mouth, a very well-marked 'raised beach' occurs at 130 feet


Chimitkeu
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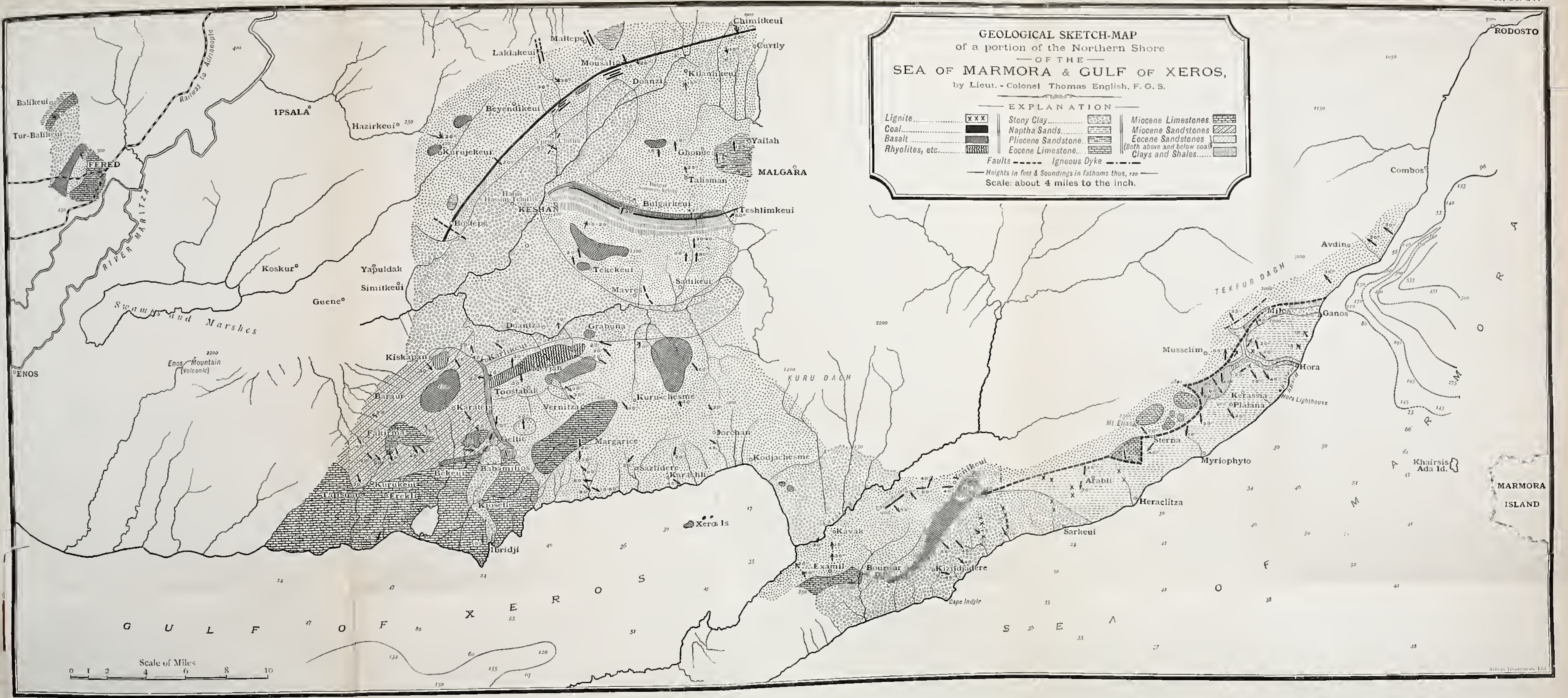
GEOLOGICAL SKETCH-MAP
of a portion of the Northern Shore
—OF THE—
SEA OF MARMORA & GULF OF XEROS,
by Lieut.-Colonel Thomas English, F. G. S.
EXPLANATION
Lignite
Coal
Basalt
Rhyolites, etc.
Stony Clay
Naptha Sands
Pliocene Sandstone
Eocene Limestone
Miocene Limestones
Miocene Sandstones
Eocene Sandstones (Both above and below coal)
Clays and Shales
Faults
Igneous Dyke
Heights in feet & Soundings in fathoms thus, 220
Scale: about 4 miles to the inch.
Scale of Miles
0 1 2 4 6 8 10
GULF OF XEROS
SEA OF MARMORA
RODOSTO
MARMORA ISLAND
Khairsis Ada Id.
Xeros Is
ENOS
Enos Mountain (Volcanic)
IPSALA
FERED
Balikeui
Tur-Balikeui
Railway to Adrianople
RIVER MARITZA
Swamps and Marshes
Koskur
Guene
Yapuldak
Simitkeui
Hazirkeui
Laklakeui
Maltepe
Mousalie
Chimitkeui
Curtly
Kilanikeui
Doanzi
Beyendikeui
Kurujekeui
Ghonue
Yailah
MALGARA
Talisman
KESHAN
Bulgarkeui
Teshlimkeui
Bostepe
Tekekeui
Sadikeui
Mavres
Doantza
Grabuna
Kiskapan
Karlikeui
Toostabal
Vernitza
Kuru-chesme
Baraur
Karatepe
Geltie
Margarice
Dorehan
Kodjachesme
Sazlidere
Karabli
Bekeui
Babamilios
Kurukeui
Ereklí
Kiosetle
Ibridji
KURU DAGH
TEKFUR DAGH
Avdin
Combos
Milos
Ganos
Musselim
Hora
Hora Lighthouse
Kerassia
Platana
Mt. Elias
Sterna
Myriophyto
Afabli
Heraclitza
Sarkeui
Kavak
Examil
Bourgar
Kizildjadere
Cape Indjir
Artists Illustrators, Ltd.

above the present sea-level. The remains consist of rounded sandstone-pebbles up to 2 inches in diameter, cemented into a strong concrete by a calcareous matrix. Where the underlying sands, which dip about 10° north-eastward, are weathered out, large tabular masses of concrete, 3 and 4 feet thick, have tumbled down the slope; but the upper surface, where preserved, is singularly level, and can be traced for ¾ mile along the coast.

The lighthouse is built on the most salient remaining knoll. The natural concrete contains, between the pebbles, abundant specimens of the recent fluviatile shell *Dreissensia polymorpha*, and a *Neritina* (probably *N. danubialis*), showing that, at the time of the formation of this beach, the Dardanelles Channel could not have been open to its present depth. The fresh water within the Sea of Marmora must, at that epoch, have stood at a sufficient height to collect the drainage of the whole of South-eastern Europe and Western Asia, an area of at least 2,000,000 square miles, into a freshwater sea, from which the volume of water discharged would, even with the present small rainfall, not be less than twice that of Niagara.

The Dardanelles Channel is itself a gorge cut back through soft horizontal Miocene strata, with every appearance of rapid erosion by falling water.

At Myriophyto, 6 miles west of Hora, there are obscure traces of a pebble-conglomerate at about 330 feet above sea-level; but I could not find enough material *in situ* to enable me to speak with confidence as to whether the remains are those of another 'raised beach.'

Along the Anatolian coast of the Black Sea, terraces occur at several points, at various heights up to about 700 or 800 feet, as judged from the sea. Prof. Wright, in his paper read before the Society on March 6th, 1901,[1] described one of these at Trebizond at the 650-feet level, as a deposit of fresh-looking beach-gravel. I think that the freshwater beach at Hora affords a strong presumption that the water, when standing at these higher levels, was also fresh, and not brought in from the Mediterranean.

A high level of fresh water, gradually collected by rainfall or ice-drainage, and released by rapid erosion of the drainage-channel from the levels indicated by these beaches, may account for a number of perplexing problems in these regions, without invoking a series of inland continental subsidences and subsequent re-elevations.

I have to thank Mr. R. B. Newton, F.G.S., for very kindly identifying many of the fossils collected.

EXPLANATION OF PLATE IV.

Geological sketch-map of a portion of Turkey-in-Europe, bordering the Gulf of Xeros and the Sea of Marmora, on the scale of one quarter of an inch to the mile.

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[1] Quart. Journ. Geol. Soc. vol. lvii, p. 249.

Discussion.

Prof. Sollas remarked on the great interest of the observations contributed by the Author to the history of a district which would always be associated in the minds of geologists with the genius of Neumayr. That Eocene beds were involved in the structure of the Ægæan 'island' was a new and hitherto unsuspected fact, which would render necessary some corrections in its outlines, if not a fundamental change in our conceptions concerning it. Hitherto the oldest post-Palæozoic beds recognized in the district were the Sarmatian, and curiosity was naturally aroused as to the nature of the succession intervening between these deposits and the Eocene. It was to be hoped that the Author would be able to furnish sections in illustration of this question.

As regards the origin of the Dardanelles, Neumayr had supposed that they had been produced probably as a valley along a line of fracture, and at a time so recent as the Pleistocene. Prof. Andrussov, however, had given reasons to show that they were probably already in existence during the Upper Pliocene, since the Cháuda Beds of Kerch occur, according to him, near Gallipoli, where they contain *Didacna crassa* and *Dreissena Tschaudœ.* Besides this, *Dreissena rostriformis* is found both at the bottom of the Pontus and of the Sea of Marmora, thus proving the existence of Pontic conditions in that Sea during late Pliocene times. In view of these facts, the age of the 'raised beach' becomes a matter of extreme importance; if it is not on the horizon of the Cháuda Beds, fresh difficulties arise in our study of this problem, which may be welcomed as likely to lead to a more complete solution.

Virchow had described undulating ridges stretching across the alluvial plains of Troy, containing large blocks of stone derived from the mountains behind; and Neumayr commented on the interest of this discovery, in view of the fact that no signs of extended glacial action had been furnished by the Balkan Peninsula. The present Author's observations confirmed and extended the conclusions of Virchow, even if the evidence as to the existence of glacial striæ were of a very doubtful character, as to him (the speaker) it seemed to be.

Prof. Hull considered the paper of great interest, as bearing on the view that the Mediterranean Sea consisted in Pleistocene times of a series of freshwater lakes connected with the Black Sea by the Straits of the Dardanelles, and by channels now submerged, one of which had been traced by soundings by Admiral Spratt. When elephants and hippopotami inhabited Malta—as shown by Leith Adams—the surrounding waters were unquestionably fresh, the outlet into the ocean being closed. The Author's description of the great boulder-clay formation suggested the agency of glaciers in Asia Minor during Pleistocene times; and this was by no means improbable, when we recollected that glaciers had descended from the Lebanon, and had left their terminal moraines at a level of 4000 feet above the sea, from which the cedars were now rising, as described by Sir Joseph Hooker.

Prof. Seeley desired that the Author should state the physical evidence on which he inferred the former great development of the freshwater lake assumed to be represented by the Sea of Marmora. The genus *Dreissena* was met with in the marine Miocene of France, and *Neritina* was separated by so uncertain a boundary from the marine *Nerita*, that the palæontological evidence was not conclusive that freshwater conditions had given place to marine in the way stated. The change was not improbable, but it needed demonstration. It did not appear evident to the speaker that the rhyolitic outbursts could be determined as of definite geological age: they pierce indeed the Nummulitic Series, but there was need of local evidence to fix their age.

Mr. H. W. Burrows remarked that the assemblage of fossils was not very convincing, as to either exclusively marine or exclusively freshwater conditions; and they might well be of fluvio-marine origin. The presence of foraminifera, however, would be distinctive, and he therefore recommended microscopic examination of the specimens.

The Author replied that he thought that the occurrence of marine Miocene (Helvetian) shell-beds at Erekli on the Gulf of Xeros required a much greater change in the position of the coast-line of the Miocene Ægean land, than Prof. Sollas seemed inclined to admit. The displacement would not be less than 100 miles from the line shown in Lapparent's 'Traité de Géologie.'

The Author had quite recently examined the Quaternary shell-beds at Gallipoli, referred to by Prof. Sollas, of which a sketch-section was given in Calvert & Neumayr's paper.[1] This section is described in their paper as composed of eroded remains of Tertiary beds, tilted and dipping inland, overlain by the horizontal shell-beds to a depth of 30 or 40 feet, the latter forming steep cliffs towards the Hellespont.

The Quaternary beds examined by the Author form a very solid shell-conglomerate, with horizontal partings, split vertically in many places into columnar masses, and protected from further erosion by a talus of their own material in large tabular blocks, extending in places for 100 feet into the water. These blocks are generally tilted, so as to present the appearance of an inland dip, but no older material is at present visible. In any case, the Author did not think that these shell-beds materially affected the question of the erosion of the Dardanelles, as they did not make up more than a twentieth part of the height of the cliff-sections visible in the channel. He also thought that the deposition of these shell-beds was subsequent to the erosion of the channel, as Calvert & Neumayr stated that out of 33 species of shells occurring in them, 29 were still living in the Mediterranean, generally widely spread.

The Author quite admitted the fact pointed out by Prof. Seeley,

[1] 'Die jungen Ablagerungen am Hellespont' Denkschr. k. Akad. Wissensch. Wien, vol. xl (1880) pp. 357–78 & 2 plates.

that the presence of *Neritina* in the raised beach at Hora did not necessarily imply absolutely fresh water (though the identification of *Neritina danubialis* was confirmed by Vicomte d'Archiac on a specimen from the same place)[1]; but he submitted that this was not necessary to his argument, which was that the presence of these shells did show that at the time of this deposit there was no influx, as there was at present, of Mediterranean salt-water to the locality. The only way, as it appeared to him, by which it could be kept out, would be by a difference of level between the Mediterranean and the Sea of Marmora, the latter being the higher. If this were granted, the Author saw no reason to prevent the fresh or brackish water from having stood at one period at the level indicated by this beach, or at any other level required to effect the erosion of the Dardanelles Channel.

[1] Viquesnel's 'Voyage dans la Turquie d'Europe' vol. ii (1868) pp. 480, 481..

10. *A* Process *for the* Mineral Analysis *of* Rocks. By William Johnson Sollas, D.Sc., LL.D., F.R.S., F.G.S., Professor of Geology in the University of Oxford. (Read January 22nd, 1902.)

It seems now to have become generally recognized that a natural classification of igneous rocks must rest ultimately on a chemical basis. The petrographer has thus become confronted with the necessity of an indefinite multiplication of chemical analyses, and may well shrink from the vast expenditure of time and labour that this involves. For many rocks there is no escape from this unpleasing prospect, but in the case of others, that is, all holocrystalline kinds which are not too fine-grained, the question suggests itself whether a quantitative estimation of the mineral composition might not solve the problem with sufficient accuracy. Provided that the chemical composition of the mineral constituents does not vary capriciously, but is definitely related to their physical properties, such for instance as their specific gravity, there would seem to be no good reason why it should not; while, as I hope to show later by instances, there even appear to be grounds for concluding that the question can be more positively answered in the affirmative.

In attacking the problem, the first step is to devise a method for obtaining a quantitative estimation of the mineral composition of a rock; and I may therefore proceed at once to describe a process which has been found to yield remarkably accurate results.

A fragment of the rock required for analysis having been selected, it is reduced to powder, by the usual process of crushing in a steel mortar and sifting through copper wire-gauze. The meshes of the sieve should number on the average 12 to the square millimetre, with a variation not greater than 2 on each side of this. The whole of the fragment of rock should be powdered, and none of the grains rejected.

The specific gravity of the several components must next be determined, by means of a diffusion-column such as has frequently been described elsewhere. The heavy fluid used in this process should be methylene-iodide; acetylene-bromide is much less expensive, but its viscosity is far greater, and its vapour in a closed room may prove very injurious to the eyes. As is well known, the density of methylene-iodide may be increased up to 3·6 by saturating it with iodoform, or it may be diminished by dilution with carbon-tetrachloride, xylol, or benzol. It is convenient to have always ready for use a series of methylene-iodide and carbon-tetrachloride mixtures of definite specific gravity, differing from each other by intervals of 0·1, say from 3·34 to 2·44.

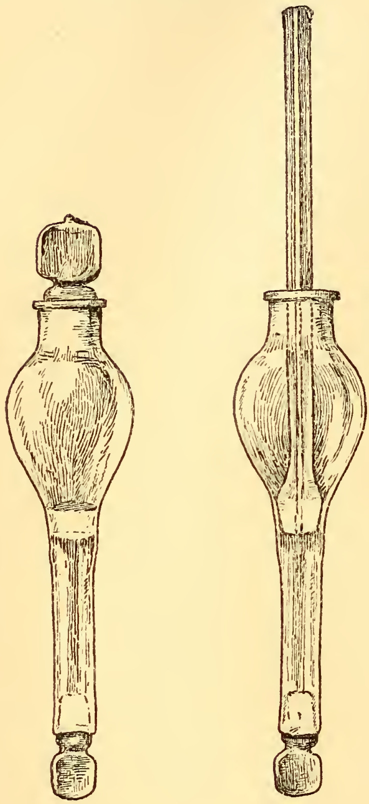
A long, narrow, glass tube, graduated in centimetres, and fitted with a well-ground glass stopper to prevent evaporation, is used for making the diffusion-column. Methylene-iodide is first introduced by means of a pipette, till its surface reaches the first centimetre; fluid of sp. gr. 3·24 is next added, till the second division is reached; and so on, till the lightest fluid required is finally added. A tube to contain the entire column would be inconveniently long: it is better therefore to make the column in two or more parts, two will usually suffice, using two tubes for the purpose. The column may extend from 3·34 to 2·84 in the one and from 2·94 to 2·44 in the other. Into each of these the powdered rock is introduced, as much being added as will lie on the point of a broad-bladed pocket-knife: the tubes are then stoppered, and left to stand. The mineral grains soon separate out into layers, according to their specific gravity. If each mineral were of a constant composition, and if each grain of the powdered rock consisted of but one kind of mineral, the layers would always be sharply defined, but this is very rarely the case. As a rule the grains arrange themselves in dense zones,—thus showing that to this extent they are homogeneous; but the fluid in the spaces intervening does not by any means remain clear, mineral grains extending from one zone to another. It might at first sight appear as if this fact alone presented an insurmountable obstacle to the quantitative determination of the mineral composition of a rock, at all events by any process of mechanical separation. Fortunately, however, this is not the case. The chief reason why the grains extend from zone to zone is that they are not all small enough to be homogeneous, some consisting partly of one mineral and partly of another. But evidently, on the doctrine of chances, in a mixture of two minerals in equal proportions as much of the heavier mineral associated with the lighter one will lie above the mean line between two zones, as of the lighter associated with the heavier below it; and thus, if the mixture be introduced into a fluid of a specific gravity which is the mean of that of the two minerals, the lighter with a certain quantity of associated heavier mineral will float above, and the heavier mineral with a corresponding contingent of lighter will sink below. The fallen grains, together with those floating in the lower half of the separating liquid, may be collected and weighed, and their weight will represent that of the heavy mineral taken alone. Similarly with the lighter grains. Were the grains needed for the purpose of chemical analysis separation in this manner would be futile, but for our purpose the method is both logically correct and successful in practice. If the two minerals in the case which we have supposed should not be present in equal proportions, that circumstance will not affect the argument.

The component minerals having assumed a position in the diffusion-column corresponding with their specific gravity, this must next be determined: it may be taken as that of the middle of each zone into which they have collected. The determination is most quickly and conveniently made by means of beads of known specific gravity. A series of beads should be at hand, differing in specific gravity by intervals of two or three units in the third place of decimals. When one of these is found to float above a zone but not far removed from it, and another similarly below, the difference in vertical distance between each and the centre of the zone is directly proportional to the difference in specific gravity, which may thus be calculated. This determination having been made, the actual separation of the minerals of the rock may next be undertaken. Before I proceed to describe this, I may call attention to the important information which is incidentally afforded by the use of the diffusion-column; for it not only provides us with a knowledge of the specific gravity of the component minerals of a rock, but shows at a glance what minerals are absent as well as which are present, thus supplementing in a ready manner the knowledge acquired by an examination of thin slices. Orthoclase, which might readily be overlooked when present in small quantity in a basic rock, thus frequently reveals its existence, while its absence is as often confirmed.

In describing the process of separation, we may suppose as an instance that we are provided with a rock containing orthoclase (sp. gr. 2·56), quartz (sp. gr. 2·65), andesine (sp. gr. 2·67), biotite (sp. gr. 3·1), pyroxene (sp. gr. 3·3), and magnetite. The fluid used for the first separation should then have a specific gravity of 2·885, the mean of that of andesine and biotite. The rock may by its means be divided into two portions, the heavier of which will contain the biotite, pyroxene, and magnetite; the lighter the orthoclase, quartz, and andesine. If, however, one of the minerals present a wide range of specific gravity, the line of separation between it and its neighbours should be drawn midway between its extremes. Thus in the case of biotite, which may range from 2·9 to 3·1, we should divide it from andesine by fluid of sp. gr. 2·78. The quantity of the rock taken for analysis should have been previously determined by weighing. The sum of the weights of the separated portions should be compared with this, and the loss distributed. Each of the two portions may be treated in the same way, the quartz and orthoclase being separated from the andesine by fluid of specific gravity 2·66, the orthoclase from the quartz by fluid of specific gravity 2·605, and so on for the other constituents. By making the first separation in the middle of the series, we are able to operate simultaneously upon the resulting portions and thus to save time.

The separating apparatus (figured on p. 166) that I have found most convenient in practice consists of a wide glass tube, expanded into a pyriform enlargement at its upper end. It is fitted with well-ground stoppers above and below; and with a third stopper carried at the end of a long glass stem, both stopper and stem being traversed by an axial canal of narrow, but not capillary lumen. This stopper fits into the separator at about the commencement of the pyriform enlargement. In making a separation, the lower stopper having first been securely fitted in, heavy fluid of the required specific gravity is introduced, till it fills the vessel up to the level of the greatest width of the upper part: 2 or 3 grammes of the powdered rock are then added, the upper stopper inserted, and the whole well shaken. The separator is laid horizontally on the table till separation appears complete; it is then tilted slowly into the vertical position; is again shaken, and left to stand. The separation will be the more complete the more frequently the fluid is agitated. As there may be a slight leakage at the lower end, the separator is placed to stand in a beaker, resting in a gently inclined position, so as to offer as large a surface as possible to the floating powder. When the separation is nearly complete the separator is restored to the vertical position, so that all the heavier material may find its way into the lower leg. The upper stopper is then removed, and the middle stopper gently pushed through the layer of floating material, the open end of the canal traversing it being kept closed by the thumb. After passing through the upper layer, the stopper may be washed to free it from adhering grains by carefully moving it from side to side in the clear fluid below; directly it appears to be clean it may be suddenly dropped into place. Experience shows that it does not carry down any appreciable quantity of the supernatant grains. The separator is next placed in a conical glass vessel—the receiver—having a constriction near its base, into which the lower stopper fits by its head. By gently rotating the separator to and fro the stopper is set free, and the heavier material may be removed from the lower leg. If this should not be present in large amount it will flow out along with the heavy fluid, as the thumb is

Apparatus for separating minerals of different specific gravity.



removed from the capillary of the stopper, or even sometimes before. If, however, there be a considerable quantity of the heavy powder, it will not at once leave the tube, but will form a plug stopping up the orifice; advantage may be taken of this, to save the intermediate step of collection in the receiver. Keeping the thumb on the opening of the canal in the stopper, the separator may be brought over a funnel containing a paper filter and the contents of the lower leg discharged at once into this. The heavy fluid which flows through is stored for subsequent use, and the first washings, made with carbon-tetrachloride, are also preserved, as they contain a considerable quantity of methylene-iodide. The powder having thus been brought onto a filter, either directly or from the receiver, the lower leg of the separator is washed by immersing its aperture below the surface of benzol contained in the receiver, and drawing this up by suction through the canal of the stopper. To complete the washing benzol may be driven from a wash-bottle through the canal of the stopper. The powder which is thus extracted is added to that on the filter, the whole is well washed with benzol, and dried in a water-oven. It is then ready for weighing.

The separator is next brought over another filter, the middle stopper very carefully removed, and the upper portion of the fluid with its floating grains allowed slowly to escape. After collecting the heavy fluid and the first washings with carbon-tetrachloride the separator is cleaned with benzol, supplied from a wash-bottle, into the filter. This cleansing also washes the powder in the filter, which is then dried and weighed.

When all the minerals have been separated and their proportion determined by weighing, the analysis may be checked by comparing the specific gravity of the rock in bulk, with that calculated from the specific gravity and proportion by weight of its components, according to the equation:

$$D=100\div\left(\frac{A}{d_a}+\frac{B}{d_b}+\frac{C}{d_c}\right),$$

where D is the density of the rock, A, B, C the proportions *per centum* of its component minerals, and d_a, d_b, d_c their respective densities.

From the mineral analysis of a rock its chemical composition can be calculated. Hence it follows that, in many cases, a mineral analysis may provide the data required in petrographical classification. I was somewhat sceptical of its truth when I first reached this conclusion, but, in order to put it to a test which should be free from the temptations of personal bias, I requested my friend Mr. Teall, and afterwards Mr. Harker, to supply me with samples of rock which had already been chemically analysed, for investigation. They were to keep me in ignorance of the results of the chemical analyses until I had informed them of mine, calculated from the mineral separation, for comparison. The rock sent to me by Mr. Teall was a specimen, as he afterwards informed me, of kentallenite, a rock which has been described by Messrs. Hill & Kynaston.[1] In making my analysis I did not weigh the several components, having found that their relative proportions could be determined in most cases by bulk-measurements made in narrow graduated tubes. Subsequently I found that this process was inapplicable to rocks containing minerals like biotite, flat-leaved scales always packing after a law different from that for angular grains, and giving results which are always too high. I have no doubt, therefore, that somewhat too great a proportion of biotite appears in my results. The error introduced into volumetric measurement by the difference in the mode of packing of differently-shaped grains may be met by first placing benzol in the measuring-tube, and recording its displacement when the mineral is added; but this destroys the simplicity of volumetric estimation, so that no advantage is offered by it over the more exact method of weighing, which I now therefore always employ.

The mineral composition of kentallenite was found to be as follows:—

	Sp. gr.	Per cent.
Soda-orthoclase (Ab_2 Or_1)	2·59	9·64
Andesine	2·67	25·15
Biotite....................................	2·98	17·77
Pyroxene (oblique)	3·20	15·92
Pyroxene (rhombic)	3·34	23·00
Olivine	3·36	6·07
Magnetite	...	2·45
		100·00

From published analyses of similar minerals with similar specific gravities the chemical composition was calculated, with the results given in the first column of the following table; in the second column the results of direct chemical analysis, as communicated to me by Mr. Teall, are given for comparison.

	I.	II.
SiO_2	50·3	52·09
Al_2O_3	12·6	12·25
Fe_2O_3	2·6	1·84
FeO	5·9	7·11
CaO	10·7	7·84
MgO	11·9	12·48
K_2O	2·1	3·01
Na_2O	2·9	2·04
H_2O	0·6	0·51
TiO_2	0·4	0·73
P_2O_5	0·3	0·34
	100·3	100·24

On my informing Mr. Harker of the results of the examination of the two specimens which he had sent me from Skye, he tabulated them along with the results of their chemical analysis, as made by Dr. W. Pollard, in parallel columns as shown on the next page:—

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 537.

	Skye Gabbro No. 8043. Calculated. (*Sollas.*)	Skye Gabbro No. 8043. Found. (*Pollard.*)	Gabbro No. 8194. Calculated. (*Sollas.*)	Gabbro No. 8194. Found. (*Pollard.*)
SiO_2	47·81	46·39	47·81	47·28
TiO_2	trace	0·26	—	0·28
Al_2O_3	24·21	26·34	21·02	21·11
Cr_2O_3	...	trace	—	—
Fe_2O_3	2·48	2·02	2·21	3·52
FeO	2·84	3·15	4·44	3·91
MnO	...	0·14	0·13	0·15
MgO	3·49	4·82	5·10	8·06
CaO	15·84	15·29	17·17	13·42
Na_2O	2·07	1·63	1·50	1·52
K_2O	0·40	0·20	0·15	0·29
H_2O	0·86	0·58	0·47	0·66
P_2O_5	...	trace	...	trace
	100·00	100·82	100·00	100·20

No doubt the close approximation between my results and Dr. Pollard's, especially in the case of specimen 8194, is to some extent due to the predominance of felspar in these rocks, and to the fact that the analyses of minerals from which I calculated the composition had been most of them made on Scottish examples.

The mineral composition of the two rocks was determined as follows:—

	Gabbro 8043. Sp. gr.	Gabbro 8043. Per cent.	Gabbro 8194. Sp. gr.	Gabbro 8194. Per cent.
Labrador-felspar	2·735 to 2·7	79·50	2·737	65·96
Pyroxene (oblique)......	3·21 to 3·335	16·18	3·280	32·43
Pyroxene (rhombic) ...	3·40	2·10		—
Magnetite		2·40		1·61
		100·18		100·00

Some time ago I worked out the mineral composition of the Leinster granite by the laborious process of weighing areas of the sections of the component minerals as observed in thin slices, and it now occurred to me that it might be of interest to apply the new method to an investigation of Cornish and Skye granites, in order to obtain material for the comparison of these various granites in regard to their mineral composition. This could scarcely fail to be of interest, owing to the fact that these rocks represent granites of Tertiary, and of approximately Permian and Silurian age. The Cornish granite was studied by Miss Davies in my laboratory; she obtained the following results:—

	Sp. gr.	Per cent.
Orthoclase	2·560	24·62
Albite	2·624	13·44
Quartz	2·645	40·23
Muscovite	2·825	10·09
Biotite..................................	3·065	11·46
Magnetite and zircon	...	0·16
		100·00

The chemical composition, as calculated from these results, is given in column I below; in columns II, III, and IV are the results of analyses of Cornish granites given by the late J. A. Phillips.[1]

	I.	II.	III.	IV.
	[*Penrhyn.*]	[*Carn Brea.*]	[*Botallack.*]	[*Chywoon Morvah.*]
	(Calculated.)	(Found.)	(Found.)	(Found.)
SiO_2	74·01	74·69	74·54	70·65
Al_2O_3	14·28	16·21	14·86	16·16
Fe_2O_3	·68	trace	2·53	1·53
FeO	1·86	1·16	0·23	0·52
MnO	0·14	0·58	—	—
MgO	0·14	0·48	—	—
CaO	0·27	0·28	0·29	0·55
K_2O	4·76	3·64	3·73	8·66
Na_2O	2·32	1·18	3·49	0·54
Li_2O	0·08	0·10	trace	—
H_2O	0·71	1·23	0·87	1·22
F	0·41	—	—	—
P_2O_5	0·10	—	—	—
	99·76	99·55	100·54	99·83
Specific gravity...	2·68	2·64	2·66	2·62

The concordance between the chemical composition found directly, as given by columns II & III, and that calculated from the mineral composition, leads to the inference that the rocks analysed by John Arthur Phillips possessed a mineral constitution similar to that of the rock examined by me: yet no two of the specimens came from the same locality. It would thus appear that the Cornish granites possess, and maintain over a wide area, a considerable degree of uniformity.

A comparison of the mineral composition of these granites with those of Leinster may be made from the following table:—

	Cornish Granite.	Leinster Three-Rock Granite.	Leinster Aughrim Granite.	New Zealand Tonale Diorite.
Orthoclase [2]	24·62	15·59	9·19	3·80
{ Albite	13·42	30·16	37·14	30·96
{ Anorthite	......	9·17	14·00	20·64
Quartz	40·23	36·16	31·89	17·00
Muscovite	10·09	} 8·93	7·33	
Biotite	11·46			21·00
Hornblende	......	......	......	4·80
Magnetite and heavy minerals...........	0·16	......	0·55 [3]	1·70

[1] Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 330.

[2] The potash-felspar is orthoclase in the Cornish granite, microcline in that of Leinster.

[3] Sphene and epidote in this case.

A greater difference appears in the mineral composition than the chemical analyses would at first suggest, owing to the excess of alkalies and calcium in the Leinster granite having found its expression in the soda-lime felspar rather than in the micas.

The transition from a typical granite, like that of Cornwall, to Tonale diorite would seem to take place through granites like those of Leinster, as will be seen by tracing the passage through them to the Tonale diorite, of which the mineral composition is given in the last column of the foregoing table. There is a steady falling-off in the orthoclase. The albite-molecules, after reaching a maximum in the Aughrim granite, diminish in number, while those of anorthite increase. The impoverishment in quartz takes place more suddenly, and muscovite disappears altogether on passing from the Aughrim rock to the Tonale diorite. There is also a marked increase in the proportion of biotite and of the heaviest minerals, while a small quantity of hornblende occurs for the first time and links on the Tonale diorite to the more common varieties of this rock. The Aughrim granite occurs as an isolated exposure to the east of the main mass, and is of somewhat later date: its position in petrological classification is evidently on the borderland between true granite and Tonale diorite. It may be observed in passing that in the examples studied the post-Ordovician granites of Britain are more basic in character than the post-Carboniferous, and these are more basic than the Tertiary.

A question will naturally arise as to the reasons by which we may be guided in making a choice of any particular one, from amid so many published analyses of a mineral species—and these generally so widely divergent in their results,—as that most likely to represent the composition of the gathering which we have obtained on the separation of a rock. There would seem to be mainly three. First, if possible, the analysis should be that of a mineral obtained from the same kind of rock as the one under investigation; evidently it would not be wise to choose an analysis of a biotite taken from a limestone or a schist, when that which we have in hand has come from a granite. It is not, however, necessary that the analysis should be that of the mineral in the form in which it generally contributes to the igneous mass, since the minerals segregated out in veins in many cases possess the same composition as those of the parent-rock.

In the next place, the mineral should, if possible, have been obtained from the same locality or district as that of the rock under examination. And last, its physical properties, under which specific gravity may be particularly mentioned as one of the highest importance, should be similar to those of the separated mineral. When all these conditions are satisfied, very exact results may be obtained from a mineral separation; but I imagine that the future success of the method will depend in greatest measure on an extension of our knowledge of the manner in which the physical properties of a mineral may be correlated with its chemical composition.

Herein lies a great field of work. At present a really satisfactory beginning has been made in the case of the felspars alone; and it is fortunate for this method that these minerals enter so largely into the composition of most igneous rocks. But with the great advance which has marked of late our processes of investigation, a rapid progress may be looked for in this direction. All that is required is that the chemist and mineralogist should work more in union: many good analyses are practically worthless, because the mineral of which they have been made has escaped a physical investigation; and many physical investigations are shorn of half their value, because they have been made on material, the chemical composition of which has been imperfectly determined, if at all.

After reaching this stage in our enquiry, it appeared to me necessary to investigate more closely the degree of exactitude with which a mineral separation may be accomplished. I have consequently made some experiments which may contribute towards a solution of this question.

The impalpable powder or 'flour,' which is necessarily produced from a rock in the process of comminution, may obviously prove a serious source of error, since, becoming entangled among the larger particles or grains, it may retain a position in the separator altogether independent of its specific gravity. To remove this flour might tend to increased accuracy, and would certainly shorten the time required for subsequent operations; but naturally, before actually venturing on such a step, we must first ascertain whether the amount of flour in relation to that of grains is constant for different minerals, or, still more important, whether any process that we may adopt for the removal of the flour may not carry away different amounts of it in different cases. To determine this, 2 or 3 grammes of a mineral were crushed in a mortar, passed through a fine sieve, and a weighed quantity placed in a wide beaker; water was added to a depth of 10 mm., the mixture stirred and allowed to stand for 15 seconds; the supernatant fluid was then poured off onto a filter, and the process repeated until at the expiration of 15 seconds the water remained clear. The grains remaining in the beaker were washed onto a filter, dried, and weighed, as also was the flour that had been removed. In this way the quantity of flour separated by washing was directly ascertained. The following are the results for a few important rock-forming minerals:—

	Per cent.
Orthoclase	22·58 to 22·94
Quartz	20·94 to 24·20
Hornblende	16·27 to 16·73
Augite	15·56
Biotite	19·50

From an examination of this list it would appear that the amount of fine flour washed away is in the first place inversely proportional to the specific gravity, and in the second dependent on the form of the grains and the brittleness of the material. Quartz has given rather widely differing results, and is still under investigation.

It appeared possible that, when two different minerals were pounded up together, the amount of flour produced might not be the same as when they were pounded separately. To determine this, an experiment was made with orthoclase and hornblende—two minerals which yield very nearly constant results when washed separately. Some fragments of adularia, weighing 4·3158 grammes, and of basaltic hornblende, weighing 2·6846 gms., were crushed in a steel mortar and passed through a fine sieve: the resulting powder weighed 6·8290 gms., so that 2·45 per cent. of the material was lost in the process of comminution. Of the powder 3·6271 gms. were taken for washing, and lost 0·8641 gm. or 24·05 per cent. The washed and dried powder was placed in the separator, 2·7150 gms. being operated upon; it yielded 1·6201 gm. of orthoclase and 1·0931 of hornblende, the loss being 0·0125 gm. Let the original weight of the orthoclase be represented by Or and that of the hornblende by Hb; also let the loss of orthoclase be represented by x and that of hornblende by y. Then, reducing the quantities given above to percentages:—

$$\text{(i)}\quad \frac{\text{Or}}{\text{Hb}}=\frac{61{\cdot}65}{38{\cdot}35}; \qquad \text{(ii)}\quad \frac{\text{Or}-x}{\text{Hb}-y}=\frac{59{\cdot}71}{40{\cdot}29};$$

and

$$x+y=24{\cdot}00.$$

Substituting the values of Or and Hb in (ii) it follows that

$$x-\frac{59{\cdot}71}{40{\cdot}29}\,y=4{\cdot}81.$$

Hence

$$x=16{\cdot}268 \quad \text{or} \quad 26{\cdot}39 \text{ per cent.}$$

$$y=7{\cdot}732 \quad \text{or} \quad 20{\cdot}16 \text{ per cent.}$$

The orthoclase is thus seen to have lost 26·39 per cent. in washing, and the hornblende 20·16 per cent.; but to compare these numbers with the loss on separate washing we have the proportion

$$26{\cdot}39 : 20{\cdot}16 = 22{\cdot}58 : 17{\cdot}25.$$

The ratio of loss of orthoclase to hornblende was thus 22·58 : 17·25, while with separate washing it was found to be 22·58 : 16·27. The hornblende would thus at first sight appear to have lost 1 per cent. more in the process of crushing and washing with orthoclase than when treated alone. But, to investigate this point further, orthoclase and hornblende were next crushed separately, weighed quantities of the powders were then mixed and washed, and afterwards separated. Without entering into details, it may be sufficient to state the result:—The ratio of the loss of orthoclase and hornblende was found to be 22·58 : 17·82, which is almost identical with that obtained when the minerals were crushed together. On now examining the separated powders under the microscope, it was found that the orthoclase contained a notable admixture of hornblende, while the precipitated hornblende was almost free from orthoclase. The change in the ratio is evidently due to imperfect separation; but as the separation was performed very carefully, it is clear that, within the limits of practicable as opposed to possible analysis, this imperfection must always be reckoned upon. It will therefore become necessary to experiment on all the chief rock-forming minerals, and to determine once for all the constant of error to be applied in each case.

So far, the proportion of loss has been determined in only a few cases. They are as follows:—

Orthoclase : Hornblende = 22·58 : 17·25.
Quartz : Hornblende = 19·26 : 18·17.
Quartz : Olivine = 22·87 : 15·85.

The next step was to ascertain how far the presence of flour in the separator would affect our results. Orthoclase and hornblende were powdered together, the mixture containing 61·65 per cent. of orthoclase and 38·35 per cent. of hornblende. Without any preliminary washing this was introduced into the separator, and yielded 59·65 per cent. of orthoclase and 40·35 per cent. of hornblende; or almost precisely the same relative amounts as were obtained from the washed material, which gave 59·71 per cent. of orthoclase and 40·29 per cent. of hornblende.

In all these cases, acetylene-bromide and benzene were used for the separating fluid, but it is doubtful whether the lower viscosity of a fluid produced by mixing methylene-iodide and carbon-tetrachloride would greatly affect the results. The conclusion, however, is clear that a preliminary washing of the powdered rock may conduce to greater accuracy, provided that we have previously established the constant of error for each mineral constituent. Of course, in order to apply this we must always inform ourselves by weighing of the amount of material removed in the process of washing. The saving of time thus ensured is twofold. In the first place, separation can be produced more rapidly, and in the next the number of necessary weighings is diminished one-half, for in the case of grains of appreciable dimensions they may be turned out of the filter-paper into a capsule without leaving an appreciable quantity behind, and thus the labour of incinerating the filter and weighing the ash is avoided.

It may be observed that the general tendency of the errors incidental to separation is to give an under-estimate for minerals of lower specific gravity, an over-estimate for those of higher specific gravity ; and to this is doubtless due the greatest discrepancy in my calculation of the composition of kentallenite, the silica falling 2 per cent. below the amount found by analysis. An error of almost the same amount appears in two other cases that I have studied—one a Tonale diorite from Adamello, and the other a similar rock from New Zealand. In the Adamello rock the results of a mineral separation and the deduced chemical composition are as follows :—

Per cent.	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O
Orthoclase ...... 3·20	2·07	0·59	......	......	......	......	0·54		
Quartz ....22·18	22·18								
Andesine ....50·62	30·29	12·89	......	......	3·53	......	......	3·91	
Biotite ....17·53	6·45	2·54	3·07	2·95	0·29	1·22	0·98	0·03	
Hornblende...... 6·19	? 3·44	......	......	0·52	0·80	1·43			
Magnetite and sphene ...... ·28									
	64·43	16·02	3·07	3·47	4·62	2·65	1·52	3·94	
Analysis by G. vom Rath... (Total: 98·99.)	66·91	15·20	......	6·45	3·73	2·35	0·86	3·33	0·16

Even if we disregard the small quantity of magnetite and sphene, it is clear that G. vom Rath's analysis is not perfect, since it indicates all the iron as existing in the ferrous state ; while an independent analysis of the biotite, also by him, showed the presence in this mineral of a larger quantity of ferric than of ferrous iron. The sum moreover is more than 1 per cent. too low. These inaccuracies, however, do not greatly diminish the importance of the differences between the results, as found by calculation on the one hand and by analysis on the other. The silica in my estimate is over 2 per cent. too low, while the alumina, calcium, potassium, and sodium are too high ; and this is a natural consequence of an over-estimate of the proportion of the ferro-magnesian to the more acid minerals.

It still remains to point out certain cases in which the mineral separation alone will fail to inform us certainly of the chemical composition of the rock. Foremost is the question of the alkalies, which may most forcibly be illustrated by an instance such as that of the Plauen syenite. Neglecting the quartz, the amount of which I have not determined, the mineral composition of this rock is as follows :—

	Per cent.
Orthoclase and microperthite	28·72
Oligoclase (spec. grav. 2·645)	51·99
Hornblende (spec. grav. 3·2)	16·87
Zircon, magnetite, and sphene...............	2·42
	100·00

The chemical composition as deduced from this is as follows :—

Per cent.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO MnO	CaO	MgO	K_2O	Na_2O	H_2O
Sphene ....0·464 ...	0·142	0·184	0·008	......	0·01	0·11	0·004			
Magnetite and zircon } 1·956 ...	......	......	......	1·349	0·607					
Oligoclase......51·99 ...	33·72	......	11·47	......	......	1·57	......	......	5·23	
Orthoclase ...28·72 ...	18·59	......	5·27	......	......	......	......	4·86		
Hornblende...16·87 ...	7·38	......	0·10	......	5·04	2·75	2·61	(by	differe	nce)
(Total: 100·79.)	59·832	0·184	16·85	1·35	5·65	4·43	2·61	*4·86*	*5·23*	
Analysis by Prof. Zirkel (Total: 101·03.)	59·83	......	16·85	......	7·01	4·43	2·61	*6·57*	*2·44*	1·29

The specific gravity, as calculated from the composition, is 2·73. Prof. Zirkel gives it as 2·865. The specific gravity of the specimen that I examined was 2·724.

Not only do my results yield a larger total amount of the alkalies than is obtained on analysis (10·09 per cent. instead of 8·99 per cent.), but the relative amount of potash and soda is reversed, the soda being in excess of the potash, instead of falling considerably below it. Quite possibly the amount of orthoclase in the rock has been under-estimated, but scarcely, we may fairly conclude, by more than 2 or 3 per cent., so that the excess of potash must be looked for in the oligoclase and hornblende. As a matter of fact, both these constituents give an obvious potassium-reaction to the flame-test.

The next difficulty arises from the occasional association of quartz with a felspar of the same specific gravity as itself. In the event of this unfavourable conjunction, a separation of the quartz and felspar from the other constituents must be made within narrow limits of specific gravity: a silica-determination will then give data for calculating the relative amounts in which the associated minerals are present.

The chance of substitution of ferrous iron for calcium and magnesium, and of ferric iron for alumina, may sometimes lead to error, and in the case of rocks from localities in which the prevalent minerals have not been analysed, this must be met by chemically determining the amount of iron in the rock, a not very laborious operation by volumetric methods.

Discussion.

The President remarked that this was not the first time that the Author had made an important contribution to the improvement of petrographical methods. Most petrographers in this country were extremely indebted to him for the invention of the method of the diffusion-column. The method now put before the Society had yielded in the Author's hands more accurate results than would have been expected. It was true that he had not yet brought the process to its full perfection, but it seemed highly probable that the discrepancies between the observed and the calculated results were due to the fact that the Author had had inaccurate mineral-analyses to work from.

Mr. Holland said that he had frequently made a similar use of heavy liquids for the quantitative estimation of special constituents in mineral mixtures like anhydrite and gypsum, quartz and magnetite, and other cases in which there was a sufficient disparity of specific gravities to reduce and eclipse the experimental error. But he had failed to make a successful application of this method to ordinary crystalline rocks, and did not consider that it could ever replace, for the purposes of the practical petrologist, the recognized bulk-analysis by chemical methods. With rock-constituents containing microscopic inclusions of foreign matter, varying in degree of alteration, intimately intergrown on a minute scale (like the various types of pyroxenes and the microperthitic felspars), or subject to zonal variation by isomorphous replacement, it would be impossible to obtain a constant of error for application to the results of separation by heavy liquids. With well-crystallized, simple rocks, like some granites and gabbros, approximate agreement between this and the direct chemical method might be possible. But in the case of such rocks, whose minerals have been separated and analysed, there is in general no call for any process that does not surpass the chemical method in precision; while to new occurrences of rocks, whose constituents have not been so examined, the process is, *ex hypothesi*, inapplicable. Even in the illustrative examples worked out by the Author, there are serious departures from the actual chemical analyses, especially in connexion with the lime and magnesia, indicating only partial success in discriminating between the rhombic and the monoclinic pyroxenes. Errors of a similar nature must always occur with couples or trios of minerals which are totally distinct in chemical composition, and yet exhibit differences of specific gravity less than their own internal variations. One has only to recall cases like the spinels and garnets, soda-pyroxenes and sphene, epidote and hypersthene, sillimanite and hornblende, or partly altered olivines with any but the densest of these, to show how frequently it must be impossible to make separations clean enough for chemical calculations. From the standpoint of the practical petrologist, therefore, the process is capable of very limited application, and could never be relied on as a general substitute for the ordinary laborious method of chemical analysis. Nevertheless, the quantitative estimation of rock-constituents might with advantage be practised more frequently, and for facilities to this end petrologists would ever be indebted to the Author for his simple and ingenious diffusion-column.

The Rev. J. F. Blake pointed out that the separation of minerals by means of heavy liquids was in some cases interfered with, theoretically at least, by the surface-tension between the mineral particles and the liquid. If the material had to be ground fine, so as to ensure that each particle contained only one mineral, its arrangement would depend not only on the specific gravity but also on the sizes of the particles, so that heavier and smaller ones might be mixed with lighter and larger ones. In other cases, no doubt, this action might have practically no effect.

Mr. H. W. Burrows referred to the process of calculating chemical composition from measurement of areas of the different minerals seen in rock-sections, and asked the Author whether he considered that method approximately reliable.

The Author expressed his thanks to the President for the kind words with which he had received this communication. It was gratifying to think that this method, powerful as it might already be, was still open to improvements; the Author hoped to continue his work on the subject, and meanwhile would welcome any criticism, especially when of the nature of experiment. There were necessary limitations to the application of the method, and a discussion of these would be found in the paper; but some which were suggested by Mr. Holland were he thought *à priori*, and were disposed of in some instances by the examples that he had just laid before the Society. The objections alleged by the Rev. J. F. Blake were also theoretical; in a well-made diffusion-column every mineral took up a position in strict accordance with its specific gravity. Mr. Burrows was to be congratulated on his successful employment of the well-known method of weighing areas, but the process was too laborious for common use.

11. *On the* MATRIX *of the* SUFFOLK CHALKY BOULDER-CLAY. By the Rev. EDWIN HILL, M.A., F.G.S. (Read February 5th, 1902.)

MUCH study has been bestowed upon the boulders included in the Glacial Clays, their nature, origin, and distribution. The matrix in which they lie has received comparatively little attention. Yet the matrix, in many or most, forms by far the largest part. I have been endeavouring to study this matrix under the microscope, by washing it, shaking it up with water, and so separating the material which will settle quickly to the bottom from that which remains longer in suspension. The process has to be repeated until the water remains clear, else dust still suspended dries on the surfaces of the grains which had settled and masks them from examination. I have collected and dried this finer dust, but it cakes together: I have not obtained from it much information. The coarser material, that which subsides first, forming from 40 to 75 per cent. of the whole, dries to a sand or powder and lends itself readily to examination with the microscope. I have tried several methods, and have succeeded best by inspection under direct daylight of the powder strewn on a slide. Inspected in this manner, Glacial Clays from localities in East Anglia tell something of their sources. I have examined specimens from places along a belt of country in Suffolk extending from Lowestoft to Bury St. Edmunds, a distance of more than 50 miles; Lincolnshire material dredged up in deepening the ship-channel to Boston (kindly sent by Mr. W. H. Wheeler, C.E.); Cambridgeshire specimens from Ely Cemetery and from the neighbourhood of Bishops Stortford (the latter kindly sent by the Rev. Dr. A. Irving); and a Middlesex specimen from the Marylebone Cemetery, Finchley.

The coarser residuum, after washing these clays, is a sand or powder containing grains of quartz, chalk, chert, and other homogeneous minerals, generally some sponge-spicules, a few fragments of shells, and occasionally foraminifera, probably derived. Besides these many samples contain granules which are portions, generally rounded, of grey or dark limestone or clay. Some contain cream-coloured granules which seem to be of a limestone. In some are granules which appear to be mere aggregates of sand-grains cemented together. In a sample from the Boston dredgings there are granules of sand-grains in a chalky paste. A pit about 2 miles south-east of Saxmundham, where clay is resting on some sands, affords, in the residue from the clay, fragments, not rounded, of a quartzite which reminds me of sarsenstone. The grey clay- and dark limestone-granules are found in the samples from League Hole and Corton (north of Lowestoft), Halesworth, a pit 1 mile south-west of Saxmundham, Stowmarket, Norton and Woolpit (about 7 miles east of Bury St. Edmunds), Cockfield (about 7 miles south of Bury), and also in the specimen from Finchley (Middlesex). The cream-coloured granules are found in samples from Ely, Horringer (1 mile south-west of Bury), and Stort Hill near Bishops Stortford. Samples from Pakefield (south of Lowestoft), Thorley and Hockerill (near Bishops Stortford), and, as above mentioned, from the Boston dredgings and the pit south-east of Saxmundham, contain granules of other kinds or none. Now, if these localities be laid down on a map, it will be found that all those from which come granules of the grey clay or limestone lie within a certain area, and the rest outside it. The washed residues which yield those granules are, to the eye, all grey powders; the original clays are all dark (sometimes called blue); they are so like each other in hand-specimens, that samples from different places are often indistinguishable. Presenting so many common features, and occupying a definite district, they must be classed together as one.

The clays, the washed residues of which do not yield granules of this kind, are red, yellow, or grey, and their residues red, yellow, or whitish. Some are probably samples of the first kind altered; the alteration, however, has not removed the fragments of chalk. At several of the localities—Pakefield, the pit south-east of Saxmundham, Horringer, Ely—the clay is thin, and the sample came from near the base. The Woolpit samples were obtained from a well which was being sunk: the lowest, from some 60 feet down, shows very few granules. It is easy to suppose that thin beds, or lower parts of the clay, may have suffered some alteration.

For the origin of these granules we naturally look to the Secondary clays and limestones. The dark clay frequently contains recognizable fossiliferous boulders of Kimeridge materials, some exceeding 12 inches across. Portions of these, on being pounded and washed, produce fragments closely resembling the granules of limestone. Granules in a specimen from a well at Colchester Green, Cockfield, contain visible microscopic fragments of black fibrous material similar to some fossils of the Gault. Gryphæas of the Lias are well-known inmates of the East Anglian Glacial Clays. All these Secondary rocks rise to the surface west of the Suffolk area. The bulk of the materials which make up the matrix may well, therefore, have been brought from the west.

I notice among most of the residues a few peculiar grains which differ markedly from the rest. They are always well-rounded, usually highly polished, in colour dark, most often brown; varying in size, but seldom exceeding 0·5 millimetre. They are not seen in every sample; I have noticed none in the residues from Corton, League Hole, and Boston. These localities lie on or outside the eastern and northern boundaries of the dark-clay area. As I have also not noticed these grains in residues from Cromer, still farther north-east, there may be some significance in their distribution. Dr. G. J. Hinde, F.R.S., has kindly looked at some for me and says:

'They do not show any structure, and I conclude that they are of inorganic origin. I have seen similar grains in Lower Greensand material, and also in Middle Liassic marlstone.'

This again points to sources among Secondary rocks, and in a westerly direction.

The residues all contain grains of silica, but the dark clays much fewer than the red and yellow; indeed, often extremely little. For instance, in the residues from Corton and League Hole the grey granules form the chief part, and in the small remainder chalk predominates. These two localities are on the coast-cliffs north of Lowestoft, looking out on to the North Sea, with its sandy bottom: under the clays lie sands which extend to the north for several miles—the so-called Mid-Glacial Sands. It is difficult to conceive how a material containing so little quartz could be produced or brought by any agent moving over the sea-bottom. If this be true for coast-cliffs, it must hold good of the other dark clays, on the landward side of these. Therefore we must not look for the origin of these clays eastward, in the direction of the sea.

While examining the clays of the Yorkshire coast, I have several times noticed in the cliffs included patches of coal-gravel. Microscopic coal I have found in the samples from that district universally. The Geological Survey Memoir on East Lincolnshire repeatedly mentions small pieces of coal as occurring there in the Boulder-Clay.[1] It came into my mind to examine whether such coal-fragments could be detected in the East Anglian area. Accordingly I have scrutinized all the washed residues with an eye to this point. Coal is so unchangeable by weathering or decomposition, that one would expect the question to be readily settled. It is, however, not so easily disposed of. There is little difficulty with such pieces as can be removed from the powder for separate examination; but black grains occur, too small for me to pick out. As in the residues are fragments of black chert, very dark limestones, black spines, enamel, or bone, black grains may belong to these. I have to rely upon eye-comparison with the coal-dust in similarly treated clay-residues from Tynemouth, Sunderland, and the Holderness cliffs. My conclusions therefore may not be absolutely certain, still they agree fairly well together.

In some of the samples there appear to be no black grains at all; in most, such as are there seem to me not to be coal. Only at Pakefield, and perhaps in the pits near Saxmundham, I incline to think that some may be present,—microscopic grains merely; no fragment large enough for me to isolate. Pakefield is on the coast, Saxmundham about 6 miles from the sea, on the edge of the clay-plateau. This apparent absence of coal from the main dark-clay area, and also from Boston and Ely, contrasts not only with the presence of coal visible to the unaided eye in East Lincolnshire and in the Leicestershire clays, but also with the presence of what seems

[1] A. J. Jukes-Browne, Geol. Surv. Mem. 1887, pp. 72, 87, 89, & 98.

to me microscopic coal even south of the Wash, in several Cromer deposits. There was an agent of transport in Glacial times able to spread coal-dust from the mouths of the Tees and Humber southward certainly as far as the south of Lincolnshire, probably to the north of Norfolk, possibly even to Suffolk itself. It seems that no similar agent of transport came out of the Humber Basin down the landward side of the Lincolnshire Wolds.

To summarize the foregoing conclusions:—The deficiency in sand-grains indicates that the materials of the matrix in these clays did not come from the east. The abundance of matter derived from Secondary rocks, points to sources in the west or north-west. The apparent absence of coal shows that nothing came from the east side of the Lincolnshire Wolds; adding also the conclusion that the agents which brought these Secondary materials did not bring materials from the coalfields of Staffordshire, Leicestershire, Derbyshire, or Yorkshire. It appears, then, that the matrix of the Suffolk Boulder-Clay consists of materials drawn from a limited belt lying on one side of the basin which it occupies.

The larger stones embedded in this matrix consist chiefly of flints: besides these, in some places are assemblages of chalk-blocks, in others similar assemblages of Kimeridge limestone and shales. Palæozoic or igneous fragments are extremely rare. I should think that, taking matrix and inclusions together, 99 per cent. or more is of Secondary and western origin.

Discussion.

Prof. H. G. Seeley said that, while the Boulder-Clay in the East of England was full of fragments which correspond with local rocks, there were reasons for believing that it was in part formed when the level of the land was much higher; so that the existing coast-lines could not have influenced the distribution of its constituent rock-material. He noticed that all the strata on the East of England strike eastward over the North Sea, and some of them appear to be indicated eastward by differences in soundings. There is evidence that part of the Boulder-Clay came from the north-east, in the presence in it of rocks from Norway; and as the bed of the North Sea exposed the Secondary rocks, he would suggest that the materials of this part of the Chalky Boulder-Clay had a north-easterly origin, being derived from the submerged outcrop.

Mr. F. W. Harmer said that he was interested to find that the important investigations of the Author tended to confirm the view taken by the late S. V. Wood and himself twenty-five years ago, that the Chalky Boulder-Clay ice came from the north-north-west, from the region lying between the Wolds and the Lincoln heights, which contains a series of the Secondary rocks between the Chalk and the Lias. It could not have come from the North Sea, as has been often supposed, as no Chalky Boulder-Clay exists in North-eastern Norfolk, that is, in the region lying between Norwich and the Cromer and Happisburgh coast. It comes on suddenly to the south of Norwich, and extends in an unbroken sheet to the brow of the Thames Valley.

There is a marked difference in the erratics of the Lower Glacial Beds to the north of Norwich, which are mostly of crystalline rocks, and those of the Boulder-Clay south of that city, in which hard Chalk from the Wolds and Kimeridge Clay preponderate. His view was that an ice-stream, which he suggested might be called 'the great eastern glacier,' travelled towards East Anglia from Lincolnshire, keeping to the west of the Wolds, and spread itself out like a fan as it reached the lower ground. As the Glacial Period passed away, the glacier still kept to its original course, but was confined to the valleys, as those of the Yare and the Waveney, which had the same alignment as that of the supposed ice-flow.

His friend, Mr. J. Lomas, had been for some time engaged in the microscopical examination of the matrix of the Boulder-Clay, and his investigations, together with those of the Author, would, the speaker believed, lead to important results. He was inclined to think that Eastern England stood at this period at a higher level than now.

Mr. H. B. Woodward thought that the materials of the Chalky Boulder-Clay might have been derived from the north-west and north rather than from the west, as we had to account for fragments of Red Chalk. Certain crystalline rocks might have been derived from the earlier Boulder-Clay of the Cromer coast. In considering the source of the materials, the question of the distribution of the Chalky Boulder-Clay should not be neglected: and in Buckinghamshire and Hertfordshire we approached the margin of the deposit, where Boulder-Clay was intercalated among coarse gravels. Carbonaceous fragments were common in the Drifts of East Anglia, and might have been derived from the Estuarine Beds of Yorkshire.

Mr. A. E. Salter said he was glad to hear that the evidence brought forward by the Author was in accord with that of the gravel-deposits of Suffolk, etc., and pointed in a westerly direction for the source of the Glacial deposits in that area. The broad Waveney gap pointed to former fluviatile connection with the Midland district, where Liassic strata reached 800 feet above Ordnance datum even now, after a long period of subaërial denudation. In his opinion Glacial geologists, who wished to explain the origin of East Anglian Boulder-Clays, would be forced sooner or later to consider seriously the following points:—

(1) The denudation of the Midlands which has brought about the formation of the Oolitic and Cretaceous escarpments;
(2) The possibility of long-continued earth-movements of a differential character over wide areas;
(3) The fact that the Lower Cretaceous strata of the Midlands contain far-travelled boulders; and
(4) That the present outline of the North Sea is quite different from what it was when the Boulder-Clays were deposited.

Mr. Lamplugh acknowledged himself unable to adopt the attitude of the Author in discussing these Glacial questions. He urged that the phenomena should be considered as a whole, and not piecemeal. He would reiterate that all the facts converged to one conclusion, from which there was no escape—that the North-Sea basin had been filled with an ice-sheet. The details now brought forward by the Author could be as well explained by transportation of material from the north-east as from the north-west.

Mr. Whitaker supported the Author's contention as to the general westerly derivation of the materials of the Suffolk Boulder-Clay. He mentioned certain gravels in Norfolk, which were largely composed of Secondary materials, evidently derived from the Secondary outcrops to the west of the valleys in which these gravels occurred. The Author had, after all, confined his remarks to a comparatively small district in Suffolk, and this very restriction seemed to lend additional force to his contention.

Prof. Sollas remarked that the Author's argument against a derivation from the north or east depended, not on the assumed absence of Secondary rocks in these directions, but upon the rarity of sand in the Boulder-Clay under consideration. This, however, might be explained in more than one way, and did not to his mind preclude the possibility of a northerly and easterly origin. It would be interesting to know whether such sand-grains as were present showed signs of wind-action.

The Author, in reply, remarked that most speakers seemed to have assumed the clays to be the work of a certain agent, and to have argued for sources of the materials on that assumption. He had preferred to investigate the direction of the source; if that were found, enquiry as to the agent would be assisted. Mr. Lamplugh thought that the Yorkshire cliff-clays had been pushed up from the sea-bed: then the Suffolk clays had not been thus pushed up, for the sandy matrix of the former was totally different from the fine tenacious material of the latter. In regard to Prof. Sollas's enquiry as to the wind-polished sand-grains, if present these still might have been derived out of other beds. He used the word 'western' in a general sense.

12. *On the* Relation *of* Certain Breccias *to the* Physical Geography *of* their Age. By Prof. Thomas George Bonney, D.Sc., LL.D., F.R.S., F.G.S. (Read February 5th, 1902.)

I. Introductory.

Breccias and conglomerates have always attracted me, and the former especially since I had opportunities, about ten years ago, of examining one of the most interesting examples in Europe. They afforded problems, to which I failed to find answers in all respects satisfactory; so in the hope of obtaining further information I spent, during the summer of 1900, some days in the Western Thüringerwald, with my friend the Rev. Edwin Hill, in order to study the noted breccias of the Rothliegende, and last July again examined, and more fully than before, the beds of breccia, sections of which are well displayed along the high road in the Val des Ormonts above Le Sepey. In former years I had visited the Permian Breccias of the English Midlands and those now assigned to that period in Devon. All these exhibit certain features in common, some of which are also found in the so-called Dolomitic Conglomerate in the South-west of England. So I purpose to give a brief summary of the principal characters of each of these deposits, concluding with some comparatively modern breccias, in order that, if I cannot completely unravel their history, I may at least bring the more significant facts into a clearer focus.[1]

II. The 'Brockrams' of North-western England.

These I have never had an opportunity of examining, but gather the following facts from the careful descriptions which have appeared in print.[2] The beds of Brockram are intercalated in the red Penrith Sandstone, which in the vicinity of that town is uninterrupted either by them or by shales. Brockrams can be traced in a north-westerly direction from Kirkby Stephen to beyond Appleby,[3] and are also strongly developed in Dumfries-shire, where they thin towards the south or south-west. The authors of the Survey Memoir describe in the Appleby district two Brockrams, separated by a mass of false-bedded red sandstone, the lower one of which they describe more minutely. This (according to Mr. Woodward's

[1] I have referred in the course of this communication to the books and papers which I have consulted with profit; and I have to thank Dr. W. T. Blanford, Dr. R. H. Scott, Prof. Garwood, and Mr. Wickham King for their great kindness in giving me information in reply to enquiries.

[2] Mem. Geol. Surv. 1897 'Appleby, Ullswater, etc.' p. 72; and papers by Murchison, Harkness, Goodchild, Irving, and others, for references to which see H. B. Woodward's 'Geol. of England & Wales' 2nd ed. (1887) *s. v.* Permian p. 210.

[3] From one town to the other is about 10 miles.

summary[1]) is sometimes 100 feet thick, and the upper 150 feet. But a diagram drawn by Mr. Goodchild[2] shows that there may be more than two beds: the solid Brockram-mass at Kirkby Stephen tailing off wedge-fashion as it approaches Appleby. The lower bed is strongly jointed, forming bold mural escarpments, and often supplying a good building-stone. The fragments are usually crowded confusedly together in regard to size, though their longer axes tend to lie parallel with the bedding-planes. Those about 2 inches in diameter dominate, but they run down to mere grains on the one side and occasionally up to blocks 2 or 3 feet in diameter on the other; being either angular or but little rounded. As a rule from 85 to 90 per cent. are Carboniferous Limestone, the remainder being sandstone from the same system,[3] with a little chert, and shale. A few rounded pebbles of liver-coloured quartzite have probably been derived from some older conglomerate. A red sandstone occasionally forms subordinate bands in the Brockram, and the middle mass of that rock is strongly false-bedded. The fragments are hardly ever striated, but in one case the discoverers were satisfied that the marks were due to ice-action. The materials in the Dumfries breccia represent the rock of that district.[4] These Brockrams have evidently formed a marginal fringe to a rocky or mountainous region. Mr. Goodchild, who considers the ordinary Penrith Sandstone to be a desert-formation, suggests that the Brockrams were transported by shore-ice and deposited in water.[5] If so, the drift must have been (roughly) north-westerly in the one district and south-westerly in the other, the sand being indicative of winds blowing more directly from the east.

III. The Armagh Breccias.

Beds closely resembling these Brockrams, according to Prof. Hull,[6] occur in the Permian of Armagh. The sections described exhibit in the lower part a bed of breccia, 10 or 12 feet thick, composed (as I infer) of more or less angular fragments, embedded in a reddish sandy matrix, which passes locally into sandstone. The upper surface of this sometimes is eroded; at others the mass graduates into a stratified conglomerate and boulder-bed, the blocks being from 18 inches to 2 feet in diameter. These vary from angular to rounded, consisting of grit, felspathic sandstone, vein-quartz, and occasionally of limestone. Prof. Hull says that the boulders of grit (Silurian and Old Red Sandstone) must have travelled from 20 to 30 miles, and he attributes a glacial origin to the deposit.

[1] 'Geology of England & Wales' 2nd ed. (1887) p. 212. The thicknesses given in Harkness's paper, Quart. Journ. Geol. Soc. vol. xviii (1862) p. 206, are considerably less.

[2] Geol. Mag. 1882, p. 223.

[3] In one locality the bulk of the fragments consist of this sandstone.

[4] The 'Crabrock' of the Barrow district probably is a kind of brockram, and a thin bed of breccia forms the base of the Permians near Whitehaven.

[5] Trans. Cumberl. & Westmorl. Assoc. vol. ix (1885) pp. 46–47.

[6] Quart. Journ. Geol. Soc. vol. xxix (1873) p. 402.

IV. North-eastern England.

A seam of breccia sometimes appears at the base of the Permian in North-eastern England. This, in the Nottinghamshire district, was described by the late Edward Wilson [1] as attaining a maximum thickness of about 4 feet and consisting of angular to subangular fragments—sandstone, ironstone, and shales from the neighbouring Coal-Measures, with similar fragments of slate, quartzite, quartz, etc.; these seams of breccia also occur locally in the overlying sandstone. This basement-breccia, he states, maintains its average thickness and coarse texture, and must have been simultaneously deposited over a considerable number of square miles. It might be attributed, in his opinion, to droppings from melting icebergs or floes, but he remarks that, as it comes above a line of erosion, no special explanation may be needed. He regards it as the base of the equivalent of the 'Marl-Slate,' the Rothliegende not being represented in this district.

V. The Midland Breccias.

Some of the most important sections of this breccia are well exposed on the Clent Hills, along the margin of the Malvern-Abberley range and to the west of Enville, cropping out over an area of about 500 square miles; but they have also been found, though thin, in Leicestershire. In the former region they attracted the attention of geologists more than sixty years ago; but full descriptions have been given and their origin discussed, by the late Sir Andrew Ramsay,[2] Prof. Hull,[3] and recently by Mr. Wickham King.[4]

In the Enville district the breccia is underlain by a mass of sandstones, interstratified with marls, about 850 feet thick (maximum), in which are two beds of conglomerate, rather local, one of which attains to 60 or 80 feet. Here the breccia is followed by sandstones and marls, its principal outcrop running in a general north-westerly and south-easterly direction, and the greatest thickness being about 225 feet. In the Clent district the breccia attains its maximum, 450 feet, and covers Wychbury Hill (about 750 feet), Clent Hill (997 feet), Walton Hill (1036 feet), and Romsley Hill (930 feet).[5] Here it runs nearly north to south, parallel to, and mainly on the western flank of, a strip of older Palæozoics, from the northern end of which it continues in a north-westerly direction. The breccia is rudely stratified, and is occasionally interrupted by thin layers of sandstone, its materials becoming rather less worn in the upper parts until it passes into marl; the fragments vary from angular to subangular, and are very commonly from 5 to 6 inches in diameter,

[1] Quart. Journ. Geol. Soc. vol. xxxii (1876) p. 535.
[2] *Ibid.* vol. xi (1855) p. 185.
[3] Mem. Geol. Surv. 1869 'Triassic & Permian Rocks of the Midland Counties.'
[4] Quart. Journ. Geol. Soc. vol. lv (1899) p. 97; see also Proc. Geol. Assoc. vol. xv (1898) p. 372.
[5] W. Wickham King, 'Midland Naturalist' vol. xvi (1893) p. 25.

but those of smaller size are numerous. At Northfield, however, many measure about 9 inches, not a few about 12 inches, and one was 21 inches across. Now and then in the Clent district pieces quite 2 feet broad have been found:[1] these are usually Llandovery Sandstone. In some localities fragments of a compact igneous rock are so abundant, that the deposit obtained the name of 'trappoid' or 'trappean breccia.'

According to Mr. Wickham King, who has studied the materials of the Midland Permian more minutely than any predecessor, Carboniferous Limestone usually predominates in the underlying conglomerates, while the breccias in most places are formed of yet older rocks, namely, of compact felstones (late pre-Cambrian volcanics), tuffs and agglomerates, hälleflintas, Cambrian quartzite, and Silurian rock, especially Llandovery Sandstone: the majority of these representing older Palæozoic or late pre-Cambrian rocks, which are exposed to view (being brought up by faults) on the western flank of the Clent range.

Two explanations have been offered of the origin and mode of transport of the materials of these breccias. Sir Andrew Ramsay, followed by Prof. Hull, thought that they had been carried by floating ice from the Welsh Borderland, 20 or 30 miles away, and asserted that some of the fragments bore glacial striations. But the specimens exhibited at Jermyn Street always appeared to me to have been marked by mutual pressure, and this view, I am glad to find, commends itself to Mr. Wickham King. He also points out that the thickness of the breccias in the Clent and Enville districts is greatest at their southern extremities,[2] and that they have been derived from rocks *in situ* to the south or south-east in the 'Mercian Highlands,' of which a little is exposed in the above-named tract, but the major part is concealed beneath the Trias.

The Permian deposits of Leicestershire have been admirably described by Dr. Horace Brown,[3] and I obtained some further particulars as to the materials of the breccia from the study of a collection made by Mr. W. S. Gresley.[4] Here outcrops are few, the whole system is thin,[5] and the breccia at most a few feet thick. The fragments, according to Dr. Brown, are embedded in a calcareous sandy matrix, are generally angular, and seem to become more so in a southerly direction. They are derived from rocks of various ages, the proportion varying with the locality. The Carboniferous Shales are generally well represented, amounting occasionally to

[1] As stated by Mr. Wickham King (*op. cit.*) and more fully explained in a written communication (to which I am much indebted), the size of the fragments varies much in different localities.

[2] The thick breccia at Clent is replaced by sandstone at Sedgeley (8 miles); that at Northfield has nearly died out at Handsworth (5 to 6 miles); and two of the Enville breccias almost or quite die out in 4 miles.

[3] Quart. Journ. Geol. Soc. vol. xlv (1889) p. 1. They were also briefly described by Prof. Hull, Mem. Geol. Surv. 1860 'Leicestershire Coal-Field.'

[4] 'Midland Naturalist' vol. xv (1892) pp. 25, 49.

[5] Only in one case does it exceed 30 feet. The breccia seems to vary in position; occasionally there are two seams, and the total thickness is something like 4 yards.

about 28 per cent. Igneous rocks and volcanic ash, in one case amounting to 15 per cent., are also present, with slates, argillites, and felspathic grits or quartzites, the last two together varying from 34·5 to 84 per cent. Certain specimens closely resemble some rocks in the lower part of the Hartshill Quartzite (basal Cambrian), the nearest exposures of which are now 12 miles away. In Mr. Gresley's collection I detected syenite, altered dacite, some slaty rocks—all of Charnwood type, with other slates and grits, a remarkable conglomerate with pebbles of a dark rhyolitic rock, representatives of the Coal-Measures including the 'burnishers' (ironstone-nodules), and probably Millstone Grit. At Coton Park Colliery two boulders (felspathic grits) were found; one weighing about a ton measured 3 ft. 11 in. × 3 ft. 9 in. × 2 ft. 3 in., and the other 3 ft. 3 in. × 2 ft. 9 in. × 2 feet. Both these were distinctly striated, as were ten other smaller fragments, in regard to which I wrote [1]:—

'While it is difficult to deny that certain of these markings may be striæ, which have been produced in some way or other by the action of ice, I am more than doubtful of others, and am not convinced that this explanation is necessary for any..... At the same time, the very angular character of many of the fragments, their size, and the great diversity which they exhibit, might fairly be brought forward in support of the hypothesis that ice had been one of the agents of transport.'

At this stage it will probably save time to make a few remarks on the source and transport of these Midland breccias. Those of Leicestershire, according to Dr. Brown and Mr. Gresley, apparently have been derived from the south and south-east. I infer from their variety that the materials have been gathered from a fairly large area, and from their form that they have not been much worn either by rivers or waves. The breccias of the western region (Clent, Enville, etc.) lead to the same conclusion. These occur as wedge-like fringes, very thick on one side, but dying out in a few miles. The land-mass which has furnished the breccias of the Clent Hills, if close at hand, must be represented in part by the rocks exposed in the lower Lickey Hills, and it must extend underground for a considerable distance to the north-west. That which has supplied the Enville breccias must be concealed somewhere to the east of that place. The rapid thinning-out of the Lower Trias in Central England towards the south-east, and the exposures of early Palæozoic or late Archæan rocks at Charnwood, Hartshill, Dosthill, and the Lickey, indicate that an upland region once extended across, at any rate, this part of England in a general north-easterly and south-westerly direction. Much, however, of this is even now covered up by Coal-Measures, which in the South Staffordshire and Warwickshire district are often overlain by Permian. Indeed, even at the Lickey, the strip of Silurian and older rocks is flanked on both sides at its northern end by Coal-Measures.[2] From Dudley to Sedgeley, and over a rather large area about Walsall, Silurian rocks, mostly of Wenlock

[1] 'Midland Naturalist' vol. xv (1892) p. 57.

[2] A very interesting section, showing Coal-Measures with a seam of coal, resting on Cambrian quartzite, was exposed in digging the foundations for the County Lunatic Asylum at Rubery.

age, underlie the Coalfield. Moreover, the area covered by the higher Permian deposits in the immediate neighbourhood of the breccias, even if augmented by that now occupied by the Lower Bunter, seems, under the most favourable circumstances—that is supposing the ranges of this old land-mass to run athwart it,[1]—to afford a very straitened site for a really important hill-mass. The Bunter also, as it is thinning rapidly, can hardly exceed 1000 feet in any part of this district and must often be much less, so that any buried summit cannot rise high above the general level. Though a large land-mass undoubtedly occupied this part of England during the earlier half of the Carboniferous Period, the distribution of the Coal-Measures proves that very much of it was afterwards buried, and was not laid bare again before the Permians were deposited. Thus the masses of more ancient rock from which the breccias were supplied cannot have extended far, or risen high; so that to call this region the 'Mercian Highlands' seems to me more picturesque than accurate, for I should expect it to be comparable rather with the Southern Uplands of Scotland than the great hill-masses farther north.[2] If then we are compelled to restrict, vertically as well as horizontally, the area which supplied these masses of Permian breccia, we are driven to assume that agencies have been at work which were capable of shattering the bare rocky slopes and transporting the materials for some few miles.

VI. The Devon Breccias.[3]

Mr. Ussher has given a very full description of these interesting deposits,[4] from which I extract the following facts as having most bearing on their origin and formation. They vary considerably in shape and in mineral character, being generally angular, as, for instance, about Dawlish and Teignmouth,[5] but subangular or rounded in the neighbourhood of Bradninch and Roundham Head

[1] As suggested by Mr. Wickham King.

[2] Some may reply that these Mercian Highlands were destroyed during the later Permian and earlier Triassic periods. But, if so, they must have been planed away, work which takes rain and rivers a long time to perform, and it is very doubtful whether, during this interval, the sea ever overflowed this district. [A speaker in the discussion mentioned Charnwood as a truly 'Highland' mass. But this is some 35 miles away: the highest summit also at the present day does not rise more than 400 or 500 feet above the Coalfield and the overlying Permians (which here are thin), and we have no reason for supposing that the relative levels have been materially altered since the end of the Palæozoic era.]

[3] I accept these as Permian, in accordance with the views of Conybeare, Buckland, and Murchison, which since Dr. A. Irving's excellent paper in vol. xliv (1888) of this Journal (p. 149) have regained favour. It would not affect their general significance even if they were Trias.

[4] Quart. Journ. Geol. Soc. vol. xxxii (1876) p. 387.

[5] In this district, according to the late Mr. R. N. Worth, the biggest boulders occur (sometimes 4 or 5 feet in diameter) in the Dawlish Valley; here also they are most varied in composition, and contain the largest proportion of granitic rock.

near Paignton, and about Torquay.[1] Fragments of shale and grit are abundant when they rest upon the Culm-Measures north of the Tiverton Valley; those of igneous rock predominate at Dawlish and Teignmouth, and almost exclude all others in parts of the Crediton Valley.[2] The red matrix is more or less sandy; sometimes rather incoherent, at others hard enough to furnish a good building-stone.[3] The mass often shows stratification, and is occasionally interrupted locally by bands of sand or clay, into which it passes. These breccias are exposed over an area, east and north of Dartmoor, which is not unfrequently from 6 to 8 miles broad. The maximum thickness of the group, sandstones and breccia, is about 1000 feet; but I cannot find a precise statement as to the latter, which, however, must sometimes reach a few hundred feet. It will be inferred from what has been said that the fragments have not travelled for any great distance. The sedimentaries have been derived, as the case may be, from Devonian or Carboniferous strata. For the igneous fragments also we probably need not go very far.[4] Many of the more compact may have been derived, as suggested by Mr. Worth, from almost contemporaneous volcanoes at no great distance. The ordinary granite of Dartmoor is said to occur rarely, but fragments of a fine-grained rock, in which crystals of felspar are conspicuous, seem to me likely to represent external portions of the massif which have now been removed. If so, some of them can hardly have travelled less than 7 or 8 miles.

VII. The Breccias of the Thüringerwald.

So many authors have described this typical example of Rothliegende breccia, that I shall content myself with referring to their publications and giving an epitome of some notes which I made in the summer of 1900, when Mr. Hill and I visited Eisenach. A great mass of this rock forms the western end of the Thüringerwald hill-region, which cannot be less than 600 feet in thickness. Slight indications of stratification are generally visible; and in the lower part, as may be seen in the Annathal, and in the Georgenthal west of the Wartburg, it is regularly interstratified with beds of sand or marl into which it passes rapidly, as shown in the appended section (fig. 1, p. 192). When the breccia is not thus interrupted, it often forms bold crags. The matrix, which frequently makes up about half the volume, is dull red in colour and more or less sandy. The fragments vary in shape from angular to subangular, are commonly less than 2 inches in diameter, but occasionally 4 or 5 inches, and sometimes rather over 12. On the Wartburg they

[1] Here they are generally subangular or even rounded, and from the Devonian Limestone.

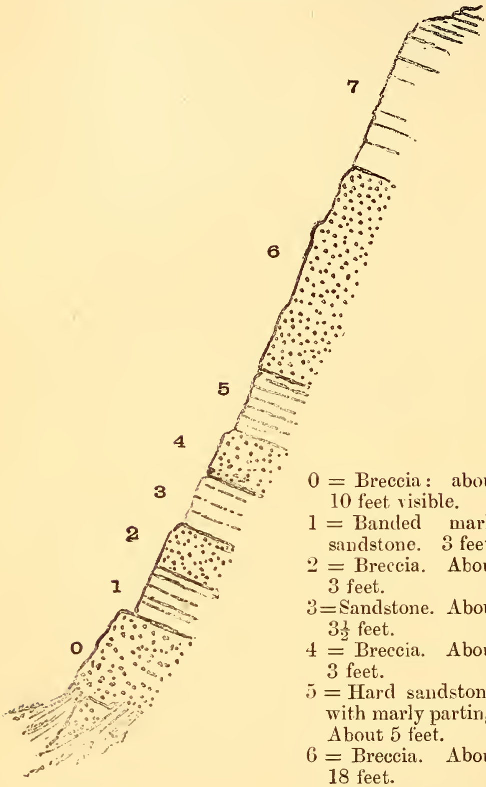
[2] For the variations in the materials and their shape, see Ussher, Quart. Journ. Geol. Soc. vol. xxxii (1876) p. 388.

[3] As, for example, St. Mary's Church, north of Teignmouth, and Heavitree near Exeter.

[4] For the fullest information on this subject, see R. N. Worth, Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 69.

apparently become a little larger towards the summit. They consist of vein-quartz (abundant), fine-grained grey granite and gneiss, a micaceous schist, felstone, and slaty rock or grits. At Ruhla, in the bed of a well-marked valley which opens out some 4 miles east of Eisenach, a lead-coloured micaceous schist is exposed, and about half a league farther up, a porphyritic granite; and more than one variety of felstone is passed on walking over the elevated upland to the Hohe Sonne, south of Eisenach. At Friedrichsroda, about 12 miles east by south of Ruhla, Permian 'porphyries' abound; but some bedded Rothliegende is seen, in which is an occasional seam of small breccia. According to the geological map, the breccia in the Eisenach district occupies an area measuring at first nearly 4 miles from west to east, but narrowing towards the south, and about 9 miles in a transverse direction. The mica-schist, such as we see at Ruhla, extends about 5 miles along a line from a little east of north to west of south, and half that distance in a direction at right angles to this. Then comes the granite, which at first is a mere strip, but broadens out southward until it nearly replaces the other rock. East of these crystalline rocks Permian deposits set in again. Thus the area of more ancient rocks, which can have been exposed in Rothliegende times, does not exceed 3 miles in breadth, and so cannot then have been surmounted by an important mountain-range.[1]

Fig. 1.—*Section near the railway-bridge, Georgenthal, Eisenach.*



0 = Breccia: about 10 feet visible.
1 = Banded marly sandstone. 3 feet.
2 = Breccia. About 3 feet.
3 = Sandstone. About 3½ feet.
4 = Breccia. About 3 feet.
5 = Hard sandstone, with marly parting. About 5 feet.
6 = Breccia. About 18 feet.
7 = Bedded sandstone. About 20 feet visible in places.

[1] If the average slope were 1 in 10, the height of the part removed would be about 800 feet.

VIII. The Dolomitic Conglomerate.

In former years I often saw, but without minutely studying, sections of this deposit, which has been so admirably described by Mr. R. Etheridge.[1] The following is a brief summary, chiefly derived from his paper, of facts which are germane to this investigation. The Dolomitic Conglomerate fringes the Mendip Hills and other prominences of Carboniferous Limestone, almost surrounding the Somerset and Gloucestershire Coalfield; it occurs over an area probably about 140 square miles in extent, and at various elevations up to about 300 feet above sea-level, rarely exceeding 30 feet in thickness. It can often be traced horizontally into a sandstone, is interstratified with the Keuper Marl, and sometimes two beds may be seen in an open section, separated one from another by 3 or 4 feet of the latter: the breccia itself occasionally exhibiting signs of stratification. The fragments vary in size, but usually are less than 3 inches in diameter, though much larger blocks—a yard or so in diameter—sometimes occur. They generally are either angular, or only slightly worn at the edges, but occasionally are well enough rounded to make the name 'conglomerate' the more appropriate. The great majority are of Carboniferous Limestone, though Millstone Grit, Carboniferous Sandstone, and even Old Red Sandstone are sometimes found: the materials depending on the character of the adjacent rock-masses.[2] These are embedded in a reddish marly or sandy matrix, more or less cemented by calcite or dolomite, so that the breccia sometimes makes an excellent and a very handsome building-stone. It was regarded by Sir Andrew Ramsay,[3] with whom Mr. Etheridge practically agrees, as a shore-deposit, composed of materials which had mainly been formed on old land-surfaces, but had been more or less worked up, as these subsided, by the waters of the Keuper lake or inland sea. It may be sometimes cliff-talus, but even in Upper Triassic times the land-surface must, I think, have been a region of craggy downs, rather than of great hills with precipitous flanks. If so, the fragments must have mainly accumulated on the bare limestone-slopes, from which they were either swept down more or less tumultuously into the water, or else washed off and re-arranged as shingle-beaches during a period of slow subsidence. In an inland sea the fragments, though most of these are of rock no harder than Carboniferous Limestone, would not generally be much rounded; for there tidal action would be inappreciable, and that of waves seldom strong. Striations have been observed, though not often, on the surfaces, but these probably have been produced subsequently by earth-movements.[4]

[1] Quart. Journ. Geol. Soc. vol. xxvi (1870) p. 174.

[2] In the Quantock district (for instance) breccias, referred to the same age by Mr. Etheridge, consist of Devonian rocks.

[3] Quart. Journ. Geol. Soc. vol. xxvi (1870) p. 191.

[4] It may be well to mention that a breccia occurs at the base of the Bunter in Southern Shropshire and Northern Worcestershire. It reaches a maximum of 60 feet or so near Kidderminster, but is not important enough to call for special notice. Prof. Hull thinks that the fragments have not travelled far; see Mem. Geol. Surv. 1869 'Triassic & Permian Rocks of the Midland Counties' p. 44.

IX. Jurassic Breccias.

We are indebted to Prof. Judd[1] for a very full and precise description of the remarkable beds of breccia which occur in the Upper Oolite of Sutherland. As they bear in many respects a very close resemblance to those which I am about to describe in the next section, I shall content myself with referring to his paper for particulars, merely stating that these breccias are not quite so difficult to explain as some others, because the source of their materials is more easily determined. He concludes that they were deposited in a sea in the neighbourhood of its shore, and were brought down from a mountainous region by flooded streams, but that the great size of occasional blocks—some measuring 20 by 10 feet—suggests that ice aided in the transport.

X. Breccias in the Alpine Flysch.

The breccia-beds in the Flysch may be traced practically over the whole length of the Alpine chain,[2] but the more remarkable developments are on the northern side. The Flysch itself is obviously a result of physical conditions which were not simultaneous, but set in and ended earlier in the east than in the west, the breccias being sporadic in distribution. I select for description two localities which I have myself examined, and believe to be among the most remarkable instances.

The first is the noted one in the Habkerenthal. As this has been frequently described, I shall restrict myself to mentioning the points which seem to me to bear more immediately on the question of its origin. Here the Flysch itself is a brownish to blackish, rather gritty, fissile[3] mudstone. It contains occasionally thin bands of hard sandstone and lenticular masses of breccia or conglomerate. The fragments in this are commonly subangular or subrotund; sometimes it becomes a coarse grit, and sometimes contains boulders bigger than a man's head. The material of the matrix (generally indurated) apparently has been derived from granitic rocks; in parts it becomes a fairly uniform quartz-felspar grit, which occasionally might even be mistaken for a granite, but when the fragments vary much in size a few represent sedimentary rocks. Thin streaks of mudstone sometimes interrupt the lenticular masses towards the outside, and the mudstone itself may contain isolated boulders or fragments.[4] I was unable in the time at my disposal to find one of the very large boulders actually *in situ* in the Flysch, but several lay in the bed of the stream, the biggest of which

[1] Quart. Journ. Geol. Soc. vol. xxix (1873) p. 187.

[2] Erratics are said to occur in the Flysch of the Carpathians and Apennines: Lyell, 'Principles of Geology' 11th ed. vol. i (1872) p. 209.

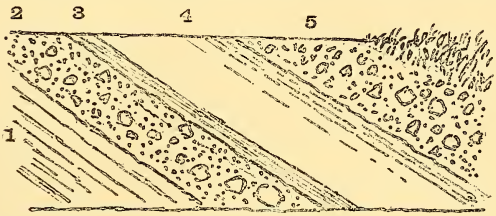
[3] Whether due to cleavage or bedding I could not be certain, in the time at my disposal. I do not remember to have seen a clear statement in print. The term schist of course, as used by Continental geologists, tells us nothing.

[4] In one or two places I suspected this to be the result of the shearing of a band.

(rather rounded) measured roughly $4 \times 3 \times 3$ yards.[1] Among these blocks, as is well known, more than one variety of granite is represented,[2] some of them not corresponding with any now visible in the Alps, and one, a porphyritic variety, much resembling a granite in the Schwarzwald.

The second locality is in the Valley of the Grande Eau, above

Fig. 2.—*Breccia in the Flysch, between Le Sepey and Aigremont.*



1 = Slabby, sometimes shaly limestone.
2 = Breccia; about 2 feet, slightly irregular.
3 = Shale; about 3 inches.
4 = Limestone; about 2½ feet. Slabby in the upper part.
5 = Breccia; perhaps 3 feet thick. Base a little uneven.

Le Sepey,[3] where a fine series of sections is exposed in cuttings for about half a league on the lower part of the road to Ormont Dessus, as well as on that which turns up from it to Comballaz. These exhibit a series of bedded limestones (dark), mudstones, grits, and breccias, forming apparently an ascending series, and dipping variably but, as a rule rather steeply, in a south-easterly direction. As this is a region of great folds and faults, repetition is possible; but, so far as I could see, the succession was generally undisturbed.

The following is a summary of the principal facts:—The breccia, in which signs of stratification may be detected, is regularly interbedded with limestones, mudstones, or grits, passing at the top or bottom (generally rather rapidly) into one or other of them, but in the case of the first or second a thin layer of grit may intervene. Beds of breccia are numerous between Le Sepey and the ravine of the Raverettaz, varying in thickness from less than 18 inches to several yards, but apparently becoming thicker and coarser as they ascend. On approaching that ravine we find a thick mass of grit or gritty limestone setting in, which passes locally and rapidly into a breccia, the coarser parts of which are usually characterized by abundant small fragments of a dark slaty or shaly carbonaceous rock, giving

[1] Murchison mentions, in Quart. Journ. Geol. Soc. vol. v (1849) p. 212, a block which measured $35 \times 30 \times 15$ yards, or not less than 400,000 cubic feet in volume.

[2] Some years ago I saw at least six different varieties in the Berne Museum.

[3] I ascertained the principal facts during a hurried visit in 1891, and made a more careful examination last summer (1901).

the mass a black speckled look. In these interstratified breccias the rock-fragments generally vary from about 3 inches in diameter downward, and are mixed up without regard to size, but in places a large boulder occurs: for instance, one or two (in volume 3 or 4 cubic feet) may be found in a mass where the bulk of the fragments do not exceed 5 inches in diameter, and are mostly much smaller. On the left bank of the Raverettaz stream we speedily come (near Aigremont) to the great mass of breccia.[1] This is exposed, forming a cliff, higher up the mountain, and the road, on emerging from the ravine, crosses its outcrop.[2] Beyond this are found two or three comparatively thin beds of breccia, one of which contains a block of granite some 5 yards long. Afterwards the road passes over grassy slopes till it arrives at Ormont Dessus.

This mass of breccia, according to Prof. Renevier and Dr. Schardt,[3] can be traced for about 5 kilometres to the south-east and 2 kilometres to the north-west, but it may extend much farther in this direction; the latter observer gives it a breadth of 6 to 7 kilometres from north-east to south-west, the blocks diminishing in size towards the east, north, and west, but increasing towards the south, where they are lost beneath overthrust Jurassic strata. The fragments in the Flysch, he remarks, vary with the locality.

The materials of the breccias must now be briefly noticed. In the great mass, mentioned above, the matrix is a dark gritty mudstone, the volume of which is less than that of the fragments. Of these the majority are less than 5 inches in diameter, but the rest may be of any size up to several cubic feet, the largest being some variety of granite or gneiss. Crystalline rocks predominate in the fragments, many of them showing pressure-foliation; but among the sedimentaries I noticed a dark limestone and dark shaly or slaty rocks, some of the latter containing fragmental mica (? from the Carboniferous system). Vein-quartz is common. The following kinds of rock are enumerated by Messrs. Favre & Schardt[4] as occurring in the Aigremont breccia:—(*a*) At least eight varieties of granite, greyish or greenish, fine and coarse; (*b*) at least three varieties of gneiss; (*c*) mica-schist, with white to yellowish mica; (*d*) green schist, with more or less chlorite; (*e*) green talcose clay-schist; (*f*) quartzite; (*g*) green petrosilex or felsite; (*h*) dark slaty rocks, generally in small bits; (*i*) grey limestones, sometimes in large blocks. My own observations, though less minute, are in accordance with this. Some of the green schist reminded me of members of the 'Grüner Schiefer' group elsewhere in the Alps, but occasional fragments were unusually bright in colour. A few, more compact, recalled a 'petrosilex' that I had found near the Pissevache waterfall (Vernayaz).

The microscopic structure of some of these rocks may now be briefly described, for it is needless to dwell on the more minute

[1] The road crosses a 'berg-fall,' which occurred in the 16th century.

[2] So far as I could estimate from this, the thickness must exceed 100 feet.

[3] I am much indebted to these gentlemen for kindly sending me particulars, in reply to my letter of enquiry.

[4] 'Beiträge z. geol. Karte d. Schweiz' vol. xxii (1887) p. 204.

details.[1] In the Aigremont breccia the cementing-material is calcite, more or less dolomitic. The fragments represent quartz, felspar (often plagioclastic), mica (mostly white), a green chloritic mineral, containing minute black needles, perhaps replacing biotite, gneiss, mica-schist, a microcrystalline green schist, sometimes rather quartzose, one or two fragments of a black micaceous schist, resembling one in the Binnenthal, compact felstone more or less porphyritic, marble (?), limestone with small fragments of organisms, some probably foraminifera, (?) chert with traces of radiolaria; also fragments of polyzoa, echinodermata, nautiloid foraminifera, and an occasional *Globigerina*. In the grits from the west side of the Raverettaz stream the calcareous matrix is more abundant, and so are quartz-grains, but the other minerals can be identified, and among the rocks, gneiss, a coarse mica-schist, and one representing a compact 'porphyry.' The dark fragments already mentioned prove to be a more or less gritty bituminous-looking rock, possibly with a slight cleavage, very probably from the Carboniferous system. In one slice (which exhibits a slight tendency to become oolitic) fragments of mollusca are rather common, in another those of polyzoa; those of echinodermata also occur.

The presence of these organisms accords with what has been observed by Prof. Renevier, Dr. Schardt, and other Swiss geologists.[2] They place the Flysch at the top of the Eocene, immediately above the calcaire à nummulites, and state that this fossil and schistes à fucoïdes (*Chondrites arbuscula*) have occurred associated with the breccias. So these must be, as a rule, marine deposits, although, as the form of the fragments indicates, they cannot have been either very much rolled by the waves or transported far by torrents. Yet materials so various must have been collected from a fairly large area. The granitoid and gneissoid rocks have a general resemblance to what I have seen in adjacent Alpine regions: the nearest exposures of such rocks at the present day being 11 or 12 miles to the south-south-west. The ordinary green schists resemble those common in the Pennines; and I saw a similar rock in going from Kippel to the Lötschen Pass, which is over 30 miles away in an easterly direction. The 'porphyry' reminds me of the reddish variety which occurs occasionally in the Swiss Alps, and of which a small specimen was given to me many years ago by Prof. Renevier, from one of the valleys descending to the Rhone from the Dent de Morcles: in this also are the nearest exposures of Carboniferous rocks, 11 or 12 miles away.[3]

[1] I have examined eight slices, four representing the coarse breccia east of the Raverettaz Stream, three the grits west of it, and another a breccia, the precise locality of which is uncertain. As I had contented myself with a single typical specimen of each of the first and second, I am much indebted to Miss C. A. Raisin, D.Sc., for the loan of specimens collected during a visit in 1894.

[2] Renevier, 'Beiträge z. geol. Karte d. Schweiz' vol. xvi (1890) p. 427, etc.; Favre & Schardt, *ibid.* vol. xxii (1887) p. 267, etc.; Schardt, Bull. Soc. Vaud. Sci. Nat. ser. 2, vol. xx (1884–85) p. 10, etc.

[3] I have not forgotten the Miocene deposit with erratics on the Superga near Turin, but do not discuss it, as the sections which I saw in 1862 were not good, and its difficulties are not quite so great as in the case of the Flysch.

XI. Breccias of Recent Age.

We must next enquire what physical conditions at the present or in post-Tertiary ages are most favourable to the formation of breccias like those that I have described. We find no such deposits either now forming in Europe, or among those of Glacial or later days in the Alps, Pyrenees, or Scandinavia. One instance only is known to me, which presents any resemblance—the breccia-beds at the Rock of Gibraltar. The late Sir Andrew Ramsay and Prof. James Geikie, after a lucid discussion of the evidence, concluded that these were mainly formed by frost and transported by melting snow.[1] In fact, as more than one observer has informed us, the physical conditions now existing in the Arctic regions are particularly favourable to the production of breccias.[2]

XII. Stone-Rivers of the Falkland Isles.[3]

In the Falkland Isles the land, generally low, rises in places into ridges which are seamed by the basset-edges of a white quartzite, like stone walls: the ground elsewhere being peaty and boggy. In the East Island most of the valleys are occupied by pale-grey glistening masses, from a few hundred yards to a mile or two in width, which at a distance look like glaciers, apparently descending from the adjacent ridges, and being gradually increased in volume by tributary streams, till they reach the sea. They are composed of blocks of quartzite, angular and irregular in form, and often rudely diamond-shaped, but edges and points in most cases are slightly rounded. In length they measure from 2 to 8 or 10 feet, and perhaps half as much in width; their thickness corresponds with that of the quartzite-beds. A stream often makes its way beneath them along the valley-bottom. The following is Sir Wyville Thomson's explanation:—As some of the quartzite-beds are much softer than others, these crumble readily away, leaving the harder projecting, till at last they fall, when they are quickly embedded in a peaty soil, which under the combined action of the rain, of expansion, and of contraction, creeps down the slope, carrying with it the embedded blocks. On reaching the bottom they continue their crawling motion, though more slowly, down the valley, and percolating water gradually removes the peaty material from among them, leaving little more than the blocks of quartzite. Though these islands approximately correspond in latitude with England between Stafford and Salisbury, their mean temperature is about 7 degrees lower; the winters indeed are not at all severe, but the thermometer in summer does not often rise above 65° Fahr., and fog or rain are far more frequent than sunshine.

[1] See Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 505.

[2] See especially E. J. Garwood, Quart. Journ. Geol. Soc. vol. lv (1899) p. 683 (Spitsbergen); H. W. Feilden, *ibid.* vol. xxxiv (1878) pp. 564–65 (Smith Sound District).

[3] This account is condensed from a very clear and precise description by Sir Wyville Thomson, in 'Voyage of the *Challenger*: Atlantic' vol. ii (1877) pp. 245 *et seqq.*

XIII. Breccias in Persia.[1]

Probably more than half the surface in the Persian upland is covered by breccia, gravel, sand, or loam (of recent origin, geologically speaking), the thickness of which is so great that no other formation can be seen for hundreds of square miles. The elevated plains or broad valleys, surrounded by mountains of moderate height, are covered in the central part with a fine pale-coloured loam—probably lœss, and thus of subaërial origin, though lacustrine deposits exist in places. But from the foot of the hills, a fringe of breccia extends over this on either side, for a distance of 3 or 4 miles and sometimes more, its surface sloping at a very low angle, usually from 1° to 4°.

A very brief description of the district near Bághin may suffice as an example. Here the valley-plain, some 5500 feet above the sea-level, is about 13 miles in width, and runs in an east-to-west direction, between hills which rise on either side from 1500 to 2000 feet above it. On the northern side the breccia-fringe extends for about 3 miles, the angle of its upper slope being less than 2°; on the southern is a similar fringe, 4 to 5 miles wide, its inclination being a little under 1°;[2] and between these is the flat central plain (lœss) about 6 miles across.

The climate of the Persian plateau is one of extremes. At Teheran (lat. 35° 41′ N.), about 3700 feet above the sea, the mean temperature of January is 35·6° Fahr., of July 79·3°, of the year 60·3°; at Ispahan (lat. 32° 38′), altitude 5020 feet, it is, for January 31·6°, for July 82°, for the year 59·4°. In the region of the breccias, some 2000 feet or so higher above the sea, the annual temperature would be about 6° lower, and the winter-temperature affected to at least the same amount, and perhaps yet more. The rainfall also is small—probably not more than 10 inches (it is 10·4 at Teheran), and on the hills most of this descends as snow. The same type of climate—extremes of heat and cold, with a limited rainfall—prevails in a large part of Central Asia from Persia to Eastern Tibet, in which similar formations are frequent. They occur also in parts of the mountains of Northern Hindustan.[3]

It may be well to mention that the 'alluvial fans' produced by 'mud-avalanches,' which are such conspicuous features in many

[1] This description is founded on Dr. W. T. Blanford's account of the 'Geology of Eastern Persia' vol. ii (1876) p. 465, and Quart. Journ. Geol. Soc. vol. xxix (1873) p. 493; and I have to thank him for kind information which has allowed me to make one or two verbal changes. I have also referred to papers by E. Tietze, Verhandl. der k.-k. Geol. Reichsanst. 1874-77, esp. 1875, p. 130.

[2] Even this low slope would give a thickness of about 450 feet near the hills. At Teheran, however, as Dr. Blanford informs me, the slope of débris which extends from the town to the base of the Elburz, a distance of about 10 miles, shows a difference in level of 3500 feet, and at Kashan, about 150 miles to the south, where the slope is of about the same breadth, he found this to be 2250 feet.

[3] See 'The Making of a Frontier' by Col. A. Durand, chapters i & ii, for an excellent description of breccia-slopes and alluvial fans.

parts of the Karakorams and Himalayas (see my paper in Geol. Mag. 1902, p. 8), are by no means identical with these breccia-beds. In these the proportion of mud is very much larger, so that they bear closer resemblance to an ordinary boulder-clay. Mr. R. D. Oldham,[1] in a most suggestive paper, expressly identifies the Permian breccias of the Midlands with the 'gravel-fans' of Western and Central Asia; but I venture to think that he does not quite sufficiently emphasize this distinction, between the breccias in question and the ordinary 'mud-avalanche' or 'glacial-schotter.'

XIV. Inferences as to the prevailing Physical Conditions when the Breccias were formed.

My apology for describing these breccias at some length must be that inferences as to the physical conditions which led to their formation are dependent on the details. Those of the Rothliegende are fringe-like in distribution, attain considerable thickness, and can be traced occasionally for some few miles from their source. The area of this often is not large, compared with the volume of the breccia-bed; so that they were more probably derived from a highland region with bare rocky slopes, than from a lofty mountain-range. The close resemblance between these and certain Asiatic breccias suggests that the climate of both our islands and Germany was then distinctly continental in character; perhaps hot in summer, but cold in winter, possibly with a considerable snowfall at that season, though this, as we see, is not an absolute necessity, for occasional torrential rains might produce the same effect. Remembering that contact with a sheet of water would greatly check the movement of scree-like material, we infer that, as a rule, these breccia-beds were subaërial rather than subaqueous deposits; and it is not impossible that even the intercalated beds of finer material may be wind-borne. There is no proof of the existence of glaciers, but floating ice is sometimes suggested as a possible agent of transport; in any case, these breccias indicate that the epoch of the Rothliegende was characterized by a considerable range of temperature and rather cold winters.[2]

When the breccia-fringe extends continuously from the mountainous district for 4 or 5 miles, it is probably a subaërial deposit. It is certainly so in Persia, where I was perplexed to explain how the fragments could travel so far on an almost level surface. At moderate distances we might attribute it to melting snow, which imparted a sort of fluidity to the mass, so that it spread out laterally under the action of gravity, somewhat as a mud-avalanche may ultimately do. But for the Persian breccias

[1] Quart. Journ. Geol. Soc. vol. l (1894) p. 463.

[2] I have not referred to the glacial deposits of Permo-Carboniferous age in Australia, Hindustan, and, perhaps, South Africa, because they are outside the purview of my paper, and the question of their exact age might introduce complications.

neither this nor any other explanation that I could devise was satisfactory. So I consulted Prof. Garwood, in the hope that his wider experience of cold regions might supply the key to the problem. His reply was to this effect:

'What can be seen in Spitsbergen will explain it. There the rocky mountain-slopes are greatly shattered by the frosts, and the material is always slipping down when the season permits. A talus is formed; this is covered up by snow in winter; when the fragments come showering down from above, they slide easily over this. Year by year this process is repeated, and so the fringe mainly grows on its outer edge. The fragments which fail to reach this, or fall when the scree is exposed, go to raise it; but these contributions are the less important. A stone which has acquired considerable velocity before reaching the snow will travel for long distances before it comes to rest.'[1]

This explanation seems to meet all difficulties, so that while more than one may be applicable to breccias which have not travelled far, or are very sporadic in character, we are justified in assuming wide fringes to indicate physical conditions such as now exist in Persia.

The Keuper breccias suggest, though less forcibly, a recurrence of Rothliegende conditions, and the British Trias as a whole appears to be a 'continental' deposit.[2] If I am right in regarding the Bunter Beds as the product of rivers far greater than any of our present British streams, and in denying the existence of Mercian Highlands of real importance, the sands and pebbles of the Bunter and the Lower Keuper may have been deposited on a lowland, which, notwithstanding, or perhaps because of, heavy precipitation on the mountains to the north and west, was itself arid, like many similar districts in Asia. Even the Keuper Marls, though deposited in an inland sea, do not necessarily imply a climate like that of the Dead Sea. At the Great Salt Lake the mean annual temperature is 51·98° Fahr., that of July being 76·64° and of January 25·88°: the rainfall, so far as I can ascertain, being about 10 or 11 inches. On the Caspian, the annual temperature at Baku is 61·88° Fahr., being 78·44° in July and 38·12° in January; while salt-lakes are abundant in Turkestan, where the winters are exceedingly cold. So the Dolomitic Conglomerate is also probably indicative of a continental climate, with cold winters and a rather limited rainfall. The Upper Oolite of Sutherland seems more likely to be the product of a mountainous

[1] The velocity, he tells me, acquired by a toboggan in sliding obliquely down some 70 or 80 feet to the St. Moritzer See, will carry it across the snow-covered ice (about half a mile).

[2] Mr. Goodchild, in his paper on 'Desert Conditions in Britain' Trans. Geol. Soc. Edin. vol. vii (1896) p. 203, comes to much the same conclusion in regard to the 'New Red Sandstones'; so I wish to say that the present paper was written without having read his, for I did not come across a reference to it until a few days before sending mine to the Geological Society. I should, however, hesitate to press one or two of his arguments: as, for example (p. 215), I would not say more than that the red colour of these breccias made it rather probable that they had a desert origin. In regard to the Torridon Sandstone, I may add that for some years I have been in the habit of pointing out to my students that subaërial conditions would be very favourable to its formation; but I should not like to use a stronger phrase. There is a suggestive paper bearing on the subject by Dr. W. Mackie, in the same volume of the Trans. Geol. Soc. Edin., at p. 443.

district, with a heavy rain- or snow-fall during part of the year,[1] possibly also with glaciers, and it bears a greater resemblance (though on a more limited scale and with fewer difficulties) to the beds of the Alpine Flysch, which I must now discuss in some detail.

These, though agreeing in general character with the rest, except in the frequent presence of unusually large blocks, differ from them in being more commonly interbedded with fine-grained materials, and those of marine origin. Taking all the facts, already mentioned, into consideration, I see no escape from the conclusion, that late in the Eocene or at the beginning of the Oligocene Period, within a few miles —probably less than 10—was either a mountain-range or an important highland district. Here the climatic conditions must have been favourable to the formation of breccias which must have been transported to the sea, by 'creeping' or by rolling down the hill-sides, or by swollen torrents, after torrential rain or rapid melting of the snow. In either case we must assume the coast to have been slowly sinking, and in the former the breccias to have been deposited when an accumulation of silt had replaced the shallow sea at the foot of the hills by a flat alluvial plain. In the latter case we must suppose these floods to have occurred at rather irregular and long intervals, because the thickness of the intervening sediments is often considerable. The great size of some of the Habkeren boulders and the sporadic distribution of the débris are suggestive of transport by ice-rafts. This would relieve us of two difficulties,—one that the nearest crystalline rocks (in the Oberland) are about 12 miles away, which is rather too far for a breccia-fringe; the other, that some of the most marked varieties of granite in the boulders cannot now be identified anywhere in the Alps.

The Val-des-Ormonts breccias also present great difficulties. They require a more or less mountainous region, with considerable outcrops of crystalline rocks, besides others of Palæozoic or later ages; but where is this to be placed? The increase in the thickness of the breccia-beds and in the angularity of their fragments, as they are followed towards the south-east, suggests that the land lay in that direction; but in the Western Oberland the older rocks appear to be buried beneath a considerable thickness of Cretaceous and Jurassic strata, with occasionally some Trias. In other words, the Mesozoic Era in this, as in other parts of the Alps, appears to have been one of steady subsidence, and its rocks (except at the beginning of the Trias) to be generally fine-grained. It is, of course, possible that the great earth-movements, of which the existing Alpine ranges are the results, had produced conspicuous effects before the close of the Eocene Period, but of this, so far as I am aware, no proof can be found. The difficulty has been eluded by assuming a mountain-range to have existed parallel with, and just north of, the present Alps, on a site now occupied by Nagelfluh or Molasse. But as this must have been high at the end of the Eocene, its disappearance (for it nowhere projects from the Miocene

[1] This appears also to resemble in some respects the 'stone-rivers' of the Falkland Isles.

strata) in less than one geological period is, to say the least, remarkable.

Again, ice-action in any form postulates either a low temperature near the sea-level, or very high mountains. The former must be intercalated in an epoch during which, so far as we can infer from fossils, the climate was distinctly warmer than it now is in Europe; and for the same reason the mountains must have been very lofty, if they sent down glaciers to the sea. From this dilemma[1] I see no escape, and I know not which horn is the worse.

To conclude, breccias such as those described in this paper, though the last-named is more open to doubt, indicate a climate, arid, liable to extremes of temperature, with cold winters. The precipitation probably was connected with this season, and took the form of snow; though in some cases, with a high mean temperature, hot summers[2] and occasional torrential rainfalls, as in Sinai, might produce the same effects. In other words, these breccias are usually indicative of continental conditions, such as are at the present day rather exceptional. Thus in Permian, perhaps also in Triassic, times our Islands and Northern Germany must have been separated from any western ocean, either by a great extent of land or (more probably) by a mountain-region sufficiently broad and lofty to arrest the vapour on its passage, and the facts suggest that in the Rothliegende a rather abnormally low temperature prevailed. A recurrence of cold seems possible in the Upper Oolite; and if it did not also characterize the epoch of the Flysch, then we must admit that during this a great mountain-range existed in the immediate neighbourhood of the breccias.

Discussion.

Prof. Lapworth welcomed this paper as a most valuable contribution to a very important, but hitherto little-studied geological phenomenon. The subject of breccias had for many years been of keen interest to geologists in the Midlands, because of the presence there of the much-contested Permian breccias. He was very glad to learn that the Author endorsed the views of Jukes and the Midland workers generally, that these breccias were in the main of local origin. It was, perhaps, a little unfortunate that Mr. Wickham King's collective title of 'Mercian Highlands' might naturally be open to the interpretation that it was meant to suggest a connected

[1] It remains no less difficult than when Sir Charles Lyell wrote a summary of what was then known, in his 'Principles of Geology' vol. i, ch. x (11th ed. 1872). In New Zealand (western coast) the Fox Glacier comes within 670 feet of the sea-level, the mean annual temperature being 50° Fahr. In British Columbia (lat. 54° N.), with the same mean temperature, the ice reaches the sea. At the present day the Alpine glaciers do not descend to 4000 feet; but even if we assume more favourable conditions (as in those two countries) the mountain-range would have to be not inferior to that of the West-Central Alps.

[2] Livingstone observed ('Zambesi,' pp. 429, 516) that about 12° lat. S. in Central Africa, with a range of temperature from 42° to 137° Fahr., sharp angular fragments, weighing from a few ounces to a couple of hundred pounds, were broken off abundantly from the exposed surfaces of rocks.

mountain-chain of more or less Alpine elevation. But practically all that was meant to be implied was, that in Permian times a chain or series of sharp ridges—probably disconnected—traversed the Midlands, on or about the line joining the present ridges of Charnwood, Nuneaton, the Lickeys, and the Malverns. The essential feature of these ridges was probably not so much their height as their steepness, and the co-existence of a local physiography and climate bringing about the formation of angular screes or talus upon a fairly large scale, and the preservation thereof as a definite rock-formation.

He was also very pleased to hear the Author dwell upon the vital importance of Dr. Blanford's paper on the continental Persian deposits for the study of this breccia-question, for that paper had always been regarded by Midland geologists as affording by far the best suggestion of what were probably the physical and climatic conditions of the Midlands in the Permian Period.

With regard to the difficulty of accounting for the disappearance of some of the solid Midland ridges of Permian times, while their loose screes are preserved to us, it should be borne in mind that their relics suggest that the sequence within them was probably downward through hard Cambrian quartzites, through volcanic rocks of Uriconian types, into more shaly rocks of Longmyndian aspect; and that, once the hard outer coating which afforded most of the materials to the breccias had been worn from off them, the softer beds would rapidly disappear.

The Alpine breccias studied by the Author, and associated with the Flysch, are rather coastal than continental. They occur in regions eminent for crust-movements, and the possibility, still held by some, that overthrust-ranges with a core of hard rocks, and resting upon softer deposits, may have furnished angular fragments to the Flysch and the breccias, does not yet appear to be wholly excluded. Midland geologists, at any rate, had long been prepared for evidences of much local crust-movement in Britain during the formation of the Permian brockrams and breccias.

Prof. Watts pointed out that, in Charnwood Forest at least, the 'Mercian Highlands' must have had steep slopes and considerable altitudes in Jurassic times. He referred to the view of Mr. Wickham King that landslips had borne a share in the formation of the Midland breccias, and he demonstrated that important landslips in the Alps frequently occurred along the crests of overfolds. Flims, Elm, and the Klönthal at the back of the Glärnisch, were examples in point. He considered that these examples indicated that something more than mere denudation was at work in producing the breccias, and that denudation was hastened by the continuance of overfolding movements. This would explain the constant association of breccias with mountain-forming epochs.

Prof. Seeley remarked that, although some conglomerates contained marine fossils, it was probable that their materials, like those of breccias, for the most part acquired their forms upon land-surfaces. The palæontological history of these accumulations lent some support to such an origin. Thus, it was a series of terrestrial reptiles that was associated with the Dolomitic Conglomerate of the West of England. But in the Sivalik rocks of the North of India, pebble-beds of enormous thickness occurred in strata with a very large mammalian fauna. The absence of marine fossils supported the conclusion that the rock-materials of such strata were formed upon land, rolled down from a mountain-chain as boulders, and were rounded at the present day in the tributaries of the Indus, but extended along the flank of a range, such as the Himalayas, which furnished the supply.

Mr. Ussher thought the paper too brief for so interesting a subject, and he hoped that it was only an instalment of a series of contributions from the Author's facile pen. The Author had not made enough of Devon, where there were several distinct types of breccias, some of them resembling the Flysch and some containing huge igneous fragments. Water-action failed to account adequately for their transportation; Ramsay had suggested ice-action, but failed to adduce evidence in support of it. On the borders of Dartmoor there were quartz-porphyry dykes *in situ* in the Culm-Measures, identical with the material found in certain New Red breccias.

Mr. Strahan called attention to some features in the Dolomitic Conglomerate of South Wales. The rock there fringed inliers of Carboniferous Limestone, which had obviously been Triassic islands. The islands were of no great height, and often quite small. They could scarcely have given rise to landslips, yet the breccias extended from them for half a mile or more. Some of the islands survived until Liassic times; the material which fell from them into Liassic water was rolled into shingle, whereas that which fell in Triassic times remained angular or nearly so. Among the breccias had been found slabs of rock bearing the impressions of reptilian footprints, a circumstance which was in favour of their subaërial origin. But, on the other hand, in a subaërial talus the largest blocks always travelled farthest; whereas, in the Triassic breccias, the material became gradually finer the farther it receded from the source, until the breccia tailed away in a thin sheet scarcely coarser than the marls with which it was interbedded.

Mr. Clement Reid pointed out that there were extensive flats in Sussex, made up of a breccia of angular flint-rubble and Chalk. The fossils found in association with these were unmistakably terrestrial, and pointed to a dry and cold period. Across the Channel similar deposits occurred, interstratified with lœss and containing mollusca indicative of a cold climate. One need, however, go no farther than Brighton to see an excellent Pleistocene breccia.

Mr. H. B. Woodward remarked that the breccias in the North-east of Scotland should be spoken of as the Sutherland, and not the Caithness breccias. There detritus which had broken away from old cliffs had been commingled with sands and muds, in which remains of cycads and corals occurred; and probably the climatic conditions were less severe than in some other regions to which reference had been made. That the Sutherland district had been affected by earth-movements during the formation of the breccias was indicated by certain sandstone-dykes.

The AUTHOR, in replying, said that he fully accepted Mr. Wickham King's view of the origin of the Clent breccias, but thought the word 'uplands' preferable to 'highlands' for the district which had supplied the materials. Where denudation was subaërial, any 'planing-down' would be slow work. Charnwood was too distant to be quoted in support of the term 'highlands.' As for the origin of the Flysch, the Diablerets district was doubtless folded and faulted; but, as it was fairly dissected, surely the crystallines which had supplied the materials (as Prof. Lapworth suggested) ought to have been somewhere exposed. Those great foldings also were of later date than the Flysch. The point mentioned by Prof. Watts about the present landslip-zone in Switzerland was very interesting, but the material of the breccias hardly corresponded with that of the landslips which the Author had examined. In reply to Prof. Seeley's complaint that he had not included conglomerates in his paper, he had already written a fair amount about them, and thought that an Author had a right to choose his own subject. As to the complaint of brevity, he had studied that in his paper, because he wished to summarize, not to reprint, and on this occasion further condensation had been made necessary by no fault of his. The occurrence of footprints in association with the Dolomitic Conglomerate, which he feared had slipped his memory, was an interesting fact.

13. *On the* Origin *of the* River-System *of* South Wales, *and its* Connection *with that of the* Severn *and the* Thames. By Aubrey Strahan, Esq., M.A., F.G.S.[1] (Read February 26th, 1902.)

[Plate V—Map.]

Contents.

I. Introduction.

The Welsh rivers, of which I shall endeavour to trace the history in the following pages, flow through a hilly region composed almost wholly of Palæozoic rocks. The greatest height is attained in the Old Red Sandstone of the Brecknock Beacons, which fall but little short of 3000 feet; but the Coal-Measures also rise into escarpments exceeding 2000 feet, and form large areas of mountain-land with an elevation of 1000 feet or more. This high ground is trenched by a series of valleys, of no great length, but important from their depth and from the fact that they penetrate a busy region otherwise difficult of access.

A watershed map of Wales presents at first sight the appearance of a meaningless mosaic, and it will be convenient to commence by disentangling its leading features. A main water-parting, separating the westward- from the eastward-flowing rivers, runs from the northern coast of Pembrokeshire near Fishguard, through the counties of Cardigan and Montgomery. It will be noticed that it commences with an east-and-west trend, but curves gradually northward in Central Wales, keeping near and almost parallel to the west coast. Westward from this water-parting there runs a series of short streams into the Irish Sea; eastward from it flow the Severn and the Wye, both of which traverse Wales in a south-easterly direction, but then turn south-westward to the Bristol Channel. South of the Wye we come to a group of rivers rising on subsidiary water-partings in the counties of Brecknock, Monmouth, and Glamorgan, and three which traverse the counties of Carmarthen and Pembroke from the Central Wales water-parting southward. It is these South Welsh rivers which I propose to discuss in detail. Taken in order from east to west, they include the Usk, with its

[1] Communicated by permission of the Director of H.M. Geological Survey.

tributary the Afon Lwyd, the Ebbw Fawr and Ebbw Fach, the Sirhowy, the Rhymney, the Taff, the Nêdd or Neath, the Tawe, the Loughor, the Towy, the Tâf, and the Cleddau.

II. Relations of the Valleys to the Geological Structures.

The Usk takes its rise in the Old Red Sandstone and Silurian rocks near Brecon, and flows eastward at the foot of the great Carboniferous escarpment of the north side of the Coalfield. At Abergavenny it turns southward, and, meandering across the Usk inlier of Silurian rocks, enters the Bristol Channel near Newport. It is to be noticed that it does not make for the synclinal region of Carboniferous rocks, but, on the contrary, cuts right across the area of great upheaval which has brought the Silurian rocks to the surface.

The Afon Lwyd rises on the southern slopes of the northern escarpment of the Coalfield. It then maintains a south-easterly and southerly course, crossing the Blaenavon Fault without being deflected along it, and skirting the margin of the Coalfield in preference to following the dip-slopes towards the central syncline. Finally it escapes from the Carboniferous area by a gorge at Pontypool, and passes close by a Silurian inlier on its way to join the Usk at Caerleon.

The Ebbw Fawr rises in the northern margin of the Carboniferous area, and traverses the Coalfield in a direction slightly east of south. The Ebbw Fach originally followed a similar course, but having suffered the loss of its head-waters by the cutting back of the gorge of the Clydach, as described by Mr. Walcot Gibson,[1] it now commences existence some 3 miles farther south. The two rivers unite at Aberbyg, traverse the central syncline, and, escaping through the Carboniferous escarpment by a gorge at Risca, join the Usk near Newport.

The Sirhowy follows a parallel and similar course. It joins the Ebbw a mile above Risca, and to effect the junction makes a sharp turn eastward, instead of continuing a course which would have led it into the deep Caerphilly syncline.

The Rhymney in its upper part resembles the Sirhowy and Ebbw, but it enters the Caerphilly basin, a deep trough both structurally and physically, and, turning eastward along it, traverses the Carboniferous escarpment at Machen. At first sight the turn might be attributed to the syncline, but it corresponds to the turn made by the Sirhowy, which was away from the syncline, neither to it nor along it. The Rhymney then makes direct for a Silurian inlier near Cardiff, despite the fact that the strata have there been raised 7000 or 8000 feet higher than in the Caerphilly syncline.

The Taff Fawr and Taff Fach differ only from the rivers already described, in the fact that they rise on the dip-slopes of Old Red Sandstone to the north of the Coalfield. Flowing slightly east of south, they cross the Vale-of-Neath disturbance, which here takes

[1] Mem. Geol. Surv. 1900 'Geology of Abergavenny' p. 93.

the form of a wedge faulted down to a depth estimated by Mr. Gibson at about 900 feet, and unite to form the Taff near Merthyr Tydfil. The Taff passes without deflection both the steep central anticline of the Coalfield at Pontypridd, and the Caerphilly syncline to the south of it, escaping from the Coalfield by a narrow gorge at Walnut Tree. Thence its course lies on Keuper Marl.

Some tributaries of the Taff, known as the Cynon and the Rhondda Fawr and Rhondda Fach, rise within the northern margin of the Carboniferous area, and join the main stream at Abercynon and Pontypridd respectively. While flowing almost in the direction of some north-north-westerly faults, they do not actually follow any one of them.

Some small streams west of the Taff deserve a brief mention. The Ely rises on the north side of the central anticline of the Coalfield, and crosses it, steep though it is. It leaves the Coalfield by a break in the escarpment at Llantrissant, which is probably of pre-Triassic age, and then flows eastward to Cardiff over the Secondary rocks which occupy the hollow of the deeply-denuded Cardiff anticline. The Ogwr, Garw, and Llynfi rise in the Coalfield north of the central anticline, the southern limb of which is here replaced by a great east-and-west fracture known as the Moel Gilau Fault. They unite to form the Ogmore, and pass the Carboniferous escarpment by a broad gap, probably of pre-Triassic age. Other smaller streams follow a similar course, the high Pennant land to the south of the fractured anticline offering no obstacle to their assumption of a southerly direction.

It may be remarked of the rivers described in the foregoing paragraphs, that they show parallelism in a south-south-easterly direction, and that their courses are maintained regardless of the structure of the rocks over which they flow. That they are not diverted by the great east-and-west flexures, such as the anticlines and synclines of the Coalfield, is too obvious to need further proof, but their independence of the north-north-westerly system of faulting is not immediately apparent.

The faults of the north-north-westerly system form a conspicuous feature in the structure of the district, and recur at frequent and fairly regular intervals throughout the Coalfield, where their courses and effects are known with considerable certainty. Out of so many faults and valleys, agreeing approximately in direction, it might have been expected that several would coincide. Examination of the maps [1] will show, on the contrary, that coincidence of valley with fault is rare. Of the nine or more long ridges of Pennant which divide the valleys enumerated above, more than half are cut longitudinally by north-north-westerly faults; but not one of the valleys follows a fault, though they sometimes cross the faults at an oblique angle. The want of coincidence is equally marked in the Lower Carboniferous escarpments: neither of the Taff rivers has utilized a fault in passing the northern

[1] The area under consideration is included in the Ordnance Survey (New Series) 1-inch Maps 230, 231, 232, 247, 248, 249, 262, & 263.

escarpment of the limestone, nor is there any fracture along the gorges at Pontypool, Machen, or Risca. At Walnut Tree alone is there a displacement, the coincidence of gorge and fault here presumably being accidental. The parallelism of the valleys with the faults, moreover, is more apparent than real: the faults run a few degrees more east of south than the valleys, and the difference is maintained. Consequently the valleys cross the faults, but at so oblique an angle as to make it the more remarkable that they do not follow them. Lastly, we shall find that, although in the region about to be described the north-north-westerly system of faults is fully developed, the valleys take a different direction. I infer, therefore, that the north-north-westerly system of faulting had no more share in determining the river-system than the east-and-west folds.

We come now to a series of valleys of a different character—they run about west 30° to 40° south, that is, almost at right-angles to those already described. The change of direction takes place in the region in which a set of powerful disturbances first manifests itself (A, B, C, D, & E, on the map, Pl. V); and the direction assumed so closely coincides with that of the disturbances as to prove that it was determined by them.

The Vale of Neath, or Nêdd, forms one of the best examples. The sources of the river lie on the southern slopes of the Old Red Sandstone of Fforest Fawr; and from this upland region the Hepste, Mellte, and (upper) Neath make their way southward, crossing the Lower Carboniferous rocks, and a number of north-north-westerly faults, in narrow and precipitous gorges with numerous waterfalls. The Hepste and Mellte unite, and reach the belt of plicated and overthrust strata which we have called the Vale-of-Neath disturbance (E on the map, Pl. V), at the Glyn Neath Powder-Mills; the Upper Neath reaches the same disturbance a mile farther west, at Pont Nedd Fychan. Once in the disturbed belt the water never leaves it, but follows it in a straight trench-like valley for 12 miles to Neath. There the disturbance dies away, the trench comes to an end, and the river turns southward to the sea at Briton Ferry. The valley is about 1000 feet deep in the Pennant region, and contains a strip of alluvium from a third to half a mile in breadth. The margin of the alluvium, which marks the limits of the lateral swinging of the river, coincides with the margin of the disturbed strata, and the walls of the valley are formed by the unbroken strata of the north and south sides of the disturbance. The alluvial flat, however, ceases at the Powder-Mills, where limestone and Millstone Grit are thrown up along the axis of the disturbance. From that point eastward a ridge marks the axis of the disturbance, except at the spots where it is crossed by the Taff Fawr, Taff Fach, and a gap at Penderyn.

Travelling 7 miles to the north-west over undisturbed strata, we reach a second belt of plication and fracture, which we have called the Cribarth disturbance (D on the map, Pl. V), after a hill in which its effects are well exhibited. Here again is a no less intimate connection between disturbance and river. The Tawe is fed by streams from the Old Red Sandstone. These unite before reaching the Carboniferous Limestone escarpment, and pass that great feature in a winding gorge, near, but not along, the line of the Cribarth disturbance. In the Coal-Measures, however, a little to the south, the river falls into the line and follows it thence to Swansea, a distance of about 12 miles. The disturbed belt is less closely defined than that of the Vale of Neath; but evidence of its existence recurs at frequent intervals. The Red Vein of coal, for example, is thrown down to the north-west at Ystalyfera, and the Hughes Vein is similarly shifted near Pontardawe. Some great north-and-south faults are deflected by it in a manner described later on; while, lastly, in following the line of disturbance to Morriston near Swansea, we are led to an extremely deep faulted syncline, known as the Tir Canol Fault, which has been thoroughly explored in working the coals under the alluvial flat. There is no known fault, however, in the gorge by which the Tawe traverses the southern escarpment of the Pennant Grit at Swansea.

The Loughor River rises in the northern margin of the Carboniferous area, and runs in a direction slightly west of south. It follows no great line of disturbance, but meanders across the Coalfield, passing several considerable north-north-westerly faults and east-and-west folds without deflection.

The Towy flows wholly on the north side of the Carboniferous area. It is fed by a number of streams from the main water-parting which runs through the counties of Pembroke, Cardigan, and Montgomery; but these tributaries are all gathered into a main stream, the course of which from Llandovery by Llandilo to Carmarthen is obviously connected with the strike of the Silurian and Ordovician rocks. Recent work by my colleagues Messrs. Cantrill and Thomas[1] has shown that that strike is due to movements of great energy, which have not only rendered the strata vertical, or nearly so, along a belt of country some 2 miles in width, but have caused much overthrusting. The disturbance (A on the map, Pl. V), which may be conveniently named after Llandilo, is allied in direction and character with those of Cribarth and Neath, as will be shown in discussing the age of the various movements evidenced in South Wales. Near Carmarthen, where it loses energy, it releases the river, which then takes a southward direction into Carmarthen Bay. Before quitting the Towy, however, brief allusion may be made to a small tributary known as the Cennen, which rises in a strike-valley at the foot of the Carboniferous-Limestone escarpment. The valley follows a subsidiary disturbance (B on the map, Pl. V) parallel to the Llandilo movement, the effect of which has been to form a faulted syncline, and to introduce a conspicuous little crag of limestone, known as Cerig Cennen, into the middle of the outcrop of the Old Red Sandstone. The drainage

[1] Mem. Geol. Surv. Summary of Progress for 1901. (In the press.)

of the strike-valley is carried partly westward by the Cennen, and partly eastward by a stream flowing eastward along the same line of strike, the parting between the two streams being ill-defined. Both streams leave the line of strike as soon as the disturbance loses intensity, and turn northward into the Towy.

The remaining rivers to be mentioned are the Tâf and the Cleddau. Rising west of the region affected by the Llandilo disturbance, they pursue an uninterrupted course from their sources in the main watershed to the southern coast of Pembrokeshire. In so doing they ignore great east-and-west folds, which are in a direct line with the pre-Triassic folds of South Glamorgan; the Western Cleddau, for example, crosses in succession an area of Archæan rocks and the synclinal region of the Coalfield. In Milford Haven the valley pursues a westerly course along the strike of the beds, and thus gives, what is rare in South Wales, an example of a valley coinciding with the pre-Triassic strike.

The influence of the group of south-westerly disturbances may be inferred also from a consideration of the catchment-basins of the rivers. The Vale-of-Neath disturbance dies away a short distance east of the Taff Valley; the Usk consequently escapes its influence, and rises in the next belt of disturbance, namely, that which I have named after Llandilo. The Llandilo disturbance broadens out in the neighbourhood of Builth; the Wye consequently, and the Upper Severn, go beyond it to the main water-parting of Wales for their sources. Similarly the Pembrokeshire Tâf and the Cleddau rise in the main water-parting, and flow directly from it, both the Llandilo and the Cribarth disturbances having died out before entering their catchment-basins. All the rivers, in fact, have assumed a course at right-angles to the main water-parting, except those which have been deflected along local subsidiary disturbances. This prevalent, or normal, direction of flow locates the axis of the elevatory movement by which the drainage was initiated, and it is of the greatest interest to note that that axis is parallel to those subsidiary disturbances which have controlled the river-courses wherever they are developed.

III. The Age and Character of the Structures.

That the movements which have affected this region are characterized by their direction is apparent at once, and this fact alone suffices to distinguish them into the three systems, the directions of which are expressed by Prof. Lapworth under the names of Armorican, Charnian (or Hercynian of Suess), and Caledonian. These three systems, moreover, differ no less in character than in direction.

(1) The east-and-west, or Armorican, movement, was one of compression from south to north. It reached its greatest intensity in Somerset and Devon, but extended so far north as to fold sharply the Lower Carboniferous rocks south of the Coalfield, and to throw the Coal-Measures themselves into great synclinal and anticlinal

folds. The existence of the Coalfield is, in fact, due to a broad synclinal structure produced by that movement. The period during which the Armorican movement was active in this district is well defined. It affected equally all rocks from the Silurian to the youngest Coal-Measures, and was therefore post-Carboniferous. On the other hand, it affected neither the Keuper in South Wales nor the New Red rocks (including the so-called Permian) in Devon, and was therefore pre-Triassic.

The movement is characterized by folding and overthrusting, and was essentially of an elevatory type. It marked the commencement of a prolonged continental epoch, and was the direct cause of the enormous denudation which took place between Carboniferous and Triassic times. A river-system must have existed; and Sir Andrew Ramsay even attributed the Welsh valleys to erosion continuously proceeding 'ever since the close of that great continental epoch that ended with the influx of the Rhætic and Liassic sea.'[1] I should suggest that the erosion more probably took place during the continental epoch than after its close; but, so far as I am aware, no part of the valley-system now in use can be proved to be of this early age, except some breaks in the escarpment already mentioned, and certain broad low-lying tracts, such as the Vale of Glamorgan and the Bristol Channel, which are, or have recently been, deeply overspread by Keuper Marl. That the existing rivers make for these tracts is true; but it is to be remembered that in so doing they ignore the Armorican folding which determined the positions of those tracts, and were therefore themselves determined by another cause.

(2) The north-north-westerly, or Charnian, faults show a remarkable persistence through England, Wales, and probably Scotland.[2] So far as South Wales is concerned, it can be proved that the movement was in progress after the deposition of the Lower Lias, but that it had commenced at an earlier date; for the faults, though they affect strata of all ages, are more considerable on the average in the Carboniferous than in the Secondary rocks. In other parts of the kingdom it can be shown that the movement was in full activity in post-Cretaceous times, for its effects are shown in the Chalk both of Devon and Yorkshire. If the injection of the innumerable dykes of the North-west of the British Isles, which have this direction, was due to the same movement, the period of activity is extended into Eocene times, and, as a fact, one of the north-north-westerly fractures in Staffordshire has been injected with basalt of a Tertiary type.[3] Whatever their age may be, however, the north-north-westerly faults had no share in determining the courses taken by the rivers; and this I believe to be true not only of South Wales, but of other districts. The Vale of Clwyd would seem to be an exception: the existence of the Vale,

[1] 'Physical Geology & Geography of Great Britain' 6th ed. (1894) p. 363.
[2] Geol. Mag. 1899, p. 111.
[3] W. W. Watts, Proc. Geol. Assoc. vol. xv (1898) p. 397.

however, is due, not directly to the fault, but to the introduction by the fault of a strip of soft strata among the Silurian slates and grits.

The Charnian movement, as manifested in the north-north-westerly faults, was essentially one of subsidence. It is characterized by faults which hade normally to the downthrow, and each fault represents a gain in horizontal extent of the rocks that it shifts, proportionate to its throw and the lowness of its hade. In the Coalfield alone, this gain must amount to some hundreds of yards.

(3) The age of the west-south-westerly, or Caledonian, movement in South Wales is more difficult to determine, for it did not extend to the area now occupied by Secondary rocks. The belts of disturbance attributable to this movement in the area under consideration may be enumerated as follows:—

The Vale-of-Neath disturbance, which runs from the Old Red area north of Dowlais to Neath, a distance of 25 miles, in a general direction of west 27° south (E on the map, Pl. V).

The Cribarth disturbance, which follows at a distance of 7 miles, runs from Fan Gihirych to near Swansea, a distance of 20 miles, in a general direction of west 40° to 50° south (D on the map).

The Tair-Carn disturbance is an anticline which arches up the Millstone Grit 8 miles north of the Cribarth disturbance. It runs in about the same direction, but its course through the Coalfield is still under investigation (C on the map).

The Cerig-Cennen disturbance runs about 2 miles north of Tair Carn, in a direction of west 20° south (B on the map).

The Llandilo disturbance runs a mile or two farther north again, in a direction of about west 17° to 20° south, but curves northward to west 45° south (A on the map[1]).

Direct evidence proves no more than that these disturbances were of post-Carboniferous age; and from the fact that they resemble the east-and-west folds in being due to a movement of compression, and do not differ widely from them in direction, I was disposed at first to regard them as contemporaneous with that system. That view is untenable, for the following reasons:—The two systems are developed in different regions, and do not amalgamate; the Caledonian movement lost energy in the district in which the Armorican movement was most intense, the one displaying itself in Central Wales, the other in Devon and Somerset. Secondly, the difference in direction, though slight, is maintained. Lastly, the Armorican disturbances were due to a movement or impulse from the south, and die gradually away northward in South Wales, while the Caledonian movement records an impulse from the north, and dies gradually away southward in the same region. The detailed structure of the Caledonian disturbances, enumerated above, indicates this thrust

[1] The re-surveying of the district extends no farther north than Llandilo, and I am, therefore, unable to say what further disturbances occur to the north of that town.

from the north, for at the head of the Vale of Neath the Carboniferous Limestone has been thrust southward over the Millstone Grit [1]; while the relations of the Ordovician and Silurian rocks in the Llandilo neighbourhood shew that the fold takes the form of a great sigmoidal curve, supplemented in places by fracture and thrusting from the north.[2]

It being evident, therefore, that the Caledonian movement was distinct in character, distribution, and, presumably, age from the Armorican, it remained to compare it with the north-north-westerly faults of the Charnian movement. Theoretically the later movement would shift the structures due to the earlier; and this test, when applied to the Charnian and Armorican structures, gave a definite result, for the north-north-westerly faults maintain their direct courses across the east-and-west folds everywhere. As regards the relations of the Charnian with the Caledonian movements the evidence is as follows:—

A considerable number of north-north-westerly faults have been mapped on either side of the Vale-of-Neath disturbance, but a few only could be traced across it. At Penderyn there is a cross-fracture, but the details of the structure are hidden by Drift. Of the many faults visible in the ravines of the Hepste, Mellte, and Upper Neath, not one could be recognized in the belt of disturbed ground. The Glyn Corrwg Fault reaches the disturbance on its south side at Blaengwrach. It has there a large westerly downthrow, but no fault of corresponding magnitude was to be found on the north side of the disturbance. The strata, however, are much plicated; and it is possible that the fault continues, though it is certainly smaller. The behaviour of the Pen-y-Castell Fault scarcely admits of this explanation. It runs into the disturbance from the south 3 miles below the Glyn Corrwg Fault, and has been proved at a point about 2 miles south of the intersection to have a westerly downthrow of 118 yards. The bold Pennant features on the north side of this part of the Neath Valley give facilities for a full investigation, but I was unable to find any trace of the Pen-y-Castell Fault. Two explanations are possible: either the fault died away, or it turns abruptly, through more than a right-angle, along the Vale of Neath. The latter involves the supposition that a line of weakness already existed along the Vale, which is tantamount to saying that the Caledonian preceded the Charnian movement. I put forward this explanation in 1900 (while the Survey was in progress), and it seemed to be supported by the fact that a north-and-south fault crossed the Cribarth disturbance near Pen Wyllt [3]; but since then further evidence has been obtained, leading to an opposite conclusion.

Both the Vale-of-Neath and the Cribarth disturbances are crossed

[1] Mem. Geol. Surv. Summary of Progress for 1898, pl. ii, facing p. 118. The illustration will be reproduced in the Memoir on Sheet 231 (Merthyr Tydfil), in preparation.

[2] Mem. Geol. Surv. Summary of Progress for 1901. (In the press.)

[3] *Ibid.* 1898, pp. 118, 119.

by the extremely deep trough-faults known as the Rhydding and the Dyffryn Faults. The Rhydding Fault has a westerly downthrow of 800 yards at its maximum, and of 580 yards at its intersection with the disturbance. The Dyffryn Fault has an easterly downthrow of about 300 yards at the intersection. Both faults hade normally to the downthrow, and therefore in opposite directions. If, then, they were crossed by a later fracture, their surface-positions should be shifted in opposite directions; but, so far from this being the case, both are shifted, or rather curved, considerably to the south in crossing to the north side of the Cribarth disturbance. The same effect is produced on other faults, notably the Gardener's Fault at Clydach; and it may be the explanation of a remarkable twist in the Gnoll Fault at Neath, the tracing of which has puzzled successive generations of coal-miners. It would seem that the whole block of country north of the disturbance has moved south-westward relatively to the block south of it—a movement which would account also for the difference in level noticeable in strata on either side of the disturbance. The north-north-westerly faults suffered the shift, and therefore preceded the Vale-of-Neath and Cribarth disturbances. In the case of the Llandilo disturbance, Messrs. Cantrill and Thomas have traced several considerable north-north-westerly faults through the upturned Lower Carboniferous and Silurian rocks which flank the axis, but have found no clear case of one of these faults cutting clean through the axis itself, along which the overthrusting sets in.

IV. Determination of the River-System by a Caledonian Movement.

The behaviour of the rivers now becomes explicable. They were initiated by the latest of the three systems of movement, and during a period of elevation, which is evidenced by the character of that system. An axis, presumably of maximum elevation, formed the water-parting, and from it the rivers flowed east and west on its two sides respectively, but some subsidiary axes of elevation formed minor water-partings, or locally diverted the rivers in their courses from the major axis. Thus the Severn, Wye, Towy, Tâf, and Cleddau rise in the main water-parting, and take a normal course from it; but the Towy, encountering the Llandilo disturbance, is deflected along it to the south-west, so far as the disturbance runs. The Usk rises in the Llandilo disturbance, assumes the normal direction and keeps to it. The Tawe, rising in the same subsidiary water-parting, encounters the Cribarth disturbance, and is deflected along it to the south-west. The Neath and the Taff rise in an elevated region which is in the line of the Cribarth disturbance, and assume the normal course; but the Neath is caught in the Vale-of-Neath disturbance, and is deflected by it. The Taff encounters the same disturbance, but, for a reason explained subsequently, crosses it. The group of rivers, including the Afon Lwyd on the east and the Ogmore on the west, rise south of the belt affected by the subsidiary disturbances and pursue a normal course.

The fact that the Taff crosses the Vale-of-Neath disturbance needs further explanation. The effect of these subsidiary disturbances upon the drainage is attributable to their having been axes of elevation. The strata are crumpled up and overthrust along them. More than this, the Vale-of-Neath disturbance, where it so effectually traps the head-waters of the Neath, is accompanied by an uplift of the strata on its south side of about 600 feet, and would thus be likely to throw a southward-flowing river out of its course. Where it is crossed by the Taff it assumes a different structure. There Mr. Gibson finds that the disturbance is not accompanied by an uplift of the south side, but that it takes the form of a faulted syncline about a mile broad, along which a wedge of Carboniferous Limestone is dropped into the heart of the Old Red country, to a level of about 900 feet below its normal position. The disturbance dies out about 3 miles to the north-east of the Taff Fach, and the absence of those evidences of compression which abound farther to the south-west, may be regarded as symptoms of diminishing energy. As a result no intercepting feature was formed, and the Taff Fawr and Fach kept their southward courses.

The fact that the rivers ignore the structures produced by the Armorican and Charnian movements proves that the physical features produced by those structures had either been completely levelled by denudation, or, what is more probable, had been buried under later formations, after being partly levelled down. Of the elevation and vast amount of denudation which resulted from the pre-Triassic Armorican folding we have ample proof, as shown by Ramsay more than fifty years ago.[1] To mention one example—the Keuper Marl rests directly upon Silurian strata near Cardiff. At that spot there must have been removed in pre-Triassic times about 3500 feet of Old Red Sandstone, 1400 feet of Carboniferous Limestone and Millstone Grit, and not less than 2800 feet of Coal-Measures, or about 7700 feet of strata in all.[2] Evidence to this effect is yielded also by many rocky inliers of Carboniferous Limestone in the Keuper Marl, for much of the landscape produced at that early period still survives, though later erosion has only partly freed it from its envelopment of Secondary rocks.

Of these inliers many sank beneath the water in Triassic time, but others survived as islands in the Liassic sea. In such cases the Lias always overlaps the Trias; and it may be inferred that the same overlap took place along the main coast-line of the Liassic sea. Evidence exists (in the shape of veins filled with hæmatite, and even with marl, in the limestone) that the Trias extended farther and to a greater elevation than now, both to the west in Gower and to the north near Cardiff. Presumably the Lias extended still farther; but the fact that it assumes a littoral type in parts of South Wales, proves that its limits were not far distant. In these

[1] Mem. Geol. Surv. vol. i (1846) p. 297.

[2] I give here measurements recently obtained. Ramsay's estimates were rather greater.

conclusions I agree closely with the views expressed by Sir Andrew Ramsay in 1872.[1]

In speaking of the later Secondary rocks, he stated his opinion that it was 'even possible during the Upper Cretaceous period Wales may have sunk almost entirely beneath the sea.' This hypothesis, so guardedly put forward, is likely I think to receive support. The Upper Cretaceous rocks, though they thin westward, are well developed at Haldon in Devon. They have there overlapped all the older Secondary formations, except a small part of the Red Rocks, and must obviously have overspread much of the Palæozoic area. In the Midlands also, as well as in the North-eastern Counties referred to by Ramsay, they overlap the Upper Jurassic strata with a marked unconformity, while finally they re-appear in Scotland and the North of Ireland. This overlap by, and wide extension of, a purely marine formation, proves a period of general subsidence, which possibly was connected with the equally wide development of the subsiding movement indicated by the north-north-westerly, or Charnian, faults—these, as we have seen, having been in part only of post-Cretaceous age. If we can add to these arguments that the great uplift was due to activity of the Caledonian movement in post-Cretaceous times, the possibility suggested by Ramsay becomes a probability, for it would imply that the uplands of South Wales had not come into existence, and that there was therefore no obstacle to the advance of the Upper Cretaceous sea. I may add that Mr. Jukes-Browne, on a totally different line of argument, has concluded that the Upper Chalk covered all Wales, except a small area overlying the present Snowdon range.[2] A statement, by which Ramsay was influenced, that no trace of Upper Cretaceous rocks exists in South Wales, except for some flints in a gravel on the Wye, is not wholly correct, for small fragments of flint occur sparingly in the Glacial Drift of South Glamorgan. I attach no importance to the fact, however, for they may have travelled far. Their great abundance in the 'raised beach' of parts of Cornwall is more significant.

Eocene gravels in their turn overlapped the Chalk. Evidence of this has been obtained by Mr. Clement Reid in the composition of the Bagshot gravels of Dorset,[3] and recently by Mr. H. B. Woodward at Lyme Regis.[4] Part of the evidence, however, consists in the occurrence of pebbles of Oolitic rocks in the gravels; a fact which proves that the Chalk had already been denuded, and that the uplift in the west had therefore commenced. The inference that the limit of the Eocene basin was not far distant receives support from the character of the Eocene strata, and the rapidity of the change undergone by them in a westerly direction. That they extended over South Wales seems scarcely probable.

[1] Quart. Journ. Geol. Soc. vol. xxviii (1872) p. 148. The substance of that paper is reproduced in his 'Physical Geology & Geography of Great Britain' 6th ed. (edited by H. B. Woodward) 1894, ch. xxxi, pp. 346–66.

[2] 'Building of the British Isles' 1888, p. 194.

[3] Quart. Journ. Geol. Soc. vol. lii (1896) pp. 490–95, & vol. liv (1898) pp. 234–38.

[4] Mem. Geol. Surv. Summary of Progress for 1901. (In the press.)

It is a reasonable assumption, therefore, that the river-system of South Wales was initiated upon a slope of Upper Cretaceous rocks, by which all features in the Palæozoic strata were blanketed over, and that in this may be sought the explanation of the complete disregard by the rivers of structures due to the Armorican and Charnian movements. The case is comparable to that of a part of Dorset, where folded Jurassic rocks form the substratum to the Upper Cretaceous. There also the rivers, initiated upon a Chalk-plain by post-Cretaceous movements, have maintained their courses after the removal of the Cretaceous rocks, and occupy valleys which have no connection with the structures in the Jurassic strata.[1]

V. Connection with the Course of the Severn, and of the Thames and Frome.

The courses taken by the Severn and the eastward-flowing rivers of the South of England were discussed by Sir Andrew Ramsay in the paper already quoted. The southward direction assumed by the Lower Severn was accounted for, on the supposition that the country received a tilt after Miocene times, by which a slope to the north-west was produced. The Chalk having been denuded along the route which the Severn was thus induced to follow, the Chalk-escarpment came into existence. In order to account for the easterly direction taken by the Thames and Frome, he found it necessary to suppose a later tilt of the country by which a slope to the east was produced. The argument, however, in favour of the tilt to the north-west was not regarded as convincing, and the course taken by the Severn remained unexplained.[2]

The evidence on which the history of the eastward-flowing rivers of the South of England may be reconstructed is fairly complete. The initiation of the two main lines of drainage, the Kennet-Thames and the Frome-Solent, has been discussed elsewhere,[3] and it will suffice now to recall the fact that they follow the London and Hampshire synclines respectively, and collect their tributaries from the intervening anticlines. Further, it was shown that these synclines and anticlines, while running east and west, are arranged in échelon along a line which is parallel to the Chalk-escarpment.

The Chalk-escarpment now forms the main water-parting through much of its range across England, as shown on the map (Pl. V). There is reason to think that originally the coincidence between escarpment and water-parting was closer even than it is now. The escarpment, in that part of it which extends from Dorset to the borders of Hertfordshire, diverges from the water-parting three times, namely, in the Vales of Wardour and Pewsey, and in the valley of the Upper Thames. In all these cases, rivers rising in

[1] Mem. Geol. Surv. 'Geology of the Isle of Purbeck' 1898, p. 233.

[2] The theories put forward by Mr. S. S. Buckman in Proc. Cotteswold Nat. Field Club, vol. xiii (1900) p. 175, following the lead of Prof. W. M. Davis, appear to me to transgress the limits of legitimate speculation.

[3] Mem. Geol. Surv. 'Geology of the Isle of Wight' 2nd ed. (1889) p. 248, & Proc. Geol. Assoc. vol. xiv (1896) p. 406.

the low-lying Oolitic region flow eastward against the general run of the country, and make their way through the Chalk-escarpment to the Thames or Frome. The explanation did not escape Ramsay. Their courses were initiated upon an eastward slope of Chalk, and the distance from their sources to the existing escarpment is a measure of the recession of the escarpment since the initiation.[1] The amount of denudation accomplished in this main escarpment is not out of proportion to that which has cut back the North and South Downs of the Wealden area to their present position in the same period of time. The original position of the escarpment, therefore, coincided closely with the water-parting of the eastward-flowing rivers. But the general dip of the Chalk is sufficient to carry it high into the air over the line of the water-parting, and it is evident that it cannot have continued westward. In other words, there must have been an anticline along the line of the water-parting. Traces of such an anticline have been detected by Mr. Buckman in the Vale of Moreton.[2]

We may now compare this main water-parting of the South of England with that of South Wales. From both, the rivers take a normal eastward course. On the west side of the one the rivers are deflected to a south-westerly course, as in the case of the Avon and Severn, or to a north-easterly course, as in the case of the Ouse and Nen. Along the other a similar deflection takes place, as in the case of the Teifi, or of the various streams previously described. The Chalk-escarpment again, in Suffolk and Norfolk, where the tilt is less pronounced, ceases to form a water-parting, as was the case with the Llandilo, Cribarth, and Neath axes in Wales. Lastly, the axis of upheaval in the Chalk is parallel to the Caledonian disturbances which initiated the Welsh rivers, and took place in that area in which the geographical arrangement of those lines of disturbance would have led us to look for it. I infer, therefore, that *the initiation of the South-Wales and South-of-England river-systems, and the southward deflection of the Severn were due to one and the same movement, and that in that movement, though accompanied by east-and-west folding in the London and Hampshire Basins, the Caledonian direction was paramount.*

VI. Date of the Initiation of the River-Systems.

Evidence for the age of the Caledonian movement, though deficient in South Wales, is fairly definite in England. The movement took an equal share with the Armorican folds of the London and Hampshire Basins in determining the Thames and Frome systems, and was presumably contemporaneous with them. But the age of those Armorican folds is definitely fixed by two facts. They were *post-*

[1] The existence of certain valleys breaching the escarpment, but not now occupied by streams, is explained by Prof. Gregory, 'Natural Science' vol. v (1894) p. 97, on the supposition that they carried the drainage from that part of the Chalk-plain which has perished.

[2] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 146.

Oligocene, inasmuch as Oligocene strata have been uplifted by them in the Isle of Wight; they were pre-Pliocene, inasmuch as no Pliocene strata have been folded into either syncline.[1] The uplift of the Chalk, therefore, along the Caledonian axis, the position of which has been inferred by reference to the Chalk-escarpment, took place between the deposition of those formations.

But in view of the close analogy which holds between the Caledonian disturbances in South Wales and this Caledonian uplift of the Chalk, not only in direction, but in their effect upon the river-drainage, these also may be inferred to have been contemporaneous, and the initiation of the whole of the river-systems referred to in this paper would have taken place between the Oligocene and Pliocene Periods.

Passing in review the principal movements which have affected the regions referred to in this paper since the Carboniferous Period, we may construct a chronological table as follows:—

Date.	*Character.*	*Direction.*
Post-Carboniferous Pre-Triassic	Elevatory movement. Impulse from the south.	Armorican.
Do. do.	Subsiding.	Charnian.
Intra-Cretaceous ...	Elevatory. Impulse from the south.	Armorican.
Post-Cretaceous and perhaps Eocene...	Subsiding.	Charnian.
Post-Oligocene ...... Pre-Pliocene	Elevatory. Impulse from the north.	Caledonian.
Do. do.	Elevatory. Impulse from the south.	Armorican.

Of all these, the post-Oligocene movements alone have had any direct influence in determining the existing river-systems. There may be reluctance in accepting this conclusion, on the ground that it assigns a late date to great movements and to denudation on a sweeping scale. Not only, however, have movements as great or greater taken place at a still later date in other parts of the world, but we have in the Isles of Wight and Purbeck direct evidence of the date of the disturbances and of the great erosion consequent upon them. It should be remembered also that, of the vast mass of Palæozoic strata which has been removed from South Wales, by far the greater part was denuded in pre-Triassic times. Post-Oligocene denudation need be called upon to account for little more in that region than the removal of the Upper Cretaceous rocks, and the excavation of the valleys occupied by the existing rivers.

[1] C. Reid, Mem. Geol. Surv. 'Pliocene Deposits of Britain' 1890, p. 69. Prestwich's view, that the Chalk- and Oolite-escarpments were of Pleistocene age, has not met with acceptance. It was ably combated by Prof. Gregory in his paper on the Evolution of the Thames, 'Natural Science' vol. v (1894) p. 97.

EXPLANATION OF PLATE V.

Map of South Wales and of a portion of South-Western England, on the scale of 30 miles to the inch, illustrating the relation of the water-partings to the geological structure.

The main water-parting of South Wales, and the limits of the basins of the Thames and Frome, are shown by thick broken lines; other water-partings being indicated by heavy dotted lines.

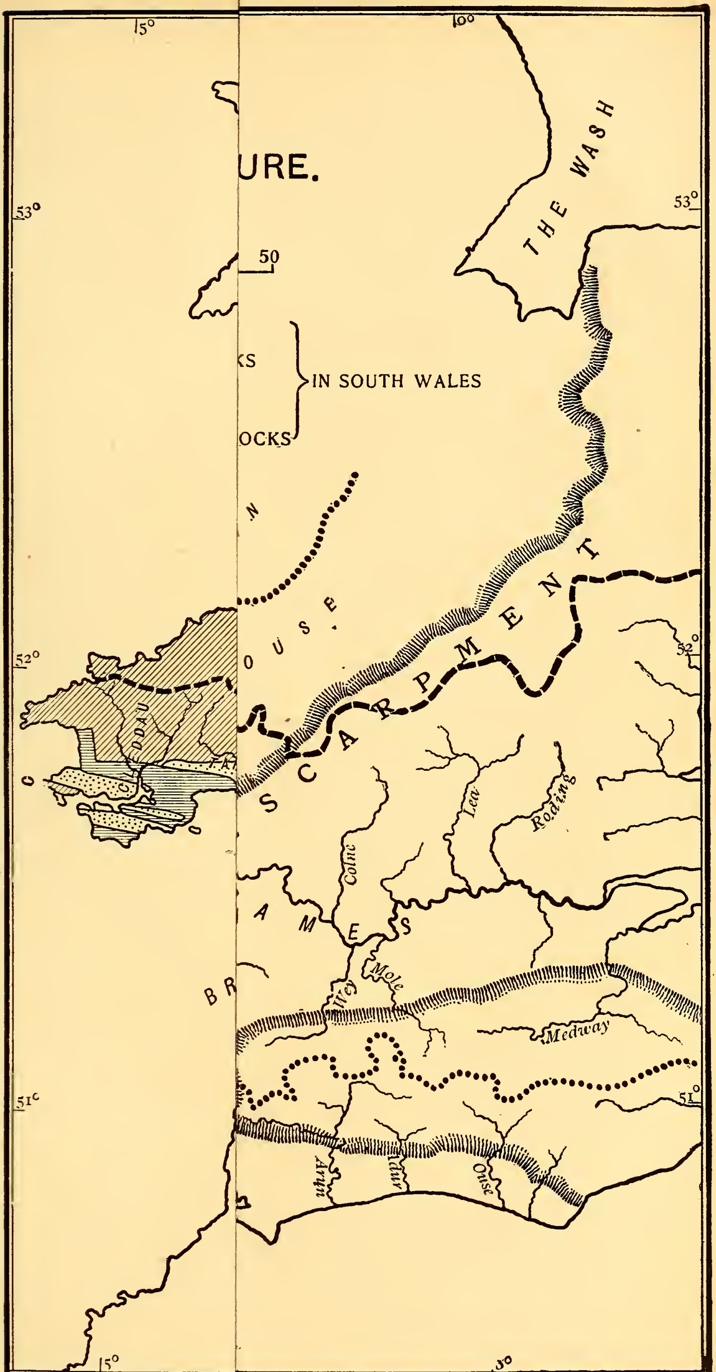
Strong black lines indicate the Caledonian disturbances of South Wales referred to in the text:—

A = The Llandilo disturbance.
B = The Cennen do.
C = The Tair-Carn do.
D = The Cribarth disturbance.
E = The Vale-of-Neath do.

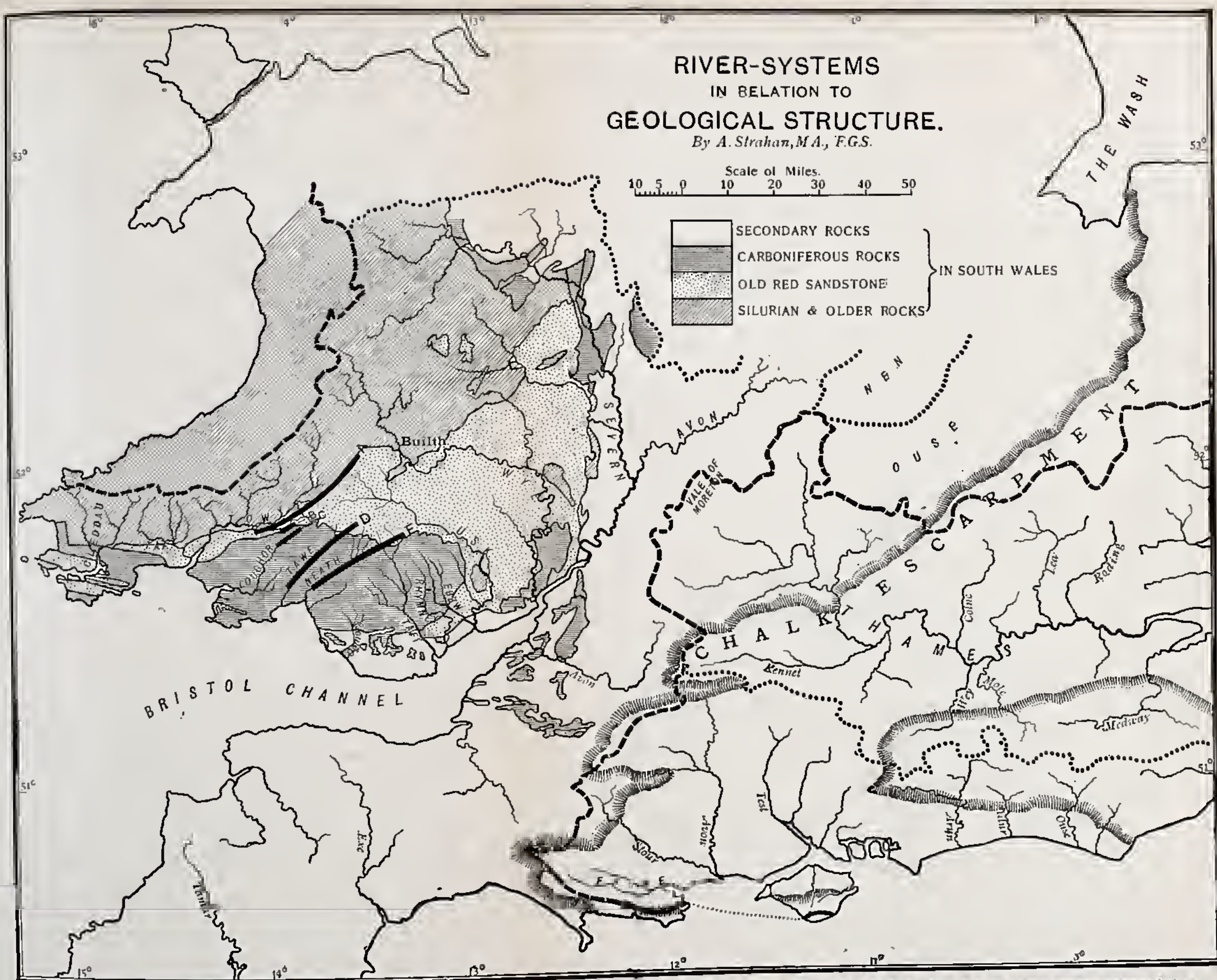
Discussion.

Prof. Groom said that he had listened with great interest to the paper, since it dealt with an area with part of which he was familiar. He regretted, however, that the term 'Caledonian' had not been used in conformity with its original application, and had been employed to designate movements which had taken place in a different district and at a different time from those which gave rise to the 'Caledonian Range' of Suess. This, he was afraid, might lead to confusion.

As to the substance of the paper, while there was much in it with which he could agree, he felt great hesitation in accepting the Author's conclusions on one important point. According to the Author, the movements that gave rise to the south-westerly trend of the rocks in Central Wales were of later date than those that produced the Armorican branch of the Hercynian system. The speaker thought, however, that the evidence available tended the other way. The general progress of folding in Britain, as on the Continent, appeared to have been from the north-west; and the disappearance of the north-easterly and south-westerly folds in the southern parts of Wales and Ireland along the line of the Armorican folds, seemed to be best explained by supposing the latter to have been superimposed on the former. Moreover, there was direct evidence that the folding termed Caledonian by the Author had made very considerable progress in pre-Carboniferous times. Thus in Radnorshire, and farther north-east in Shropshire, important movements, during the Llandovery Period, appeared to have already impressed on the beds a south-westerly trend. Further movements had probably taken place in later Silurian times, and again before the deposition of the so-called Upper Old Red Sandstone and Carboniferous Limestone. In the Berwyn Hills, indeed, according to recent investigations by Mr. Philip Lake and the speaker, the folding in pre-Carboniferous times had been so great that, at a time when the Carboniferous Limestone was horizontal, the underlying beds already dipped at 70° or more. Here, as also in the neighbourhood of Llandilo, the creep had been from the north-west, as the Author had maintained for the latter area; and in both cases inversion of the beds occurred on the south-east. Doubtless later movements in the same



[The main water-p broken lines; other water-partings being
indicated by h the Llandilo disturbance, B=the Cennen,
C=the Tair C



[The main water-parting of South Wales, and the limits of the basins of the Thames and Frome, are shewn by thick broken lines; other water-partings being indicated by heavy dotted lines. Strong black lines indicate the Caledonian disturbances of South Wales:—A=the Llandilo disturbance, B=the Cennen, C=the Tair Carn, D=the Cribarth, and E=the Vale-of-Neath disturbance.]

direction had occurred along the Welsh Border, as observations in Shropshire seemed to indicate; but it was probable that much of the folding along this tract took place in Old-Red-Sandstone times, and therefore at an earlier date than that of the Hercynian folding.

As to the faults showing a 'Charnian' direction, the speaker would like to ask whether, like the different systems of parallel folds, they might not be of various ages.

Mr. A. E. Salter thought that this interesting paper had brought out two most important points to students of post-Pliocene geology: firstly, the action of long-continued earth-movements which have affected the drainage-systems of Southern and Central England; and, secondly, that subaërial denudation has taken place on a large scale. The presence at high elevations north of the present Thames Valley, of débris from the Lower Greensand of the Wealden anticlinal which can be traced from Hampstead, Barnet, etc., right across Southern and Eastern Essex to Walton-on-the-Naze, pointed to an accentuation of the east-and-west (Armorican) folding in comparatively recent times.

The Author did not seem to have taken the Oolitic escarpment into serious account. As this was on a grander scale than that of the Chalk, it appeared to deserve more consideration, especially as it could be shown by its outliers to have had much influence on the formation of the Severn-Avon Valley. He noted that the syncline of the Thames Valley was stated to have been initiated in post-Oligocene and pre-Pliocene times; and wished to enquire whether the presence of Lower Pliocene fossils at Lenham (600 feet above Ordnance datum) did not require a later age to be assigned to them.

Mr. Greenly observed that evidence as to the relative ages of movements along Caledonian and Charnian lines was obtainable in the Anglesey region within an area of quite moderate size. The dominant strike of the Carboniferous and various older rocks was here north-east to south-west, or Caledonian; but the lines belonging to this series were cut and shifted by a considerable number of fractures having a north-westerly to south-easterly, or Charnian trend. The dykes also of the series, regarded by the speaker as probably of Tertiary age, ran in the same north-westerly to south-easterly direction; and, moreover, often coincided with lines of displacement. Finally, in the Central area, dykes with this trend were broken and shifted by still later north-easterly to south-westerly, or Caledonian, fractures. It was thus clear that Caledonian and Charnian movements had occurred alternately one with the other, within the limits of what is now the island of Anglesey.

Mr. P. Lake said that he was somewhat surprised to find that the views of the Author were so similar in many respects to those which he had himself advanced two years ago concerning the development of the rivers of North Wales; views which were at the time adversely criticized by the Author. He was completely in agreement with the Author in believing that the north-east to south-west valleys were directly determined by earth-movements, and that the other river-valleys were not so determined; and he looked upon the valley of the

Bala Fault and the other parallel valleys in North Wales as belonging to the same system as the valleys of the Neath, etc., described by the Author. He did not infer that the Bala Fault, as a whole, was of modern origin, but he believed that a certain amount of displacement had taken place along the line of this fault in comparatively recent times; and he could see no reason why the Author (who attributed the north-east to south-west valleys of South Wales to a modern system of earth-movements) should have denied the possibility of displacement along the Bala Fault during the same period. In support of the view that such movements actually had taken place in a comparatively recent geological period, he pointed to the fact that, whatever might be the nature of the rock on the two sides of this fault, the whole country on the south side stood at a much higher level than it did on the north. He also observed that at least one recent earthquake had taken place along the line of the Bala Fault, and that earth-rumblings were commonly heard at several farms which stand upon the fault. All this was equally evidence in favour of the Author's views.

In conclusion, he remarked that the only essential difference between his own views and those of the Author, was that the latter seemed to think that the north-easterly to south-westerly folds were initiated at the same time as the rivers; whereas he (the speaker) believed that a general drainage-system was first established, and that these folds were subsequently formed across the direction of the main drainage-lines, and produced very extensive changes in the original courses of the rivers.

Dr. H. R. Mill said that the watershed which coincided with, or ran parallel to, the Oolite-escarpment, breached only by the Humber, struck him as the most remarkable feature in the hydrography of England. There was nothing in the existing configuration to account for the position of this watershed; and he asked whether the series of events so interestingly outlined by the Author might possibly afford an explanation.

Prof. Watts thought that the anticline mentioned by the Author supplied a necessary modification of Ramsay's views with regard to the origin of the Severn and Thames. The recent age of the movements postulated by the Author presented little difficulty to those who had seen the great effects of recent movements and denudation in the North of Ireland and the Inner Hebrides.

The President said that the meeting had had the advantage of listening to the inferences respecting the river-drainage of South Wales, drawn by a man whose actual work in the field for several years past had made him thoroughly familiar with the detailed geology of the district in question. It appeared to him that the Author's conclusion, that the apparently complicated drainage-system could be simply explained by the theory that it was initiated upon a gently sloping Cretaceous rock-mantle which overspread and masked the folded and faulted rock-formations of earlier date, and was itself locally deformed by later crust-movements having a Caledonian trend, was not only new, but most significant. In lecturing upon the various directions of crust-creep in the British Islands, as shown by the long axes of the folds and the run of the faults, he had himself taught for many years that they were four in number—namely, (1) a northerly-and-southerly, longitudinal or Malvernian; (2) an easterly-and-westerly, latitudinal or Armorican; (3) a north-easterly and south-westerly, diagonal or Caledonian; and (4) a north-westerly and south-easterly, diagonal or Charnian. These names were especially useful when employed as indices of direction, without regard to geological time. Thus the Caledonian deformation is distinguished by a north-westerly to south-easterly creep and a north-easterly to south-westerly trend; the terms 'creep' and 'trend' being related one to the other much as are dip and strike. Folds with a Caledonian trend were as old as the Torridonian and as new as the Tertiary. He saw no objection, therefore, to the employment of the term 'Caledonian' for the post-Cretaceous system of north-easterly to south-westerly folds of the Towy and the Tawe.

With regard to the Upper Severn, he had himself advocated the opinion that it originally formed a part of the system of the Dee, the gorge through the Wenlock Edge at Ironbridge having probably been cut in earlier Glacial times.

It appeared to him that the Author's suggestion that the basins of the Thames-Kennet and the Severn-Avon owed their original dividing to a low anticlinal form or 'swell' with a Caledonian trend, was worthy of serious consideration, especially as minor anticlines having this trend are already known along this line; and if the suggested synchronism of the two river-systems could eventually be demonstrated, a most important advance would be made in our knowledge of British geology.

The Author replied to Prof. Groom that the terms 'Caledonian,' 'Armorican,' etc. were used as indicative of direction only. Movements having those directions had been renewed at many different periods, but he was concerned only with the latest, which had controlled the river-system. He had been unable to find any clear case of a north-north-westerly fault crossing one of the late Caledonian disturbances, except the great trough-faults described in the paper, and these had been dragged out of their course in the disturbed belt. The disturbances in Anglesey, referred to by Mr. Greenly as being crossed by north-north-westerly faults, no doubt belonged to an earlier display of movement in a Caledonian direction. The Pliocene beds mentioned by Mr. Salter did not share in the synclinal folding, and presumably were deposited after it took place. All the faults and fractures referred to in the paper were wholly of pre-Glacial age. He had had in mind a possible connection between the latest movements and the occurrence of earthquakes, and was much interested in the remarks made by Mr. Lake on this subject. The Oolitic escarpment referred to by Dr. Mill, though so conspicuous a feature now, was wholly buried under Upper Cretaceous rocks when the river-system was initiated, and only came into relief as a result of subsequent erosion.

14. *The* FOSSILIFEROUS SILURIAN BEDS *and* ASSOCIATED IGNEOUS ROCKS *of the* CLOGHER HEAD DISTRICT (Co. KERRY). By CHARLES IRVING GARDINER, Esq., M.A., F.G.S., and Prof. SIDNEY HUGH REYNOLDS, M.A., F.G.S. (Read January 22nd, 1902.)

[PLATE VI—Map.]

CONTENTS.

I. INTRODUCTION.

THE area dealt with in this paper is situated in County Kerry, at the westernmost extremity of the Dingle promontory. The exposures are met with over an area measuring about 4 miles from north to south by 3 miles from east to west; but, owing to the great amount of peat and alluvium, the exposures inland are somewhat scanty, and one depends mainly on the magnificent coast-section for geological information.

The area is one of great interest to a geologist, from the splendid development in it of acid volcanic rocks, associated with beds mainly of Wenlock age. Except at Tortworth in Gloucestershire, and probably in counties Mayo and Galway, it is in the Clogher-Head district alone in the British Isles that contemporaneous volcanic rocks of Silurian age are definitely known to occur. While, too, the Tortworth volcanics are basic or intermediate in character and are mainly, if not entirely, of Llandovery age, in the Clogher-Head area the volcanic rocks are acid in character, and range throughout the Wenlock and up into the lower part of the Ludlow Series.

Considering the number of interesting features shown, the area has been comparatively little described by geologists of recent years, but this is readily explicable owing to its remoteness and inaccessibility.

The earliest reference to the geology of the district with which we are acquainted is contained in a paper by Thomas Weaver,[1] entitled 'On the Geological Relations of the South of Ireland.' In this paper, which was read before the Geological Society of London on June 4th, 1830, the author mentions a number of fossils from the Ferriter's-Cove beds, and refers to the existence of a strong resemblance between many of the casts of fossils found there and similar casts occurring at Tortworth in Gloucestershire.

In a paper published in 1838, C. W. Hamilton[2] compares some features of the geology of the Dingle promontory with that of North Wales, and notes the occurrence of Silurian fossils in the Ferriter's-Cove beds.

Sir Richard Griffith, writing in 1839,[3] also refers to the occurrence of Silurian fossils in the Dingle promontory, and notes the fact that the Old Red Sandstone is there unconformable to the clay-slate beds beneath it.

In 1857, J. B. Jukes & G. V. du Noyer[4] brought a very important account of the district before the British Association, an abstract of the paper being published in the report of the Transactions of the Sections. The authors note the presence of contemporaneous traps as well as ashes among the Silurian beds. They are the first to recognize the peculiar structure of the district, which they describe as 'an inverted S-like contortion or anticlinal and synclinal curve,' and they lay stress on the strong unconformity between the Dingle Series and the Old Red Sandstone.

In the same volume is an abstract of a paper by J. W. Salter,[5] in which it is stated that the

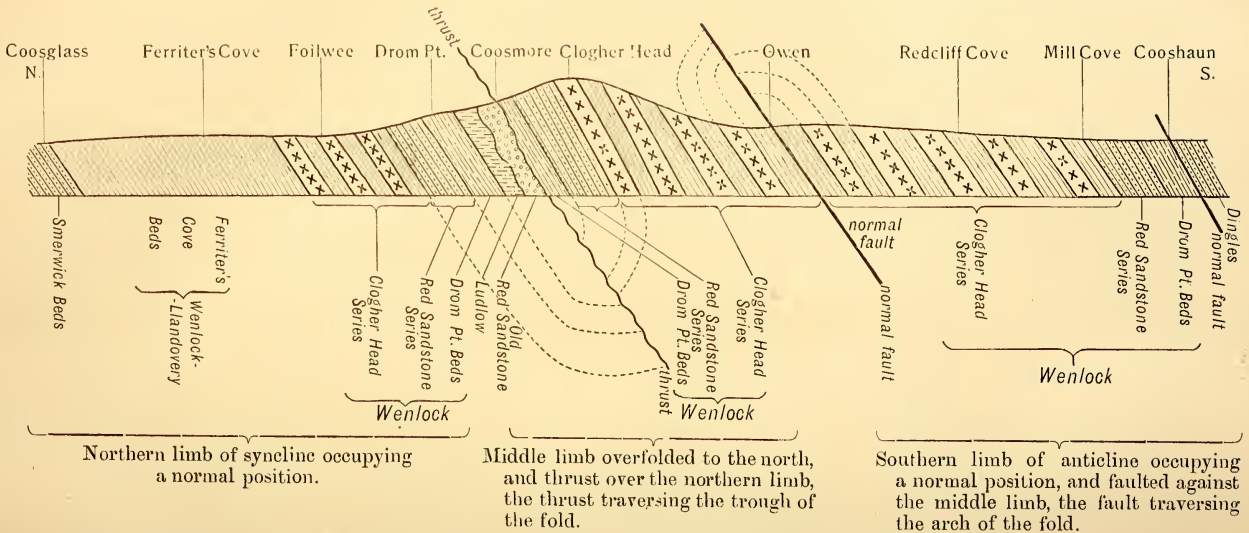
> 'Silurian and Lower Devonian, taken in a rough sense, lie in a rude, faulted, and broken synclinal, the lowest beds being respectively at Sybil's Head on the north, and at the Bull's Head promontory east of Dingle on the south.'

Salter remarks also upon the persistent 'fucoid-beds' at the base of the Ludlow Series, and on certain noteworthy points in the distribution of the Wenlock and Ludlow fossils: for example, that *Chonetes lata* (*Ch. striatella*, Dalm.), a characteristic Ludlow fossil in Britain, is most abundant in the Lower Wenlock Beds of the Clogher-Head district.

The only full account of the district is that by Jukes & Du Noyer, contained in the Explanation of Sheets 160, 161, 171, & 172 of the Geological Survey Map of Ireland. This account, which was published in 1863, proved of very great value to us. The authors remark on the extreme difficulty in understanding the structure of the district, and regard the classification of the beds which they propose as merely provisional. Although in their previous paper, to which reference has already been made, they alluded to the occurrence of contemporaneous 'traps' as well as ashes among the Silurian beds, here mention is made of ashes only:

[1] Trans. Geol. Soc. ser. 2, vol. v (1840) p. 1.
[2] Journ. Geol. Soc. Dublin, vol. i (1838) pp. 276-85.
[3] *Ibid.* vol. ii (1843) p. 78.
[4] Rep. Brit. Assoc. 1857 (Dublin) Trans. p. 70.
[5] *Ibid.* Trans. p. 89.

Fig. 1.—*Generalized section across the Clogher-Head inlier.* (*Horizontal scale: 1 inch=3 furlongs.*)



many rocks being referred to as 'pisolitic ash,' which have subsequently proved to be nodular rhyolites.

Prof. Hull's[1] paper, 'On the Geological Age of the Rocks forming the Southern Highlands of Ireland, generally known as the Dingle Beds & Glengariff Grits & Slates,' contains much which bears reference to our area, though the scope of the paper is wider. It contains also a valuable summary of previous communications on the geology of the South-west of Ireland, which proved very useful to us. Prof. Hull lays stress on the conformable passage of the fossiliferous Silurian into the Glengariff Grits. He gives a table correlating the Kerry Silurians with those of Mayo and Galway, and refers to the occurrence in both areas of contemporaneous volcanic rocks.

Lastly, Sir Archibald Geikie, in his 'Ancient Volcanoes of Great Britain,'[2] gives a summary of recent observations on the Clogher-Head area, and draws attention to the fact that in the Geological Survey Memoir certain rocks are described as tuffs which are now known to be lavas.

II. Detailed Description of the Exposures.

(*a*) The Coast-Section from Dunquin to Owen.

This shows the following beds, from above downward:—

		Thickness in feet.
A (1)	Green and brown sandy and slaty beds, ashy towards the base, of Yellow Cove (top not seen)	480 (seen)
A (2)	Green ash, with large dark fragments	8
A (3)	Red sandstone and fine ash	330
A (4)	Intrusive greenstone	150
A (5)	Nodular and banded rhyolite, with ash-bands	113
A (6)	Ashes	350
A (7)	Calcareous flags and slates	75
A (8)	Coarse ashy conglomerate	56
A (9)	Greenstone intrusive in A (8)	120
A (10)	Pale purple ash	10
A (11)	Purple rhyolite	25
A (12)	Pale-red ash	16
A (13)	Compact purple ash	40
A (14)	Purple rhyolite	25
A (15)	Ash, in places green, with large dark fragments	14
A (16)	Calcareous flags, with coral-layers and bands of conglomerate	85
A (17)	Purple rhyolite	38
A (18)	Ash	18
A (19)	Purple rhyolite	130
A (20)	Coarse ash, with grit-bands	55
A (21)	Calcareous flags and slates	60
A (22)	Pale coarse ash and slates	16
A (23)	Compact, light-green, banded ash	14
A (24)	Coarse ash	8
A (25)	Purple slate	20

[1] Quart. Journ. Geol. Soc. vol. xxxv (1879) p. 699.
[2] Vol. i (1897) pp. 254–56.

		Thickness in feet.
A (26)	Purple and dark-green rhyolite	18
A (27)	Calcareous flags, with coral-layers, ashy at the base.	90 (seen)
	Fault.	
A (28)	Compact rhyolite	80
A (29)	Calcareous flags and slates, with a few small bands of ash	120
A (30)	Brown sandy slates, with green ashy conglomerate below	40
A (31)	Calcareous flags, with coral-layers and bands of fairly coarse, ashy conglomerate........................	65
A (32)	Thinly-bedded sandy slates	10
A (33)	Fine purple ash	12
A (34)	Coarse purple ash	120
A (35)	Finely-banded rhyolite ....perhaps	150

Excluding the greenstones, this gives a thickness of 2680 feet.

All along this strip of coast the amount of dip varies little from 30°, the direction being generally about 30° E. of S., but varying slightly.

A (1). The junction between the Silurian and the overlying Dingle Beds is seen in the inlet of Cooshaun, immediately south of the village of Dunquin. The Dingle Beds are chiefly purple, micaceous, fine-grained grits, though some of them are green. Within some feet of the junction-line they show evidences of squeezing; and near the junction they are very much crushed, and become quite soapy to the touch. The underlying Silurian shows also some disturbance, and several small faults are seen in the cliffs of Cooshaun and Yellow Cove. The junction between the two sets of beds is therefore to be considered as a faulted one, despite the fact that both the Silurian and the Dingle Beds dip at the same angle to the south-east.

That these underlying yellow strata (A 1) are Silurian is proved by their containing 'fucoid'-beds[1] a few feet below the Dingles, and crinoid-stems and *Spirifer* towards their base, and by their relation to the underlying beds. They are considerably disturbed and quartz-veined as one goes westward from Yellow Cove, and their dip, which was at first southerly, becomes more easterly; towards their base they become distinctly ashy, and finally end in a bed of grey sandy limestone 11 feet thick.

A (2). This limestone rests upon a bed of green ash (A 2), with numerous thin flakes of a dark-green rock, which is to be seen on both sides of the inlet, north of the point called Foilclea. There has been a certain amount of movement along the line of this green ash, which is seen to be crushed and squeezed in places.

A (3). These red sandstones, with thin ash-bands, occupy the coast from Foilclea to Mill Cove, and have an approximate thickness of about 330 feet. Both at the northern end near Mill Cove, and at the southern end at Foilclea, the direction of dip is south 20° east;

[1] The term 'fucoid' is used throughout the Geological Survey Memoir, in referring to the impressions seen in these Upper Wenlock Beds; they are more probably, however, worm-tracks (see Mem. Geol. Surv. Irel. 1863, Explan. Sheets 160, etc. p. 22).

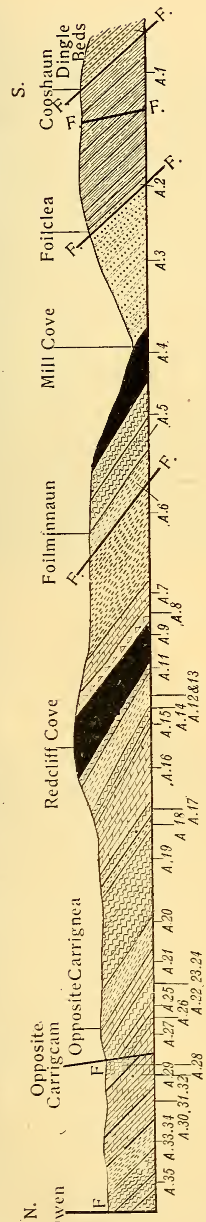


Fig. 2.—*Section along the coast from Cooshaun, near Dunquin, to Owen. (For explanation of A 1, etc., see pp. 229–30.)*

[Horizontal scale: 4 inches = 1 mile.]

but the amount varies, from 25° near Mill Cove to 50° at the south-western end of Foilclea.

A (4). The greenstone of Mill Cove extends round the promontory to the head of the next little inlet, and is also seen for a short distance up the watercourse running southward from Carhoo. It is generally a compact, pale, fine-grained rock, but so much altered that it is almost impossible to say what was the original character of the rock. The general direction of the band seems to coincide with that of the adjacent rocks, and there is no sign of metamorphism along its boundaries. Its north-western margin shows a horny texture, perhaps due to chilling.

A (5). Nodular and banded rhyolite with ash-bands occupies the coast from the head of the first cove north of Mill Cove, as far as the inlet of Foilminnaun. It shows the following bands. At the top:—

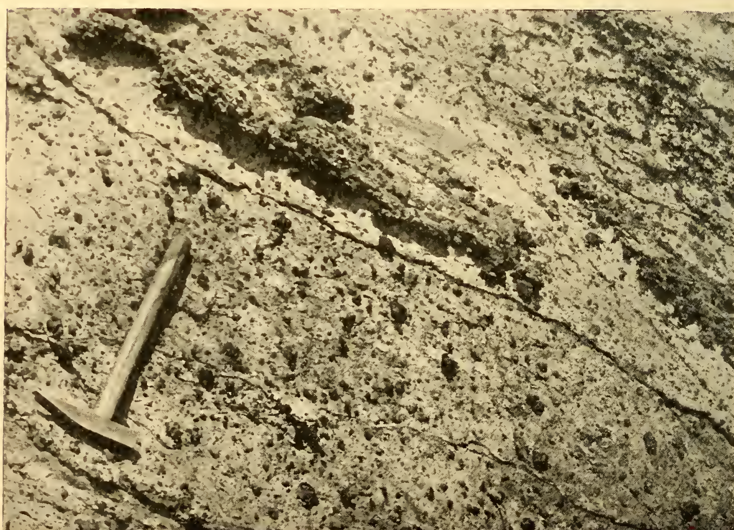
	Thickness in feet.
Purple rhyolite....................	25
Ash-band	10 to 15
Very nodular rhyolite	60
Banded and nodular rhyolite...	18

The most conspicuous rock is the 60-foot band of nodular rhyolite, which extends from the point terminated by the Cooraums to the little 10-pole island in Foilminnaun. It contains a lenticular patch of ash, apparently faulted-in. This rhyolite is a light-grey or purplish rock, sometimes banded, but generally nodular. The nodules, which are especially well seen in the south-eastern corner of Foilminnaun, are sometimes as much as 3 inches across. They are frequently hollow, and lined with little quartz-crystals.

A (6). This thick band of ashes occupies the coast, from the middle of Foilminnaun to the inlet south of the long tongue of land which runs out

Fig. 3.—*Calcareous flags, overlying coarse ashy conglomerate (A 8); south of Redcliff Cove, Clogher.* *See p. 233.*

Fig. 4.—*Weathered surface of ash of medium grain (A 13); Redcliff Cove, Clogher.* *See p. 233.*



to sea south of Redcliff Cove. It is made up of the following bands: at the top:—

	Thickness in feet.
(*a*) Purple ash, with included fragments of purple and green rhyolite about 2 inches in maximum diameter	30
(*b*) Pale ash	20
(*c*) Compact purple ash, with bands of rhyolite	100
(*d*) Pale coarse ash, with rounded lumps of purple rhyolite some $1\frac{1}{2}$ inches in diameter	40
(*e*) Compact purple ash	80
(*f*) Pale-yellow sandy ash	80
	350

Between (*b*) and (*c*), at the head of Foilminnaun, is a strike-fault, the direction of which is marked by a layer of slickensided quartz about 12 inches thick. This fault determines the western limit of the inlet.

A (7). This band of calcareous flags and slates occupies the northern side of the first cove south of Redcliff Cove. The beds dip 34° south 30° east at the base of the point, and 25° south 20° east farther along it. From them we obtained:—

Atrypa reticularis (Linn.).
Chonetes striatella, Dalm.
Spirifer sp.
Pterinea (?) subfalcata, Conr.
Crinoid-stems.

A (8). This is an extremely coarse ashy conglomerate, the fragments of which range from less than an inch to more than 2 feet in length. They consist of rhyolite, or of rhyolitic ash. This bed can be followed inland to the north-north-east, and is met with in the neighbourhood of the Stone Cross marked in the 6-inch Ordnance-Survey map.

A (9). This greenstone occupies the south-eastern side of Redcliff Cove, and, judging from loose fragments found abundantly inland, it occurs also in the neighbourhood of the Stone Cross. Usually it follows the bedding, but is seen here and there to cut across it. Most of the greenstone is extremely weathered.

A (11) is a prominent band of compact purple rhyolite, forming a tongue that juts out into Redcliff Cove, and it is to this rock that the cove no doubt owes its name. Xenoliths of rhyolite are included in the rock, especially near the upper surface, and cause some hand-specimens to have the appearance of ashes.

A (13), which extends northward from the point west of Redcliff Cove, is a medium-grained ash, full of small angular fragments of rhyolite; these range up to a third of an inch in length, and show up well on the weathered surface. (See fig. 4, p. 232.) The coast runs with the strike of this band for a long distance.

A (16). These are thinly-bedded calcareous flags, containing coral-layers, and becoming at times somewhat conglomeratic. They occupy the point south-west of the Stone Cross, and can be followed in a north-north-easterly direction along the top of the cliff, as far as west of the Penitential Station. They have yielded the following fossils:—

Favosites polymorpha, Lonsd.
Strophonella funiculata, M'Coy.
Spirifer bijugosus, M'Coy.
Sp. crispus, His.
Sp. elevatus, Dalm.
Orthis elegantula, Dalm.
Rhynchonella nucula, Sow.
Rhynchonella cuneata, Dalm.
Rh. borealis, var., Schloth.
Pterinea retroflexa, Wahl.
Pt. orbicularis (?) M'Coy.
Modiolopsis mytilimeris, Conr.
Horiostoma discors, Sow.
H. globosum, Schloth.

The foregoing assemblage of fossils is consistent with the beds being either of Ludlow or of Wenlock age.

A (17). This band of purple rhyolite is seen below the sedimentaries, near the end of the point south-west of the Stone Cross. It occupies the coast, which follows its strike, as far as a point west of the Penitential Station.

A (19) is a purple-banded rhyolite, with very well-marked flow-structure. It occupies the coast around the unnamed inlet due west of Carhoo.

A (20). These ashes dip at 20° south 35° east, and contain fragments of banded and compact rhyolite and of slate.

A (21) occupies the coast around the little bay opposite Carrignea. It is a fossiliferous band of sandy limestone, weathering yellow.

A (22) is a thin band of pale coarse ash, containing fragments of rhyolite and slate, which sometimes are 6 inches in length.

A (23) is a well-marked, fine-grained, pale-green ash. It is sometimes remarkably well-banded, and elsewhere shows dark-green oval markings about a quarter of an inch long. Both these structures, though visible on the freshly-broken surface, are better seen on the weathered surface. Some thin ash-bands of a coarser character are intercalated with the fine ash.

A (27). These calcareous flags, with coral-limestones and earthy slates, occupy both sides of the little inlet south-east of Carrigcam, and show the following bands: at the top:—

	Feet	inches.
Blue calcareous flags, weathering brown	5	0
Coral-band	1	0
Blue calcareous flags, weathering brown	2	0
Coral-band	0	9
Blue calcareous flags, weathering brown	6	0
Coral-band	0	9
Calcareous flags, with many thin coral-bands and a few conglomeratic layers	36	0
Coral-band	0	9
Brown earthy slates	7	0
Coral-band	1	6
Brown earthy slates	14	0
	74	9

The lower layers of these beds have yielded:—

Monticulipora.
Halysites catenularia (Linn.).
Favosites polymorpha, Lonsd.
Cornulites serpularius, Schloth.
Leptæna quadrata, Lindstr.
L. rhomboidalis, Wilck.
Rhynchonella borealis, var. *diodonta*, Dalm.
Spirifer crispus, His.
Sp. bijugosus, M'Coy.
Orthis elegantula, Dalm.
Stropheodonta imbrex, Pander, var. *semiglobosa*, Dav.
Pterinea subfalcata, Conr.
Horiostoma globosum, Schloth.
Calymene Blumenbachii, Brongn.

A (28). Opposite the little island of Carrigcam the series is cut off by a fault running in a general east-north-easterly and west-south-westerly direction. In its neighbourhood the beds are much disturbed, but beyond it the same general strike is maintained. At the top of the cliff, to the west of this fault, a band of bluish rhyolite (A 28) is well exposed. This band, with some overlying ashes and sandy beds, is also well exposed in the ravine which, crossing the high road, strikes the coast a little north of Carrigcam.

A (30). The sections of the ashy conglomerate show it to contain well-marked rounded lapilli—not only of rhyolitic, but also of andesitic rocks.

A (31). These beds are identical in general character with (A 27). They occupy most of the bay between Owen and Carrigcam, and have yielded:—

Alveolites Labechii, M.-Edw.
Spirifer bijugosus, M'Coy.
Sp. elevatus, Dalm.
Stropheodonta imbrex, Pander, var. *semiglobosa*, Dav.
Fenestella sp.
Pterinea sp.
Horiostoma globosum, Schloth.

Mr. F. R. C. Reed says, with regard to the bands (A 31) and (A 27), that there is nothing in the fossils to prevent the ascription of a Wenlock age to the beds.

The little 10-pole island, east of the peninsula south of Owen, has its eastern half formed of the fine ashes (A 33), and its western half of the coarse ash (A 34).

A (35) is an extensive exposure of fine-grained blue rhyolite, forming the whole of the peninsula south of Owen. Its base is not seen; it is impossible, therefore, to estimate the thickness of the rhyolite, which is very considerable, probably not less than 150 feet.

(*b*) The Coast-Section from Coosmore to Owen.

This part of the coast-section includes the promontory of Clogher Head, and (we believe) forms the middle limb of a great **S**-shaped fold which has been overfolded to the north and thrust over the northern limb. (See fig. 1, p. 228.) The newest, but, owing to the inversion, the lowest beds are seen in the deep inlet of Coosmore to be thrust over a series of coarse red conglomerates which occupy the coast for some distance to the east and west of the inlet. The red conglomerates are regarded by the officers of the Geological Survey as of Dingle (that is, Lower Devonian) age. But it seems to us more probable that they are of Old-Red-Sandstone (that is, Upper Devonian) age, both from their resemblance in lithological character to the Old-Red-Sandstone conglomerate of Sybil Point, and from the fact that they rest unconformably upon the Silurian; while the Dingle Beds, except where their junction with the Silurian is faulted, appear to be conformable.

The beds can best be followed from north to south, the following being the succession: at the base, as the beds now lie:—

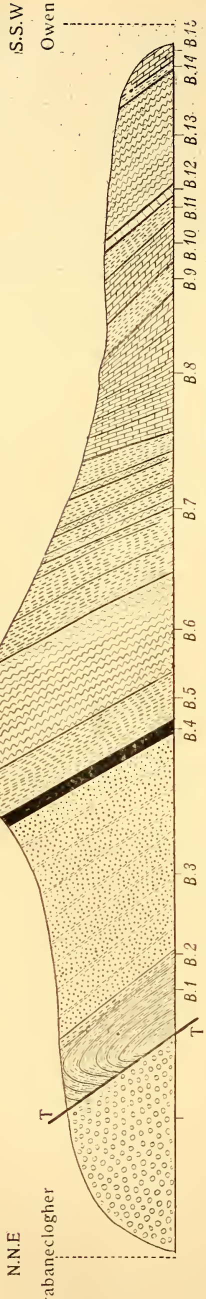


Fig. 5.—*Section through the base of Clogher Head.*

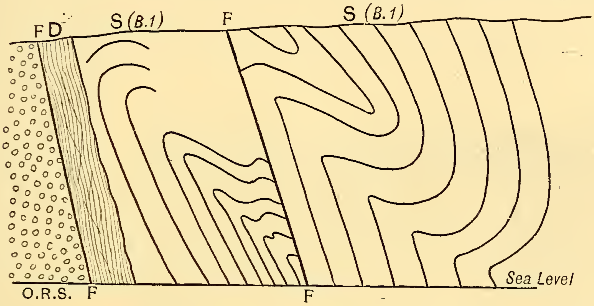
[Horizontal scale : 12 inches = 1 mile vertical scale exaggerated.]

		Thickness in feet.
B (1)	Green sandy grit, ashy towards the original base; original top not seen	?
B (2)	Green ash, with large dark fragments......	6
B (3)	Red sandstone, with fine ash-bands......	350
B (4)	Intrusive greenstone .	46
B (5)	Fairly coarse ash ...	75
B (6)	Rhyolite of Clogher Head..................	175
B (7)	Ash, with rhyolitic bands	320
B (8)	Calcareous flags	230
B (9)	Green ash, with large dark fragments ...	40
B (10)	Calcareous flags	60
B (11)	Coarse ash	25
B (12)	Calcareous flags	10
B (13)	Rhyolite, with some ash-bands	250
B (14)	Ash	15
B (15)	Calcareous flags	{ perhaps 50 feet seen.

Excluding the intrusives, this gives a thickness of at least 1556 feet.

B (1). In Coosmore these newest, but (as they now lie) lowest beds are seen to be gritty slates containing *Orthis elegantula*, Dalm., *Atrypa reticularis* (Linn.), and abundant worm-tracks—the 'fucoids' of the Geological Survey Memoir. These worm-tracks are very abundant in the Upper Wenlocks of the district. The beds are highly disturbed, traversed by several faults, and overfolded in the neighbourhood of the thrust. Fig. 6 (p. 237) shows a section along the eastern side of Coosmore; while the further succession is seen in the gully which leads down into the head of Coosmore, and also farther along the northern coast of the Clogher-Head promontory. There the beds, which are seen to be thrust over the coarse conglomerate, are red and green grits, much contorted in the neighbourhood of the thrust and traversed by a rude cleavage (see fig. 7, below).

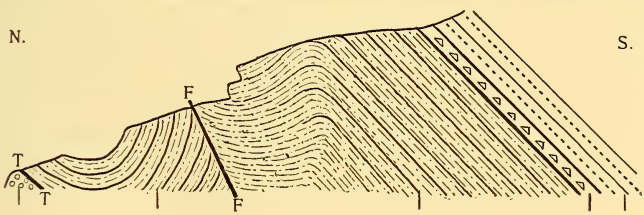
Fig. 6.—*Section along the eastern side of the inlet of Coosmore.*



[Horizontal scale: 1 inch=50 feet; vertical scale exaggerated.]

O.R.S. = Old Red Conglomerate. S (B 1)=Silurian gritty slates.
D = Fault-débris. F =Faults.

Fig. 7.—*Section through the northern slope of Clogher Head.*



[Horizontal scale: 3 inches=100 yards.]

T=Thrust. O =Old Red Conglomerate. B (2)=Green ash.
F=Fault. B (1)=Fossiliferous hard green grits. B (3)=Ashy red sandstone.

We obtained the following fossils from these beds:—

Lindstrœmia sp.
Heliolites sp.
Worm-tracks.
Orthis elegantula, Dalm.
Spirifer bijugosus, M'Coy.
Plectambonites transversalis, Wahl.
Leptæna rhomboidalis, Wilck.
Atrypa reticularis (Linn.).
Atrypa hemisphærica, Sow.
Orbiculoidea rugata, Sow.
Whitfieldella sp.
Encrinurus Stokesi, M'Coy.
Lichas anglicus, Beyrich.
Phacops caudatus, Brünn.
Proetus sp.
Crinoidal ossicles.

The foregoing list of fossils leads us to regard these beds as of Upper Wenlock age, and to correlate them with the Drom-Point Beds.

B (2). This is a very well-marked rock, and shows numerous dark-green fragments embedded in a pale-green matrix. For a description of it, see p. 262. It is seen in Coosmore, and also towards the end of the Head.

B (3) is a well-marked bed of a red colour, often ashy in character, but at times more sandy, exactly resembling A (2). This and the underlying bed are seen to be affected by a fault, which runs down the gully leading to Coosmore, and has no doubt determined the formation of this inlet. The downthrow is about 20 feet on the west side of the fault-line. These red beds are well seen, forming the northern part of the extreme point of Clogher Head, but they have yielded no fossils.

Fig. 8.—*Weathered surface of coarse ash (B 5); north side of Clogher Head.*

B (5) is a tuff, showing fragments of purple and green rhyolite, one of which was found to reach a length of $1\frac{1}{2}$ feet, although as a rule they are very much smaller. (See fig. 8.) North of the Minnaunmore Rock, fragments of granite occur in the tuff.

B (6) is a very characteristic, purple, banded rhyolite. The banding is less marked in the immediate neighbourhood of Clogher Head than it is farther east, and is best seen on a weathered surface. The rock does not weather readily, and so stands up, forming the backbone of the Clogher-Head promontory. Near the Dunquin and Ballyferriter road a north-and-south fault cuts across the base of the promontory, and the outcrop of the various bands is shifted about 120 yards to the south. The rhyolite-band also forms the Minnaunmore Rock, and is here slightly nodular in parts.

The coarser ash (B 5) is very well exposed north of the Minnaunmore Rock, and many blocks of the red sandstone and fine ash (B 3) are strewn about over the tract of country farther north again, though the rock is not seen there *in situ*. South-east of the Minnaunmore Rock is a mass of the same banded rhyolite, dipping, however, east-south-eastward, which has been probably faulted into its present position.

Fig. 9.—*Croaghmarhin Hill (to the left), formed of Ludlow flags and grits; the Minnaunmore Rock (to the right), formed of rhyolite.*

The mutual relations of the bands (B 6), (B 5), and (B 4) are very well seen in the little inlet opposite the rock called Carrignahogha, at Clogher Head. Here the rhyolite (B 6) is seen overlying the coarse ash (B 5), which in its turn overlies the greenstone (B 4). The peninsula to the south of the little inlet is chiefly composed of the rhyolite.

B (7). Ashes with rhyolite-bands form the southern border of the little peninsula just referred to, and occupy the coast as far as the head of the bay north of Carrigard. Judging from observations in the field, (B 7) would appear throughout to be clearly an ash. Sections, however, show that part of the matrix is crystalline, and it is probable that a considerable part of the apparent ash is a rhyolite containing many xenoliths.

B (8). This band of sandy limestone, ashy in parts, forms the rock of Carrigard and the shores of the little bay at the mouth of which it lies. The dip of these beds is somewhat variable and is, as a rule, a little west of south. They have yielded :—

Chonetes striatella, Dalm.
Rhynchonella nucula, Sow.
Spirifer crispus, His.
Spirifer elevatus, Dalm.
Pterinea sp.
Crinoidal ossicles.

B (9). This band of green ash occupies the little inlet immediately east of Carrigard.

B (13) is a thick band of rhyolite, which forms almost the whole of the rocky peninsula north-west of Owen. The rock is generally of the compact pale-green type, but shows a considerable amount of variability, and is sometimes banded. Often it contains numerous xenoliths, causing it to resemble a tuff; and there are some undoubted tuff-bands present in it.

In the southern part of the exposure the rocks begin to show signs of crushing and disturbance. These are still more marked in B (14), and increase till the fault at the little inlet of Owen is reached.

(*c*) The Coast-Section from Coosmore to Coosglass.

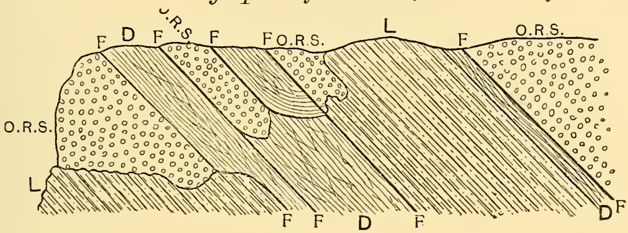
For the greater part of this long coast-section the succession is easy to make out, as the beds, though sometimes faulted, are not much disturbed. From Trabaneclogher to Ferriter's Cove, the coast runs in the main with their strike. The following is the succession : at the top :—

		Thickness in feet.
C (1)	Gritty flags and slates	about 550 seen
	[Here follows a gap without exposures, equivalent to a thickness of about 200 feet.]	
C (2)	Green and yellow sandstones and slates, with ashy bands in the lower part	about 420 seen
C (3)	Green ash, with large dark fragments	8
C (4)	Red sandstone with ash-bands	340
C (5)	Intrusive greenstone	30
C (6)	Fairly coarse ash	7
C (7)	Rhyolite, with two ash-bands	248
C (8)	Ashes, weathering pale-grey or white	25
C (9)	Calcareous sandstone and flags, with thin ash-bands.	1390
C (10)	Coarse conglomerate, with a fine grit-band	30
C (11)	Sandy and ashy beds and conglomerate	70
C (12)	Rhyolite	23
C (13)	Ash	31
C (14)	Sandy limestone, weathering yellow	40
C (15)	Red sandstone, with ashy and shaly layers	180
C (16)	Brown and yellow sandstone, much crushed and veined	40?
C (17)	Green rhyolite and ash	6
	Fault.	
C (18)	Labradorite-porphyrite	115
	Fault.	
C (19)	Pink and green slates	210
C (20)	Conglomerate	6

Excluding the intrusives, this gives a thickness of 3624 feet seen.

C (1). The junction between the Silurian beds and the Old Red Sandstone which, as already mentioned, extends along the northern coast of the Clogher-Head promontory, is well shown on the southern side of the point midway between Coosmore and Trabaneclogher (see fig. 10). The conglomerate is seen resting on the Silurian with an

Fig. 10.—*Section through part of the coast, north-east of Coosmore.*



[Horizontal scale: 1 inch = 50 feet.]

F = Faults. D = Fault-débris.
O.R.S. = Old Red Conglomerate. L = Ludlow Grits (C 1).

unfaulted unconformity; but both beds are markedly affected by a large compound fault, and repeated. The Silurian beds have become stained red where in contact with the conglomerate, but they are elsewhere green flaggy grits, weathering yellowish-brown. They occupy the whole of the southern side of the inlet of Trabaneclogher and part of its eastern side; while they are also to be seen all the way up the stream which comes down from the village of Clogher, as far as the village itself. Their dip near the conglomerate is 45° south 25° east, while in the Clogher-village stream it is 41° south 21° east. They have yielded *Monticulipora* sp. (?), *Halysites* sp. (?), and *Atrypa reticularis* (Linn.), and are often crowded with worm-tracks, while coral-layers are seen at intervals. We regard these beds as belonging to the lower part of the Ludlow Series.

C (2). On the east side of Trabaneclogher a sandstone is seen underlying the beds just described, except for a short distance near the spot where the road from Teeravane comes down to the beach. This sandstone, the colour of which varies from green to yellowish-brown, dips at about 45° south 20° east, and forms the whole of Drom Point. It is occasionally ashy, particularly towards the base, fragments of purple and green rhyolite being abundant in these ashy beds. Worm-tracks are very common (see fig. 11, p. 242), and we have also found:—

Favositella sp.	*Atrypa reticularis* (Linn.).
Favosites Forbesi (M.-Edw.).	*Pterinea* sp.
Streptelasma sp.	Pieces of crinoid-stems.

C (3) is identical with the band B (2) on Clogher Head. (See p. 238.)

C (4) is a thick mass of fine red sandstone, with abundant bands of both coarse and fine ash. (See fig. 12, p. 242.) Rhyolitic fragments are not conspicuous, except in the lower beds.

Fig. 11.—*Worm-tracks ('fucoids') on the weathered surface of the Upper Wenlock Sandstone (C 2); Drom Point, Clogher.*

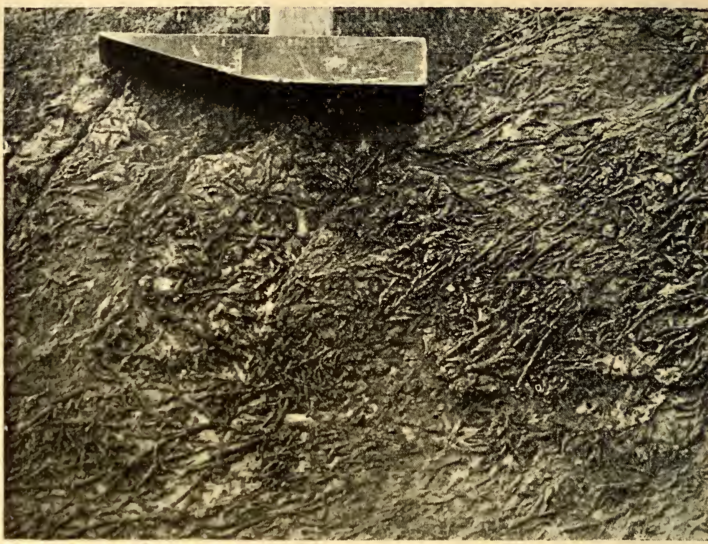
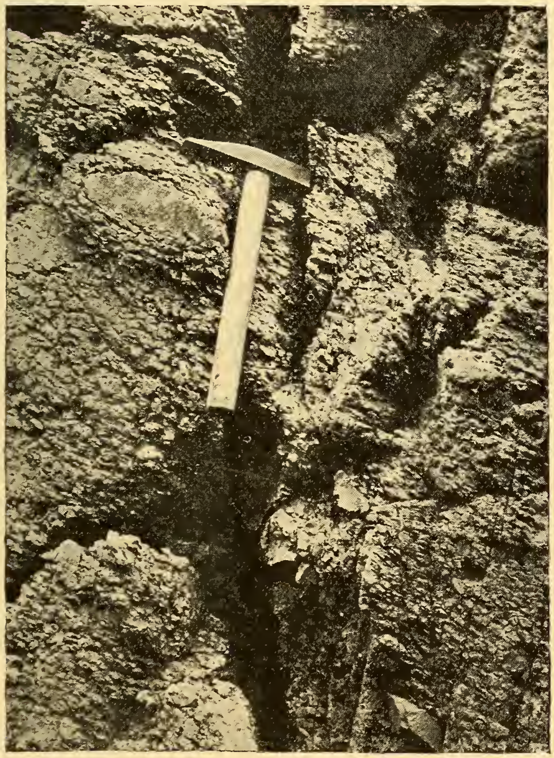


Fig. 12.—*Red sandstone and ash (C 4); north of Drom Point, Clogher.* *See p. 241.*

C (5). This well-marked greenstone-band is seen in the deep inlet at the south-western base of the promontory of Foilwee. It strikes across that promontory, and is seen again in the inlet of Coosaneal. Here it certainly seems to be intrusive, and perhaps the band which strikes across the base of the promontory may be a sill, as suggested by the officers of the Geological Survey.

Fig. 13.—*Weathered surface of nodular rhyolite (C 7); Foilwee, Clogher. See below.*



C (7) is a well-marked rhyolite with ash-bands, forming the main part of the Foilwee or Poulnakeragh promontory. The rhyolite is sometimes compact and purple, sometimes banded, and sometimes nodular; in all these respects it resembles the rhyolite of Clogher Head, with which we correlate it. It includes the following bands; at the top:—

	Thickness in feet.
(*a*) Purple ash and banded rhyolite	120
(*b*) Pale ash	18
(*c*) Rhyolite, sometimes nodular ...	35
(*d*) Pale ash	50
(*e*) Purple ash	25

Beyond the ash (C 7 *e*) is a small gap occupied by the sea, and then follows a series of flags or sandy slates (C 9), forming the rock of Doonycoovaun.

In the inlet of Coosaneal a fault shifts the outcrop about 100 yards to the south-east, bringing the rhyolite (C 7 *c*) against the greenstone (C 5).

C (8).—The rhyolite (C 7) is here seen to be overlain by the ash-band (C 8), which can be traced across the base of Poulnakeragh (where it is slightly shifted by a fault) to the head of the next little inlet, which it occupies. Then it passes inland, and is exposed near the south-eastern corner of Ferriter's Cove, at the point where the road from Ballincolla goes down on to the beach.

C (9).—This thick series of brown, grey, and purple calcareous sandstones and flags with thin ash-bands, which as one proceeds northward is first met with at the rock of Doonycoovaun, occupies the whole coast from Coosaneal to the base of Doon Point, the deep inlet of Ferriter's Cove being excavated in it. We estimate the thickness to be as much as 1390 feet. The highest of the ash-bands is seen forming the western boundary of the little promontory north-west of the inlet of Foilteela. On the southern coast of Ferriter's Cove this band is apparently represented by a small mass of rather coarsely nodular rhyolite. A second band is met with, striking across the peninsula some 50 yards to the north-west; while a third forms the end of the peninsula opposite the islands of Carrignaman and Carrignanoon. These last two bands are seen on the east side of Ferriter's Cove, at the point known as Cloghadoo. A fourth band occurs on the north side of the Cove, due south of Poulgubadda; and a fifth at Coonakeel. Below this the beds become somewhat conglomeratic.

Fossils proved to be very plentiful in these beds. At Poulnakeragh, at the base of Clogh Point, we obtained the following:—

Chonetes striatella, Dalm.	*Atrypa reticularis* (Linn.).
Orthis elegantula, Dalm.	*Rhynchonella nucula*, Sow.
Spirifer crispus, His.	*Pterinea pleuroptera*, var., Conr.
Sp. elevatus, Dalm.	*Pt. squamosa*, M'Coy.
Sp. bijugosus, M'Coy.	*Horiostoma globosum*, Schloth.

On the same line of strike, a little farther north-east, we obtained *Rhynchonella borealis* var. *diodonta*, Dalm.

If it were essential to draw a boundary-line between the Wenlock and Llandovery Series, we should be disposed to do so at some point between the fossiliferous horizon just described and the next, although, owing to the conflicting nature of the fossil evidence, any such boundary-line must be, to a great extent, arbitrary.

In the band of calcareous sandstone between the second and third ash-bands, at the extreme south-western point of Ferriter's Cove, is a very fossiliferous horizon, yielding:—

Lindstrœmia bina, Lonsd.	*Spirifer bijugosus*, M'Coy.
Cyathophyllum sp.	*Sp. crispus*, His.
Favosites sp.	*Pentamerus oblongus*, Sow.
Labechia conferta, Lonsd.	*P.* sp.
Alveolites Labechii, M.-Edw.	*Atrypa reticularis* (Linn.).
Halysites catenularia (Linn.).	*Leptæna rhomboidalis*, Wilck.
Cœnites interstinctus, Eichw.	*Stricklandinia lens*, Sow.
Heliolites sp.	*Stropheodonta imbrex*, Pander,
Streptelasma sp.	var. *semiglobosa*, Dav.

Horiostoma globosum, Schloth.
H. discors (?) Sow.
Encrinurus Stokesi, M'Coy.
Lichas anglicus, Beyrich.
Lichas sp.
Proetus sp.
Phacops sp.
Crinoidal ossicles.

At the same horizon, on the north side of the Cove, we obtained *Syringopora bifurcata*, Lonsd., and *Encrinurus* sp. The occurrence of *Stricklandinia lens* and *Pentamerus oblongus* is strongly suggestive of a Llandovery age for these beds; but the general facies of the fauna is of Wenlock type.

A third fossiliferous horizon occurs near the base of the series at Coonakeel, yielding :—

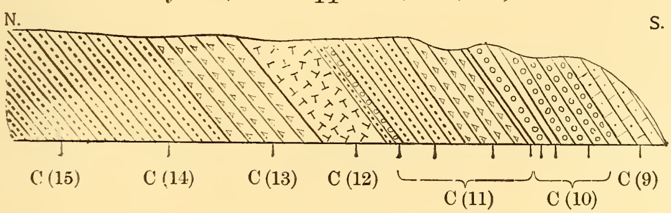
Spirifer bijugosus, M'Coy.
Orthis elegantula, Dalm.
O. hybrida, Sow.
O. basalis (?) Dalm.
Atrypa reticularis (Linn.).
Stricklandinia lirata, Sow.
Stropheodonta filosa, Sow.
Horiostoma discors, Sow.
Encrinurus Stokesi, M'Coy.
E. punctatus (?) Brünn.
Phacops Downingiæ, Murch.
Crotalocrinus sp.
Crinoidal ossicles.

The beds of the third horizon appear at intervals along the southern coast of Doon Point, and near the extreme end have yielded :—

Cyathophyllum sp.
Lindstrœmia subduplicata, M'Coy.
Orthis calligramma, var. *Davidsoni*, de Vern.
Orthis sp.
Horiostoma discors, Sow.
Horiostoma globosum, Schloth.
Proetus sp.
Lichas sp.
Encrinurus Stokesi, M'Coy.
Crinoidal ossicles.

C (10). This well-marked band of coarse conglomerate is first met with in the inlet known as Coonakeel, from which spot it can be

Fig. 14.—*Section through Ferriter's Castle Cove. (For explanation of C 9, etc. see pp. 240, 244, etc.)*



[Horizontal scale: 1 inch = 60 feet.]

followed almost continuously to the end of Doon Point. The existence of the point is, in fact, largely due to it. It contains pebbles of quartz, jasper, rhyolite, ash, diabase, purple sandstone, dark limestone, and fine conglomerate. Some of the pieces are as much as 12 inches long.

Good sections through the beds from (C 10) to (C 14) are seen in the little cove opposite Carriganeena, and in that south of the ruins of Ferriter's Castle. A comparison of the two sections gives the following succession:—

Ferriter's Castle Cove.

		Feet	inches.
C (10)	Coarse conglomerate	20	0
	Fine red grit	3	0
	Coarse conglomerate	7	0
C (11)	Fine red sandy beds	2	0
	Ashes	18	0
	Red sandy slates	20	0
	Conglomerate of medium grain	3	0
	Red sandy slates	3	0
C (12)	Purple rhyolite	23	0
C (13)	Ash	31	0
C (14)	Yellow sandy beds	40	0

Carriganeena.

	Feet	inches.
Coarse conglomerate	13	0
Green grit	8	0
Fine green ash	14	0
Purple, fairly coarse ash	6	0
Fine green ash	15	0
Red sandy slate, with coarse layers	24	0
Conglomerate of medium grain	6	0
Green ash of medium grain	5	0
Purple rhyolite	18	0
Green ash of medium grain	38	0
Green sandy grit, weathering yellow	32	0

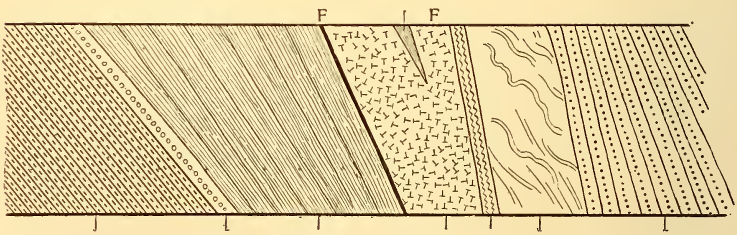
In the above synopsis the term c o a r s e implies fragments at least 4 inches long; the term m e d i u m - g r a i n e d, fragments up to half an inch long; and f i n e, fragments less than half an inch in length.

C (15). This series of red sandstones, with conglomeratic ashy and shaly layers, forms the greater part of Doon Point, and extends into the cove of Foilnamahagh to the north. Its lower layers show signs of disturbance, while the sandstones with shales and ashes (C 16), upon which it rests, show much crushing and veining.

Below comes a green rock (C 17), probably including both rhyolite and ash. It is very amygdaloidal in places, and much decomposed; it is faulted against

C (18), a coarse labradorite-porphyrite, which occupies part of

Fig. 15.—*Section across the inlets of Coosglass and Foilnamahagh.* (*For explanation of C 15, etc. see p. 240.*)



[Horizontal scale: 12 inches = 1 mile. F=Faults.]

the head of Foilnamahagh, and extends across the little point to the next cove on the north. This rock is unlike any other met with in the Clogher-Head district, and in hand-specimens resembles the coarsely porphyritic rock which occurs associated with the Bala Beds of Kildare, Lambay Island, and Portraine. As a whole, the rock is coarse-grained and amygdaloidal in Foilnamahagh, while in the cove to the north it is much finer-grained and more compact. The northern, as well as the southern, boundary of the porphyrite is faulted.

C (19). North of the fault just mentioned, the coast is occupied by a series of dull pink and green slates and fissile sandstones, which form the next point and the head of the inlet of Coosglass. They dip generally at 50° to 60° south 45° east, and have yielded

Lindstrœmia subduplicata (?) M'Coy.	*Encrinurus* sp.
Rhynchospira Baylei, Dav.	*Phacops (?) caudatus*, Brünn.

C (20). At the head of Coosglass the beds just described rest on a coarse conglomerate, which we follow the officers of the Geological Survey in regarding as the boundary between the undoubted Silurian and the Smerwick Beds. The pebbles of this conglomerate, which sometimes reach a length of 18 to 20 inches, consist chiefly of a fine-grained, micaceous, fissile sandstone, but there are also pebbles of jasper, quartz-porphyry, and rhyolite of two varieties.

These beds rest with perfect conformity on the Smerwick Beds.

(*d*) The Western Side of Smerwick Harbour.

The Silurians of the Ferriter's Cove neighbourhood strike across the base of the Smerwick peninsula, and occupy some 600 yards of the coast on the west side of Smerwick Harbour. A broad tract of blown sand and peat intervenes between the outcrop of the Silurian at Gortnagan Point and the nearest exposure of Dingle Beds, which lies on the south coast of Smerwick Harbour, north-north-east of Ballyferriter. The Silurians are on the strike of those at Ferriter's Cove, and are clearly a reduced development of the series so well exposed there, but the correlation of the two sets of exposures is by no means easy.

Their succession is: at the top:—

		Thickness in feet.
D (1)	Yellow calcareous flags and slates, with many fucoids.	320 (seen)
	FAULT.	
D (2)	Calcareous flags and slates, with a band of hard green grit	320
	FAULT.	
D (3)	Ashes pale at the top, red below; fine red sandy layers at intervals	50
D (4)	Yellow calcareous flags and slates	290
D (5)	Green sandy ashes	12
D (6)	Red sandy and fossiliferous ashy beds, very coarse in part	8
D (7)	Nodular rhyolite	50
D (8)	Red sandy ashes	40
D (9)	Yellow calcareous flags and slates	35
D (10)	Red sandy and ashy beds	50
D (11)	Yellow calcareous flags and slates of Fort Dunore[1]	60
D (12)	Green sandy ashes	20
D (13)	Red ashes	18
	FAULT-DÉBRIS.	
D (14)	Coarse conglomerate	24

[1] Also called Fort Dolore.

D (1). The yellow calcareous flags and slates of Gortnagan Point dip near the southern end of the exposure at 70° south 35° east. 'Fucoids' or worm-tracks are very plentiful throughout, and the beds have also yielded *Rhynchonella Wilsoni*, Sow., and *Atrypa reticularis* (Linn.). South of Illaunaportan they are cut off by a fault, which runs nearly due east and west.

D (2). North of the fault the beds, though presenting the same lithological characters, are far more fossiliferous, and have yielded:—

Lindstrœmia bina, Lonsd.	*Atrypa reticularis* (Linn.).
Favosites.	*Anodontopsis perovalis*, Salt.
Orthis biloba, Linn.	*Pleurotomaria Lloydii (?)* Sow.
O. hybrida, Sow.	*Pl.* sp.
O. elegantula, Dalm.	*Murchisonia* sp.
Spirifer crispus, His.	*Loxonema sinuosum*, Sow.
Sp. elevatus, Dalm.	*Horiostoma globosum*, Schloth.
Rhynchonella Wilsoni, Sow.	*Holopella* sp.

This assemblage of fossils is noticeable for the abundance of gasteropods, and is suggestive of a Wenlock age for the beds.

At Coosbeg a compact felspathic grit occurs, and below that more flags with worm-tracks. Nowhere else in the district are beds with Wenlock fossils under- as well as overlain by beds with abundant worm-tracks.

Towards the base the flags become slightly ashy, and in the inlet of Coosavaud are faulted against a series of red ashes and sandy beds (D 3) which occupy the peninsula of Illaunfraoid. This fault is marked by much quartz-veining.

The bed (D 3), which contains rhyolitic fragments up to an inch in length, is followed by a series of calcareous flags and slates (D 4), containing coral-layers composed of *Favosites* sp. (?). This type of rock is characteristic of the Wenlock Beds of the district, and gives us good reason to suppose that we are still dealing with strata of Wenlock age. These yellow beds extend to the peninsula of Foilavaddia, dipping at first 55° south 60° east, but at Foilavaddia 70° south 25° east (see fig. 16, p. 249).

They are underlain by ashes of variable character (D 5 & 6) dipping at 67° south 35° east, and containing many red and green slaty rhyolitic fragments and scoriaceous lapilli.

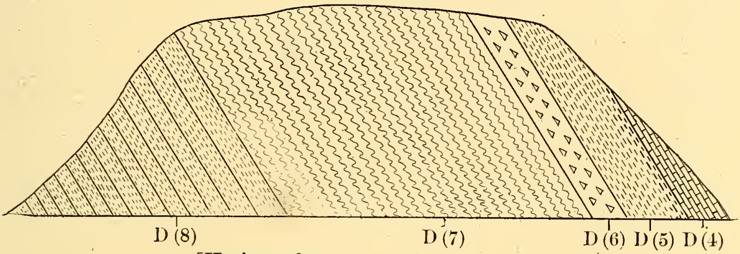
D (6) has yielded the following fossils:—

Favositella sp.	*Pleurotomaria* sp.
Monticulipora sp.	*Horiostoma* sp.
Fistulipora sp.	*Orthoceras* sp.
Pterinea retroflexa, Wahl.	

D (7) is a pale, often nodular rhyolite, forming the Point of Foilavaddia. Close to the end of the Point it appears to cut abruptly across the bed (D 5), but this may be merely due to the ash having been deposited on an uneven surface of rhyolite.

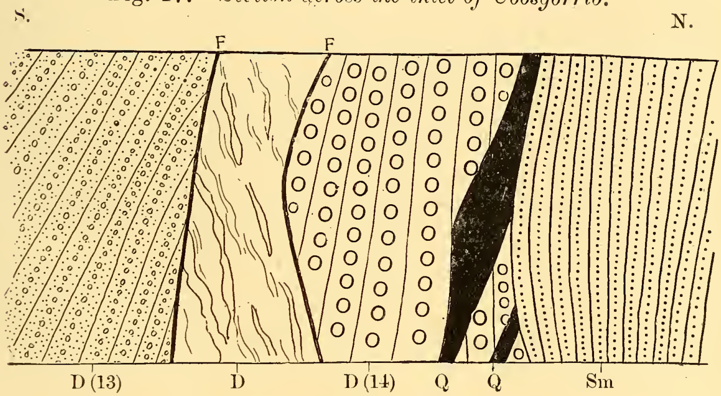
The calcareous flags and ashy beds (D 8–11), which succeed, did not prove fossiliferous. Fort Dunore stands on the calcareous flags and slates (D 11). The conglomerate (D 14), which is separated by a well-marked fault with crushed material and much quartz-veining from the overlying beds, contains well-rounded blocks, chiefly of sandstone resembling the Smerwick Beds immediately beneath, but granitic and rhyolitic pebbles also occur. Mainly below it, but at one point penetrating this conglomerate, is a quartz-porphyry of

Fig. 16.—*Section across Foilavaddia. (For explanation of D 4, etc. see p. 248.)*



[Horizontal scale: 1 inch = 10 yards.]

Fig. 17.—*Section across the inlet of Coosgorrib.*



[Horizontal scale: 1 inch = 10 yards.]

D (13) = Red ashes.
D (14) = Conglomerate.
D = Fault-débris, with many quartz-veins.
Q = Intrusive quartz-felsite.
Sm = Smerwick Beds.

somewhat peculiar character, described on p. 263. This rock is probably intrusive along the junction of the conglomerate and the Smerwick Beds which come immediately below (see fig. 17, above).

From the foregoing account of the rocks seen on both sides of the Sybil peninsula, it is clear that a well-marked conglomerate occurs between the fossiliferous Silurian and the Smerwick Beds; but, while on the west side of the promontory the junction between the conglomerate and the overlying beds is conformable, on the east side it is a faulted one. This renders the correlation of the two sets of exposures more difficult than would otherwise be the case.

(*e*) Inland Exposures of Rhyolites and Ashes.

With the exception of those in the neighbourhood of the Minnaunmore Rock, which are conveniently described when dealing with the rocks of Clogher Head, the most important inland exposures of igneous rocks are those in the neighbourhood of Carhoo village, which lies about two-thirds of a mile north of the village of Dunquin. As one proceeds up the stream which follows the old road from Mill Cove to Carhoo, and runs in a more or less southerly direction from Carhoo, a series of banded and nodular rhyolites is met with. They strike north 40° east, and are very similar to those forming the band (A 4) on the coast. They contain an ash-band in their lower layers, and overlie a series of rhyolites and ashes which extend for some little distance north of the Dunquin and Clogher road. Just south of the latter road they dip at 50° south 60° east; while north of the road the direction is south 50° east. Rhyolites then again come on, and extend through the village of Carhoo, and for about a sixth of a mile along the old Clogher road to the north of the village. Then ashes come on again, followed once more by purple nodular rhyolites. This brings us to a point about a quarter of a mile north of the village of Carhoo, where the stream which we have been following is joined by a small westward flowing tributary. From this point for a third of a mile to the north no exposures are seen, and then one reaches the rhyolites, which have been already described as occurring in the neighbourhood of the Minnaunmore Rock. A band of ash, overlain by sandy limestones and underlain by green grit dipping at 46° south 40° east, is seen in the ravine which strikes the coast a little north of Carrigcam, the exposure being immediately east of the point where the ravine is cut by the new road.

If one follows up the little westward flowing tributary of the Carhoo stream above mentioned, exposures of ash and sandstone are met with striking east 50° north, a strike which, if prolonged, would bring them against the rhyolites of the neighbourhood of Carhoo. The presence of a fault between the two exposures is thus suggested. A small band of pale ash occurs in the northernmost stream of the two which run down the hillside towards Clogher village, the exposure lying not far east of the old wheel-track.

(*f*) Inland Exposures of Sedimentaries.

(1) The neighbourhood of Dunquin, Coumaleague, and Croaghmarhin.—East of the villages of Dunquin and Carhoo, between them and the hills of Croaghmarhin and Coumaleague, are very numerous exposures of sedimentary rocks, principally in the beds of the Dunquin River and its numerous tributaries. They are all of the nature of grits, flags, and sandy limestones and slates; no igneous rocks whatever are seen associated with them; and the fossils, which are often very plentiful, are in almost every case indicative of a Ludlow age.

(1 *a*) The Glanlack and Vicarstown exposures.—In the stream-bed immediately east of the hamlet of Glanlack, and on the hill-slopes just to the north, are good junction-sections between the purple Dingle Beds and the green gritty beds which are here considered as the top of the Silurian. The Dingle Beds on the hillside dip at 40° south 10° west; while in the stream-section the dip is greater, varying from 60° south 10° east near the junction to 75° south 10° east farther up the stream. The underlying Silurians in each case dip conformably beneath the Dingle Beds, and, as previously noted by Prof. Hull,[1] there is nothing to lead one to suppose that the junction is anything but a conformable one. The upper beds of the Silurian are harder and more micaceous in the neighbourhood of the Dingle Beds than they are elsewhere. There is a good series of exposures down the stream, as far as its junction with the one coming from Vicarstown. The dip from Glanlack as far as the high road is a little east of south; but from this point to the junction of the streams the dip is very variable, and just at the stream-junction the dip is north-westerly. There seems every probability of a fault between this exposure and the coast.

(1 *b*) The Dunquin Church and Ballynahow exposures.—East of Carhoo, in a deeply-cut wheel-track going down to Dunquin Church, is a continuous section of grey and brown fossiliferous flags, with a band of hard blue grit about 50 feet thick. About 900 feet of these beds are seen in this track; while, if one includes the ashes and sandstones (already described as met with in the stream running westward to the Carhoo road) which dip in the same general direction, another 500 feet may be added to the above thickness; and we may say that at least 1400 feet of Ludlow Beds are seen dipping about south-eastward between Dunquin Church and the westernmost exposure in the east-and-west stream north of Carhoo. But there may be a concealed fault between the flags and the ashy and sandy beds, and we can only say with certainty that 900 feet of Ludlow Beds are exposed. If the ashes and sandstones are to be counted among the Ludlow Beds, we have here evidence that the volcanic activity had not died out in Ludlow times.

The large stream running down past Dunquin Church, between the hills of Coomaleague and Croaghmarhin, and its tributaries afford an excellent series of exposures of the Ludlow Beds. Starting at the foot of the wheel-track above mentioned, we find that the beds have the same lithological character and the same south-easterly dip as have those in the track, but about a quarter of a mile up the stream we meet with a very different dip, namely, 52° south 10° east. The beds frequently contain coral-layers with *Halysites catenularia* (Linn.) and *Favosites aspera*, d'Orb. About 350 yards above the point where the stream is crossed by the road, a small tributary from Coumaleague Hill joins the main stream. It shows many exposures of grey calcareous flags dipping in general at south 30° to

[1] Quart. Journ. Geol. Soc. vol. xxxv (1879) p. 703.

40° east, very fossiliferous, and containing especially numerous corals (*Heliolites cæspitosa*, Salt.). At a spot about 200 yards east of the point where this stream is crossed by the Ventry and Dunquin road these beds yielded :—

Monticulipora sp.	*Spirifer plicatellus* (Linn.).
Strophonella funiculata, M'Coy.	*Plectambonites transversalis*, Wahl.
Atrypa reticularis (Linn.).	*Pterinea squamosa*, M'Coy.
Orthis elegantula, Dalm.	*Cardiola interrupta (?)* Sow.
Dayia navicula, Sow.	*Lichas anglicus*, Beyrich.
Cyrtia exporrecta, Wahl.	Crinoidal ossicles.
Pentamerus sp.	

The rocks in the main stream, below the point where this tributary joins it, dip at 65° to 85° south 10° to 15° west, while in the tributary and higher up the main stream the general direction is easterly. There may be a fault between the two sets of exposures.

Continuing up the main stream, we next come to a tributary which, running nearly due south from Ballynahow Common, enters on the right bank. In this are numerous exposures of brown calcareous sandstones dipping at 35° to 50° south 65° to 80° east. At about a quarter of a mile up this tributary, at a point where it is joined by a ravine from the east, is a very fossiliferous exposure of brown calcareous sandstones, from which we obtained :—

Halysites catenularia (Linn.).	*Rhynchonella Wilsoni*, Sow.
Heliolites cæspitosa, Salt.	*Rh.* sp.
H. Murchisoni, M.-Edw.	*Atrypa reticularis* (Linn.).
Monticulipora poculum, Salt.	*Orthis elegantula*, Dalm.
Favosites aspera, d'Orb.	*O. calligramma*, Dalm., var. *Davidsoni*, de Vern.
F. Forbesi, M.-Edw.	*Chonetes (?) lævigata*, Sow.
Favositella interpunctata, Quenst.	*Dayia navicula*, Sow.
Lindstrœmia sp.	*Pterinea retroflexa*, Wahl.
Spirifer crispus, His.	Crinoidal ossicles.
Sp. bijugosus, M'Coy.	
Pentamerus undatus, Sow.	

The occurrence of *Dayia navicula*, Sow., a typical Ludlow species, associated with *Orthis calligramma*, var. *Davidsoni*, de Vern., and *Pentamerus undatus*, Sow., species which are not generally met with above the Llandovery, is noteworthy. The little ravine above mentioned shows the exposures of the same type of rock dipping at one point north 25° east; and, when followed up for some 500 yards, bears sharply first northward and then north-westward, exposing more grey calcareous flags dipping north-eastward at 47°, and containing

Labechia conferta, Lonsd.	*Strophonella funiculata*, M'Coy.
Atrypa reticularis (Linn.).	

Similar compact, grey and green, calcareous flags can be traced, more or less continuously, all the way to the top of Croaghmarhin, and also round the top of the hill and away along the ridge towards Ballyferriter; until at a point nearly due west of the northernmost of the two hamlets called Marhinmore, the purple Dingle grits come on. Unfortunately, it is impossible to ascertain the character of the junction between the two series, owing to the occurrence of a gap of about 300 yards without exposures. The green Silurian flags, when last seen, dip at 25° south 50° east, while the Dingle Beds, at their first appearance, are dipping at 60° south 30° west. At a point about 150 yards north-east of the summit these flags yielded

Orthis elegantula, Dalm.	*Strophonella funiculata*, M'Coy.
O. sp.	*Chonetes striatella*, Dalm.

West and south-west of the summit of Croaghmarhin there is a puzzling and irregular series of dips, indicating the presence of faults or sharp flexures.

Returning to the Dunquin River, we find, east of the point where the Ballynahow-Common tributary joins it, further exposures of coral-bearing sandy limestone and grey and green unfossiliferous flags. At a point about 150 yards west of the main road, the beds yielded *Dayia navicula*, Sow., and *Orthis elegantula*, Dalm. In the ditch at the south side of the road which descends from the top of the watershed to join the road from Marhinmore, brown calcareous flags, of the type so common in the neighbourhood, are frequently exposed. Some 470 feet of these beds are here seen. Similar beds are seen close to the Marhinmore road, about 300 yards from its point of junction with the Dunquin road. The northernmost of the two streams which run down the east side of Coumaleague Hill to unite near the hamlet of Coumaleague, shows purple Dingle Beds overlying grey flaggy Silurians. Both series dip south 45° east, and there can be no doubt that here, as in the neighbourhood of Glanlack, the Dingle Beds succeed the Silurian conformably.

(2) Exposures in the neighbourhood of Teeravane, Clogher, and Gortadoo.—Around the hamlet of Teeravane, at the northern foot of Croaghmarhin, are a number of exposures of yellow and brown, sandy flags and slates, the general dip of which is about 45° south 30° east. There are many other exposures of similar brown sandy flags in two stream-courses which run down the hillside in a north-westerly direction towards Clogher village. In the northernmost of these two streams the dip of the upper beds is similar in the main to that of the Teeravane beds, that is, south-easterly; but just above where the stream crosses the old wheel-track the dip is south 15° west. In the southernmost stream, the dip is southerly or a little west of south; about 600 feet of these beds are seen in that stream. A small band of pale ash is exposed in the bed of the northernmost of these two streams, close to the old wheel-track.

Beyond the high road are other exposures of green gritty flags, in the neighbourhood of Donaghcoor Fort, and along the road from the village of Clogher to the coast.

About half-a-mile east of Ferriter's Cove, in the neighbourhood of the hamlet of Gortadoo, is a small exposure of very hard green grits, which dip at 28° south 75° east. They have yielded *Fistulipora* and *Spirifer crispus*, His., and resemble the hard grits of Croaghmarhin

Table I.—Suggested Correlation of Series A, B, and C.

Series A	Thickness in feet.
A (1) Green and brown, sandy and slaty beds, ashy towards the base; top not seen (seen)	480
A (2) Green ash	8
A (3) Fine red sandstones and ashes	330
A (4) Intrusive greenstone	150
A (5) Nodular and banded rhyolite, with ash-bands	113
A (6) Ashes	350
A (7) Calcareous flags and slates	75
A (8) Coarse ashy conglomerate	56
A (9) Greenstone intruded into (A 8)	120
A (10–14) Rhyolites and ashes	115
A (15) Ashes, including green ash	14
A (16) Calcareous flags and slates, with coral-layers and bands of conglomerate	85
A (17–20) Rhyolites and ashes	241
A (21) Calcareous flags and slates	60
A (22–26) Rhyolites and ashes, with slate-band	76
A (27) Calcareous flags, with coral-layers	90
A (28) Compact rhyolite	80
A (29–32) Calcareous flags and sandy slates	235
A (33–34) Ashes	132
A (35) Rhyolite (seen)	282
Fault.	

Series B	Thickness in feet.
B (1) Green sandy grit, ashy towards the original base; original top not seen	?
B (2) Green ash	6
B (3) Fine red sandstones and ashes	350
B (4) Intrusive greenstone	46
B (5) Fairly coarse ash	75
B (6) Rhyolite of Clogher Head	175
B (7) Ashes, with bands of rhyolite	320
B (8) Calcareous flags and slates	230
B (9) Green ash	40
B (10–12) Calcareous flags, with coarse ash.	95
B (13–14) Rhyolite and ash-bands	265
B (15) Calcareous flags (seen)	50
Fault.	

Series C	Thickness in feet.	
C (1) Gritty flags and slates	about 550	Ludlow.
C (2) Green and yellow sandstones and slates, ashy towards the base:	about 570	Wenlock.
C (3) Green ash	8	Wenlock.
C (4) Fine red sandstones and ashes	340	Wenlock.
C (5) Intrusive greenstone	30	Wenlock.
C (6) Fairly coarse ash	7	Wenlock.
C (7) Rhyolite, with ash-bands	248	Wenlock.
C (8) Ash weathering grey or white	25	Wenlock.
C 9 (in part) Calcareous sandstones and flags, with ash-bands	1390	Wenlock.
C 9 (in part) to C (20) Sandstones, flags, slates, ashes, and rhyolite.		Wenlock-Llandovery.

more than any other beds in the district. As they are entirely surrounded by peat and alluvium, their relation to the other Silurians cannot be ascertained.

III. Correlation of the Exposures, and Conclusions as to the General Succession.

If the theory with regard to the structure of the Clogher Head inlier which we have adopted is correct, the three series which we have described as A, B, and C are repetitions of one and the same set of deposits, and it should be possible to correlate and compare the several bands. This we have attempted to do in Table I (p. 254), but the subject is beset with numerous difficulties. The newest beds are easily correlated: in each case we have a thick series of slates and grits followed, after an intervening green ash, by a thick series of red sandstones and ashes, and then by a band of greenstone succeeded by a thick mass of rhyolite.

The chief difficulty lies in the enormously thick series of calcareous sandstones and flags (C 9): for there is nothing in the A or B series comparable to this in thickness. At certain horizons in the band (C 9) too, fossils of distinctly Llandovery type occur; while neither A nor B has yielded fossils clearly of Llandovery age.

These Llandovery fossils are, however, associated with many others of Wenlock type, and hence we do not feel justified in definitely styling these beds Llandovery, but call them Wenlock-Llandovery. The non-representation of the Wenlock-Llandovery Beds in the A and B series may be due to their being cut out by the big fault at Owen; or it may be that further search will disclose the fact that fossils of Llandovery type do actually occur in the older beds of the A and B series. A further difficulty is to decide where to draw the line between the Ludlow and the Wenlock Series. The officers of the Geological Survey regarded a well-marked green ash (A 2, B 2, C 3), which occurs in each limb of the fold, as the top of the Wenlock Series, and considered that the overlying beds, which, as a rule, contain few fossils but worm-tracks, are of Ludlow age. From the fact, however, that fossils of Wenlock type occur in the worm-track-bearing grits and flags (B 1), we were compelled to include the beds and their equivalents (A 1) and (C 2) in the Wenlock Series. The beds which should succeed (A 1) and (B 1) are cut off from them by faults. In the C series, however, at Trabaneclogher, after a small area where the succession is obscured by blown sand, we meet with a series of beds (C 1), the age of which it is by no means easy to determine. They contain worm-tracks, but no distinctively Wenlock fossils, and lithologically resemble the Croaghmarhin Beds, which are clearly of Ludlow age. We therefore feel justified in grouping these beds with the Ludlow Series.

The correlation of series C and D is even more puzzling than that of A, B, and C. We believe that the following table (p. 256) represents the relationship:—

Table II.—Suggested Correlation of Series C and D.

	Thickness in feet.		Thickness in feet.
D (1) Yellow calcareous flags, with fucoids. Top not seen ...	320	C (2) Green and yellow sandstones and slates............ about	570
Fault.		C (3–8) Mainly volcanic.	
D (2) Calcareous flags, with a band of hard green grit	320	C (9) Calcareous sandstones and flags, with ash-bands, of Ferriter's Cove .... (correlated with D (2)–D (4))	1390
Fault.			
D (3) Ashes, with sandy layers......	50		
D (4) Yellow sandy beds	290		
		C (10) Coarse conglomerate, with grit-band	30
D (5 & 6) Green and red, sandy and ashy beds	20	C (11) Red sandy beds, with ashy and conglomerate-bands .	70
D (7) Nodular rhyolite	50	C (12) Rhyolite	23
D (8) Red sandy ashes	40	C (13) Ash	31
D (9–13) Variable sandy and ashy beds	183	C (14–16) Sandy limestone and sandstone..................	260
Fault.		C (17) Green rhyolite and ash	6
		Fault.	
		C (18) Labradorite-porphyrite......	115
		Fault.	
		C (19) Red and green slates.	
D (14) Conglomerate	24	C (20) Conglomerate	6

It may be thought unjustifiable to correlate (D 1) with (C 2), and at the same time (D 2) with (C 9), which is separated from (C 2) by beds 658 feet thick. But it must be remembered that the non-representation of (C 3–8) in the D series may be partly due to the fault at Illaunaportan; while we must not lose sight of the fact that the beds unrepresented in the D series are, with the exception of part of (C 4), entirely lavas, ashes, or intrusives, and might well be subject to rapid variation in thickness in a limited area. These very beds (C 3–8), which are 658 feet thick, are the equivalents of (B 2–7), which are 972 feet thick, and also of the beds (A 2–6), still farther south, which are as much as 1026 feet thick.

We are now in a position to summarize what we believe to be the general succession in the Clogher Head district: at the top:—

		Thickness in feet.
Lower Devonian.	Dingle Series.	
Ludlow.	5. Croaghmarhin Beds, calcareous sandstones and flags of Ludlow age	?1000
Wenlock.	4. Drom-Point Beds (A 1, B 1, C 2, D 1) ... about	600
	3. Red sandstones and ashes (A 3, B 3, C 4), with green ash (A 2, B 2, C 3) at the top	350
	2. Clogher-Head Series, calcareous flags and slates, with abundant contemporaneous igneous rocks (A 5–35, B 5–15, C 6–9 [in part], D 2) ...	2000 *
Wenlock-Llandovery.	1. Ferriter's-Cove Beds, chiefly calcareous flags, with a subordinate development of contemporaneous igneous rocks (C 9 [in part]–20, D 3–14)..	1400
	Smerwick Beds.	

* Maximum thickness seen.

5. The uppermost Silurian beds, which east of Dunquin and south of Marhinmore underlie the Dingle Beds with apparent conformity, are the Croaghmarhin Beds, of Ludlow age—a series of grey

and green calcareous flags often very fossiliferous, and containing in places abundant *Dayia navicula*, Sow., and coral-layers composed of *Heliolites* and *Halysites*. These beds are certainly not less than 900 feet thick, and may be much thicker. The only sign of contemporaneous volcanic action having taken place during their deposition, is afforded by certain thin beds of ash seen north-east of Carhoo and east of Clogher village. The great majority of the inland exposures of Silurian beds belong to this series, and, as already stated, we believe that the series of gritty flags and slates exposed on the south side of Trabaneclogher are also to be grouped with the Croaghmarhin Beds, and regarded as of Ludlow age.

4. Below comes a series of beds which, from the fact that they are best developed at Drom Point, may be called the Drom-Point Beds. They consist of brown gritty and slaty beds with, as a rule, few fossils except abundant worm-tracks. In the lowest beds of this series we meet with traces of contemporaneous volcanic action; but volcanic action was, on the whole, little rife during their deposition.

3. Below comes a thick series of red sandstones, with numerous ash-bands, well exposed north of Drom Point and south of Mill Cove. These beds have yielded no fossils.

2. Below comes the Clogher-Head Series, a remarkable and varied succession of ashes and rhyolites, alternating with calcareous flags and slates, containing fossils mainly of Wenlock type. The igneous rocks largely preponderate over the sedimentaries in the southern part of the area. They overlie :

1. The Ferriter's-Cove Beds, a thick series of calcareous sandstones and flags with subordinate ash-bands. The fauna, though in the main of Wenlock type, contains some species which are generally regarded as distinctly Llandovery (see § IV, below). The Ferriter's-Cove Beds rest with apparent conformity upon the unfossiliferous Smerwick Beds.

IV. Further Remarks on the Fossils.

Mr. F. R. Cowper Reed [1] writes :—

'The facies of the fauna from all the localities is Silurian ; I have not seen any fossils that would lead me to suspect the presence of Ordovician beds.'

The distribution of the fossils shows, however, several anomalous features. Thus *Pentamerus oblongus* and *Stricklandinia lens*, which are generally characteristic of the Llandovery, occur in the south-western corner of Ferriter's Cove, in beds the general facies of whose fauna is more of Wenlock type. At a slightly lower horizon, on the other side of the Cove, *Stricklandinia lirata* occurs associated with fossils of Wenlock type. On the other hand, at one of the exposures in the stream which flows from Ballynahow Common to join the Dunquin River, *Pentamerus undatus* and *Orthis calligramma* var. *Davidsoni*, both forms not generally met with above the Llandovery, occur associated with so typical a Ludlow form as

[1] Mr. Reed has, as on three former occasions, most kindly examined our fossils for us. We are very greatly indebted to him.

Dayia navicula. *Chonetes striatella*, too, as remarked by Salter,[1] is here most common in beds of Wenlock or Llandovery age, as at Poulnakeragh and north of Carrigard; while in Britain it is a characteristic Ludlow fossil. In this district it occurs in beds of Ludlow age on the north-western slopes of Croaghmarhin.

With regard to the general facies of the Silurian fossils from the locality Mr. Reed writes:—

'The lack of cephalopods, the great poverty of crinoids, and the scarcity of trilobites and gasteropods may be noticed. The trilobite *Encrinurus Stokesi* appears to me to differ from the typical specimens of *E. punctatus* from the Wenlock rocks of England; but it may prove to be only a local variety of the latter species. *Horiostoma* is the most abundant genus of gasteropods, and *Encrinurus* of trilobites. The only peculiar species from these Silurian beds of the Dingle district appears to be *Spirifer bijugosus*, and it is a generally abundant form.'

Rhynchonella nucula occurs from the top of the Ludlow to the lower part of the Wenlock (as, for example, at the base of Clogh Point).

V. Petrographical Details.[2]

(*a*) The Lavas.

These, which are invariably rhyolitic in character, form the most remarkable of the volcanic rocks of the district. They are fine-grained white, pale-grey, or purple rocks, with a groundmass which under the microscope is generally seen to be mainly cryptocrystalline, though commonly with microcrystalline or micropœcilitic patches and bands which are elongated in the direction of flow, and often merge imperceptibly into the surrounding cryptocrystalline material. None of the rocks show vesicular structure, and the phenocrysts, which are almost always felspar (generally orthoclase), are never very abundant, and are often completely absent. Phenocrysts of quartz are never met with. The prevailing cryptocrystalline character of the groundmass is probably due to devitrification.

The rhyolites may be divided into the following groups:—

(1) Nodular rhyolites;
(2) Banded rhyolites; and
(3) Rhyolites not showing nodular or banded structure.

(1) Nodular rhyolites.—The best examples of these rocks occur on the east side of the inlet of Foilminnaun, north of Mill Cove (band A 5) and in the thick band of rhyolite (C 7) which forms the greater part of the promontory of Poulnakeragh or Foilwee. The Clogher-Head rhyolite is also sometimes nodular, as too is that seen south of the village of Carhoo. The mass exposed on the foreshore of the south side of Ferriter's Cove is another example of a rather coarsely nodular rock. The nodules in all these

[1] Brit. Assoc. Rep. 1857 (Dublin) Trans. p. 89.
[2] We are much indebted to Mr. Alfred Harker for help in the determination of some of our rocks.

rocks are of all lengths up to 5 inches, and generally stand out prominently from the weathered surface. They are sometimes solid, but occasionally contain irregular hollows, which are often lined with chalcedony or with small, though often well formed, quartz-crystals. We have no theories to offer in regard to the formation of these nodules, but may remark that we have not detected spherulitic structure in connection with them. The rock exposed at the point north of Mill Cove is pale purplish-white in a hand-specimen, with many small dark nodular lumps. When viewed in ordinary light under the microscope, patches are observed which resemble xenoliths, but in polarized light these merge more or less completely into the surrounding matrix, and are seen to consist of quartz and felspar intergrown in a micropœcilitic fashion. No phenocrysts were met with.

A micropœcilitic character is also strongly marked in two other sections of rhyolite from the same locality: in one case micropœcilitic patches are thickly strewn throughout the section, in the other almost the whole of the groundmass is micropœcilitic.

Some of the rhyolites from the Foilwee promontory also show numerous small micropœcilitic patches in the groundmass.

(2) Banded rhyolites.—These are the most plentiful and important of the lavas. The great mass of the Clogher-Head rhyolite is markedly banded in its eastern portion near the Minnaunmore Rock; while in the western exposures near the headland the banding is not, as a rule, so well marked. Next to the Clogher-Head mass the most important banded rhyolite is the upper part of the Foilwee or Poulnakeragh flow. In the banded variety of the Clogher-Head rhyolite, the bands are seen under the microscope to be identical in character with many of the small nodules, and to consist of quartz and felspar intergrown in a micropœcilitic fashion, while the rest of the section is cryptocrystalline. A considerable amount of epidote is developed in connection with these bands.

Some sections of the Poulnakeragh rock show very numerous small spots in the groundmass, which are free from sericitic mica, and appear black in polarized light. Mr. Harker, to whom we submitted a section, says that these spots seem to be micropœcilitic areas, and drew our attention to the occurrence of similar spots in rhyolites described by him from Caernarvonshire[1] and from Dufton.[2]

Among the various types of rhyolites exposed in the fine coast-section due west of Carhoo village, is a compact purple rhyolite which presents a banded appearance in a hand-specimen, owing to the occurrence of elongated lenticular patches marked out by the abundance of brown iron-oxide. In section, orthoclase-phenocrysts are seen to be plentiful, and the groundmass shows excellent flow-structure round them. The rhyolite seen south of Carhoo is also occasionally banded.

[1] 'Bala Volcanic Area of Caernarvonshire' Sedgwick Prize Essay for 1888 [1889] pp. 22–23.

[2] Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 519.

(3) Rhyolites not showing nodular or banded structure.—Several varieties of these rocks are met with. The most important is perhaps the hard compact purple rock (A 11) which forms the prominent flow to which Redcliff Cove owes its name. This has a cryptocrystalline groundmass, somewhat iron-stained. It shows no lenticular patches coarser-grained than the rest. Felspar-phenocrysts are abundant, and often show corrosion by the groundmass. They exhibit, however, no sign of a general parallel arrangement, and often appear broken, so that the section presents features which suggest an ash. As already mentioned, when describing this rock in the field, this is also suggested by the occurrence of included xenoliths of rhyolite.

In the inlet of Carrignaneena, on the south side of Doon Point, occurs a compact purple rhyolite (C 12), quite unlike in character any of those of the Clogher-Head Series. In section the groundmass, which is much stained with red iron-oxide, is seen to be microcrystalline, and to show good fluxion-structure round the numerous phenocrysts of orthoclase.

The large mass of rhyolite exposed at the point north-west of Owen also consists largely of a compact purple rock which shows neither banding nor nodules. This rock is very fine-grained, and almost uniformly cryptocrystalline. A fair number of phenocrysts of orthoclase, and also of albite, occur in it. Magnetite is fairly plentiful, occurring in minute patches thickly disseminated over small areas of the section, and also in larger grains. Sometimes xenoliths are present.

The Fort-Dunore mass, the only important exposure of rhyolite occurring in the section along the west side of Smerwick Harbour, is a very compact fine-grained rock, showing no banding and only a few much-altered phenocrysts.

(*b*) The Ashes.

The number and variety of the ashes is very great. They vary in colour from white, through various shades of green, yellow, and grey, to purple, and in coarseness from extremely fine-grained and flinty rocks, to a rock the constituent fragments of which may reach a length of 2 feet. Some have the matrix silicified, and from this and other causes are often extremely hard to distinguish from rhyolites. Sometimes the best guide (as remarked by Mr. Harker) for discrimination between a rhyolite and a rhyolitic ash lies in the orientation of the felspars : in a rhyolite they tend to have a parallel arrangement, in an ash the arrangement is more irregular. One of the most noteworthy points with regard to the ashes, is that while the fragments sometimes resemble the local rhyolites, they are frequently of an andesitic nature, and often amygdaloidal, bearing no resemblance to any of the local rocks.

The different types of ash may be grouped as follows :—

(1) Very fine-grained pale ash.—The best example of this type of rock is band (A 23) exposed near the top of the cliff south-

east of Carrigcam. The appearance of the rock in the field has already been described. Under the microscope, it shows a very fresh fine-grained matrix, through which are scattered broken quartz-grains, a few felspars, and sometimes fragments of pumice recognizable by the curving outlines of the cavities. Small zircons and flakes of muscovite also occur in it. The marked banding seen in some hand-specimens is due to the accumulation of broken quartz-grains along certain lines. A somewhat similar rock is exposed on the cliff-face opposite Carrigcam. Both these rocks are highly silicified.

(2) Moderately fine-grained purple ash.—This type of rock is widely distributed; it occurs overlying and underlying the big series of rhyolites at Poulnakeragh. It is found also at the south-western corner of Clogher Head (B 7) and in the inlet of Carrignaneena (C 6 in part).

The rock which forms the south-western corner of Clogher Head, in a hand-specimen is a compact purple rock, showing many felspar-crystals and some signs of parallel arrangement. Under the microscope, many broken felspars are to be seen. This rock shows signs of crushing, and much calcite is developed in strings along parallel planes. Lava-fragments are not very plentiful; but two kinds are present—one of a rock composed of fair-sized felspar-crystals, short and square-ended, with very little intervening groundmass; the other, with numerous larger singly-twinned phenocrysts, embedded in a fine-grained groundmass in which felspar-needles can be detected.

A slightly coarser-grained rock, one of the big series (C 4) of sandstones and ashes exposed at Drom Point, is noteworthy for the very small amount of fine-grained material between the fragments, which are mainly of an andesitic character, and lie closely packed together. The ash which is exposed in the northernmost of the two streams that run down the western side of Croaghmarhin towards Clogher village, shows many small pumiceous fragments recognizable by the curving outline of the vesicles.

(3) Fairly coarse ash.—This type of ash is widely distributed, and may be further subdivided into purple ash and pale ash.

Purple ash forms the band (B 5) well seen along the northern slope of Clogher Head, and is met with again at Foilnamahagh, Foilavaddia (D 5), where it is fossiliferous, and north-east of Carhoo. The length of the fragments in this type of ash ranges up to three-quarters of an inch, but it is generally somewhat less. No features requiring special comment were disclosed by microscopical examination.

Fairly coarse, pale ash may be seen at Foilminnaun (A 6 in part) at the points west of Redcliff Cove (A 13), north-west of Owen (B 14), among the series exposed north of Drom Point (C 4), in the stream-course south of Carhoo, and in the band which crops out at Poulnakeragh and in the south-eastern corner of Ferriter's Cove (C 8). The microscopical characters of these rocks call for little comment: broken felspar-crystals and lava-fragments, chiefly andesitic, are plentiful; in some cases the sections are freely traversed by veins of granular quartz, and the fine matrix surrounding the fragments is considerably silicified.

(4) Coarse green ash.—This is a very well-marked rock, and proved of much use in correlating and grouping the exposures in the three limbs of the great fold. In the southern limb it is seen at Foilclea (A 2); in the middle limb it occurs along the northern slopes of Clogher Head (B 2); and in the northern limb it is seen at Foilwee (C 3). Similar green ashes occur west of the Penitential Station (A 15), and east of Carrigard (B 9). In a hand-specimen, these rocks show a pale-green groundmass, full of irregular dark-green fragments commonly less than three-quarters of an inch in length, which, under the microscope, are seen to consist of crystalline rocks. While, however, some of the fragments are rhyolitic, the great majority are of andesitic type, and bear no very close resemblance to any of the local rocks.

(5) Very coarse ashy conglomerate or breccia.—This rock, probably the most remarkable of any exposed in the inlier, is met with only in the southernmost of the three limbs, being seen at the point south of Redcliff Cove, whence it can be followed inland to the neighbourhood of the Stone Cross.

The blocks which form this remarkable deposit consist chiefly of local rhyolites, and are sometimes rounded, sometimes angular in outline. The fine-grained material filling up the spaces between the fragments is sandy in character, and sometimes contains fossils.

(c) The Intrusives.

The intrusive rocks of the district occur mainly in the form of sills, but include one dyke. They are of three types, namely, 'greenstone,' labradorite-porphyrite, and quartz-porphyry.

(1) The greenstones.—Greenstone-sills occur at Mill Cove, at Redcliff Cove, where the rock can be followed inland to the neighbourhood of the Penitential Station on the northern side of Clogher Head, and at the base of the peninsula of Foilwee. The last-named sill appears to be given off from a small boss seen in the inlet of Coosaneal. These rocks are all in a very poor state of preservation, and it is difficult to obtain any reliable evidence as to their original character, though perhaps the Redcliff-Cove rock was originally an enstatite-porphyrite or andesite.

The groundmass is very fine-grained, and usually contains much epidote and ilmenite. The ilmenite may, or may not, be altered into leucoxene. The epidote is sometimes, as in the Clogher-Head rock, aggregated in approximately parallel bands. In almost every case the groundmass shows felspar-laths, which, in the case of the Clogher-Head rock, give a maximum extinction-angle of 8°.

The phenocrysts are of plagioclase, sometimes fairly fresh, and giving (in the case of the Clogher-Head rock) a maximum extinction-angle of 24° (labradorite), but generally much altered. In the Foilwee rock no phenocrysts occur. There is very little trace of any ferromagnesian constituent, but the Redcliff-Cove rock contains a few small patches of serpentine, which may represent altered rhombic pyroxene. Needles of apatite are seen in the Mill-Cove rock. Vesicles sometimes occur: in the Clogher-Head rock they are mainly filled with chlorite, but have brilliant epidote round the margin. The Coosaneal rock contains a great number of small irregular cavities, occupied by chlorite and chalcedony.

(2) The labradorite-porphyrite.—This rock is seen only in the inlet of Foilnamahagh, where it is bounded by a fault on either side. It is very similar in appearance to the porphyrites of Eastern Ireland seen at Kildare, Lambay, and Portraine. There is little to show whether it is contemporaneous or intrusive; the fact that its upper surface is amygdaloidal might be regarded as a small piece of evidence in favour of its contemporaneity, while its difference in character from all other rocks of the district to some extent lends colour to the view that it is an intrusive.

The groundmass shows numerous felspar-laths giving a maximum extinction-angle of under 10°, and probably to be referred to oligoclase. The spaces between them are filled up with a fine-grained, much iron-stained material. The phenocrysts consist of large plate-like crystals of labradorite, which are fairly fresh and reach a length of three-quarters of an inch or more. Large patches of magnetite occur, which appear to have been developed in relation to destroyed augite-crystals.

(3) The quartz-porphyry.—This rock forms a small dyke in the inlet of Coosgorrib, on the west side of Smerwick Harbour.

The groundmass shows quartz-grains and numerous flakes of muscovite, which are arranged with their long axes parallel one to the other. Numerous phenocrysts of quartz occur, commonly crushed and cracked. Some are just cracked, others have the cracked fragments displaced and the groundmass appearing between them. A few of the grains also show marked corrosion by the groundmass. Phenocrysts of orthoclase also occur.

VI. General Summary and Conclusions.

(1) The Smerwick Beds, though yielding no fossil evidence by which their age can be determined, are undoubtedly the oldest rocks in this area. It is probable that they are of Llandovery age, as they are conformably overlain by fossiliferous Wenlock-Llandovery beds.

(2) All the fossiliferous rocks of the Clogher-Head inlier are of Silurian age. The majority of those exposed on the coast are of Wenlock or Wenlock-Llandovery age; the majority of those exposed inland are of Ludlow age. The Wenlock and Wenlock-

Llandovery Beds are mainly calcareous flags and slates associated with a great amount of volcanic material. No pure limestone and no black graptolitic shales occur. Volcanic rocks are first met with low down in the Wenlock-Llandovery Series, and reach their maximum in the Wenlock Series, this being especially noticeable in the southern part of the area. Ashes occur interbedded with the lower beds of the Ludlow Series, but no lavas; and in the higher Ludlow Beds and the conformably overlying Dingle Series, we have found no signs of contemporaneous volcanic action. The volcanic rocks are all of the same general character, and include thick beds of rhyolitic lava and of coarse and fine ash.

(3) After the deposition of the Dingle Beds extensive earth-movements took place: for, not only is the Old-Red-Sandstone (Upper Devonian) Conglomerate now found resting unconformably upon the upturned Dingle Beds (Lower Devonian), as, for example, along the northern shore of Dingle Bay, but it also rests upon the Ludlow Beds on the north side of Clogher Head, and upon the Smerwick (? Llandovery) Beds from Sybil Point to Smerwick Harbour.

During some succeeding age this capping of Old Red Sandstone, with its overlying Carboniferous deposits, was bent into an immense anticline, the crest of which was over Brandon Mountain, where the Old-Red-Sandstone Conglomerate now lies at a height of some 3000 feet above sea-level.

(4) The general structure of the Silurian inlier may be defined as an **S**-shaped fold, the middle limb of which is overfolded to the north and thrust over the northern limb, the thrust traversing the trough of the fold. The arch of the fold between the southern and middle limbs is also traversed by a fault. The most marked effect of this overfolding is that all the beds exposed along the coast appear to dip approximately in the same direction—south-eastward or south-south-eastward.

(5) This great overfold cannot have occurred in the pre-Old-Red-Sandstone and post-Dingle period of earth-movement; for we find the Wenlock Beds of Clogher Head thrust over the Old-Red-Sandstone Conglomerate there, which rests with an u n f a u l t e d unconformable junction upon the Ludlows of Trabaneclogher.

It is very possible, however, that the overfold and thrusting took place during the post-Carboniferous period of earth-movement, which brought about the huge anticline of Old Red Sandstone and Carboniferous rocks reaching right across the Dingle promontory.

(6) But before this great overfold took place, there had been a certain amount of intrusion of igneous rock. This is, in the main, a fine-grained diabasic rock, often much altered, and is the 'greenstone' of the Geological Survey Memoir. It is met with between similar beds in the three limbs of the great **S**-fold, and this points to its intrusion before the formation of the fold.

It is possible that this period of intrusion may have coincided with the post-Dingle and pre-Old-Red-Sandstone period of earth-movement. And colour is lent to this view, by the occurrence of greenstone, recorded in the Geological Survey Memoir as intrusive in the Dingle Beds of Smerwick Harbour, and by the absence of any intrusions into the Old Red Sandstone.

The quartz-porphyry, seen near Fort Dunore, intruded between the Smerwick Beds and the overlying Silurian, is of uncertain age, and so also is the labradorite-porphyrite near Ballyferriter Castle.

(7) There is very little evidence as to the position of the vents from which the Silurian ashes and lavas came. The only fact which may possibly give a clue to the solution of this problem, is that the thickness of the beds formed by volcanic agency is greater in the southern part of the area, and hence it is possible that the vent or vents from which they came may have lain to the south of the Dingle promontory.

(8) The land during the deposition of the Silurian rocks could not have been very far off: for the Silurian sediment found here points to a shallow sea, or to the proximity of land. Even when coral-life abounded, the rock in which the corals are now preserved is never a pure limestone, but always of a very arenaceous character, though the corals are preserved not in broken fragments, but in layers of growth. Moreover, there are beds of conglomerate found in places throughout the series, which show that the volcanic beds in the neighbourhood were being continually denuded. They also point to the former presence at the surface of rocks now not seen in the neighbourhood, for granitic pebbles sometimes occur.

EXPLANATION OF PLATE VI.

Geological sketch-map of the Clogher-Head and Smerwick-Bay District (County Kerry), on the scale of 3 inches to the mile.

Discussion.

Prof. Watts congratulated the Authors on this excellent paper; it probably was merely an instalment of the work, which he hoped they would continue, of re-examining the less-known Ordovician and Silurian districts of Ireland. It appeared to be only in the West of Ireland that volcanic ashes and lava-flows were actually interbedded with Llandovery and Wenlock rocks. He would be glad of a clearer expression of opinion from the Authors in regard to one or two points. First, in regard to the occurrence of fossils of different horizons at one distinct horizon (spoken of by the Authors as Wenlock-Llandovery), he could hardly believe that zones so distinct in England could be merged into one in Ireland. Was it not possible that, besides the proved inversion on a large scale, there were other phenomena of inversion and faulting on a small scale? Secondly, was it perfectly certain in this area that the igneous rocks were non-intrusive? Were there, for example, fossils in the tuffs and tufaceous fragments in the ordinary sediments? Finally, recalling that, among the specimens in the Irish Geological Survey Collections, he had seen and described intrusive rocks of Tertiary age in the South-west of Ireland, he asked whether there was also Tertiary volcanic material in the district worked over by the

Authors. He congratulated them meanwhile on having found a new locality for the 'Lambay Porphyry.'

Prof. Groom said that the Society would welcome the work of the Authors as an important addition to our knowledge of the Dingle promontory. A comparison with the Killary district to the north would probably prove interesting, particularly in respect to the development of igneous rocks in the Silurians. He inquired whether, in view of the circumstance that the 'Dingle Beds' had been regarded by some as Silurian, the existence of an Upper Ludlow horizon had been definitely established in the underlying series. He thought that it should be clearly recognized that of the two series of movements, to which allusion had been made by the Authors, the first might have taken place after the deposition of the Lower Old Red Sandstone, and the second partly before the close of the Carboniferous Period.

Prof. Sollas said that he had listened with pleasure to the Authors' account of what seemed to him an excellent piece of work, but hoped some further light might be thrown on the apparent commingling of Llandovery and Wenlock fossils. *Pentamerus oblongus*, however, occurs in the Wenlock of Gotland.

Prof. Reynolds stated, in reply to Prof. Watts, that some of the tuffs were fossiliferous, and that the Authors had no doubt at all about the contemporaneity of both rhyolites and tuffs. With regard to Prof. Watts's suggestion that the peculiar association of Llandovery fossils with a fauna which, on the whole, was indicative of a higher horizon, might be due to inversion on a small scale, he stated that he did not think this suggestion would explain the state of affairs, as, although there was one great overfold in the district, the beds, taken as a whole, were not much disturbed and the included fossils showed little sign of distortion. No olivine-dolerites, or rocks the character of which at all led one to suppose that they were of Tertiary age, occurred in this inlier. In reply to Prof. Groom, he stated that the Authors had not recognized any particular horizon in the Ludlow Beds described, and that it was quite possible that the lower part of the Dingle Series might be of Upper Ludlow age. The rocks referred to in the paper as Old Red Sandstone were generally correlated with the Upper Old Red Sandstone of Britain.


Marhinmore
Dingle Beds

GEOLOGICAL SKETCH-MAP OF THE CLOGHER HEAD AND SMERWICK BAY DISTRICT (Co. KERRY)
by C.I. GARDINER & S.H. REYNOLDS.
Unmapped areas show no exposures. Faults both observed & inferred are indicated in the same way.
Scale: 3 inches to 1 mile.
EXPLANATION.
Old Red Conglomerate
Red Sandstone
Dingle Beds
Ludlow Beds
Slaty Beds
Calcareous Flags (except Ludlow)
Rhyolite
Rhyolite with Ash
Ash
Coarse Ashy Conglomerate
Smerwick Beds
Greenstone Labradorite-Porphyrite etc.
SMERWICK HARBOUR
Smerwick
Farran
Gortadoo
Gortnagap
Ballyferriter West
Marhinmore
Marhin
Ballyaglisha
Ballincolla
Ballyoughteragh
Teeravane
BALLYNAHOW COMMONS
Coumaleague Hill
Dingle Beds
Ludlow Beds chiefly calcareous flags
Line of outcrop of Smerwick Beds
outcrop of Dingle Beds
SYBIL HEAD
SYBIL POINT
Feaghl Rock
Doon Point
Clogher
Dunquin Ch.
VICARSTOWN
Carhoo
Dunquin
Minnaunmore Rock
Great thrust
big compound fault
CLOGHER HD.
Penitential Station Stone Cross
rhyolite
Arists Illustrators Ltd. sc.

15. *On some* Gaps *in the* Lias. By Edwin A. Walford, Esq., F.G.S. (Read February 26th, 1902.)

The calcareous beds of the Middle Lias attain a maximum thickness near Banbury in Oxfordshire. They form the highlands of the escarpment (the outcrop) on the North Oxfordshire border at their highest altitude, 720 feet above Ordnance-datum.

The several zones of the Middle Lias may be put broadly into three lithological divisions:—

1. Zone of *Ammonites spinatus,* and Transition-Bed. (Calcareous.)
2. Zone of *Ammonites margaritatus.* (Argillaceo-calcareous.)
3. Zone of *Ammonites Jamesoni* or *ibex* and *Amm. capricornus.* (Argillaceous.)

The deposition of divisions 2 and 3 followed a long period of sedimentation, mainly of argillaceous type. They are, in fact, repetitions of the previously existing conditions of the Lower Lias, differing only in a gradual increase in the thickness of the argillaceous limestones towards the top of the zone of *Ammonites margaritatus.* Similar conditions prevailed over the whole of the English Liassic seas. Though the incoming of the zone of *Amm. spinatus* was with some argillaceous deposit, the true zonal type was reached in the calcareous bands at the base of the great Ironstone Series, wherein the true fauna of the zone rests. In the Midlands and in Yorkshire these limestone-beds are at the lowest part of the 30 feet of rock and clay of the *Amm.-spinatus* zone. Nodular and concretionary bands characterize them. The nodular limestones are represented in Somerset, Dorset, and Gloucestershire by marly limestones yielding also the molluscan fauna of that part of the zone.

The ferruginous limestones of the superior part of the zone I have elsewhere [1] shown to be mainly a sub-crinoidal bank of great thickness and importance in Northern Oxfordshire and Cleveland (Yorkshire), both now important centres of the iron-industry. Hence the zone of *Ammonites spinatus* may be divided into an upper and lower series:—

		Feet.
Zone of *Amm. spinatus.*	1. The Ferrocrinoid-Beds (superior)	30
	2. The *Spiriferina-oxygona* Beds (inferior)	20

Variations in thickness of the superior division in Oxfordshire are frequent, ranging from 30 feet (at an altitude of 700 feet) to 6 feet on the edges of the Cherwell Vale (at an altitude of 350 feet), owing to waste by water-flow.

Special or abundant fossils of the Ferrocrinoid-Beds (1):—

Ammonites spinatus (very rare).
Rhynchonella tetrahedra.
Rh. tetrahedra, var. *northamptonensis.*
Terebratula punctata.
T. Edwardsi.
Waldheimia indentata.
Ferrocrinoids.

[1] 'On the Making of the Middle Lias Ironstone of the Midlands' Journ. Iron & Steel Inst. vol. xlix (1896) p. 74.

The special or more abundant fossils of the *Spiriferina-oxygona* Beds (2) are :—

Ammonites margaritatus.	*Harpax lævigatus.*
Amm. spinatus.	*Cardinia Philea.*
*Belemnites paxillosus.**	*Ostrea submargaritacea.*
Rostellaria admiranda.	*O. sportella.**
Trigonia lingonensis.	*Rhynchonella acuta.*
Protocardium truncatum (mainly derived).	*Spiriferina oxygona.*
	Thamnastræa Etheridgii.
Lima Elea.	*Leucandra Walfordi.*

[The fossils marked with an asterisk are especially abundant.]

Division 1 (the Ferrocrinoid-Beds) I take to be unrepresented in Dorset, Somerset, and Gloucestershire. There the marlstone yields large *Gryphæa*, *Ostrea*, and *Cardinia*, together with *Ammonites spinatus* and *Amm. margaritatus*. The fauna is that of the *Spiriferina-oxygona* Beds of Oxfordshire with, however, many of the brachiopoda of the higher division. The Leicestershire and Rutland beds are of the Oxfordshire type.

While the concretionary beds of division 2 with a typical coral-fauna were being deposited, the more marly beds of Somerset and Dorset developed a fauna of large growth but of more widely-spread forms. The same conditions appear to have extended over Northern France, and I have grouped the Middle Lias of Calvados in Lower Normandy and that of the counties of Dorset, Somerset, and Gloucester together as the Anglo-Norman Basin. In Normandy, as in the South-west of England, the remains of the later Middle Lias and the Upper Lias are found resting upon Palæozoic rocks. The late Prof. E. Eudes-Deslongchamps brought evidence to prove the possession of the Palæozoic sea-floor by a Liassic fauna. My endeavour is to show that the fragmentary type of those deposits may be explained by long-continued waste (inter-waste) rather than by contemporaneous erosion.

The Ferrocrinoidal ironstone (div. 1) bears a sparse generic fauna, though from its thickness and apparently slow accumulation other results might be expected. Beds of brachiopoda make up in number of individuals for the deficiency in number of species. The common *Rhynchonella tetrahedra* attains wide diversity of form, reaching however its largest growth in the preceding *Spiriferina-oxygona* division. Banks of *Terebratulæ* occur, replacing for a time the *Rhynchonellæ*, but nearly all the species are common to the two horizons. Beds crowded with the remains of Ferrocrinoids range through the whole of the deposit of this time. The green limestone of the bottom beds and the fawn-coloured, more marly limestone of the top bed are packed with their sinuous stems, which may often be seen in the weathered masonry of old buildings. The excellence of the flaggy stone, locally known as 'top rag' and in great use as a paving-stone, is owing to the packing of the several beds with the stems of the same organism. This great calcareous bank, it may be assumed, was of sufficiently indurated type to allow the accumulation in its hollows and sides of the clinging masses of brachiopoda, after the manner of their occurrence at the present day in the great Australian Barrier-Reef.

East of the Cherwell Vale the Ferrocrinoid-Beds lose type and importance. Along the Middle Liassic outcrop, on the north-western border of Northamptonshire, and trending eastward into Rutland, the same Ferrocrinoidal life appears to have prevailed, though perhaps less prominently. In the famous iron-ore-field of Cleveland it was a great factor in the making of the Liassic limestone, though of difference in type from the Oxfordshire beds.

Passing to consideration of the close of the Ferrocrinoid time, I think it is certain that the area of deposition was narrowed, or that waste over wide areas has supervened. We have been too prone to assume that the fact that several zones are welded into one course of limestone constitutes sufficient evidence of continuity of conditions. I shall show, by three sections from the neighbourhood of Banbury, that such conditions do not prove continuity.

At Bloxham, 3 miles north-west of that town, the 3 feet of the Liassic rock-bed at the top form one course, in the main made up of the stems of the Ferrocrinoid, but passing at the junction with the Upper Liassic clays into pinkish compact limestones crowded with Upper Liassic organisms. The pink limestones are of the *Ammonites-communis* zone, the intermediate Transition-Bed and zone of *Amm. serpentinus* having been removed by inter-waste.

At Fernhill, 6 miles north-west of Banbury, the rock-bed (*Amm.-spinatus* zone 2) is overlain by the Transition-Bed (*b*), the *Posidonomya*-shales and limestones of the zone of *Amm. serpentinus* (*c*), and by thin fossiliferous limestones and thicker clays of the zone of *Amm. communis* (*d*). Rather high up, a thin limestone, made up of Pentacrinite-segments, constitutes a convenient line for demarcation. At the eastern end of the same cutting at Fernhill, the conditions of the Bloxham section are shown in the removal of the Transition-Bed and the whole of the zone of *Amm. serpentinus*. This is even more clearly shown at the Astrop Ironstone Company's works at Cobbler's Pits, near King's Sutton, where remains of certain of the fossils of each horizon prove a former continuity of zones. At Fawler, the farthest point south-westward, yet more waste is shown, the zone of *Amm. bifrons* being indicated by a few fossils characteristic of its limestone, of the same species as at Bloxham.

On the north-western border of Oxfordshire, where the Ferrocrinoidal ironstone is of greatest thickness, the Upper Lias has been removed for the most part, and here and there a patch with the limestone of the zone of *Amm. bifrons* welded with the limestone of *Amm. spinatus* shows an equal amount of inter-waste. The preservation of the several zones has been effected by the earlier subsidences of the Eastern Cherwell border, and by another small area of subsidence of the western border of Oxfordshire, where the fall is to the west and the River Avon. They are both in the areas of a divide—the one in the divide of the drainage of the Ouse and Cherwell, the other in the divide of the Avon and Cherwell.

However complete the sequence of the sections may appear to be, there is at the top of the Middle Lias of the Northamptonshire border a palæontological gap perhaps better defined than any other in the Lower Jurassic Period. It is shown in the stratum of marl that I have called the Transition-Bed of the Middle Lias, and the section of Fernhill near Banbury, on the Great Central Railway, is one, from its completeness, best suited for illustration. Other sections that I described twenty years ago are at Chipping Warden and Byfield, a few miles north-west of Fernhill.

Zone	Bed	FERNHILL, G. C. R. (Aqueduct cutting, S. bank.) Ft.	In.	FERNHILL ROAD BRIDGE. (N. bank.) Ft.	In.	KING'S SUTTON. (Astrop Ironworks.) Ft.	In.	BLOXHAM. Ft.	In.	FAWLER. Ft.	In.
	1. Humus and waste	2	0	6	0	2	4	2	0	2	0
Amm. communis.	2. Blue Clay	8	0	......		......		15	0	16	0
	3. Pentacrinite-limestone		1	16 (2–4)	0 (2–4)						
	4. Clay, with line of ferruginous rubble	2	0	......		2	0				
	5. Limestone with *Am. bifrons*	1	0		10		5	......			1
	6. Clay, with small ammonites and belemnites	4	0	7	6	3 (6–8)	6 (6–8)				
	7. Limestone, with small ammonites and belemnites		5		6						
	8. Clay	3	0	3	0						
Amm. serpentinus.	9. Blue Limestone (sharp fracture) with *Am. Strangwaysii*		9		8						
	10. Paper-shales		6		5						
	11. Purple and black limestone (fish-bed) with *Amm. Strangwaysii, communis*, etc.		4		2	a trace					
Amm. spinatus.	12. Calcite-veined limestone	Transition (12–14)	2								
	13. Grey argillaceous marl		3	......		a trace					
	14. Red-brown marl		3	4 (14–15)	7 (14–15)						
	15. Marlstone—zone of *Amm. spinatus* (1)		......	......		5	0	20	0	11	0

In part welded with the upper part of the Middle Liassic rock-bed, and in part resting upon it, is a stratum of fawn-coloured marly limestone weathering to marl, varying from 3 to 6 inches in thickness. It brings in a large assemblage of life-forms, and attains greater importance owing to the Ammonitidæ being so abundantly developed therein. Tate & Beesley[1] noticed the occurrence of the fauna at Adderbury, but it is not there distinguished as a separate horizon. In Northamptonshire, where better conditions prevail, I collected and tabulated from the several localities 175 species of mollusca: now the number is considerably greater.

No period of geological life is better marked than the time of the incoming of *Ammonites communis* and its allies in the Lias. Throughout the whole of England, and also throughout the whole of the Anglo-Norman area, there had been a long pause in conditions favourable to the growth of the Ammonitidæ. The Spinati almost died out at the base of the great Ironstone Series of the Midlands, and it was apparently the same elsewhere. They occur but rarely in the ironstone of the Ferrocrinoid time. Early forms of the

[1] Thomas Beesley, Rep. of Excurs. to Banbury, Proc. Geol. Assoc. vol. iii (1873) p. 197.

communis-type do come in at the top of the Ferrocrinoid rock-bed, but not lower than a foot below the overlying Transition-Bed. With the incoming of the Transition-Bed limestones representatives of five groups of ammonites appear, not dwarfed but frequently of luxuriant growth. They are not represented by a few individuals, but by thousands, in which every gradation of growth and ornamentation seems to find place. Whenever and how they came in we do not know. England, France, and Germany fail to supply the genetic links of the chain. Perhaps we should look to the Middle Lias of Spain and Italy for deposits which may tell us the history of this interval of time. The gasteropoda partake much of the type of those of the *Spiriferina-oxygona* Beds, but are mainly of distinct specific form—about forty species in all. Polyzoa of like kind occur in the *Sp.-oxygona* Beds at the base of the *Ammonites-spinatus* zone and in the Transition-Bed at the top.

An interesting part of the record of this time is the alteration in the type of the fauna in its spread over the Midland area. In the outlier of Badby, 14 miles north of Banbury, Mr. Beeby Thompson [1] found a Transition-fauna, and I have also collected from it. The Ferrocrinoidal rock is wasted, and the Transition-fauna occurs in holes and pockets in it. A remarkable group of Tellinidæ replaces the ammonites, which are few and dwarfed, and the rock is bored. The gasteropoda are dwarfed in size and in ornamentation, though very abundant; and the pelecypoda are of small size also. There are few corals. At Byfield, 4 miles to the south, the fauna is of normal type, as it is also in its easterly spread. At Fernhill, farther south-eastward, the ammonites are of larger growth. It may be that this was the coral-fringe of a deeper sea where the warmer shallows developed life, as in the inner shoals of the Great Barrier-Reef which Prof. Alexander Agassiz has described so well.

The Transition-gap, as I have shown, rests for evidence wholly upon a sudden appearance of molluscan life of new type. If the Ferrocrinoid-bank was reef-like and the development of life went on outside it, evidence of the sedimentation in the interval has yet to be sought for. The passage of life during the building-up of the 60 feet of strata of the *Ammonites-spinatus* zone went on with the usual alternating conditions. No one of the ammonites at the end of the Middle Liassic day is the same as at its dawn—no one of the ammonites of the '*spinatus*' beginning lives to the end of that time. It is an index of the imperfection of our study of genetic life.

Turning to the western and south-western side of the Cherwell Vale, with the exception of Adderbury which rests on its western bank, no remnant of the Transition-period has been found. Farther westward, a patch in the Vale of the Stour proves its extension there. At Constitution Hill, 1 mile west of Banbury, at Bloxham, and Milcombe, 3 or 4 miles farther south-west, the pink and white

[1] 'Middle Lias of Northamptonshire' 1888, p. 43.

limestones of the Upper Lias (*Ammonites-communis* zone) are welded with the Middle Liassic Ferrocrinoid-Beds; the whole of the intervening Transition-Bed, fish-bearing limestones, and paper-shales of the *Amm.-serpentinus* zone have been wasted. As far as the north-western escarpment near Shennington there is the same hiatus, and *Ammonites bifrons* is in the same rock-course as the *spinatus*-fossils. The interval must be looked upon as a belt of waste, such as the Inferior Oolite limestone shows at the base of the argillaceous beds of the Bathonian. Inter-waste seems to me a convenient term to define the removal of strata long subsequent to their deposition.

A succeeding gap, though in point of waste of strata represented best by the absence of 3 feet 2 inches of clays and limestones, yet corresponds with the 19½ feet of the same series at Alderton in Gloucestershire, and with the 50 or 60 feet of the zone of *Ammonites serpentinus* in Yorkshire. In point of palæontological time it includes:—

The genesis and expiry of groups of minute brachiopoda (*Leptæna*, *Thecidea*, etc.) and of many of the gasteropoda and pelecypoda. Charles Moore, in 1867,[1] made out 70 species from his *Leptæna*-beds.

The genesis of many large falciform ammonites and of the Belemnitidæ of the fish- and insect-beds (zone of *Posidonomya Bronni* of French authors); also its numerous gasteropoda, noticeably *Euomphalus minutus*. The first appearance of 6 species of saurians, 8 species of fishes, 6 forms of crustacea, and of many of the insecta and microzoa.

In all, adding the Somerset lists to those of the Midlands, quite 400 distinct species, fully one-half of which have not been collected or recorded from strata above or below the gap. Yet it is exceptional in the Midlands to meet with the fragmentary remains even of the beds which hold so important a record of life. Middle Liassic rock merges into high Upper Liassic rock without a line of interval or separation. Before the many processes of interstratal waste were understood, the gaps were put down to cessation of deposit, contemporaneous erosion, and like causes.

A curved band drawn through Central England from Yorkshire to Somerset, widening at the two ends, puts before us the waste of this gap in the Midlands, where yet the Middle Liassic rock rests at an altitude of 720 feet. The broadening of the band to the north-east and to the south-west indicates the remaining greater thickness of strata there.

A third gap of minor importance, both in its waste of strata and in its change of life-forms, can be measured in Oxfordshire and Northamptonshire by the occurrence of a thin bed of Pentacrinite-Limestone. The layer is recognizable, owing to its being made up wholly of crinoid-segments. It is found to the north at Byfield in Northamptonshire, and southward as far as Souldern in Oxford-

[1] Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 449.

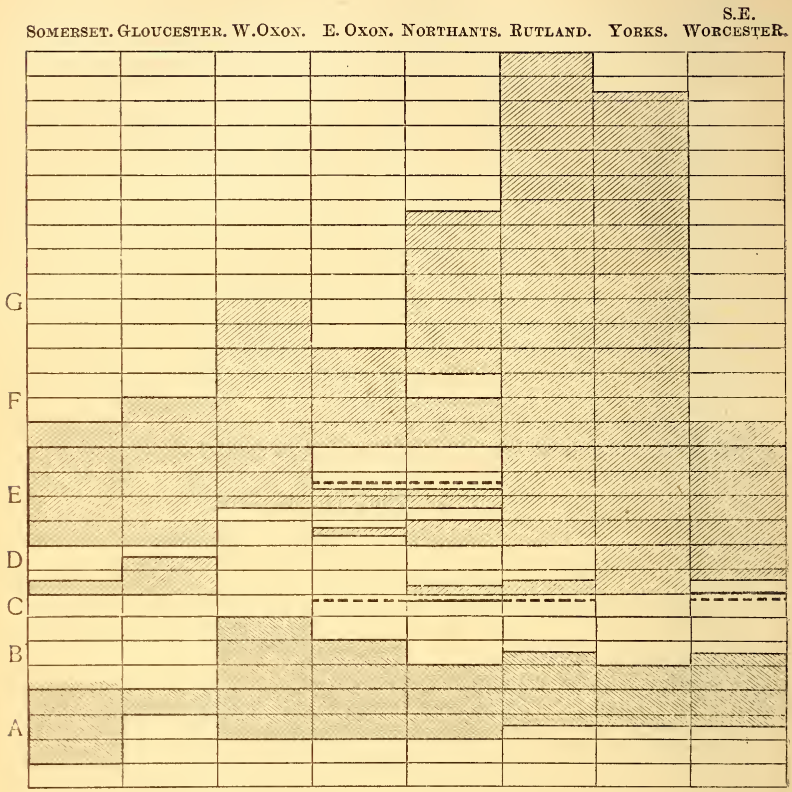
shire; to the east it comes in at Fernhill, and extends thence to Bloxham on the south-west side of Banbury. Its area I have traced for 20 miles north and south by 10 miles east and west. Between the fish-bearing limestones of the *Ammonites-serpentinus* zone and the overlying Pentacrinite-band at Byfield but a few inches of strata occur; at Fernhill there is a thickness of $12\frac{1}{3}$ feet. At Bloxham the Pentacrinite-Limestone rests upon an argillaceous limestone of the lower part of the zone of *Ammonites communis*, with only 3 feet of deposit between the crinoidal limestone and the Middle Liassic rock below. A thin yellow limestone of the same zone lying upon the Middle Liassic rock I term 'the hemera of *Waldheimia Lycetti*,' and it yields a large and special fauna. At Fawler only a trace of it rests directly upon the Middle Lias.

At Fernhill, within the mile's length of the long cutting on the Great Central Railway, differences in sequence of strata are found, which elsewhere have to be sought for over wide areas of adjoining country. Fernhill is in itself the key to the right sequence of the stratigraphy of the Middle and Upper Lias, though in other localities palæontological stations are better marked. The Pentacrinite-Limestone rests upon the *Ammonites-communis* rock in places where the intervening beds have wasted, and the occurrence of *Waldheimia Lycetti* marks the hemera there. The subsidence or fault which runs along the line of railway at Fernhill breaks the bed on the west bank of the cutting abruptly down, and the *Waldheimia-Lycetti* beds are seen to rest upon the Middle Liassic ironstone in much the same way as at Bloxham. Worn out on it are great cable-like markings, bearing the appearance of remains of massive arborescent or trailing growth. The waste of the 'funnel-fault' at Fernhill has removed the strata of the intervening zones, in the same way as the slower and long-continued inter-waste has done on the 10-mile long slopes of the country from the western Middle Liassic outcrop to the banks of the Cherwell.

The measure of displacement of the Lias over the Cherwell Vale may be gathered by noting that the *Ammonites-margaritatus* zone at Fernhill occurs at the altitude of 570 feet near the divide of the Ouse and Cherwell, while on the western escarpment the altitude of the same beds I take to be 680 feet; fragments of the same zone along the river-banks are found at about 300 feet above Ordnance-datum. What was the old line of altitude is beyond our ken of today.

The key to the problem of inter-waste is sought in the necessarily associated lines of fall and drainage. Our local conditions show that the long fall from the escarpment south-eastward lessens the thickness of the Middle Liassic calcareous ironstone only as it nears the main line of drainage (the Cherwell). The thickness ranges from 30 to 10 feet. The drainage on the east side of the Cherwell with a south-westerly fall, and of but one third of the area of that to the west, alters the rule. Twelve feet may be taken as the maximum of the Middle Liassic calcareous ironstone—the thickness ranging from 6 to 12 feet irregularly over that region.

Stratigraphical Table, showing the Gaps in the Upper and Middle Lias of England.



[Vertical scale: 1 inch = 16 feet.]

A = Middle Lias (*Spiriferina-oxygona* zone).
B = Middle Lias (Ferrocrinoid-zone).
C = Middle Lias (Transition-Bed).
D = Upper Lias (*Ammonites-serpentinus* zone).
E = Upper Lias (*Ammonites-communis* zone).
F = Upper Lias } (*Ammonites-bifrons* zone) { *Leda-ovum*
G = Upper Lias } { Bed.

Westerly vales draining into the Stour from the western escarpments and with a westerly fall show similar results in that area. The fall is also short. The Middle Liassic calcareous (ironstone) beds thin down to 4 or 5 feet.[1] At the hill dipping into Brailes the thickness is greater. I have spoken before of a remnant of the Transition-Bed, and of the fish-bearing limestones and paper-shales of the *Ammonites-serpentinus* zone in that part of the Stour Vale, preserved in like manner to similar beds in the Cherwell area draining westward.

There is no reason to doubt that the calcareous (ironstone) beds of the zone of *Ammonites spinatus* were formerly as thick on the eastern side of the Cherwell Vale as on its western side. We must not overlook the fact that there was some difference in the organisms and growth of the Ferrocrinoid-bank of the east. Why should not the waste be the same, with the overlying clays and limestones of the east side of the Vale, with the shorter fall? Vales of shorter drainage, whether on the scarp-edge to the west, or on the east side of the Cherwell, show preservation of minor zones of the Upper Lias constituting elsewhere gaps 1, 2, and 3. On the west side of a divide, with a fall opposite to the common dip of the country, massive calcareous beds dwindle in thickness, while overlying thin strata of limestone and clay, as well as the greater capping of tenacious clays, are better preserved than on the long fall with the common dip.

I find the same preservation of minor zones of the Inferior and Great Oolite systems on the short flanks of a divide. Thus, in the long ridge of the boundary-lines of North-western Oxfordshire and South-eastern Warwickshire, remains of several of the lower divisions of the Great Oolite are found in faulted troughs on the side away from the prevailing easterly dip. In 1883,[2] I pointed out the existence of these remnants and the great interest of their fauna. The lesser volume of drainage of the short slope made less waste of strata. The faulted areas on the short slope appear also to have been of a more recent date of displacement than the longer underdrained slopes of the Cherwell Vale. When I am able to take up the description of the Great Oolite remanié deposits that I have discovered, I shall hope to enter more fully into the question of their time and conditions of displacement.

On p. 274 I have given a stratigraphical Table illustrating the gaps in the Upper and Middle Lias of England; and on pp. 276–77 Lists of the (more important) Fossils of the Upper and Middle Lias.

[1] Later search has proved 13 feet at the head of the vale draining into Tysoe.

[2] 'On the Relation of the so-called Northampton Sand of North Oxon to the *Clypeus*-Grit' Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 233.

THE FOSSILS OF THE UPPER LIAS.

	Echinodermata & Microzoa.	Pelecypoda.	Gasteropoda.	Brachiopoda.	Cephalopoda
		Astarte sp. *Nucula Hameri.* *Corbicula* sp.			
Leda-ovum Beds.		*Leda ovum.* *Inoceramus dubius.* *Thracia glabra.* *Astarte* sp.	*Cerithium* sp.	*Discina reflexa.*	*Ammonites bifrons.* *Amm. fibulatus.* *Amm. exaratus.* *Amm. lythensis.* *Amm. falcifer.*
Zone of *Ammonites communis.*	*Pentacrinus* sp. *Diplocidaris Desori.* *Peltarion unilobatum.*	*Hinnites Davæi.*	*Eucyclus capitaneus.* *Onustus heliacus.* *Pleurotomaria Theresa.* *Natica pelops.*	*Waldheimia Lycetti.* *Rhynchonella jurensis.*	*Amm. heterophyllus.* *Amm. bifrons.* *Amm. cornucopiæ.* *Amm. subcarinatus.* *Amm. Strangwaysii.* *Amm. crassus.*
Zone of *A. serpentinus.*		*Pecten textorius.* *Ceromya bombax.* *Posidonomya* sp. *Monotis substriata.*	*Euomphalus minutus.* *Cerithium coronatum.* *Dentalium elongatum.* *Neritopsis* sp.		*Amm. cornucopiæ.* *Amm. acutus.* *Amm. Levisoni.* *Amm. communis.* *Amm. serpentinus.* *Amm. exaratus.* *Amm. crassus.*

THE FOSSILS OF THE MIDDLE LIAS AND THE TRANSITION-BED.

TRANSITION-BED.	*Pentacrinus jurensis.* *Montlivaltia tuberculata.* *Cisternifera inconstans.*	*Cardinia Philea.*	*Phasianella Buvignieri.* *Cerithium ferreum.* *Pitonillus linctus.* *Littorina biornata.* *Pleurotomaria heliciformis.* *P. helicinoides.* *Eucyclus Gaudryanus.* *Nerinæa liassica.*	*Waldheimia Darwini* (?). *W. Bakeriæ.* *Rhynchonella serrata*, var. *Rh. northamptonensis.* *Rh. tetrahedra.* *Rh. Amalthei.* *Rh. Bouchardi.* *Leptæna* sp.	*Ammonites acutus.* *Amm. Holandræi.* *Amm. annulatus.* *Amm. heterophyllus.* *Amm. communis.* *Amm. subspinatus.* *Amm. subarmatus.*
FERROCRINOID-BEDS.	Ferrocrinoids.	*Pecten liasinus.* *P. æquivalvis.*		*Rhynchonella tetrahedra.*	*Amm. Holandræi.*
			Turbo socconensis.		
		P. lunularis. *P. æquivalvis.* *Hinnites Davæi.* *H. tumidus.* *Mytilus numismalis.* *Limæa cristata.* *L. Juliana.* *Lima Hermanni.*		*Rh. tetrahedra.* *Terebratula punctata.* *Spiriferina rostrata.*	
	Ferrocrinoids.		*Pleurotomaria anglica.*	*Rhynchonella northamptonensis.* *Rh. tetrahedra.* *Terebratula punctata.*	
	Ferrocrinoids.	*Pecten lunularis.*		*T. punctata.* *T. Edwardsi.* *Waldheimia indentata.* *W. florella.* *Rhynchonella tetrahedra.*	*Amm. spinatus.*
ZONE OF *Spiriferina oxygona.*	*Hemipedina Jardini.* *Leucandra Walfordi.* *Thamnastræa Etheridgii.* *Montlivaltia* sp. *Astrocœnia* sp. Ferrocrinoids. *Cisternifera inconstans.*	*Gastrochænia lugdunensis.* *Cardinia Philea.* *Harpax lævigatus.* *Spondylus Elea.* *Lima Elea.* *Avicula cygnipes.* *Ostrea sportella.* *Mytilus aviothensis.* *Trigonia lingonensis.*	*Rostellaria admiranda.* *Pitonillus turbinatus.* *Turbo linctus.* *T. cyclostoma.* *T. varians.*	*Terebratula subpunctata.* *Rhynchonella tetrahedra.* *Spiriferina oxygona.* *Sp. rostrata.* *Rhynchonella acuta.*	*Amm. spinatus.* *Amm. margaritatus.* *Belemnites paxillosus.*
		Harpax lævigatus. *Myacites.* *Pleuromya liasina.*			

Discussion.

The Rev. J. F. Blake observed that there were several points of considerable interest in the paper, as, for instance, the proof of the dwindling-out of the hard beds of the Upper Lias towards the Midland Counties. Shore-deposits seemed to be absent here, and the Author appeared to indicate that the sandy littoral zone of *Ammonites capricornus* was not to be found in the district described. The Author's junction-bed between the Marlstone and the Upper Lias was what he (the speaker) would term an 'aggregate-deposit.' He criticized the use of such a term as 'ferrocrinoid,' which appeared rather to suggest the advent of such appellations as 'pyritograptolites.' He failed to see any true crinoidal remains in the slides last shown, and the so-called 'stems' had more the look of worm-tubes made up of fragments of shell. He enquired whether 'inter-waste' was intended to express subsequent or contemporaneous erosion. If the phenomena described were examples of Mr. Rutley's 'dwindling of limestones,' the most soluble part should disappear first. The strata thin naturally eastward, and an original dip would more or less follow the same direction. There were examples of occurrences similar to those described in the Lias of the South of England, but not in the Yorkshire Lias.

Mr. W. Whitaker pointed out, with regard to the Author's observation that the calcareous beds on the scarp-face are thin, that the conditions of the underground waters are very different on either face. The flow is quick on the scarp-face and slow on the dip-slope, a difference which would probably affect calcareous deposition. Moreover, deposits on a scarp-face are more liable to landslips.

The Author, in reply, said that the microscopic sections shown through the lantern were of the Pentacrinite-Bed from the Upper Lias; of a crinoid from the Middle Lias; and of stems of the ferro-crinoid, also from the Middle Lias.

16. *On a* Deep Boring *at* Lyme Regis. By Alfred John Jukes-Browne, Esq., B.A., F.G.S. (Read March 26th, 1902.)

I. Introductory.

During 1901 a boring was made near Lyme Regis in search of coal, and was carried to the depth of 1300 feet without reaching the base of the Upper Triassic marls.

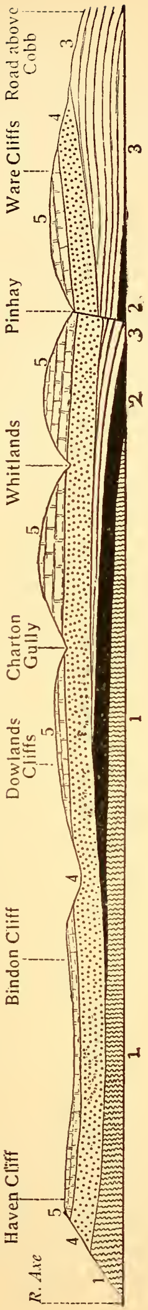
The story of this endeavour to find coal at a place where no geologist would have recommended the attempt, is one which has often been repeated at different places. The undertaking was promoted by a 'practical man' who had experience of coal-mining in South Wales, and who had convinced himself that coal was likely to be found at no great depth near Lyme Regis. He obtained permission to bore, and induced a certain number of persons to form a syndicate, for the purpose of making a boring to ascertain the depth at which the expected Coal-Measures were to be found.

The results of the boring have a twofold interest: first, to all people in the South-west of England they should be a warning against the folly of expecting to find Coal-Measures at a depth of less than 2000 feet below any part of Western Dorset; secondly, they are of interest to geologists, for the information which is thus afforded as to the great thickness of the Keuper Marls in Devon and Dorset.

It was anticipated that coal would be reached at a depth of less than 600 feet, and when this limit was passed without success it was decided to continue the boring to 1200 feet. At this depth it would have been abandoned, had it not been for the interest taken in the work by Mr. A. C. Pass, of Wootton Fitzpaine, near Charmouth. Thinking it a pity that the boring should be given up without the attainment of any definite result, he found most of the funds for extending it from 1200 to 1300 feet, in the hope that between these depths the base of the Keuper Marls would be reached, and the underlying sandstones would be entered. It is also due to Mr. Pass that selections from the accumulated series of cores have been distributed to the following museums:—South Kensington, the Museum of Practical Geology (London), Bristol, Exeter, Dorchester, Taunton, and Torquay.

The strata which were traversed by the boring are those known as the Blue Lias (lower part of the Lower Lias), the Rhætic Beds, and the Keuper Marls. These beds are all exposed in the cliffs along the coast between Lyme Regis and Sidmouth; and from the regular succession which is visible in these cliffs, anyone with a very elementary knowledge of geology could infer what series of beds he might expect to meet with in a boring at Lyme Regis.

Section from the River Axe to Lyme Regis. (*Horizontal scale*: $1\frac{1}{4}$ *inches* = 1 *mile*; *vertical scale*: 1 *inch* = 1200 *feet.*)



	Thicknesses in feet.
1 = Keuper	200 to 0
2 = Rhætic	100
3 = Lias	0 to 300

	Thicknesses in feet.
4 = Selbornian	Between 160 and 170
5 = Chalk	Up to 180

II. Description of the Coast-Section.

Before describing the succession which was actually found in the boring, it will be useful to give a brief account of the strata which are seen in the cliffs, more especially as the exposures of the Rhætic Beds have never yet been fully described. The Liassic Beds have been dealt with in full detail by Mr. H. B. Woodward [1]; and the Keuper Marls and Sandstones have been described by Mr. Ussher, the Rev. A. Irving, and Prof. Hull, in the Quarterly Journal of the Geological Society.

The Rhætic Beds were briefly described by Thomas Wright in 1864,[2] and Mr. H. B. Woodward published notes on the exposures at Pinhay Bay and near Culverhole Point in 1889 and 1899 [3]; but no details of the exposures in Charton Bay have yet been printed. Mr. Woodward examined these localities in 1884, and has been kind enough to place his notes and measurements of them at my disposal.

The Blue Lias.

Starting from Lyme Regis, we find the 'West Cliff' composed of dark shales in the upper part, and of an alternating series of limestones and shaly clays in the lower part. The latter group is known as the Blue Lias, and is quarried at the Cement Works, as well as at Uplyme. Its thickness, according to Mr. Woodward, is about 105 feet, and it forms the base of the cliffs westward as far as Pinhay Bay. This group is divisible into four zones, as follows, in descending order:—

[1] Mem. Geol. Surv. 'The Jurassic Rocks of Britain' vol. iii (1893).
[2] Geol. Mag. vol. i (1864) p. 290.
[3] Proc. Geol. Assoc. vol. xi (1889) p. xxx, & vol. xvi (1899) p. 135.

4. Zone of *Ammonites semicostatus*, about 19 feet thick.
3. Zone of *Ammonites Bucklandi*, ,, 38 ,,
2. Zone of *Ammonites angulatus*, ,, 24 ,,
1. Zone of *Ammonites planorbis*, from 22 to 24 ,,

The *Amm.-angulatus* beds consist of limestone and shale, in about equal proportions; and the *Amm.-planorbis* beds, of frequent limestones, with only thin partings of shale: the limestones being of a very pale grey, and some of them drying to nearly white. The base of the *Amm.-planorbis* zone is marked by some thin, brown, laminated shales, which are crowded with spines of echinoderms.

The Rhætic Beds.

At Pinhay Bay a still lower series of limestones comes into view; and these are known as the White Lias, but are now separated from the true Lias and are grouped with the Rhætic. These beds are about 24 feet thick, and consist of soft, white, marly or earthy limestones, with thin bands of hard compact limestone; and some of the marly beds contain nodules of compact pale-grey limestone, which when weathered-out impart to the rock a conglomeratic appearance. The lowest of these beds consist of thin layers of compact bluish and of creamy-white limestone; but Mr. Woodward did not observe anything exactly like the 'Cotham Stone' or 'landscape-marble' which was seen by Dr. Wright at Uplyme. Some fossils have been obtained from the upper part of the White Lias; they include *Protocardium rhæticum*, *Modiola minima*, *Ostrea liassica*, *Pecten pollux*, *Pullastra arenicola*, *Schizodus* sp., and *Estheria minuta*.

On the west side of Pinhay Bay, the White Lias is thrown down out of sight by a fault which has a throw of about 40 feet; but the lower part of it is seen again in Charton Bay, where Mr. Woodward found near the base a thin bed of the variegated Cotham Stone, and again at Culverhole Point, where 15 feet of it can be seen, with impersistent layers of Cotham Stone at its base.

Below the White Lias are the Black Shales, sometimes called the zone of *Avicula contorta*. These beds are exposed in Charton Bay, but are more or less obscured by slips: they may be 30 feet thick, and consist mainly of black papery shales and black shaly clay, with one or more thin layers of grey limestone.

The Rhætic Beds are exposed again near Culverhole Point, and more or less of all three divisions are here visible. Mr. H. B. Woodward gave an account of this section in 1899 (Proc. Geol. Assoc. vol. xvi, p. 135), and stated the thicknesses as follows:—

		Feet	inches.
White Lias, with impersistent masses of Cotham Stone at the base	about	15	8
Black Shales, with a bone-bed at the base	,,	18	0
Green Marls, with bands of marly limestone and black clay		30	0

He mentions, however, the existence of 'slight faults, some of which appear to be due to landslipping'; and I am inclined to think that the White Lias has here slipped over the upper part of the Black Shales, so as to make the thickness of the latter appear less than it really is.

The 'bone-bed,' at the base of these shales, is not always to be seen; but Mr. Woodward's notes describe it as consisting of one or two layers of black calcareous grit, containing small pebbles of quartz, with bones, teeth, and coprolites of fishes. Among them *Gyrolepis Alberti*, *Saurichthys apicalis*, *Acrodus*, *Hybodus*, and *Lepidotus* have been identified.

Above the bone-bed are black shales, with some thin laminæ of micaceous sandstone containing *Pullastra arenicola*; and still higher are shales with *Avicula contorta*, *Protocardium rhæticum*, *Pecten valoniensis*, *Anatina præcursor*, and impressions of *Pleurophorus*, *Modiola*, and other bivalves.

Below the 'bone-bed,' which is considered by some writers to be the base of the Rhætic Group, are the 'tea-green marls,' which are now regarded by Mr. Woodward and others to belong to this group, and to be separable from the Keuper Marls. These greenish-grey marls are well exposed, both at Charton Bay and at Culverhole Point; and, according to Mr. Woodward's measurements, their thickness is from 30 to 34 feet. The highest bed is a greenish-grey calcareous marl, which forms a thick band 9 or 10 feet thick. Below this are grey marls in regular beds, separated by seams of black marl and some layers of grey marly limestone; these have a combined thickness of 12 or 14 feet. Below comes another band of greenish marl, 8 feet thick, followed by 2 feet of grey marls with dark seams.

No fossils have been found in these beds in Devon; but at Watchet, in Somerset, *Pecten valoniensis, Protocardium rhæticum*, and other fossils of Rhætic species have been recorded from them.[1] The above-mentioned grey and black marls may be regarded as the base of the Rhætic Group, because no black shales occur lower down; but pale-grey and green marls, with hard calcareous bands, continue for about 18 feet, and terminate with a band of hard grey marl or marly stone: so that it is difficult to say which horizon should be taken as the better base.

The Keuper Marls.

If the lower of the two horizons above indicated be taken as the base of the Rhætic, the highest beds of the Keuper, as seen in Charton Bay, consist of soft grey marls passing down into alternating beds of red and greenish marl. These beds are seen again at Culverhole, where they pass down into red and variegated marls, a considerable thickness of which is exposed in the lower part of Haven Cliff, east of the mouth of the River Axe.

From Axmouth westward the Keuper Marls form the substratum of the whole country bordering the coast-line, as far as the valley of the Sid; and they are exposed in the lower part of the cliffs, for the greater part of the distance between Haven Cliff and Sidmouth.

West of Seaton a cliff of red marl, which in places is somewhat

[1] W. Boyd Dawkins, in Quart. Journ. Geol. Soc. vol. xx (1864) p. 396.

sandy, extends as far as Seaton Hole, where it is faulted against the Selbornian Sands. The great syncline of Beer Head carries the Trias far below sea-level; but the red marls appear again near Branscombe Mouth, and rise gradually westward, lower beds successively emerging from the shore into the cliff as one travels in that direction. Fine sections of the lower beds can be seen by walking along the shore at the base of Weston, Dunscombe, and Salcombe Cliffs: the beds under the first two consisting of red marls, with veins and layers of gypsum, which is sometimes white and sometimes pink.

The lower beds of the Keuper Series have been described by the Rev. A. Irving, from whose accounts [1] the following appears to be the vertical succession east of Sidmouth:—

	Feet.
Red and green gypsiferous marls .... seen for	150
Pale-grey sandy marl; a continuous bed	2
Hard, splintery, red marls, with many calcareous concretions (potato-stones) and thin beds of grey sandstone at intervals	150
Massive beds of grey sandstone, with subordinate beds of red and variegated marl..	60
Coarse grey sandstone, with strong current-bedding.........	13
Hard calcareous breccia	2

It is a question whether the marls with thin beds of sandstone should be grouped with the Keuper Marls, or with the Keuper Sandstones. Dr. Irving does not venture an opinion; but, for the purposes of this paper, it will be convenient to class them with the Marls, leaving the Sandstone Group a thickness of only 75 feet.

With regard to the total thickness of the Keuper Marls above the Sandstone Group, no exact measurements are possible along the coast, because of the frequent landslips in the Weston and Branscombe Cliffs, as well as the Beer syncline and the fault at Whitecliff. The distance from Sidmouth to the point where the red marls pass below the Rhætic Beds is about 8 miles; and in 1876 Mr. Ussher made a rough estimate of the thickness by allowing a deduction of 3 miles for the Beer syncline, and assuming a constant dip of 3° for the remaining 5 miles. This gives a thickness of 1350 feet; but he considered that to be an outside estimate, and expressly says that inland the marls are not more than 1000 feet thick.

The objections to Mr. Ussher's method are that the dip is not constant, and that his allowance for the Beer syncline is altogether arbitrary. It has occurred to me that another method might be feasible; for, if the difference between the dip of the marls and that of the overlying Greensand could be ascertained, we might well assume that the dip of the marls prior to the deposition of the Cretaceous Series was fairly constant for the whole distance of 8 miles. Thus, if the dip from the basal Cretaceous plane was $1\frac{1}{2}°$, the thickness of the marls would come out at nearly 1100 feet; and if the dip was 2°, their thickness would amount to 1478 feet. We shall see in the sequel that it is certainly more than 1100 feet.

[1] See Quart. Journ. Geol. Soc. vol. xliv (1888) p. 149, & vol. xlviii (1892) p. 68.

III. Description of the Boring.

The site of the boring is in the valley of the stream which enters the sea at Lyme, at a spot about a mile north-west of Lyme and about half a mile east of Uplyme, close to the boundary-line between the counties of Devon and Dorset. The level of the surface is about 140 feet above Ordnance-datum. The work of the boring was carried out by Messrs. Vivian's Boring & Exploration Company. The diameter of the upper part of the boring down to 200 feet was 6 inches, then to 550 feet it was 5½ inches; it was thereafter narrowed to 4½ inches, and again at 700 feet it was reduced to 4 inches, and carried to 1300 feet without change.

The following is a detailed account of the strata passed through, abbreviated from the particulars with which I have been furnished by Messrs. Vivian, supplemented by some supplied by Mr. G. Haycraft, who superintended the boring on the spot. I have added notes of such samples as have been seen, either by me or by Mr. H. B. Woodward.

	Thickness.		Depth.	
	Feet	inches.	Feet	inches.
Soil, gravel, and flints	10	8	10	8
Pale-grey limestones	10	0	20	8
Soft blue shale and a bed of limestone 1 foot thick: sample of grey earthy limestone (at 22 feet)... seen	3	0	23	8
'White Lias' limestones, with partings of shale: sample from 30 feet a compact grey limestone.	14	6	38	2
Blue shale, with two thin layers of limestone ...	3	3	41	5
'White Lias' limestone	7	10	49	3
'White Lias' limestone, with shaly layers: sample at 50 feet a grey earthy limestone, with some fish-scales	27	0	76	3
'White Lias' limestone with shaly layers: sample from 80 feet a hard whitish limestone, breaking along faces which are full of small crystals of iron-pyrites; sample at 90 feet a pale-grey fissile limestone; sample at 95 feet a hard compact white limestone	18	10	95	1
Green marl: sample from 96 feet pale-grey, shaly, calcareous marl; sample from 100 feet a hard, compact, smooth grey marl, very calcareous ...	6	2	101	3
Dark-blue shale: sample marked 101 a black shaly clay, with *Avicula contorta* and *Protocardium rhæticum*	3	0	104	3
Grey limestone: sample from 104½ feet a pale-grey limestone, with casts of univalve and bivalve shells and much calcspar	0	7	104	10
Dark-blue shale with fossils: sample from 114 feet a black shaly clay with *Avicula contorta*	9	6	114	4
Grey limestone	0	6	114	10
Dark-blue shale: sample from 120 feet a dark shale with *Avicula contorta*; sample from 127 feet a black shaly clay without fossils	18	10	133	8
Grey limestone and shale	1	6	135	2
Dark-blue shale and marl	10	4	145	6

	Thickness. Feet	Thickness. inches.	Depth. Feet	Depth. inches.
'Dark-blue shale': sample from 156 feet a light-grey argillaceous marl, hard, heavy, and compact; sample from 160 feet a grey marl, rather darker	21	9	167	3
Green shale or marl	5	0	172	3
Grey limestone	0	6	172	9
Green marl: sample from 212 feet a pale-green marl, hard and but slightly calcareous	42	1	214	10
Red and green marls: samples from 240, 270, 280, 281, 284, & 297 feet, all red, greenish, or spotted marls, highly calcareous, with conchoidal fracture	82	6	297	4
Red and green marls, with gypsum: sample from 330 feet a variegated greenish-grey and red marl with gypsum; sample from 345 feet a red marly clay with grey spots, not calcareous, some gypsum	118	10	416	2
Red and green marls, with eight beds of gypsum, from 1 to 14 inches thick: samples from 440, 441, 460, 464, 480, 487, & 490 feet, all hard red or grey clays, except 480, which is a red sandy clay with much white mica	127	1	543	3
Red and green marls, with many layers and beds of gypsum from 2 to 16 inches thick: sample from 600 feet, of solid white crystalline gypsum.	66	10	610	1
Red and green marls, with fewer beds of gypsum (seven layers, from 2 to 9 inches thick)	119	11	730	0
Grey siliceous marl	0	6	730	6
Red and green marls, with gypsum	97	5	827	11
'Grey marly limestone,' probably a hard calcareous marl: no sample seen	1	0	828	11
Red and green marls, with gypsum	12	10	841	9
'Grey limestone': sample from 842 feet a compact fine-grained calcareous sandstone, consisting chiefly of fine, pale-red sand, with lenticular patches of rather coarser sand, both effervescing with acid	1	0	842	9
Red and green marl, with gypsum	4	6	847	3
'Grey limestone,' probably a calcareous sandstone	1	0	848	3
Red and green marls, with gypsum: sample from 850 feet a hard, variegated, sandy marl, effervescing with acid, and containing some large grains of quartz	14	6	862	9
'Grey limestone': sample from 863 feet a grey calcareous sandstone (like the coarser part of that from 842 feet), with an included patch of clear yellowish crystalline gypsum	1	3	864	0
Red and green marls with gypsum, including two 3-inch layers of gypsum: sample from 884 feet a dark red silty clay (not a marl); sample from 900 feet a core of fibrous gypsum enclosing a lenticular layer of grey clay	94	8	958	8
'Blue marl with gypsum'	5	0	963	8
'Brown and blue marls with gypsum': sample from 1000 feet a dark-red clay, showing glistening slickensided surfaces and some strings of fibrous white gypsum; sample from 1017 feet a dark-grey, compact, soapy marl (calcareous) ...	53	7	1017	3
Brown and reddish marl, with gypsum	14	0	1031	3

	Thickness. Feet	Thickness. inches.	Depth. Feet	Depth. inches.
'Grey limestone': no sample seen	1	6	1032	9
Blue, brown, grey, and red marls: sample from 1050 feet a light-grey marl, somewhat calcareous	18	6	1051	3
Dark-blue marl, with gypsum: sample from 1056 feet a greenish-grey marl	10	6	1061	9
Blue and red marls, with gypsum: small sample from 1077 feet is a hard argillaceous limestone, with a vein of black substance (? manganese-oxide), perhaps a concretion; sample from 1100 feet a fine red sandy marl	39	1	1100	10
Dark-red and blue marl, with gypsum: sample from 1115 feet a hard dull-red clay, and one from 1130 feet massive, white, crystalline gypsum; sample from 1150 feet a hard red and variegated clayey rock	60	9	1161	7
Red and blue marls, with gypsum: samples from 1200, 1213, 1230, 1237, & 1250 feet all hard, fine, silty and micaceous clays, those from 1213 & 1230 feet grey, the others red; that from 1213 contains a thin seam of hard grey sand	93	9	1255	4
Red and green marls, with gypsum: sample from 1300 feet a hard, red, fine-grained, sandy clay or argillaceous silty stone	46	8	1302	0

IV. Remarks on the Classification of the Beds.

There can be no doubt that the limestones and shales traversed in the first 70 feet form part of the 'Blue Lias' and belong to the zones of *Ammonites Bucklandi*, *Amm. angulatus*, and *Amm. planorbis*. The true 'White Lias,' or Upper Rhætic, probably commences between 72 and 76 feet, for in the coast-section (see p. 280) more than 20 feet is referred to this division; these white limestones extend to just over 95 feet. The boring then entered the shales of the *Avicula-contorta* zone, and these appear to extend to the depth of 133 feet 8 inches, having a thickness of more than 38 feet.

Grey marls with thin limestones follow, but unfortunately I have not been able to see many samples of these beds. From the record of the boring, grey shales and marls seem to have been met with down to 167 feet. Then comes what is described as 'green shale,' below which is a thin bed of 'grey limestone': of this I have not seen a specimen, but if really a limestone it would form a convenient horizon to take as the base of the Rhætic Group. If the base of this group be taken at the higher limit, the grey marls are 33½ feet in thickness, which corresponds very closely with Mr. Woodward's measurements in the coast-section: if the Rhætic marls include the limestone, their thickness is 39 feet; and the total thickness of the Rhætic Group will then be nearly 100 feet.

The boring then entered green and red marls that are undoubtedly of Keuper age, and for a depth of about 125 feet these are without gypsum. Then the usual gypsiferous series was met with, the gypsum in the higher beds occurring only in veins and strings, but lower down many layers and beds of gypsum were traversed, varying in thickness from a few inches to more than a foot.

At a depth of 730 feet a 'grey siliceous marl' was noticed, meaning probably a fine sandy clay; and at 828 feet a bed termed a 'limestone' was met with, but no sample of either of these beds has reached me.

Between the depths of 840 and 864 feet three beds of grey calcareous sandstone were traversed, each from 12 to 15 inches thick, and separated by beds of red and grey gypsiferous marl. It might have been supposed that these represented the alternations of sandstone and marl which are seen in the lower 150 feet of the Keuper Marls near Sidmouth; but if they had been, the Keuper Sandstones (75 feet), the coarse Bunter Sandstones (300 feet), and the Budleigh Salterton Pebble-beds (80 feet) would have been found below. Instead of any of these, another thick series of red and variegated marls and clays was found to lie below, and to continue for more than 400 feet.

It is highly improbable that the Bunter Sandstones and Pebble-Beds should have thinned out entirely between Sidmouth and Lyme; and, further, it is impossible to correlate the lower marls of the Lyme boring with the marls which underlie the Budleigh Beds, because the former are gypsiferous throughout, while the latter do not contain gypsum.

We are, therefore, obliged to conclude that the calcareous sandstones are simply sandy beds intercalated in the Keuper Marl Series; and there is nothing very remarkable in the fact of such intercalation. Indeed, there appear to be similar beds near Taunton and North Curry in Somerset; for Charles Moore noted the occurrence of thin beds of dull-grey and brown sandstone in the lower part of the Keuper Marls near Ruishton and North Curry, about 60 feet of marl being exposed below them at the latter place.[1]

Among the samples from the lower 150 feet traversed by the Lyme boring, there is nothing which can properly be termed a sandstone: because, though fine sand is undoubtedly a constituent of some, it is so fine and so mixed with argillaceous and micaceous matter, that to call the rock a sandstone would convey an erroneous idea of its character. Some of the beds might be called 'silt-stones,' having originally been silty muds, but others are simply hard clays; and the bed in which the boring ended at 1302 feet is a hard, dull-red, silty clay, containing many glistening flakes of silvery mica.

I am, therefore, forced to conclude that the boring did not reach the beds which near Sidmouth form a passage from the Keuper Marls to the Keuper Sandstones; that the depth of Keuper Marls proved by the boring is about 1130 feet; and consequently that the total thickness of these marls must be greater than that amount. If we add to these figures the thickness of the passage-beds near

[1] See Quart. Journ. Geol. Soc. vol. xvii (1861) p. 486.

Sidmouth (150 feet), we have 1280 feet; and as the first sandstone of these beds may well be 20 feet below the point where the boring ended, we shall not be far wrong in assuming that the total thickness of the Keuper Marl Series in Eastern Devon is about 1300 feet.

In conclusion, I append an abstract account of the boring, showing the several formations through which it passed:—

			Thickness.		Depth.	
			Feet	inches.	Feet	inches.
Soil and gravel			10	8	10	8
Blue Lias		probably	62	4	73	0
Rhætic Beds.	White Lias	do.	22	1	95	1
	Black Shales	do.	38	7	133	8
	Grey Marls	do.	39	1	172	9
Keuper Marls, 1129 feet 3 inches.	Marls, without gypsum		124	7	297	4
	Marls, with veins of gypsum		118	10	416	2
	Clays, with beds of gypsum		313	10	730	0
	Gypsiferous marls, with three beds of calcareous sandstone		134	0	864	0
	Hard clays and marls, with gypsum		297	7	1161	7
	Hard silty and micaceous clays, with some gypsum		140	5	1302	0

It may be added that, after the boring had been completed and the boring-appliances removed, water began to flow from the borehole. This proved to be a large and constant supply of water, which is now led by a pipe into the adjacent brook. I am informed by Mr. A. C. Pass that the height to which the water would rise was found to be 20 feet above the surface of the ground.

Discussion.

The President said that all geologists welcomed the careful description and publication of sections of boreholes sunk in our sedimentary formations, and this was one of more than ordinary importance. While no geologist, probably, would have recommended this borehole from the economic point of view, its failure as a commercial speculation by no means detracted from its value from the scientific aspect. Nor should it ever be forgotten that, even from the economic side, these so-called 'failures' had an important negative value, in the fact that, as in the present instance, they brought home to the minds of the engineer and the speculator an easily understood demonstration of the reliability of geological fact and deduction, which was certain to remain long in their memory, and might lead them to seek geological help in such cases in the future.

Mr. Hudleston said that he felt a local interest in this paper, having inspected the cores which were deposited in the Dorset County Museum. Hopes had been expressed that coal might be found in the county, and the public were greatly indebted to the gentlemen who had carried out this scheme. Unfortunately, the prospects of finding coal here were not good. The thickness of the Upper Keuper Beds was about what might have been expected; and if the boring had been continued we should have learnt something about the Keuper Sandstones (Ottery Beds), and possibly even the Budleigh Salterton Pebble-Bed might have been proved. But supposing that the borehole had penetrated the entire Mesozoic column, what would the prospectors have found when they reached the Palæozoic floor? The Radstock coalfield was some 45 miles from Lyme in a northerly direction, with the Mendips intervening, and the Exeter beds some 30 miles to the westward. Hence it was probable that the Culm-Measures of Devon were more likely to be found at Lyme than the Coal-Measures of Northern Somerset.

Turning to the section on the screen, he commented on the increased thickness of the Rhætic as compared with the development at Pylle Hill (Bristol), where Edward Wilson had assigned 16 feet to the Rhætic as restricted by him. He also enquired what palæontological evidence there was for placing the grey or tea-green 'marls' in the Rhætic Series, contrary to the conclusions of that author. He furthermore criticized the use of the term 'marls,' as applied to the Keuper of this area. Most of the cores from that formation in the Dorchester Museum had been tested, and no carbonate of lime had been found.

Mr. H. B. Woodward, replying on behalf of the Author, said that the fossils from the grey and tea-green marls of Watchet were the *Microlestes* found by Prof. Boyd Dawkins and *Gervillia* recorded by Mr. Etheridge. It would no doubt be a satisfaction to have further discoveries in these marls; but at Gold Cliff, in Monmouthshire, there was a bone-bed with Rhætic fish-remains in the Green Marl below the Black Shales. There and in South Wales Mr. Strahan had taken the base of the Black Shales as the lower limit of the Rhætic Beds, because it was the sole apparently-persistent plane of division. At Lyme Regis there were dark clayey bands in the Grey Marls, which foreshadowed the Black Shales; and there was no doubt that these marls formed passage-beds between the Keuper and the Rhætic.

17. *On a* Remarkable Inlier *among the* Jurassic Rocks *of* Sutherland, *and its* Bearing *on the* Origin *of the* Breccia-Beds. By the Rev. John Frederick Blake, M.A., F.G.S. (Read March 26th, 1902.)

Contents.

I. Introduction.

The remarkable deposits, consisting of large angular and rounded stones, that skirt the western shores of the Moray Firth, on either side of Helmsdale, have already attracted the attention of two eminent geologists.

Sir Roderick Murchison, who was the first to describe them in 1826,[1] considered them to be the result of the upheaval of the neighbouring granite. This upheaval of the granite, in his view, broke up the Jurassic rocks along its south-eastern border, and scattered their fragments haphazard in the neighbourhood of the fault. In the phraseology of some modern writers he considered them to be crush-conglomerates, but his own name for them was 'brecciated beds.' This name and his explanation assumed the exclusively Jurassic age of the fragments, and both were therefore rendered untenable by the discovery in some of these fragments of Old-Red-Sandstone fish-remains.

Prof. Judd, who, in 1873,[2] first determined the general age of the rocks as Upper Jurassic, and described them in far greater detail, would not bind himself to any definite theory of their origin, but hoped that at some future time the question would be elucidated by the discovery of analogous phenomena elsewhere—a hope which the present communication aspires to fulfil. Meanwhile he suggested as the most probable hypothesis at that time, that the blocks composing the breccia had been carried by floods in a large river that did not reach the sea-shore in the form of a glacier.

At the present time, the only possible explanation before the world is still that given by Prof. Judd, who, whatever modifications his hypothesis may require, has clearly laid the following foundation of fact:—

[1] Trans. Geol. Soc. ser. 2, vol. ii, pt. ii (1827) p. 293.
[2] Quart. Journ. Geol. Soc. vol. xxix (1873) pp. 97–195.

(1) The breccias are contemporaneous, that is, were deposited at the same general period as the surrounding strata;
(2) None of the fragments have been observed to be striated, but several are rounded;
(3) The age of the series containing the breccia-beds is exclusively Upper Jurassic;
(4) The age of the fragments is that of the Old Red Sandstone;
(5) A strip of this rock occurs, *in situ*, to the south of Helmsdale, between the granite and the Upper Jurassic rocks; and
(6), confirming Murchison, the granite is separated from the rocks to the east of it by a fault.

To base on these facts any more definite explanation of the mode of formation of the breccias, required some more detailed observations on them, combined with further knowledge of some agency at that time little understood.

The further observations necessary are in part suggested by the facts already obtained, and should be directed to the determination of the following:—

(1) What is the relation, if any can be found, between the breccia-beds and the Old Red Sandstone *in situ*? and
(2) How are the breccia-beds distributed among the ordinary strata that form the presumably long series of Upper Jurassic rocks?

We might also hope that some hitherto unexpected feature would be discovered which in itself would suggest the method of formation. On the other hand, the most hopeful direction in which to seek the little understood agency is among the phenomena of ice.

II. The Inlier of Old Red Sandstone.

In relation to the first of the above questions, I was fortunate enough, on a visit to the district in the spring of 1900, to observe what appeared to me a very remarkable phenomenon, though it does not appear to have been fully noticed before.

On the reefs a quarter of a mile due south of Port Gower, at extreme low water, stands up a long jagged crest, which at this time of the tide is singled out from the remaining rocks by showing nearly vertical stratification, while all around nearly horizontal beds are seen. On a closer approach it is perceived that the jagging of the crest is due to breaking-off at different heights of the ends of the thin strata of which it is composed; and, on reaching the mass itself, these strata are found to be hard, micaceous, and of a somewhat purplish tint, having the character of the Caithness Flags, and, therefore, like many of the breccia-fragments. (See fig. 1, p. 292.)

The length of this crest is divided by the least elevated portions into two or three divisions, and extends seaward about 60 yards. Transversely it is about one-third as broad as this, and the height is between 30 and 40 feet on an average. As may be seen by the discoloration of the rocks, the ridge or stack is nearly covered at high water, which must be the reason why it has not previously been noticed, unless the brief reference by Prof. Judd to a remarkable example of a transported block 'found on the shore opposite Port Gower' applies to this. It must have been nearly covered by the tide at the time of his visit to this particular spot, or he would have described it in detail instead of a much smaller piece. On all sides it is surrounded by large blocks of rock resembling the material

Fig. 1.—*Inlier of Old Red Sandstone, with the beds nearly vertical, standing in the midst of Upper Jurassic rocks, with the beds nearly horizontal, on the shore near Port Gower.*

[From a photograph.]

of which it is composed, but embedded in nearly horizontal Upper Jurassic shales.

But can this be a transported block? I do not think it possible. It is more than forty times the size of any other isolated mass in the district, and would require the maximum transporting force. Its base must be some distance below the surrounding breccia-beds; but there is no sign of anything extraordinary in the beds which underlie these. I shall, therefore, take it as indubitably *in situ*.

Admitting this, the whole aspect of the question as to the source and origin of the breccia-beds is altered, and a fresh start must be made. No river need have brought the fragments from afar—their source may be here at hand.

We see in this mass a kind of sea-stack, standing on a broader rocky base at no great distance below. It is a Jurassic 'Old Man of Hoy' or 'Duncansby Stack,' but with its stratification vertical,

Fig. 2.—*Interbedded breccia-beds at the entrance to Gartymore Burn, separated by thick bands of shale.*

[From a photograph.]

therein resembling more closely the 'Needles' off the Isle of Wight. Like all sea-stacks, it would stand not far from a lofty rocky shore—the cliffs being formed of the same material as the stack, that is, of the Caithness Flags. Now, such cliffs are actually near at hand, in the strip of these rocks discovered by Prof. Judd between the Upper Jurassic and the granite. Thus, if we could clear away the intervening Jurassic deposits, blocks and all, we should have here a relic of the Old Jurassic shore. It may have been up and down since then, but has finally settled only a little higher than in its original position. This cliff, where nearest to the sea-stack, about

400 yards distant, has now a summit-height of about 140 feet above the present highest point of the stack, which is all the information that we can obtain about it here.

About half a mile to the north, however, is the opening of the gorge of Gartymore Burn, of which a general section is given in Prof. Judd's memoir. In this gorge we have a complete view of the relations between the breccia-beds and the Caithness Flags. At

Fig. 3.—*Breccia-bed overlying Jurassic shale, close to the junction with the Old Red Sandstone, Gartymore Burn, in a much thicker mass.*

[From a photograph.]

the mouth of the gorge is seen the section represented by Prof. Judd's fig. 16,[1] of the correctness of which as a diagram the photograph (fig. 2) reproduced on p. 293 bears witness. The rise towards the land is doubtless the result of later tilting, at the time when the granite was pushed up, and dragged with it some of the adjacent strata.

[1] Quart. Journ. Geol. Soc. vol. xxix (1873) p. 191.

It will be seen that the lowest breccia-bed, though the thickest here seen, has considerable masses of uniform shale or clay, both above and below. As we pass up the gorge this band of breccia thickens somewhat, until it meets with a discontinuity, or small fault, on the other side of which is a breccia-band of much greater thickness—traceable as far as a small reservoir, where it occupies the whole overhanging slope (fig. 3, p. 294), and is seen to include

Fig. 4.—*Waterfall on Gartymore Burn, showing the sides of the gorge composed entirely of broken-up Caithness Flags.*

[From a photograph.]

some large rounded stones; some portion also shows signs of stratification like a bed of solid grit, which is lost among the fragments.

At the upper end of the reservoir two streams unite: that to the south has its sides entirely composed of great angular masses of, presumably, Caithness Flags; and that to the north is of the same character, though less clearly seen at a distance (fig. 4). The rocks exposed on this side are practically continuous with those last seen, for the wall in fig. 3 ends with the post seen in fig. 4. The breccia, talus, fault-rock, or whatever we may choose to call it, is seen to go to the top of the waterfall and to continue to the base, making the surface irregular throughout.

We are here able to trace continuously the Jurassic rocks to their junction with the Caithness Flags, and to see them apparently passing into the fragments of the latter, just as we might trace the mud of a sea-bottom passing by stages into the débris which has accumulated at the base of a modern cliff. If we should imagine a fault where the streams join, or consider the fragments forming the sides of the divided gorge to be a fault-breccia, it will not alter matters much: it would merely be changing one part of the Caithness Flags for another, or a mass of broken-up rock for the solid one. We cannot get over the fact that masses full of the fragments of a given rock are interstratified with the shales, and that the breccia-beds thus produced can be traced increasing in thickness, till they come into contact with a mass composed entirely of the same fragments, beyond which at last we come to the solid rock. Whatever was the cause of this phenomenon, it was a recurrent cause, as there are at least three of the breccia-beds at the mouth of the gorge, as seen in fig. 2 (p. 293).

All this is exactly what we might expect if we were here actually looking at the talus and deposits at the base of a cliff of Caithness Flags to which the sea-stack was subsidiary. If this be so, there ought to be some relation between cliff and stack in the way of strike and dip. The question is, what relation should we expect? Now, when masses of rock are separated in this way, it may be either along bedding-planes when these approach the vertical, as in the case of the Needles: or, more commonly, along joint-planes when the beds are horizontal, as in the case of the stacks of Duncansby. Under the latter conditions, the dip and strike of the mainland rocks are practically indeterminate. But these Caithness Flags seem to be specially liable to overhang towards the sea, as shown in fig. 166 of Geikie's 'Text-Book of Geology' p. 434 (ed. 1882). When this is the case, any portion separating along a joint-plane will sooner or later heel over; its strata will have a high dip seaward; and the strike will be parallel to the direction of the joint, and so approximately of the cliff. This is exactly the case with the Port-Gower stack, and also with the other mass at Allt-a-ghruan described by Prof. Judd. All this, of course, has reference to the time previous to the production of the dips in the Jurassic rocks, and to the formation of the breccias.

In Jurassic times both the granite and the Caledonian Series were deeply buried, and the Caithness Flags did not form a mere strip, as now, but extended widely both westward and northward, probably forming the coast-line for a long distance to the north-north-east. On the south, however, they are cut off at a sharp angle, indicative of a fault transverse to the later post-Jurassic one. Its direction is possibly indicated inland by the straightness of the geological boundary-line drawn in its neighbourhood, and by the change of general dip in crossing this line. If it exists it must be pre-Jurassic, as the sequence of that series is very slightly interfered with on the shore. The boundary-line thus created runs a little south of Lothbeg, beyond which no Caithness Flags have been observed. This boundary is also very nearly that of any possible breccia-beds, which commence, as will be presently seen, a little north of the same place. Hence the local flags and the breccias are so far bound together, whatever it may be worth, by community of limit.

So much then for the relations of the Caithness Flags *in situ* to the sea-stack and the fragments in the breccias.

III. The Distribution of the Breccia-Beds in the Upper Jurassic Series.

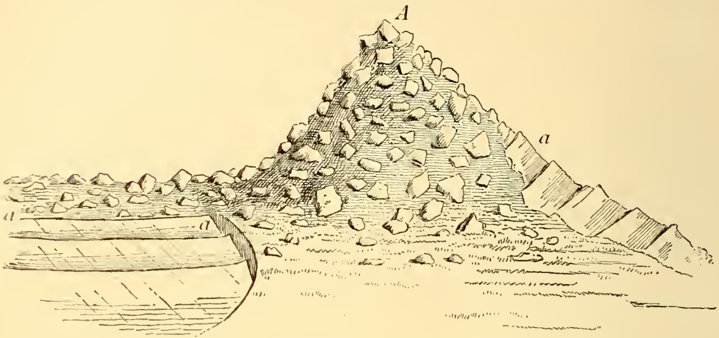
Commencing at the south, we find the basal sandstones of the Upper Jurassic Series at Allt-na-cuil, with conglomeratic portions, containing Lower Kimeridgian fossils, such as *Ostrea deltoidea*. The next succeeding recognizable horizon is found at the Lothbeg cutting. Here, at the bottom and sides of the railway-bridge, are massive grits with patches of black shales, which represent no doubt the uppermost portion of the lower beds. These are followed by two alternations of bands of shale and massive grit, above which is a thicker series of shales, yielding *Cardioceras alternans* and *Belemnites spicularis* in abundance, and thus indicating the recognizable horizon of *C. alternans*. The bands of grit here are perfectly normal, they have a gentle dip in a northerly direction, and there is no sign of brecciation.

The lowest grit-band seen at the railway-bridge keeps the shore as far as Craigie Point, on turning which we find on the scars indurated thin bands, 1 inch and less in thickness, with very little indurated grit; but the fossils are *Cardioceras alternans* and *Aucella Pallasi* (? = *Avicula vellicata*). These are in the line of strike determined at the bridge.

Passing northward, we have a considerable interval to traverse before scars again appear; though when they do, the strike of the beds exposed is the same as before, but they are more sandy. They are not, however, repetitions of the lower grits of Lothbeg, as represented on the Survey Map, being soft and white, or with very carbonaceous intervening shales, almost as black as coal; and, more particularly, they are not followed by *C.-alternans* beds, but by fossiliferous shales, characterized by the presence of *Hoplites eudoxus* or one of its allies, the horizon of which is near the base of the Upper Kimeridgian in Kimeridge Bay. In these shales the strike can be seen and traced continuously nearly parallel to its constant direction, only changing by the thickening and thinning of the lenticles of grit. Above and with the *Hoplites*-shales are the most abundant remains of leaves, ferns, etc. Everything here seems perfectly regular, without any disturbance or break. The whole might be, in general, matched in Kimeridge Bay itself.

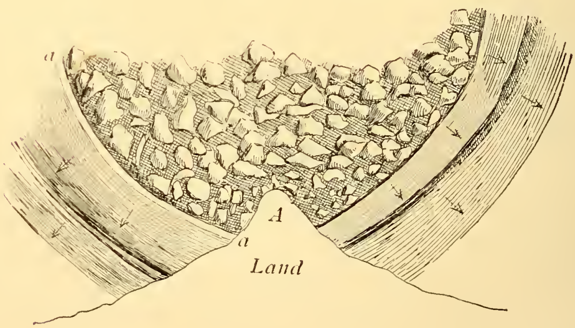
It is at the next prominence, north of Craigie Point, that the first sign of anything like a breccia-bed occurs. On reaching the first corner the strike is observed suddenly to change through nearly a right angle, and consequent confusion sets in. At the farther, more easterly, corner the reason for this appears. Here stands

Fig. 5.—*Projection of breccia from the midst of Jurassic shales forming the promontory next north of Lothbeg.*



[From a sketch.]

Fig. 6.—*Plan of the mass of breccia and surrounding ordinary strata at the promontory next north of Lothbeg.*



a remarkable nose-like projection composed of a breccia of large angular stones (fig. 5). On the land side it is an irregular conical mass, but towards the sea it has been worn away and exposes a section of the breccia, which continues as far as low tide. How much has been worn away I cannot say; but, to judge from the size of the base, the part remaining on the land must be only a small fragment of the original. Round the central core of breccia the ordinary strata form semicircles, all overlying it at the edge, and dipping away from it at the circumference (fig. 6, p. 298). This is well shown by the occurrence of a hard band in their midst, and having a band of shale between itself and the breccia. The stones in this breccia are hard false-bedded sandstones, not to be matched among the strata below. After passing this obstacle the strike and dip return to their normal direction, and the *Hoplites* and plant-remains reappear.

Whatever explanation we may give of these phenomena, it must be such as takes account of the extremely local character of this mass of breccia, the slight general disturbance which it occasions, and the dissimilarity of the fragments to the ordinary Jurassic rocks of earlier date in the district. It seems to me to be best accounted for as a buried sea-stack broken up by the waves, or a collection in any other manner of fragments of more ancient rocks—by means, it might well be, of a raft of ice. The disturbance produced by its presence is not more than can be accounted for by the sinking of the soft shales, etc., on consolidation, and the resistance which the hard mass would oppose to subsequent general earth-movements.

From this neighbourhood northward to Garty Point, I have not been able to make any observations along the shore. At that point Prof. Judd draws a fault, to the south of which he brings the Caithness Flags down to the coast-line; and certainly immediately beyond the Point we find a repetition of the beds that we have seen before, north of Craigie Point. But here their strike is changed to about north-north-east and south-south-west, which has the effect of bringing them nearly parallel to the shore which runs in a north-easterly direction, and of spreading them out over long reaches, with very slow changes towards Helmsdale.

The lowest beds seen opposite Midgarty Burn are the *Cardioceras-alternans* clays, which on the shore and in the cliff are full of that ammonite; and they are surmounted by a strong bed of grey nodular grit, which stands up in crags. A broad stretch of shore with masses of soft yellow sandstone, and black sands here and there, interferes with the visible succession of the rocks; but on the farther side the beds seem to continue the series without much change.

Here we meet for the first time a new feature of great importance. Hitherto all the fossils met with north of the Loth River have been autochthonous, but here they are heterochthonous, and have been heaped up in masses of thick calcareous shells such as *Rhynchonella Sutherlandiæ* of great size, *Perna quadrata*, and many others, including an ammonite like *Perisphinctes mosquensis*, but obscure. Such shells as these, with a speckled matrix, are mingled with large angular pieces of rock, and aggregated together into a heap forming an outstanding boss on the shore. This is the beginning of the breccia-beds on the north side of Garty Point. The agent that collected these shells was obviously entering upon virgin soil and soon exhausted it, for in the upper part there are fewer calcareous organisms, and the containing grit is hollowed out where they have been dissolved.

These grits and aggregates are soon replaced again by black and white banded shales, whence plants have been obtained and ammonites of the type of *Hoplites eudoxus*. We are here, therefore, on nearly the same horizon as we were, when the patch of breccia was seen between Garty and Craigie Points, that is, between the horizons of *Cardioceras alternans* and *Hoplites eudoxus*.

The second series of brecciated bands is that of which the higher portion surrounds the inlier. The brecciation here is on a larger scale, and the fragments are more irregularly placed, while the associated shales, if such they can be called, include several bands of comminuted organisms, in some cases almost entirely composed of echinoderm-spines. The fragments at the base of the inlier are larger than elsewhere, and make up a greater proportion of the whole bed ; but there is very little irregularity, as may be seen in fig. 1 (p. 292), and the underlying bands of breccia or shale show nothing different near the inlier from their appearance elsewhere.

Beyond the inlier we return again to uniform shales, though the strike of the beds is such that we do not rise much in the series but continue in the *Hoplites*-beds for a long way, which here contain a belemnite and a *Perisphinctes* (like *Pallasi*, usually called *Ammonites biplex*). The first repetition of breccias after this appears to be connected with the beds seen at the entrance to Gartymore Burn (fig. 2, p. 293), which can be traced on the shore, where they may be expected, from their lie and position, to be found. One of them swells out to a thickness of 10 feet by the fragments of foreign rock, among which are included here numerous masses of *Isastræa oblonga*, thrown anyhow and crowded together. These have their bases either vertical, or upside down, and more rarely in their natural position. These masses of coral are fairly large, and as they must have grown originally on some solid base, it follows that they have been detached from their place of growth, and hurried along to accumulate in one spot where the driving force was in some way counteracted.

Now, these corals cannot have been introduced into the stratum after its deposition, for there is no general disturbance of the strata overlying them, either on the shore or in the gorge-slope where they are seen in fig. 2 (p. 293). Being reef-building corals, they must have grown in less than 30 fathoms of water, which gives a limit to the depth of the sea from the bed of which they were torn, before they were deposited in shallower water. The horizon of the species, or rather of any reef-building coral known in Kimeridgian or later Jurassic times, is the Lower Portlandian ; and here they are not seen till after the appearance of *Perisphinctes* cf. *Pallasi*, so that the sequence is as usual, and the corals are not remanié. But corals would scarcely grow where mud and leaves were being deposited, for they require a firm bottom—perhaps another submerged stack of Old Red Sandstone, or one of the preceding grits of the Jurassic Series; but, in any case, the mud-deposits must be very local, and therefore probably not far from littoral, as indeed the abundant leaves also suggest.

Between the coral-locality and Helmsdale very little is to be seen; but on the other side of the town, as noted by Prof. Judd, the breccia-beds predominate, and there is little room left for ordinary strata. Such shales as appear owe their position and apparent contortion, in most cases at least, to the pressure of the stones in

Fig. 7.—*Typical breccia-beds, north of Helmsdale.*

[From a photograph.]

the breccia. On this account it is difficult to be certain of any direction of dip, or strike, in the beds. They do not, in fact, appear to have any orientation or arrangement at all, nor is any evidence of contortion possible in such deposits (fig. 7, above).

On turning the corner, however, into Navidale, fresh phenomena appear which are certainly very instructive. In the first place, though the breccias themselves are as rough as ever, there is some method in their roughness, one side being more scarped than the other, and the crests run somewhat parallel to each other.

The matrix in the breccia is full of shell-débris, and in places where the rock-fragments are locally wanting this débris consolidates into a massive white limestone-band, such as were formerly worked for lime in this locality. The surface (no doubt, in great part, due to denudation) is fairly flat. This bed proves a large amount of shell-grinding to have taken place before transport. The breccia-beds are not so closely packed one upon the other as before; and intervening shales both above and below the same bed have everywhere a low steady dip to the sea, striking parallel to the shore in its various changes of direction, or, perhaps it would be more correct to say, that the shore follows the varying strike of the beds. These intervening shales have yielded *Perisphinctes Pallasi*, two good specimens of *Natica Marcousana*, a narrow thin belemnite, and *Alectryonia*. *Isastræa oblonga* occurs as before in the breccia. All the breccia-beds north of Helmsdale as far as this point count for almost nothing in the sequence, for we are here on the same horizon as the last that yielded a fauna.

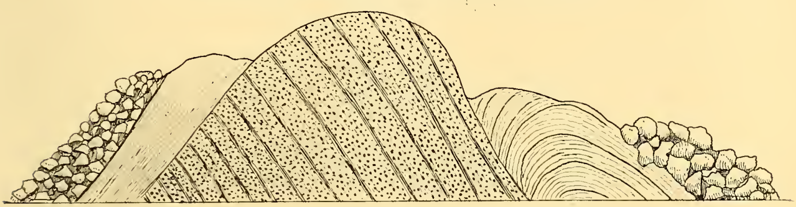
The low steady dip seen in the seaward scars is interrupted in one place, along the strike of one of the beds, by a curious arrangement of rocks at the base of the cliff, where we find a large rounded mass of Old Red Sandstone [1] which, in the light of other localities, may be taken as the summit of a boss projecting from the main mass, here depressed farther below sea-level. Like the larger inlier, it has the ordinary micaceous character and purplish tint of the Caithness Flags, and it is divided into thin bands having a high northerly dip. It is overlain immediately on both sides by Jurassic shales, followed above by a bed of breccia. The north side differs from the south in the following remarkable manner. The Jurassic shale is here squeezed up into a sharp anticline, just as a piece of whalebone would be between the finger and thumb. One end of the anticline rests against the boss of Old Red Sandstone; while on the south side the same shale coats the surface of the boss (fig. 8, p. 303). This arrangement of the strata has therefore been brought about by a pressure from the north, and this pressure is not generally manifested, but only when, as at this boss, an obstacle is presented. Overlying the shales on either side is a band of breccia, containing the *Isastræa*. If we imagine the carrier of the stones to impinge upon this boss in a solid condition, it might squeeze up the intervening shale into the form which we now see. It is quite consonant with this explanation that there should be obscure fragments of Jurassic shale in the breccia, and isolated breccia-fragments embedded in the shale. The dip of the shale on the south side, and of the breccia-beds on both sides, may be due, as before, to the sinking of the strata on consolidation, leaving the unyielding boss at a higher relative level.

Beyond Navidale the breccia-beds and their intervening shales continue to undulate gently on the scars, so that their strike, as

[1] This must be the mass, I think, described by Prof. Judd as the largest of the transported blocks, Quart. Journ. Geol. Soc. vol. xxix (1873) pp. 192–93.

before, follows the broader outlines of the coast, the dip being always gently seaward. The included fragments here become larger and more abundant, one near Navidale being about the size of a fowl-house, and another at Greentable Point about twice as large. In both these cases we can see below them and be certain that they have been transported, and they indicate probably the

Fig. 8.—*Strata squeezed up into an anticline against a boss of Old Red Sandstone, near Allt-a-ghruan.*



a = Boss of Old Red Sandstone. b = Overlying shale, squeezed up by c, Breccia-bed.

maximum force expended in the production of the breccia. In the cliffs, up to 100 feet and more, are found some ferruginous sands and sandstones, the age of which will be suggested later ; but their relations to the breccia-beds are obscure. The great fault here also affects the cliff-face, and breccias of granite are seen. No further light is thus thrown directly on the present enquiry, and beyond Greentable Point all that is seen is the straight line of the fault running northward towards the Ord, with the granite forming the cliff on the west, and the last relics of the breccia-beds forming a reef on the shore to the east.

IV. Summary of Results.

The results of the evidence thus adduced, in addition to the confirmation of the six points hereinbefore mentioned as established by Prof. Judd, may be stated as follows :—

(7) The floor on which the Jurassic rocks rest, when accompanied by breccia-beds, is at no great depth below the sea-level, nor was it at the time of their deposit.

(8) It was diversified by sea-stacks, very much as the coast of Caithness, composed of the same 'Flags,' is diversified at the present day by the Stacks of Duncansby.

(9) The fragments contained in the breccias may have come, in some cases, from the cliff and stacks of their immediate neighbourhood, and in others from no great distance.

(10) The breccia-beds are coterminous towards the south with the present exposure of the Caithness Flags, which throughout runs parallel to the shore on which they lie.

(11) Their frequency is intermittent, increasing from south to north. None

are found in the zone of *Cardioceras alternans*; but their formation commenced in the period of the Kimeridgian zone of *Hoplites eudoxus*, and continued through that of *Perisphinctes Pallasi* into the beds with *Isastræa oblonga*.

(12) The fossil contents of the breccia-beds themselves are all heterochthonous, and the agent which brought them to their final resting-place had the power to tear off massive corals from their place of growth, to collect large shells into heaps, and to grind to powder the majority of the calcareous organisms, which lay on the sea-bottom in its course.

(13) The deposition of these materials had but little effect on the strata then forming at the place of deposit, except in the event of jamming against a rock projecting from the sea-bottom, when the uppermost deposit then exposed might be puckered up against the projecting rock. The puckering seen here, in such a case, indicates a pressure from the north or north-east.

V. Comparison of the Breccia-Beds with the Work of an Ice-Foot.

We have now to enquire whether there is any agency at present known which may be expected to produce such results, and in what way that agency may have acted.

The final paragraph of Prof. Judd's paper reads as follows:—

'Here then we pause, in the expectation that future researches in the physical geography of some, as yet, little-studied region may demonstrate the existence, in the same combination, of those conditions which we have shown must have been present during the deposition of the wonderful brecciated beds of the Ord.' Quart. Journ. Geol. Soc. vol. xxix (1873) p. 195.

This expectation we are now, I hope, in a position to fulfil. The 'little-studied region' is that of Smith's Sound in lat. 79° N., and the combination of necessary conditions is found in the ice-foot.

On referring to Jukes & Geikie's 'Manual of Geology' published in 1872, we find no mention of the ice-foot and its phenomena, although the rapidity of rock-disintegration in the Arctic regions, as seen by Dr. Kane in Spitsbergen, is pointed out. In 1874, however, the British expedition to the West Coast of Greenland and Smith Sound commenced their explorations; and to the account which was afterwards published by Sir George Nares there was added an Appendix by Col. Feilden & Mr. De Rance, in which a very graphic description of the ice-foot is given with all the gusto of novelty: this was afterwards more fully elaborated in the Quart. Journ. Geol. Soc. vol. xxxiv (1878). We are thus able to compare the phenomena of an ice-foot with those of the breccia-beds of Sutherland, step by step, and trace in detail their agreement or divergence.

The definition of an ice-foot there given is as follows:—

'The ice-foot is built up, not so much by the act of the freezing of sea-water in contact with the coast, as by the accumulation of the autumn snowfall, which, drifting to the beach, is met by the sea-water at a temperature below the freezing-point of fresh water and instantaneously is converted into ice.' See 'Voyage to the Polar Sea' 3rd ed. (1878) App. pp. 340–41.

The conditions for its production, therefore, differ only in matters of intensity from those prevalent even now—where it is not uncommon in early spring to find snow-drifts by the shore, which easily consolidate into ice—not by excessively low temperature of the sea-water, but—by ordinary causes. The present mean temperature, we must remember, is abnormal; and the isotherm of 32° Fahr., were it not for the Gulf-Stream, which probably had no equivalent in Jurassic times, would almost pass through it, as it does actually through Hudson's Bay and part of Siberia. So small a change in the distribution of the temperature would bear no quantitative relation to a Glacial Epoch, but might bring back an ice-foot to fringe our northern shores.

The process by which materials are collected for transport by an ice-foot is thus described [1]:—

'Subaerial denudation of the surface of the cliffs causes vast masses of material to fall during the thaws of the short summer, on a scale so gigantic that the mind fails to realize it, unless it has been actually witnessed. The base of the cliff is concealed by a talus made up of a shifting mass of material resembling those known as screes in the English Lake District.... On the first signs of thaw large masses of rock are detached from the cliff, and falling on the [snow-covered [2]] screes slide down to the ice-foot beneath; the impetus being often sufficient to carry them on to the floe, where they remain until the general break-up of the ice, when vast quantities of material are drifted seaward.'

To compare this with Sutherland, we have in the high ground of Caithness Flags, which accompanies the breccia-beds for the greater part of their length, the necessary cliff; and the talus at its base may be that seen in Gartymore Burn, where the material which reaches the edge of the foot, which melts without much shifting, is shown in the bands of breccia of fig. 2 (p. 293). The expression used by Prof. Judd in describing the fragments as 'angular masses just separated from their parent-rock by frosts' is almost identical with part of the above; and his epithet 'wonderful,' and his description, 'a perfect chaos of blocks of stone of the most various proportions and of every conceivable shape .... the position' of which 'is as various as their form and size,' is a natural picture of the results of denudation that must be seen to be realized.

Again, the building-up of the ice-foot by the accumulation of snow to form a soft bed on which the fragments fall, and over which they ultimately slide, explains why none of the fragments are striated; while their subsequent mingling with the beach in summer will lead us to expect that some of them will be rounded. According to our authors, it is not the ice-foot but the 'sea-ice driven on to shore by gales, or moving up and down with the tide,' which is 'a very potent factor in glaciating rocks and pebbles.' If, therefore, no striated rocks be found, it indicates a temperature only low enough for an ice-foot but not for much sea-ice. To proceed:

'The typical aspect of the ice-foot in Smith Sound is that of a terrace, of 50 to 100 yards in width, stretching from the base of the screes to the water's edge.'

In this we need only change the words 'ice-foot in Smith Sound' to 'breccia-beds north of Helmsdale,' and the description is perfect.

[1] Quart. Journ. Geol. Soc. vol. xxxiv (1878) pp. 563 & 565.
[2] 'Voyage to the Polar Sea' 3rd ed. (1878) App. p. 340.

(See fig. 7, p. 301.) So far for the production of a breccia-bed or ice-foot rock *in situ*.

From this comparison of the whole, we see that it is possible to draw up a pretty full description of a remarkable set of deposits, which might be intended either for the breccia-beds of Sutherland or the ice-foot rocks of Smith Sound. Such a description would contain the following points in common :—

(1) The deposits are composed largely of fragments of rock,
(2) which are seldom striated ;
(3) but are mixed with rounded pebbles.
(4) They occur along the shore of a land which is bounded in places by cliffs,
(5) into the screes of which they may pass, and
(6) of the fragments of which they are composed.
(7) They are often, or generally, spread out in nearly flat sheets over the neighbouring sea-floor.
(8) Finally, the minor phenomenon of the appearance of partial stratification of the breccia-beds at Gartymore reservoir (fig. 3, p. 294) may possibly correspond to the curious account (too long to quote at length) of how, when the ice-foot begins to melt, a channel is formed between it and the screes (the very spot required), in which the surrounding material is re-sorted by the water which gains access to the channel.

In all the above cases the comparison is direct, between observation on one side and observation on the other. But we have no direct evidence as to what happens to the material which is carried away, as on a float, by the fragments of the ice-foot, when it breaks up under the action of the summer-thaw. Our knowledge is limited to inference. We may assume that the ice-float, when carried up and down by the tide, will have a balance of motion towards the more ice-free regions to the south, and that a considerable portion will keep along shore. Any that reaches the open sea will scatter miscellaneous blocks at wide intervals, like the blocks of coal and granite in the Chalk of the North Downs,[1] and will nowhere form beds.

The distribution of the fragments along the path of a train of floats will depend on two factors : the relative proportion of the burden to the ice, and the size of the float. The first fragment to fall will be the largest, which has only just as much ice attached as will float it at all. When by this process the relative proportion of burden has lost its importance, the fragments of ice-foot with little burden will be distributed according to size. The smaller floats will travel fastest, but they will melt soonest ; the larger floats will travel more slowly, till they reach the last resting-place of the smaller, when some part of them will still be left to travel farther. The predicated distribution can best be compared with that observed in Sutherland, by uniting into one description the points that are common to both. Hence

(9) The most northerly deposits {will / —} contain the largest fragments.

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[1] See W. P. D. Stebbing, Quart. Journ. Geol. Soc. vol. liii (1897) p. 218.

(10) The most southerly deposits {will be / are} the thinner and more isolated, and the northern {will be / are} more crowded with the deposits of successive seasons.

(11) {Any fragments detached from the ice while floating will sink / The fragments in the thinner breccia-beds have sunk} gently on to the normal deposits forming on the sea-bottom, without disturbing them (see fig. 2, p. 293).

If, on the other hand, the float is stranded before it is entirely melted, it will do so gradually—scraping, at first gently, over the sea-floor, tearing up any slight obstacle, such as a coral or sponge, that may be attached or lying there and grinding smaller shells to powder. The larger of the local materials will be carried forward with the stranded float; the smaller will be dealt with by the surrounding water.

(12) Hence we {may expect to / —} find that nearest the shore are hummocks composed of larger {objects / fossils} mixed with the breccia-fragments, and bands of fine shell- or echinoderm-débris interstratified with the deposits {there forming / of the period}.

If, again, from the sea-floor an immovable boss of rock should project, and the float should impinge thereupon, it is very likely to squeeze up a little of the subjacent deposit. Hence

(13) in the neighbourhood of a rock-mass of earlier date that part of the deposit which lies between the boss and the breccia {may be / is} bent up into an anticlinal form.

The relations thus established between forces in action at one place and results observed in another, are exactly of the kind that have convinced us of the former presence of glaciers in this country, and they should carry the same conviction.

VI. Consideration of Difficulties.

(1) The Occurrence of Plant-remains.

The stems and leaves of cycads, the stems of conifers, and the fronds of ferns are said by Prof. Judd to occur in abundance 'in the matrix of the brecciated beds.' Such an occurrence, if the words are understood in what appears to me their most natural meaning, would be very difficult to account for on the theory of an ice-foot. A place that is covered with drifts of snow every autumn, which rest there all the winter, and carry down abundant fragments in early summer, is about the last place in the world in which to look for ferns and cycad-stems in a beautiful state of preservation. Further consideration, however, shows that there is a preliminary question which has no relation to any particular theory, namely, How could these things be carried uninjured, in whatever way they were brought, if in company with the great stones themselves? If, however, the plant-remains belong to the place to which the stones were brought, the whole difficulty vanishes. In this case the stems might be fossilized at their leisure, and the leaves and ferns be buried before they were broken.

As a matter of fact, I have not been able to discover a sign of any such remains in the actual breccia-beds themselves; neither, I believe, has Mr. H. B. Woodward. I have ascertained also from Prof. Judd that the specimens which he mentions were not obtained by himself, but by the local geologists, who thus described where they had been found. It seems, therefore, probable that the meaning of the words above quoted has been misunderstood. I, at least, have taken it to mean that a single breccia-bed is made up of two parts—the fragments, and the matrix in which these are embedded; and that it is in the latter that the plant-remains are found. The true meaning may have been that the various breccia-beds, each viewed as a whole, are themselves embedded in a matrix—that is, in the 'associated beds,' and it is these latter that contain the plants. If that be the case, the plant-remains did not come with the fragments, but were found on the spot, on their arrival, and thus present no difficulty.

The magnificent cycad-stem, described by Mr. Carruthers as *Bennettites Peachianus*, was obtained from Allt-a-ghruan at the southern end of the slopes, before mentioned as composed of ferruginous sands and sandstones. This unique specimen is stated by Mr. Carruthers to have been found loose on the beach. In all probability it came out of these sandstones, which at the time of its discovery were not even distinguished from the Lias. These beds in the cliff do not fit in with the beds on the shore, and are quite distinct in character. They may in fact be Neocomian, in which strata such cycad-stems are mostly found. To this idea the finding of Neocomian fossils in boulders in the Elgin and Aberdeen area lends countenance; it is suggested by the determination by Heer of the Urgonian age of the Kome Beds of Disco Island (lat. 69° N.) on account of their floral contents.

(2) The Distribution of the Oxfordian Strata.

It is not easy to understand why the thick masses of the Oxfordian strata, from the Kintradwell Beds downward, should be absent from the north of Lothbeg, as they must be if the Port-Gower stack stands on an Old-Red-Sandstone floor. Possibly further observations, which I have not been able to make, would elucidate this point; but our ignorance will not have the weight of a positive objection, unless it should be impossible to suggest any rational explanation. We might, however, suppose that the depression, which must have taken place to produce deposits of mud overlying the conglomerates of Allt-na-cuil, brought higher ground on which hitherto no deposits had been made into the area liable to receive them; or that the supposed faulting south of Lothbeg took place after the Kintradwell Beds were laid down, and brought the northern side into the area of denudation, previous to the new depression; or, possibly, that the Oxfordian deposits are there, and that the inlier fell over on to them from the neighbouring cliff.

VII. Concluding Remarks.

It must not be supposed that all the concordances herein pointed out between the actual phenomena of the breccia-beds, and the known or probable results of an ice-foot, are essential to the existence of a relationship between the two—a caution rendered necessary by experience. Several of the phenomena noted might be proved to be due to other causes; but the result would only be to weaken the evidence, in proportion to their importance, though not to destroy it. For that purpose, some such must be found incompatible with the origin suggested. This must be difficult, owing to the wide range of variation permissible in an ice-foot deposit. It may be found where it first accumulates, or be carried elsewhere: it may ultimately rest crowded on a shore, or scattered over the sea-floor: it may contort the strata then forming at the place of its rest, or the fragments may fall gently. It may contain some rounded stones, and even a few scratched ones. They may rest one against the other, or be separated. They may be very large or small. There may be signs of stratification of the finer material in parts. The beds may be thick or intermittent, widespread or local.

The essential features of an ice-foot deposit are that the bulk of the stones of which it is composed should be angular, of various sizes, without order, definite position, or internal bedding.[1] Each separate deposit would have no more variation in the nature of the contents than could be expected in a single cliff. The breccia-beds of Sutherland possess these features, and in addition other less essential ones; and are thus proved to have originated in an ice-foot, and they are the first recognized in this country as having such an origin.

The word ice-foot has been used by Mr. Mellard Reade[2] for the agent that he supposed to have transported some gigantic boulders of the Eastern Midlands, but his definition of it as 'pack-ice . . . . frozen into a sheet or ice-foot,' shows that he is not referring to the ice-foot of Col. Feilden & Mr. De Rance.

On the other hand, the phenomenon has been described, without the use of the name, at that time (1873) unknown, by Prof. Sollas & Mr. Jukes-Browne, as shown by the Cambridge Greensand. Here there is no ice-foot melting *in situ*, but only an ice-foot-contribution to a distant deposit. This is shown by the characters assigned to the fragments. 'Most of them are subangular,' 'many of them are of large size.' 'The majority present no signs of ice-scratches.' These seem to be contributions from several localities, as the fragments 'are of very various lithological characters'; but a good

[1] See exception above (p. 306). Also in the case of the fragments dropping at sea, they would descend with their centre of gravity in its lowest position.

[2] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 233.

many are not unlike the rocks that might be gathered from the very locality with which I am here dealing.

A similar origin has been suggested by Mr. Stebbing [1] for the boulders in the Chalk; and it is not unlikely that hereafter other curious breccias and scattered angular stones may be referred to the same class of erratics.

Discussion.

Mr. H. B. Woodward remarked that he had given his explanation of the breccia-beds in the discussion on Prof. Bonney's recent paper. He saw no occasion for the introduction of ice-action. The conditions existing in the Moray Firth were even now somewhat similar to those of Upper Jurassic times, for there are steep and lofty cliffs, such as those by the Sutors of Cromarty, whence great shoots of rock fall on to the foreshore and into the sea. The relations between the Jurassic and older rocks had been modified by post-Jurassic disturbance, as some of the non-brecciated beds were much broken in proximity to the great fault. He was glad to be in general agreement with the Author regarding the sequence of the strata. He had obtained near Navidale a large ammonite of the '*giganteus*'-type, and this, together with the *Isastræa*, had suggested the existence of Portlandian Beds.

Mr. Hudleston said that he had no intimate acquaintance with the locality, and he expressed regret that Prof. Judd was not present to give his views on the additional matter brought before the Society. His classic paper on the 'Secondary Rocks of Scotland' had left as a legacy to future geologists the explanation of the breccia-beds—a challenge which the Author had taken up. The present paper was full of details, and only those intimately acquainted with the locality could grapple with the descriptive portions. The Author was especially capable of determining the horizons at which these breccia-beds occur, and it was interesting to note that they commence in Middle Kimeridge times, and culminate in the zone of *Perisphinctes Pallasi (? Ammonites biplex).* Hence the horizon of the chief breccia-beds was pre-eminently Portlandian, as indeed had been inferred by Prof. Judd, and it was further emphasized by the occurrence of *Isastræa oblonga.*

The sting of the paper was in its tail—that is to say, in the suggestion as to the origin of the breccia-beds. Such beds had always been fruitful of divergent opinion as to their mode of formation, and when geologists were hard pressed for an explanation of facts involving heavy transport, they usually had recourse to ice-action. Such a theory in this case was peculiarly inappropriate. The fauna and flora of the Jurassic Period generally indicated warmth, and the plant-remains of the Portlandian especially so. Take the case of *Isastræa* itself, a reef-building coral requiring a tropical temperature, with an isotherm of 68° Fahr. at the very least. How were we to explain this in conjunction with a postulated

[1] Quart. Journ. Geol. Soc. vol. liii (1897) p. 218.

isotherm of 32° Fahr. every time that a breccia-bed occurred in the series? The Gartymore section was quoted, where there are three breccia-beds intercalated. It was true that the Author did not require a complete glacial period in each case: he would be satisfied with an ice-foot; but an ice-foot at the present day is an exclusively Polar phenomenon, and would require a corresponding climate.

An alternative theory was not an absolute necessity, but he thought the hint thrown out by the previous speaker a very useful one. He had himself pointed out, with reference to Permian and Triassic breccias, how powerful currents, in an oscillating area, would help to distribute cliff-talus. Oceanic currents, which were strong enough to tear up masses of coral, could also disintegrate and transport old shore-accumulations. The Author had himself given us a glimpse of such a talus in the Gartymore Glen, and the speaker thought that the distribution of such material in the way mentioned afforded an explanation of the whole mystery.

Prof. H. G. Seeley remarked that many years after Prof. Judd's classic paper on the 'Secondary Rocks of Scotland' had appeared, there was found on the site of the Recreation-Ground at Tunbridge Wells a Wealden clay presenting characters of Boulder-Clay, but containing fragments of sandstone all of which were angular. These were evidently transported by the action of water, and the deposit was an instance of what that action could accomplish. Until all the ordinary methods of transport proved inadequate to account for the Sutherland breccia-beds, he would hesitate to accept the hypothesis of ice-action.

Dr. F. A. Bather said that, after examination of the district in 1885, he had come to the same conclusion as that expressed by Mr. Woodward. The idea of an ice-foot had not occurred to him, but the intermittent formation of breccia had seemed due to the fact that the beds were deposited along an irregularly sinking cliff coast-line, where the fall of overhanging masses was succeeded by their partial distribution over the shelving floor, the smaller fragments being rounded, until the process was checked by a sudden influx of mud, due perhaps to the estuarine conditions imagined by Prof. Judd. The formation of breccia only recurred when further sinking brought the talus from a fresh cliff-surface within reach of the currents. South of Lothbeg the railway had cut through a marine grit-bed, in which were numerous angular fragments of a soft yellow sandstone, as though they had sunk down into the sand where they fell. Might not the contortion of the shale shown in fig. 8 have been due to ice-pressure at a much later period?

The President said that the facts brought forward by the Author were certainly of extreme interest from the geological point of view, and there could be little doubt of the reasonableness of his opinion that the 'breccia-beds' were made up of the angular waste or screes of steep cliffs, formed of Old Red Sandstone like that of the neighbourhood; while the occurrence of marine shells and land-plants in the associated Kimeridgian shales showed that the sea-shore of the time must have run along this line, or very near it. He did not consider, however, that a complete case had been made out for the existence of an ice-foot here at the period of deposition of these peculiar breccia-beds. Nevertheless, it was as well to bear in mind that the presence of plants or of marine organisms, suggestive of warm climatic conditions, in the geological formations that include rocks for which a glacial origin is claimed, had long been recognized, as for example the Talchírs of India and the Bacchus-Marsh beds of Australia. But he rather preferred, for his own part, to look upon these Scottish breccia-beds as having been formed along a sinking coast—as already pointed out by the previous speaker. The angular fragments might have been rapidly buried by muds or sands, and so preserved from the effects of ordinary wave-action.

The Author expressed regret that he had not made his meaning clear, as speakers who suggested a cliff-talus as the origin of the breccia-beds really adopted his own views; but there was more requiring explanation, namely, the spreading-out into masses of uniform thickness and the angularity of the fragments. Cliff-taluses were forming with more or less rapidity all along the rocky sea-margins, but the breccia-beds had extraordinary characters, and could not therefore be the result of ordinary causes.

He admitted that the Upper Jurassic fauna indicated a comparatively warm climate, and that that of Sutherland, which was the northernmost locality of the deposits of the period, indicated one of the warmest. This led to the conclusion, enunciated in the paper, that the fauna belonged to the locality, but the breccia-fragments had for the most part been derived from a distance. The transport without rounding was by means of broken masses of ice-foot, some of which had been known to travel 1300 miles before melting. Fragments from such masses would fall vertically down, or, if the unmelted parts of the masses stranded, they would pucker up the sea-bottom.

The explanation offered for these breccia-beds in Sutherland would not necessarily apply to any other breccia; but the Author thanked the President for his allusion to Glacial beds in Australia associated with plants, being convinced that the knowledge of the phenomena seen in other lands was the only means of understanding those of our own.

18. *On* SOME *of the* PROTEROZOIC GASTEROPODA *which have been referred to* MURCHISONIA *and* PLEUROTOMARIA, *with* DESCRIPTIONS *of* NEW SUBGENERA *and* SPECIES. By Miss JANE DONALD. (Communicated by J. G. GOODCHILD, Esq., F.G.S. Read March 12th, 1902.)

[PLATES VII–IX.]

INTRODUCTION.

AFTER the creation of the genus *Murchisonia* by A. d'Archiac & E. de Verneuil in 1841,[1] most of the Palæozoic, *Turritella*-like, banded gasteropoda were referred to that genus by later writers. Recently attention has been drawn to the fact that these shells do not all agree with the type, and that there are at least two separate groups, each distinguished by a different form of the outer lip. The typical group is characterized by a slit of greater or less depth in the outer lip, with parallel edges, which is represented by a band on all the whorls. The other group is characterized by having merely a sinus in the outer lip, which in some cases gives rise to a band more or less distinctly limited, while in others it is not defined in any way.

Some of the oldest-known gasteropoda, both elongated and short, have an opening in the outer lip; and as, owing to age and the manner of fossilization, very few have the outer lip well preserved, it is difficult to arrive at a correct conclusion as to its structure, more especially as the form of the lines of growth on the whorls rarely shows the actual depth of the sinus in the outer lip when mature. In the adult the outer lip frequently advances, thus rendering the mature sinus much deeper than the indications of it in the earlier stages of growth. The existence of a true slit in the outer lip, with a break in the continuity of the lines of growth, is still more difficult to ascertain where the outer lip is not visible; for the lines of growth often do not give evidence of the break, but sometimes even appear continuous, as if forming a shallow sinus, from the manner in which the shell is preserved. Again, there are cases, even where the outer lip is fairly well seen, in which it is difficult to decide whether the opening should be considered a slit or a sinus. Where the lines of growth sweep back very obliquely, as in *Hormotoma*, *Ectomaria*, and allied genera, the sinus can be followed with tolerable ease. But where the lines of growth run less obliquely, as in the true *Murchisonia* and *Lophospira*, it is much more difficult to ascertain with accuracy (in the absence of the outer lip) whether there was a slit or not.

With regard to these shells, two important questions require to be answered. Firstly: are forms possessing a slit, or those possessing a sinus, the more primitive; and does the presence of a slit indicate a different line of development from that of the sinus, or is the one

[1] Bull. Soc. Géol. France, vol. xii, p. 154.

evolved from the other? Secondly: are the elongated *Murchisonia* and the shorter *Pleurotomaria* both derived from the same stock, and which appears earlier? We need also to know the full value of the presence or absence of a sinus or slit in classification, and what special characteristics are associated with each respectively.

Before considering the British evidence on these points, it may be well to review the results of the investigations of some foreign palæontologists. Messrs. Ulrich & Scofield and Prof. Koken have devoted considerable attention to the study of the origin of these shells, and the former also to these differences in structure.

The researches of Ulrich & Scofield lead them to the conclusion that the sinus is older than the slit, and they regard *Raphistomina*, Ulr.,[2] as the most primitive genus of this group, it being represented by *Pleurotomaria laurentina*, Billings, in the Calciferous Series. They place this genus in the family Raphistomidæ, and unite it with the Pleurotomariidæ, Euomphalidæ, and Trochidæ in a new suborder, which they name Eotomacea. They consider that this suborder should moreover include the Fissurellidæ, Haliotidæ, Turbinidæ; and provisionally also the Maclureidæ, because of their evident relations to the Euomphalidæ. The Raphistomidæ are characterized by a short form, and have in the outer lip a sinus only, which does not give rise to a band on the whorls. The family contains shells which these authors regard as 'the best known representatives of the original stock from which' the other families 'were almost simultaneously evolved.' They are acquainted with only two Lower Silurian (Ordovician) species possessing a deep parallel-edged slit, namely: *Schizolopha textilis*, Ulr., from the upper part of the Trenton Group, and *Sch. Moorei*, Ulr., from the Lorraine and Richmond Groups, both of which are short forms. The depth of the slit in the former is about two-ninths of the circumference of the last whorl; in the latter it is about one-fifth. *Schizolopha*, Ulr., is referred to the Pleurotomariidæ, in which family Ulrich & Scofield include all genera, whether elongated or short, that possess either a sinus or a slit in the outer lip, giving rise to a band on all the whorls. Thus they place here such elongated forms as *Hormotoma*, *Cœlocaulus*, *Turritoma*, and *Solenospira*, Ulr. (*Ectomaria*, Koken), which other writers have regarded as closely allied to *Murchisonia*, though they have not a slit, but a sinus. They state[3] that none of these genera can be properly united with *Murchisonia*, and they are doubtful whether *M. coronata*, Goldf., the type-form of *Murchisonia*, is a true member of the Pleurotomariidæ.

Prof. Koken diverges somewhat from Ulrich & Scofield in his grouping of the genera. In 1896,[4] previous to the publication of the work on Minnesota, he proposed a new suborder, which he called Sinuata; in this he placed the Raphistomidæ, Euomphalidæ, Euomphalopteridæ, Pleurotomariidæ, Haliotidæ, Fissurellidæ,

[1] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 948.
[2] *Ibid.* p. 930. [3] *Ibid.* pp. 959–60.
[4] Jahrb. d. k.-k. geol. Reichsanst. vol. xlvi, p. 61.

Bellerophontidæ, and Murchisoniidæ. Since then,[1] he has removed the Murchisoniidæ and the Bellerophontidæ from it. He differs from Ulrich & Scofield in separating the elongated forms referred to *Murchisonia* from the Pleurotomariidæ, causing them to constitute a distinct family. He considers that the Euomphalopteridæ also constitute a separate family, instead of regarding them as a genus of the Raphistomidæ; and he excludes moreover the Trocho-Turbinidæ from this suborder, placing them in a different suborder, which he calls Trochomorphi. Prof. Koken, however, agrees with Ulrich & Scofield in regarding the sinus as the earlier structure, and he considers that the slit has gradually developed from it.

It is not quite clear whether Ulrich & Scofield believe the slit to have developed from the sinus or not. On p. 948 (*op. jam cit.*) they state that the slit

'seems to be a later phase in the evolution of the majority of the lines of development that can be traced from the Lower Silurian into subsequent periods.'

On p. 949 they write that in

'*Hormotoma* we have good evidence showing a gradual development of the slit. In all the Lower and Upper Silurian species of this genus a deep V-shaped apertural notch is present, but no slit. In, however, what we consider to be Devonian representatives of the same type of shell (e. g. *Murchisonia desiderata* and *Maia*, Hall) we observe that the bottom of the notch is prolonged into a short slit, but the backward sweep of the edges of the outer lip forming the notch is quite as pronounced as in the earlier species which have no slit. From this and the preceding case, therefore, it is evident that the slit did not take the place of a deep notch, but that it is really an additional and distinct feature.'

Lower down on the same page they say,

'It is interesting to note that, as far as we now know, the slit, which furthermore seems to have been developed almost suddenly, is longer in the earliest species known to possess one than in any of the later Palæozoic forms.'

Though Ulrich & Scofield trace the earliest appearance of representatives of the family Pleurotomariidæ (as constituted by them) in America, they do not throw any light on the first appearance of true *Murchisonia*, for they state[2] that strictly speaking they do not consider that the genus is represented in America. Unfortunately Prof. Koken does not distinguish clearly between the elongated forms having a slit and those with merely a sinus, but he refers all to his family Murchisoniidæ. He considers it probable that the Murchisoniidæ and Loxonematidæ have originated from the same stock,[3] and also that the *Turritellæ*[4] may have developed from them later on. If this were correct with regard to the *Turritellæ*, we should expect them to yield some decided evidence of a very primitive origin, but this is not the case, as the recent researches of W. B. Randles clearly show. It remains to be proved whether the recent forms with a sinus, hitherto referred to *Turritella* and *Murchisonia*

[1] Neues Jahrb. 1898, vol. i, p. 12.
[2] Final Rep. Geol. & Nat. Hist. Surv. Minn. vol. iii, pt. ii (1897) p. 960.
[3] Jahrb. d. k.-k. geol. Reichsanst. vol. xlvi (1896) p. 62.
[4] 'Die Gastrop. des Balt. Untersilurs' Bull. Acad. Imp. Sci. St. Petersb. ser. 5, vol. vii (1897) p. 201.

(*in lit.*), really agree with the former genus in the structure of the animal; or whether they possess distinctive and more primitive characters allying them with these ancient gasteropods. In stating this opinion with regard to the common origin of *Murchisonia* and *Loxonema*, Koken evidently refers more especially to *M. insignis*, Eichw. and allied species having a deep sinus in the outer lip, which I have shown [1] to be distinct from the typical *Murchisonia* and members of the genus *Hormotoma*. It is, however, doubtful whether the true *Murchisoniæ* are derived from this stock. The type-species is of Devonian age, and varies greatly in its spiral angle, size, and ornamentation. I have examined the specimen of *M. coronata*, Goldf. (*turbinata*, Schloth.) in the collection of E. de Verneuil, and it gives distinct evidence (as described by him) of a slit with parallel edges in the outer lip, the filling-up of which forms a band on all the whorls, bordered on each side by a keel. The peristome does not slope back so obliquely above the band, nor advance so prominently below, as in *Hormotoma* and *Ectomaria*, and there is a break in its continuity at the slit, so that there must have been three distinct areas of deposition of the shell, as in *Pleurotomaria*. The slit is not deep, being probably about two-fifths of the width of the body-whorl, and is therefore much shorter than that of the recent species of *Pleurotomaria*. Thus, in the structure of the outer lip and of the band, the *Murchisoniæ* come nearest to the *Pleurotomariæ*; but they are distinguished by being more elongated in form, and by having the aperture longer and slightly channelled below; also they do not appear to have developed an inner pearly layer. The existing species of *Pleurotomaria*, contrary to the *Turritellæ*, are proved by recent investigations to be really primitive in structure.

At present, I know of only one British Ordovician species of the Pleurotomariidæ which has the outer lip sufficiently well preserved to show the slit. It is in the collection of Mrs. Robert Gray, and is not only a new species, but is also probably referable to a new genus, for which I suggest the name *Palæoschisma*. The slit is short and narrow, being rather more than one-fifth of the circumference of the last whorl in depth; it gives rise to a band bordered on each side by a keel, with a slighter submedian keel. Another shell has an opening in the outer lip preserved, but it has more the character of a deep sinus than a short slit; it would also be about one-fifth of the circumference of the body-whorl in depth if intact, although it is much wider in proportion than that of *Palæoschisma*. This shell most probably belongs to the genus *Lophospira*, Whitfield, and both it and the species of *Palæoschisma* are of Llandeilo age.

I shall not now consider the earliest British representatives of the Raphistomidæ, as they do not possess a true sinual band, but shall proceed with the study of the more or less elongated forms having a band. Nor do I think it advisable at present to enter into the subject of the classification and the exact relationship of the

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 257.

different families contained in the suborders Sinuata, Koken and Eotomacea, Ulr. respectively.

From what has been stated with reference to the investigations of Prof. Koken and Messrs. Ulrich & Scofield, it is evident that the earliest appearance of true *Murchisoniæ* still remains to be traced. In the lists of so-called *Murchisoniæ* several distinct genera are associated with them, and they consequently require revision. Mr. Etheridge[1] records twenty-four British species of Proterozoic *Murchisonia.* Four of these, as I have shown, probably belong to the genus *Hormotoma* : namely, *H. articulata*, *H. cingulata*, *H. (?) dubia* (referred to as *M. bellicincta*, Hall), and *H. (?) gracillima* (*M. gracilis*, Hall, var.). The specimen described as *M. angustata*, Hall, was placed by Salter in the genus *Hormotoma*, but I have pointed out[2] that it bears more resemblance to *Ectomaria*; it is, however, in too poor a state of preservation to admit of accurate determination. *M. scalaris*, Salt., too, is so bad a cast that it is impossible to discern its actual structure. Other species, again, must be excluded, as though they possess a band, and in some cases a slit, their characteristics agree more with those of *Lophospira* and some of the genera into which the original genus *Pleurotomaria* has been divided. Such fossils are—*M. angulata*, Sow., *M. balteata*, Phill., *M. cancellatula*, M'Coy, *M. corpulenta*, Sollas, *M. gyrogonia*, M'Coy, *M. inflata*, M'Coy, *M. Lloydii*, Sow., *M. pulchra*, M'Coy, *M. simplex*, M'Coy, *M. subrotundata*, Portl., *M. sulcata*, M'Coy (which is identical with *M. Lloydii*, Sow.), and *M. turrita*, Portl. The six species which remain are—*M. angulocincta*, Salt., *M. bicincta*, M'Coy, *M. corallii*, Sow., *M. elegans*, Sollas, *M. obscura*, Portl., and *M. torquata*, M'Coy. Although the general form of *M. angulocincta* somewhat resembles that of *Murchisonia*, I feel doubtful as to whether it really is a member of that genus; for the lines of growth, though not very distinct, seem merely to indicate a notch. It should probably be referred to the Cicelia subsection of the Perangulata section of the genus *Lophospira*, Whitfield. The other five species, and three new ones which I am about to describe, resemble *Murchisonia* in the band being grooved, and bounded on each side by a keel or raised thread, and also in the direction of the lines of growth. But none of the specimens of these species that I have seen have the outer lip intact, or the lines of growth sufficiently well preserved to show whether they possessed a slit or not. As a rule they are more slender than *Murchisonia*, and, with the exception of *M. elegans*, the whorls are more convex. In this latter characteristic they resemble *Hormotoma*, but the lines of growth are less oblique and the spiral ornamentation is more marked. *M. elegans* comes nearer to the description of *Goniostropha*, Œhl. than to that of any other section or subgenus of *Murchisonia*, and it seems advisable to place it there at present. The others, however, do not appear to agree with any previously described division of the

[1] 'Foss. Brit. Is.' vol. i (Palæozoic) 1888, p. 113.
[2] Quart. Journ. Geol. Soc. vol. lv (1899) p. 259.

Murchisoniidæ, and it would be convenient, at any rate provisionally, to regard them as a separate section or subgenus, for which I would suggest the name *Cyrtostropha*. At the same time, it is possible that further research may prove that these species are not all closely related one to the other, and further subdivision may be necessary.

Another new species which I am describing is from the Wenlock Formation of Dudley, and is more like the type of *Murchisonia* than any other Silurian or Ordovician species with which I am acquainted in its robust form, the direction of the lines of growth, and the structure and position of the band. The latter is not seen to be grooved as in *M. turbinata*, Schloth., but this may possibly be the result of the manner of preservation, since it only occurs as an external mould. No evidence, however, is given of a slit in the outer lip, so it cannot be referred to *Murchisonia* without a query.

From the material at present available, we find that, in the British Isles as well as in America, the elongated forms with a sinus or a notch precede those with a slit, and they also seem to do so in the Baltic Provinces. In the latter region the only shell recorded by Koken which may be a true *Murchisonia* is *M. Meyendorfi*, Kok. from Borkholm (Ordovician), but it is not clearly shown whether it possesses a slit. There are at least two, and possibly three, distinct groups of these sinuated shells with a band—the one containing *Hormotoma*, *Ectomaria*, etc., with the lines of growth sweeping back to and forward from the band very obliquely; a second, containing *Lophospira*, having the lines of growth less oblique, and agreeing more in direction with those of *Murchisonia*, only the band is prominent instead of being grooved; *Cyrtostropha* may perhaps form a third group, having the lines of growth but slightly oblique and the band grooved. In a former paper[1] I entered fully into the range of the genera *Hormotoma* and *Ectomaria*; but, for the sake of comparison, I will here repeat it briefly. In the British Isles they apparently commenced in the Durness Limestone (Upper Cambrian?), and do not appear, so far as I know, after the close of the Silurian Period; indeed, *Ectomaria* is not represented later than the Ordovician. In America, Ulrich & Scofield state that *Hormotoma* commences in the Calciferous Group and extends to the end of the Silurian. They consider that *Hormotoma* is represented in the Devonian by *M. desiderata* and *M. Maia*, Hall: species which agree with *Hormotoma* in possessing strongly retreating and advancing lines of growth; but they say that a slit is added to the bottom of the sinus. *Ectomaria* appears to be confined to the Ordovician, both in America and in the Baltic Provinces. *Hormotoma* ranges from the Ordovician and throughout the Silurian in the Baltic Provinces and Scandinavia. *Lophospira*, Whitfield, as emended by Ulrich, contains both elongated and short forms, and is said to range from the Calciferous Group upward to the middle

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 251.

of the Devonian. The British species are not fully worked out; but they begin, so far as known, in the Durness Limestone, and continue throughout the Ordovician and into the Silurian Period. The elongated forms probably have *L. (?) angulocincta* and the shorter *L. borealis,* from the Durness Limestone, as their earliest representatives. *Cyrtostropha* ranges from the Bala Formation (Ordovician) upward throughout the Silurian Period.

From what has been said, it is clear that we have no certain evidence of the appearance of typical *Murchisoniæ* in the British Proterozoic rocks, but the genus may have begun in the Wenlock Formation and be represented by *M. (?) dudleyensis* (p. 320). Possibly some of the forms from the Silurian of Gotland described by Lindström in his Ornatæ division may be true *Murchisoniæ*; but the existence of a slit is not indicated in any of the figures, and Ulrich refers them to *Lophospira*, with the exception of *M. deflexa* and *M. crispa.* The latter is represented with an opening in the outer lip, which has, however, more the appearance of a sinus than a slit. As before stated (p. 316), the earliest-known British species that exhibits a slit is a short form occurring in rocks of Llandeilo age. America possesses an older representative of *Pleurotomaria* showing the slit, in *Schizolopha textilis*, Ulr., which is from the upper part of the Trenton Group. So far, no light is thrown on the question as to whether *Murchisonia* and *Pleurotomaria* are derived from the same stock; nor have I yet met with any specimens showing a transition from the sinus to the slit.

Before proceeding to describe the species above mentioned, I would like to make two emendations in my last paper. I think that the species described as *Hormotoma antiqua*[1] should be transferred to the genus *Ectomaria*, the body-whorl being less produced, the whorls wider, and the lines of growth more oblique, than is usual in *Hormotoma.* I was previously much impressed by its resemblance to *E. Nieszkowskii*, Schmidt, the type of the genus *Ectomaria*, but the slight prominence of the keels caused me to place it in *Hormotoma.* A further examination of the specimen has led me, however, to conclude that this may be an accident in the manner of preservation, and that the weight of the evidence is in favour of its reference to *Ectomaria.*

The other correction that I wish to make concerns the locality of the specimen of *Hormotoma articulata* mentioned on p. 269 (*op. cit.*) as from the 'railway-tunnel shale' of Sedgley. Mr. Madeley informs me that the locality should be stated as Dudley. I may also mention here that I have seen another example of this species in the Nicholl Collection, in the Cardiff Museum, from the Wenlock Beds of Garcaed, Usk.

When I described *Ectomaria girvanensis*[2] from rocks of Llandeilo [Lapworth] age at Minuntion, I knew of only two specimens in the

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 270 & pl. xxii, fig. 9.
[2] *Ibid.* p. 256.

collection of Mrs. Gray. She has now six others, one of which shows the lines of growth distinctly, and is figured in Pl. VII, fig. 11.

I am greatly indebted for the loan of specimens to Mrs. Robert Gray, Edinburgh; Prof. Hughes, Cambridge; Prof. Sollas, Oxford: the late Prof. Lindström, Stockholm; the Geological Survey of Scotland: and the respective committees of the Museums at Carlisle, Bristol, and Cardiff. I must also render thanks for assistance in studying collections to Mr. E. T. Newton, Dr. A. Smith Woodward, Mr. R. B. Newton, Mr. H. A. Allen, Mr. Madeley of Dudley, and Dr. Scharff of Dublin; and for help in looking up references to Mr. C. D. Sherborn. To Mr. Goodchild I am much obliged for revising this paper.

Family MURCHISONIIDÆ, Koken.

Genus *Murchisonia*, d'Arch. & de Vern.

MURCHISONIA (?) DUDLEYENSIS, sp. nov. (Pl. VII, fig. 1.)

Diagnosis.—Shell somewhat robust, elongated, turreted, composed of more than nine whorls. Whorls increasing gradually, strongly angular below the middle of the earlier whorls and rather above the middle of the body-whorl, flattened or slightly concave above, convex below. Angle surmounted by a broad, flat band, which represents the slit or sinus in the outer lip. Lines of growth imperfectly seen, sloping forward below the band at a moderate angle. Aperture unknown. Surface apparently smooth.

Remarks and Resemblances.—This species, so far as I know, is represented only by two external moulds. In its robust form and broad prominent band it recalls the Carboniferous species *M. kendalensis*, M'Coy; also some of the smooth varieties of the type *M. turbinata*, Schloth., especially where the band of the latter is so worn as not to show its grooved form limited on each side by a strong keel. As the species under discussion is not very well preserved, it is possible that the band may also have been originally bounded by keels in the earlier stages of growth, as in *M. kendalensis*—if not in every stage, as in *M. turbinata*. Taking this into consideration, I refer it to *Murchisonia*, though the aperture and lines of growth are not sufficiently preserved to show whether it possessed a true slit in the outer lip. Among Silurian species it most nearly resembles *M. attenuata*, His., but differs in having the band situated lower on the whorl, the sutures not so oblique, and the lines of growth sloping less strongly forward below the band.

Localities and Horizon.—The largest specimen is in the Dudley Museum, and is from shale between two divisions of the Wenlock Limestone, Dudley. The apex is imperfect, and the nine existing whorls measure 56 millimetres in length and 19 mm. in width. The other and better preserved example is in the Museum of Practical Geology, London, and is figured in Pl. VII, fig. 1. It is from the Wenlock Limestone of Dudley, and is broken so that only six whorls remain, which measure 38 millimetres in length and 14 mm. in width.

Section Goniostropha, Œhlert.[1]

Goniostropha (?) elegans (Sollas). (Pl. VII, figs. 2–4.)

Murchisonia elegans, W. J. Sollas, 1879, Quart. Journ. Geol. Soc. vol. xxxv, p. 499 & pl. xxiv, fig. 8; R. Etheridge, 1888, 'Foss. of Brit. Is.' vol. i (Palæozoic) p. 418.

Diagnosis.—Shell slender, elongated, turreted, composed of about nine whorls. Whorls increasing gradually, angular generally below the middle, concave above the angle, flat below. Ornamentation consisting of a fine thread above, immediately beneath the suture, and another below which shows above the suture on some of the whorls of the spire. Sinual band composed of two strong threads placed rather near together, with a groove between them. Lines of growth not very distinct, sloping back to the band above and forward again below, with a moderate degree of obliquity; not seen on the band itself. Base produced. Aperture unknown.

Remarks and Resemblances.—All the members of this species that I have seen occur as external moulds, and the figures are drawn from wax-impressions. The type is in the Bristol Museum, and there are three other examples in the Cardiff Museum. Associated with the specimen called *M. elegans* are three individuals referred to *M. gracilis*, Hall, by Prof. Sollas, which appear identical with it, and only differ in the band being rather higher above the suture. In some specimens the sutures appear very oblique, and in others almost horizontal; the original shells have evidently been contorted obliquely, so that the degree of obliquity of the sutures differs on each side of an individual. In one case a representation of the whole contour of the shell has been obtained, and the differences in the obliquity of the suture, and in the degree of the spiral angle, may be observed according to the view taken on the single individual, instead of on different ones. The spiral angle may also appear either greater or less, according to the section of the mould made in breaking the rock. In the type (one of the individuals marked *M. gracilis*), and also in one of the specimens at the Cardiff Museum, the spiral angle appears wider than the normal; while in two other examples at the Cardiff Museum the spiral angle is less, and the whorls more exsert, which characters give the shells a very slender appearance. *Goniostropha elegans* differs from *Murchisonia gracilis*, Hall, in the whorls being more excavated above, and in the form of the band; it is quite distinct from this, and from any other species with which I am acquainted. As neither the outer lip nor the lines of growth on the band are preserved, it is impossible to decide whether the shell possessed a slit or a sinus. It is much less robust than the typical *Murchisonia*, and in general appearance agrees more nearly with the Section *Goniostropha*,

[1] Bull. Soc. Étud. Sci. Angers, 1887 (sep. cop.) p. 13.

Œhl. than any other: consequently I place it there provisionally. M. Œhlert does not state whether the forms grouped in this Section possess a slit or a sinus.

Dimensions.—The type (Pl. VII, fig. 2) has the apex broken; the six remaining whorls measure 13 millimetres in length and 5 mm. in width. The specimen marked *M. gracilis* (Pl. VII, fig. 3) has portions of six whorls preserved, in a length of 14 mm. An example (Pl. VII, fig. 4) with exsert whorls, in the Cardiff Museum, has about eight whorls in a length of 23 millimetres.

Localities and Horizon.—The specimens in the Bristol Museum are from the *Ctenodonta*-bed in the Rhymney Grit, Rhymney Hill, Cardiff, and are of Lower Wenlock age. Those in the Cardiff Museum are in the Storrie Collection, from Tymaur Lane, Rhymney, near Cardiff; and the rock in which they occur is similar to that just mentioned.

Subgenus Cyrtostropha, nov.

Diagnosis.—Shell elongated, conical, composed of numerous whorls. Whorls more or less convex, slightly flattened above, generally with a prominence or subangularity between the upper suture and the band. Band grooved, bordered on each side by a raised thread or keel, submedian, and situated on the widest part of the whorl. Lines of growth curving back to, and forward from, the band with a moderate degree of obliquity, more oblique below, and forming crescents on the band itself. Ornamentation consisting of spiral lines and a shallow groove immediately above the band. Aperture subovoid. Columella nearly straight.

Type, *Cyrtostropha corallii* (Sow.).

Remarks and Resemblances.—This subgenus differs from the typical *Murchisonia* in its more convex whorls and more oblique lines of growth, especially below the band, and probably in the presence of a sinus instead of a slit in the outer lip. None of the specimens with which I have met have the aperture well preserved, so it is impossible at present to determine this latter point. *Cyrtostropha* greatly resembles *Hormotoma* in the convexity of its whorls, but is distinguished by the less oblique lines of growth and the spiral and grooved ornamentation.

Dimensions.—The length varies from about 6 to 36 millimetres.

Range.—From the Bala Formation up to and throughout the Silurian Period.

Cyrtostropha corallii (Sow.). (Pl. VII, figs. 5 & 6.)

Pleurotoma corallii, J. de C. Sowerby, 1839, 'Sil. Syst.' p. 612 & pl. v, fig. 26.

Murchisonia corallii, A. d'Archiac & E. de Verneuil, 1841, Bull. Soc. Géol. France, vol. xii, p. 160; ? F. M'Coy, 1846, 'Syn. Silur. Foss. Irel.' p. 16; J. Phillips, 1848, Mem. Geol. Surv. vol. ii, pt. i, 'Malvern Hills' p. 258; H. G. Bronn, 1848, 'Index Palæont.' pt. i, p. 747; A. d'Orbigny, 1850, 'Prodr. de Paléont. Strat.' vol. i, p. 31; J. Morris, 1854, 'Catal. Brit. Foss.' 2nd ed. p. 259; J. Sowerby, 1867, 'Siluria' 4th ed. pl. xxiv, fig. 7 & p. 532; J. J. Bigsby, 1868, 'Thes. Silur.' p. 158; A. C. Ramsay, 1881, Mem. Geol. Surv. vol. iii, 'Geol. N. Wales' 2nd. ed. p. 468; J. D. La Touche, 1884, 'Geol. of Shropshire' p. 80 & pl. xviii, fig. 634; R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Palæozoic) p. 113.

Diagnosis.—Shell conical, composed of more than six whorls. Whorls increasing gradually, somewhat convex, adpressed at the suture. Band situated on the widest part of the whorl, near the middle of the body-whorl, and slightly below the middle of the earlier whorls, broad, flat, and rather prominent, margined on each side by a fine raised thread. Above the band is a wide, shallow groove, of nearly the same width as the band itself; below the band is a strong keel which shows just above the suture. Lines of growth moderately oblique, curving back to the band above and forward again below, where they are strong and thread-like, and forming somewhat indistinct crescents on the band itself. Aperture longer than wide, columella nearly straight, inner lip spreading round its base. Umbilicus closed. Base convex.

Remarks.—This species was first described and figured by Sowerby, in Murchison's 'Silurian System,' as a member of the genus *Pleurotoma*; but his specimen was too imperfectly preserved to show much of its real character, merely traces of the band being visible. Its specific name evidently arises from its generally occurring embedded in coral. The broad, solid-looking band distinguishes it from all other species.

Localities and Horizon.—The best preserved specimen (Pl. VII, fig. 5) with which I have met is in the Grindrod Collection, University Museum, Oxford: it is from Upper Ludlow rocks, the exact locality of which is not given, but it is most probably from the neighbourhood of Malvern. The apex is wanting; the remaining five and a half whorls measure 19 millimetres in length and 7 mm. in width. The coral in which the shell is embedded is labelled *Stenopora fibrosa* var. *incrustans*. There are also portions of several other examples in this collection from the same strata. The type, which is in the possession of the Geological Society, is from the top bed of the Aymestry Limestone at Larden: it consists of four and a half whorls, the earlier ones also are broken off, and those left have a length of 12 mm. Other localities recorded in the 'Silurian System' are Ludlow Promontory; Fownhope, Botteville, north side of Caer Caradoc; Aran, near Newnham, north-east of Gaerfawe; and Bradnor Hill, Kington. In the Museum of Practical Geology, Jermyn Street, are specimens from Prior Court, Hales End, and Frith Farm, Malvern. There are also casts marked *Murchisonia corallii*, from Whitcliff, Ludlow, and Brook Wern, Llandeilo, but they are not well enough preserved for certain identification. The Piper Collection, in the Natural History Museum, South Kensington, contains an example from Frith, Ledbury. In the 'Geology of the Malvern Hills,' Phillips records this species from the following localities:—Malvern District: Overley, Hope End Pond, Coomb Hill. Abberley District: Ankerdine Hill. Woolhope District: Perton, Pride's Court, Hayle, Pilliard's Barn, Bodenham. Builth District: Henllwyn Hill, Cwm Craigddu. In all these cases the beds in which the fossil was found are of Upper Ludlow age. La Touche states that this species occurs in Ludlow rocks at Botville, Stoke Wood. M'Coy says that *Murchisonia corallii* is found at

Knockmahon, Tramore (Waterford). I have seen the fossil to which he refers in the Museum of Science & Art, Dublin; it is merely a cast, and admits of no precise comparison. The Rev. M. S. Donald has external casts from the Kirkby-Moor Flags, Lily Mere; and there are also several external casts in the Woodwardian Museum, Cambridge, from the same beds at Benson Knott, Kendal.

CYRTOSTROPHA SCITULA, sp. nov. (Pl. VII, figs. 7, 7 *a*, & 8.)

Diagnosis.—Shell elongated, turreted, composed of more than eleven whorls. Whorls increasing somewhat gradually, slightly angular below the middle, especially in the earlier stages of growth; contour convex both above and below the angle, convexity greater in the later whorls. Band situated on the angle, grooved and limited on each side by a keel. Lines of growth fine, curving back to the band above and forward below at a moderate angle, not seen on the band itself. Ornamentation consisting of several spiral raised threads, a strong one being situated about midway between the band and the suture below, and another above, bounding a slight depression between it and the band; there are also two or three finer threads between this and the upper suture. Sutures deep. Aperture unknown.

Remarks and Resemblances.—This species greatly resembles *C. corallii* in the contour of the whorls and in its occurrence embedded in coral, and it may possibly be a variety of that shell. It differs in having a greater spiral angle and more evenly convex whorls which are not adpressed at the suture, in the band being deeply grooved, rather narrower, and its limiting threads being stronger; also the thread below the band is not so strong, and occurs midway between the band and the suture, instead of immediately above the latter. It is distinguished from *Murchisonia bicincta*, M'Coy, by its greater robustness, and in the band being higher above the suture and bounded by stronger keels.

Dimensions and Localities.—None of the specimens of this species with which I have met have the aperture preserved, and they are all embedded in coral, with the exception of a small external cast from Spital, Kendal, in the Woodwardian Museum, Cambridge, which is probably this species, though not well enough preserved to admit of precise determination. The largest is in the Piper Collection, Natural History Museum, South Kensington: it has about seven and a half whorls preserved, with a length of 27 millimetres and a width of $9\frac{1}{2}$ mm. It was found at Frith, Ledbury.

A specimen (Pl. VII, fig. 7), consisting of eleven whorls, is in the Grindrod Collection, University Museum, Oxford. It has a length of 20 millimetres and a width of 9 mm. The locality is not recorded, but the fossil is probably from the neighbourhood of Malvern.

In the Worcester Museum there is a very young individual, consisting of eight whorls, the length of which measures 6·5 millimetres, and the width 3 mm. It was found in the Upper Ludlow of Chance's Pitch, Malvern.

CYRTOSTROPHA BICINCTA (M'Coy). (Pl. VII, figs. 9, 9 *a*, & 10.)

Murchisonia bicincta, F. M'Coy, 1846, 'Syn. Silur. Foss. Irel.' p. 16 & pl. i, fig. 17; J. Morris, 1854, 'Catal. Brit. Foss.' 2nd ed. p. 258; J. Sowerby, 1867, 'Siluria,' 4th ed. p. 532; J. J. Bigsby, 1868, 'Thes. Silur.' p. 157; (?) J. Armstrong, J. Young, & D. Robertson, 1876, 'Catal. West. Scot. Foss.' p. 19; A. C. Ramsay, 1881, Mem. Geol. Surv. vol. iii, 'Geol. N. Wales' 2nd ed. p. 414; R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Palæozoic) p. 113; (?) J. Horne & B. N. Peach, 1899, Mem. Geol. Surv. 'Silur. Rocks of Britain' vol. i, pp. 682, 695 & 699; *non* J. Hall, 1847, 'Pal. N. Y.' vol. i, p. 177 & pl. xxxviii, fig. 5.

Diagnosis.—Shell small, conical, composed of about ten whorls. Whorls slightly convex, increasing gradually. Band situated on the widest part of the whorl, low down and but a short distance above the suture, almost level with the surface, being but slightly grooved, bounded on each side by a strong raised thread. There is a slight groove above the band, limited by a faint thread, and indications of two other threads are perceptible immediately below the suture. Lines of growth not preserved. Aperture unknown.

Remarks and Resemblances.—The Museum of Science & Art, Dublin, contains but one specimen of this species, which is M'Coy's type (Pl. VII, fig. 9). As neither aperture nor lines of growth are preserved, its exact relationship cannot be ascertained. It bears considerable resemblance to *C. scitula* and *C. corallii*, therefore I refer it to *Cyrtostropha*. It is distinguished from both these species by its much smaller size, less prominent whorls, and the lower position of the band. Alhough it is entered in the list of Western Scottish fossils, I have not seen any shell identical with this in the Scottish collections. This species must not be confounded with *Murchisonia bicincta*, Hall, which is quite distinct, and has since been referred to *Lophospira* by Whitfield,[1] being considered by him as one of the types of that genus.

Dimensions.—The length = 6·25 millimetres, and the width = about 3 mm.

In the Museum of Practical Geology, Jermyn Street, are three specimens which agree exactly with *C. bicincta* (M'Coy) in form and ornamentation, except that they are reversed. The varietal name *perversa* is inscribed on the tablet, but I have been unable to obtain any clue as to its origin. It has evidently been written there since the publication of the Catalogue in 1878, as it is not included therein. These shells are slightly larger than the type, and all are imperfect, none showing either apex or base. Two consist of seven whorls: the larger measures $8\frac{1}{2}$ millimetres in length; the other, which is figured in Pl. VII, fig. 10, measures 8 mm. in length. The smallest specimen has only four and a half whorls in a length of 5 millimetres.

Horizon and Locality.—The type, as well as these reversed specimens, occurs in limestone of Bala age, Chair of Kildare.

[1] Bull. Amer. Mus. Nat. Hist. vol. i (1886) p. 312.

Cyrtostropha torquata (M'Coy). (Pl. VIII, figs. 1, 1 *a*, & 1 *b*.)

Murchisonia torquata, F. M'Coy, 1852, 'Brit. Palæoz. Foss.' p. 294 & pl. xiv, figs. 19, 19 *a*; J. Morris, 1854, 'Catal. Brit. Foss.' 2nd ed. p. 259; J. Sowerby, 1867, 'Siluria' 4th ed. p. 533; J. J. Bigsby, 1868, 'Thes. Silur.' p. 159; J. W. Salter, 1873, 'Catal. Cambr. Foss.' p. 185, *non* p. 191; A. C. Ramsay, 1881, Mem. Geol. Surv. vol. iii, 'Geol. N. Wales' 2nd ed. p. 468; R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Palæozoic) p. 114; H. Woods, 1891, 'Catal. Type Foss. Woodward. Mus.' p. 108.

Diagnosis.—Shell conical, composed of about eight whorls. Whorls increasing at a moderate rate, convex, with a swelling or thickening of the upper edge immediately below the suture. Band situated near the middle of the body-whorl and considerably below on the earlier whorls, slightly grooved, and bounded by a raised thread on each side. Lines of growth sharp, stronger above than below, curving back to the band above and rather more obliquely forward below, and forming crescents on the band itself. Aperture sub-ovoid.

Remarks and Resemblances.—This species is at present known only in the form of external moulds, which are more or less weathered and imperfect. The band and aperture are not very well preserved in any of the specimens. Salter, in his 'Catalogue of the Cambrian & Silurian Fossils' p. 191, refers *Murchisonia torquata* to *Hormotoma*. Though greatly resembling members of that genus in its convex whorls, it differs decidedly in having less oblique lines of growth. It is most like some of the species of *Cyrtostropha*, and I refer it to that subgenus for the present, because although the spiral lines with which the members are generally ornamented are not visible, there appear to be traces of a groove above the band on one or two specimens. This is a very characteristic feature in *Cyrtostropha*, in conjunction with the convex whorls and grooved band.

Dimensions.—The largest example that I have seen is in the Woodwardian Museum, Cambridge, from the Kirkby-Moor Flags of Spital. It is very badly preserved, the apex is absent, and only six whorls remain: these measure 18 millimetres in length and 7 mm. in width. Next to it, in the same piece of rock, is the specimen which was probably M'Coy's type: it consists of about eight whorls, measuring 11 mm. in length and 6 mm. in width. Fragments of other specimens from both Spital and Benson Knott show the surface better. Two of the examples figured (Pl. VIII, figs. 1 & 1 *a*) are in the Rev. M. S. Donald's collection; fig. 1 measures 13 millimetres in length and 5 mm. in width.

Localities and Horizon.—M'Coy states that this species is common in the Upper Ludlow of Spital and Benson Knott, Kendal; also in the tilestones of Storm Hill, Llandeilo (Caermarthenshire). There are specimens from all these localities in the Woodwardian Museum, Cambridge. Salter (*op. cit.* p. 191) also refers an external mould from Pontaryllechau to this species; but both it and that from Storm Hill are too poorly preserved to be referred to *C. torquata* with certainty, there being no trace of band or surface-ornamentation. Some external moulds, also from Kendal, are in the Carlisle Museum. The Rev. M. S. Donald has about six specimens in his collection, from the Kirkby-Moor Flags, Lily Mere.

CYRTOSTROPHA OBSCURA (Portl.). (Pl. VIII, figs. 2, 2 *a*, & 3.)

Loxonema obscura, J. E. Portlock, 1843, 'Geol. Rep. Londonderry' p. 415 & pl. xxxi, fig. 3; (?) H. G. Bronn, 1848, 'Index Palæont.' pt. i, p. 670.

Murchisonia obscura, J. Morris, 1854, 'Catal. Brit. Foss.' 2nd ed. p. 259; J. Sowerby, 1867, 'Siluria' 4th ed. p. 197, Foss. 40, fig. 3; J. J. Bigsby, 1868, 'Thes. Silur.' p. 158; (?) J. Armstrong, J. Young, & D. Robertson, 1876, 'Catal. West. Scot. Foss.' p. 19; *pars*, A. C. Ramsay, 1881, Mem. Geol. Surv. vol. iii, 'Geol. N. Wales' 2nd ed. p. 414; R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Palæozoic) p. 113; (?) J. Horne & B. N. Peach, 1899, Mem. Geol. Surv. 'Silur. Rocks of Britain' vol. i, pp. 682 & 695; (?) B. N. Peach, J. Horne, & A. Macconochie, 1901, in 'Fauna, Flora, & Geol. of Clyde Area' publ. by Local Comm. for Meeting of Brit. Assoc. Glasgow, p. 438.

Diagnosis.—Shell elongated, turreted, composed of more than seven whorls. Whorls increasing at a moderate rate, convex, more or less smooth. Band situated near the middle of the body-whorl and below the middle of the whorls of the spire, slightly depressed, bounded by an indistinct ridge on each side. Lines of growth sloping back to the band above, and forward again below. Aperture imperfectly known, sub-ovoid. Base produced. No umbilicus.

Remarks.—The only known examples of this species are very imperfect, being fragmentary, compressed, and much weathered. It bears more resemblance to *Cyrtostropha* than to true *Murchisonia*, especially as on a wax-impression (taken from an external mould) there appear to be indications of the groove above the band bounded by a thread, so universal in this subgenus. It was originally regarded as *Loxonema* by Portlock, but the possession of a band distinguishes it from the members of that genus.

Localities and Horizon.—In the Museum of Practical Geology, Jermyn Street, are two specimens which are little better than internal moulds, and the external impression of one of these, from rocks of Bala age at Desertcreight (Tyrone). One of these (Pl. VIII, fig. 2) is Portlock's type; it has the apex broken, the seven remaining whorls measuring 27 millimetres in length and 13 mm. in width; as the specimen is flattened by pressure, the width appears greater than it must have been originally. Another fragment from Tyrone, consisting of about two whorls, is referred to this species, but I am uncertain as to its identity; it is embedded in the matrix, and the band appears to be higher than in the type. In the Harkness Collection, in the Carlisle Museum, are two examples: one from the Chair of Kildare, and the other from Pomeroy, referred to this species, but they are too badly preserved to admit of precise determination. I feel very doubtful whether the specimens in the Scottish lists which are called *Murchisonia obscura* are really referable to this species; those in Mrs. Gray's collection are certainly not identical.

CYRTOSTROPHA ROBUSTA, sp. nov. (Pl. VIII, fig. 4.)

Diagnosis.—Shell elongated, conical, composed of more than ten whorls. Whorls increasing gradually, convex, slightly flattened above. Band situated on the widest part of the whorl, rather below the middle, almost level with the surface, bounded on each side by a strong raised thread. Lines of growth sloping back to it above and advancing with greater obliquity below, not seen on the band itself. There is a shallow groove immediately above the band, and several fine threads ornament the surface. A short distance beneath the band is a subangularity, below which the base appears rather flattened; between this angularity and the band there is also a slight thread. Aperture imperfectly known.

Remarks and Resemblances.—There is but one specimen of this species at present known, and it is in Mrs. Gray's collection. It resembles somewhat *C. obscura*, Portl., but the whorls appear to be broader and the lines of growth more oblique than in that species, of which the only examples are so badly preserved that it is difficult to make a just comparison.

Dimensions.—Length=36 millimetres; width=14 mm.

Locality and Horizon.—Thraive Glen, in beds of Upper Bala age [Lapworth].

CYRTOSTROPHA ORDOVIX, sp. nov. (Pl. VIII, figs. 5 & 5 *a*.)

Diagnosis.—Shell elongated, turreted, composed of more than nine whorls. Whorls increasing gradually, more or less convex, but slightly flattened above. Band submedian on the body-whorl, but below the middle of the earlier whorls, concave, and bounded on each side by a strong raised thread. Ornamentation consisting of a ridge or swelling just below the suture, and several fine spiral lines, the strongest of which is a short distance above the band, bounding a space less than the width of the band. Lines of growth sloping back to the band above, with but slight obliquity, and advancing below with greater obliquity, not seen on the band itself. Aperture imperfectly known.

Remarks and Resemblances.—This species, so far as I know, is at present represented by only three specimens in Mrs. Gray's collection, and they are all more or less imperfect and crushed. The ornamentation is indistinct at the best, and is not seen on the earlier whorls. *C. Ordovix* somewhat resembles *Hormotoma Grayiana*, but is distinguished from it by being more slender, by the spiral ornamentation, and by the lesser obliquity of the lines of growth.

Dimensions.—The largest specimen is figured in Pl. VIII, figs. 5 & 5 *a*, and consists of seven whorls, both apex and base being broken; it measures 25 millimetres in length, and the penultimate whorl measures about 7·25 mm. in width. Another example has eight and a half whorls in a length of 22 millimetres.

Locality and Horizon.—Shalloch Mill (Ayrshire), in beds of Middle Bala age [Lapworth].

Genus *Hormotoma,* Salt.

Subgenus GONIOSPIRA, nov.

Diagnosis.—Shell elongated, composed of numerous gradually increasing whorls. Whorls angular near the middle, surface smooth. A narrow, prominent, more or less convex and indistinctly limited band on the angle. Lines of growth sloping back to the band above and very obliquely forward below, curved on the band itself, indicating the existence of a deep V-shaped sinus in the outer lip. Aperture imperfectly known, inner lip slightly thickened. Base produced. Umbilicus closed. Sutures very oblique.

Type, *G. filosa*, sp. nov.

Remarks and Resemblances.—In a former paper[1] I referred to this group of shells as greatly resembling *Hormotoma*, regarding it as a subgenus, but I had not then met with any British specimens, and therefore abstained from naming it. *Goniospira* is like *Hormotoma* in its elongated smooth form, and in the character of the sinus and the lines of growth. It differs in possessing more angular whorls, and in the band being prominent and slightly convex. From *Lophospira* it is distinguished by the band being less distinctly limited, and by the greater obliquity of the lines of growth.

Dimensions.—The length varies from 23 up to possibly 75 millimetres.

Range.—This subgenus most probably ranges from the Ordovician up to the end of the Silurian System. The only known British representative is from the Middle Bala [Lapworth] of the Girvan district. *Murchisonia Artemesia*, Billings,[2] from the Calciferous Group of Canada, which has a convex band, possibly belongs here, but the whorls appear less angular. Also *M. attenuata*, His.,[3] from the Silurian of Gotland, has the essential characteristics of this subgenus, although the angularity on the base is not so marked.

GONIOSPIRA FILOSA, sp. nov. (Pl. VIII, figs. 6 & 6 *a*.)

Diagnosis.—Shell elongated, turreted, composed of more than eight whorls. Whorls increasing gradually, angular near the middle, slightly excavated above, flat below, with a strong angle on the base, which is hidden by the suture in the earlier whorls. The only ornamentation is a raised thread immediately below the suture. Band prominent, narrow, convex, situated on the angle. Lines of growth sharply defined, curving back to the band above, and very obliquely forward below, continuing across the band, and forming a V-shaped sinus. Sutures very oblique. Aperture longer than wide; columella-lip slightly thickened. Base produced. Umbilicus closed.

Remarks and Resemblances.—This species is represented at present by only one specimen in Mrs. Gray's collection, which is remarkably well-preserved, and shows the lines of growth distinctly. As I observed in describing the subgenus, it bears most resemblance to *Hormotoma*: especially the earlier part of the spire, when the outer shell-layer is removed, obliterating the prominence of the band, which here appears level with the surface, having the lines of growth continuous across it from suture to suture. The smooth

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 260.

[2] Geol. Surv. Canad. 'Palæoz. Foss.' vol. i (1865) p. 345 & fig. 332.

[3] Lindström, 'Silur. Gastrop. & Pterop. Gotl.' Kongl. Svensk. Vet.-Akad. Handl. vol. xix, No. 6 (1884) p. 130 & pl. xii, figs. 20–24.

form, combined with the angular whorls, distinguishes it from all other species.

Dimensions.—There are five whorls, with the impression of three more in the matrix. The length = 23 millimetres, and the width = 8 millimetres.

Locality and Horizon.—Shalloch Mill (Ayrshire), in rocks of Middle Bala age [Lapworth].

Genus *Turritoma,* Ulrich.[1]

Diagnosis.—Shell elongated, consisting of numerous whorls. Whorls somewhat flattened, convex above, slightly concave in the middle, and most prominent in the lower part where the band is situated; other features apparently as in *Hormotoma.*

Type, *T. acrea* (Billings).

Ulrich states that

> 'this is a well-marked group of species, readily distinguished from *Hormotoma* (to which the group is related) by the flattened instead of uniformly rounded volutions, and by the lower position of the band.'

Besides the type, he considers that it includes *T. Ada* (Billings), *T. Boylei* (Nicholson), *T. constricta* (Whiteaves), *T. cava* (Lindström), and *T. Laphami* (Hall). The type, judging from the figure, apparently has the whorls slightly convexo-concave, but this does not appear to be the case with *Murchisonia Boylei* and *M. Laphami*; indeed, Nicholson states that the whorls of the former are flat.[2]

Remarks.—In Mrs. Gray's collection I have met with two species which correspond more nearly to the diagnosis of *Turritoma* than that of any other genus, except that the whorls are not convexo-concave, but flat or very slightly convex. I therefore refer them here provisionally. They differ from *Hormotoma* in this flatness of the whorls, in the less produced base, and also in the band being lower than is usually the case in that genus. The form of the band and the direction of the lines of growth are similar to those of *Hormotoma.* They have most in common with *H. cingulata* (His.),[3] the flattened whorls and low-lying band of which caused me to regard it as a doubtful member of the genus; and if the convexo-concavity of the whorls be not an essential character of *Turritoma*, that species should perhaps be removed hither.

TURRITOMA (?) POLITA, sp. nov. (Pl. VIII, figs. 7 & 8.)

Diagnosis.—Shell conical, of moderate size. Whorls about ten, somewhat flattened, and but slightly convex, smooth. Sinual band near the middle of the body-whorl, but very low down on the earlier whorls, appearing just above the suture, broad, flat, level with the surface, limited on each side either by a groove or by a slight, raised thread. Lines of growth curving obliquely back to the band above, much more obliquely forward below, and curved

[1] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 959.
[2] Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 547.
[3] *Ibid.* vol. lv (1899) p. 265.

on the band itself, indicating a fairly deep sinus. Sutures deep. Aperture imperfectly known, apparently sub-ovoid.

Remarks and Resemblances.—So far, only two specimens of this species are known to me, and these are in Mrs. Gray's collection. They are both more or less crushed and flattened by pressure. The spiral angle of the higher whorls of the largest individual is smaller than that of the rest of the spire; whether this is a natural condition, or caused by pressure, it is impossible to say: it may perhaps be the result of both. This shell (Pl. VIII, fig. 8) measures 16 millimetres in length and 7·5 mm. in width; it is partly embedded in the matrix. The other (Pl. VIII, fig. 7) has six whorls in a length of 13 mm., the width measuring 6 mm. in one direction, and 4·5 mm. in the other; it is disengaged from the matrix. The lines of growth are strong and well marked on part of the body-whorl. This is quite distinct from all previously described British species.

Locality and Horizon.—Shalloch Mill (Ayrshire), in rocks of Middle Bala age [Lapworth].

Turritoma (?) pinguis, sp. nov. (Pl. IX, figs. 1–3.)

Diagnosis.—Shell conical, or somewhat pyramidal. Whorls about nine, increasing rather rapidly, smooth, flat above, angular at the periphery. Band generally flat, but sometimes slightly raised and convex on the last whorl, limited by a groove on each side, situated on the periphery, near the middle of the body-whorl, just visible above the suture on the penultimate whorl, wholly or partly hidden on the earlier whorls. Lines of growth strong, sweeping obliquely back to the band above and still more obliquely forward below, forming crescents on the band, and indicating the existence of a deep sinus in the outer lip. Sutures deep. Base flattened and very slightly convex. Umbilicus closed. Aperture imperfectly known.

Remarks and Resemblances.—This shell much resembles *T. (?) polita,* but differs in being of greater size, and in the whorls increasing more rapidly, thus rendering the shell shorter in comparison to the width. Also the body-whorl appears more angular, and the base flatter and less produced. In the conical spire and flatness of the whorls it is like *Euconia Etna* (Billings)[1] and *E. Ramsayi* (Billings)[2]; but it is distinguished from both by being more elongated, having the base less flattened, the band on the periphery, the lines of growth forming a deeper sinus, and the absence of an umbilicus.

Dimensions.—There are eight specimens in Mrs. Gray's collection. The largest has five whorls preserved in a length of 23 millimetres, the width measuring 13 mm. The specimen figured in Pl. IX, fig. 1, also has five whorls, and measures 22 millimetres in length and 13 mm. in width. Another individual, if entire, would consist of about nine whorls in a length of 13 millimetres.

Locality and Horizon.—Thraive Glen, in rocks of Upper Bala age [Lapworth].

[1] Geol. Surv. Canad. 'Palæoz. Foss.' vol. i (1865) p. 226 & fig. 210.
[2] 'Canad. Nat. & Geol.' vol. iv (1859) p. 351 & figs. 3 & 4.

Genus *Lophospira*, Whitfield.[1]

This genus is thus described by R. P. Whitfield (*loc. cit.*),

'Shells univalve, with elevated spires and strongly carinated or keeled volutions; whorls closely coiled in the upper part, but often becoming disconnected below from a too rapid descent of the coil. Central keel marking the position of a sinus or notch in the outer lip of the aperture. Axis usually minutely perforate when the whorls are not disconnected. Types: *Murchisonia bicincta* = *M. Milleri*, Hall, and *M. helicteres*, Salter.'

It has since been emended and divided into sections and subsections by Ulrich.[2] I hope, in a future paper, to discuss this genus fully, and describe all the known British species. At present I am only describing two of the probably earliest representatives, and also the only one with which I have met showing the sinus in the outer lip.

Lophospira (?) angulocincta (Salt.). (Pl. IX, figs. 4 & 4 *a*.)

Murchisonia angulocincta, J. W. Salter, 1859, Quart. Journ. Geol. Soc. vol. xv, p. 380 & pl. xiii, figs. 9, 10; J. Sowerby, 1867, 'Siluria' 4th ed. p. 532; J. J. Bigsby, 1868, 'Thes. Silur.' p. 157; R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Palæozoic) p. 113.

Diagnosis.—Shell very elongated, slender, turreted, composed of about thirteen whorls. Whorls increasing gradually, strongly angular below the middle, slightly concave both above and below. There is a swelling immediately below the suture, and an angle or keel below the band on the body-whorl. Band situated on the strong angle below the middle of the whorl, prominent, rather convex. Lines of growth indistinct, apparently curving back to the band above, and forming a shallow sinus on the band itself, not seen below. Aperture subquadrangular.

Remarks.—All the specimens of this species hitherto seen are much weathered. A small example in the Museum of Practical Geology, Jermyn Street, shows the surface best, but it is more or less indistinct. A portion of one of its whorls is figured (Pl. IX, fig. 4 *a*), showing what appear to be the lines of growth, which give the band a somewhat crenulated appearance. If this be really the correct sculpture, this species can only have possessed a sinus in the outer lip, and not a slit. For this reason, and also because no well-authenticated species of *Murchisonia* have appeared so early, I refer it to *Lophospira*, Whitfield.

Resemblances.—This species is quite distinct from all known British ones. It bears some resemblance to *M. Catharina*, Billings,[3] from the Quebec Group in Canada, in form, the great angularity of the whorls, and in the position of the angle below the middle of the whorls.

Dimensions.—There are three specimens in the Museum of

[1] Bull. Amer. Mus. Nat. Hist. vol. i (1886) p. 312.

[2] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) pp. 960 & 962.

[3] Geol. Surv. Canad. 'Palæoz. Foss.' vol. i (1865) p. 231 & fig. 215.

Practical Geology, Jermyn Street, one of which is merely part of a section. The largest, which is the type (Pl. IX, fig. 4), consists of about thirteen whorls, and measures 22 millimetres in length, and 7 mm. in width. The Natural History Museum, South Kensington, and the Geological Survey Collection, Edinburgh Museum, each contain two small, badly-preserved examples.

Locality and Horizon.—Durness Limestone, Sutherland, which is regarded as probably homotaxial with the Tremadoc Beds.

LOPHOSPIRA BOREALIS, sp. nov. (Pl. IX, figs. 5 & 6.)

Diagnosis.—Shell turreted, of medium height, composed of more than five angular whorls, which increase rather rapidly. There is a strong angle, near the middle of the whorls of the spire and somewhat above the middle of the body-whorl, which represents the sinus; a slighter angle below is situated at the suture. Outline nearly flat above the submedian angle, slightly concave between it and the lower one. Lines of growth very indistinct, apparently curving forward below the angle. Aperture subquadrate; inner lip thickened. Umbilicus open.

Remarks.—There is but one undoubted specimen of this species in the Geological Survey Collection, Edinburgh Museum; and it is merely an internal mould, consisting of four distinct whorls and a much worn apex, the actual number of whorls in which cannot be made out. On the upper part of the body-whorl are traces of a fine line just below the suture. The submedian keel is much weathered, but was probably trilineate. A shell (Pl. IX, fig. 6), of which only two whorls are preserved, may perhaps belong to this species; it differs in there being two finer keels below instead of a single strong one, and it also gives the impression of being more depressed.

Resemblances.—This species differs from *L. bicincta* (Hall)[1] in not possessing so strong a keel on the upper part of the whorl below the suture, and in the lines of growth being more oblique; the former characteristic also distinguishes it from *L. obliqua*, Ulrich[2] (*Murchisonia bicincta*, Salt.). I have compared it with specimens of the latter species and the variety *perangulata* from Allumette Island in the Natural History Museum, South Kensington; and find that it differs from all also in the sinual angle being more nearly central, and thus the upper flattened part of the whorl is almost equal to the lower concave part, and the whorls are wider. It is most like *L. centralis*, Ulrich,[3] but it is likewise distinguished from it by the nearly central position of the sinual angle, and the lower keel being apparently stronger. It belongs probably to the Perangulata subsection of the Perangulata section of Ulrich.[4]

Dimensions.—Length = about 19 millimetres; width = 12 mm.

Locality and Horizon.—Durness Limestone, Sutherland.

[1] 'Pal. N. Y.' vol. i (1847) p. 177 & pl. xxxviii, figs. 5 *a–h*.

[2] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 965 & pl. lxxii, figs. 6–8.

[3] *Ibid.* p. 979 & pl. lxxiii, fig. 9.

[4] *Ibid.* p. 962.

LOPHOSPIRA VARIABILIS, sp. nov. (Pl. IX, figs. 7–10.)

Murchisonia gyrogonia, pars, J. Horne & B. N. Peach, 1899, Mem. Geol. Surv. 'Silur. Rocks of Britain' vol. i, p. 682; (?) J. Horne, B. N. Peach, & A. Macconochie, 1901, in 'Fauna, Flora, & Geol. of Clyde Area' publ. by Local Com. for Meeting of Brit. Assoc. Glasgow, pp. 428 & 438; *non* F. M'Coy, 1855, 'Brit. Palæoz. Foss.' p. 293 & pl. 1 K, fig. 43.

Diagnosis.—Shell turreted, composed of about nine whorls. Whorls increasing somewhat rapidly, the two apical ones apparently convex, the rest possessing a strong angle below the middle, where the band is situated; body-whorl convexo-concave above, the earlier whorls not so convex above, but having a raised thread immediately below the suture, slightly concave below the band. Base very convex, with a subangularity a short distance below the band, which is represented by a strong raised thread on the earlier whorls, appearing just above, or else hidden by, the suture. Band prominent, composed of three keels, the central one becoming very strong and convex on the body-whorl. Sinus deep and wide, the end pointed and almost triangular. Lines of growth sharp, numerous, fine lines being intercalated between stronger ones, retreating slightly above the band, almost vertical below. Ornamentation consisting of very fine and faint spiral lines. Aperture subquadrangular; inner lip reflected. Umbilicus apparently closed.

Remarks and Resemblances.—There are eight specimens of this species in Mrs. Gray's collection, and also two casts which probably belong to it. One of these has the outer lip well preserved, showing the sinus, which has the end and the greater portion of the sides intact. The sinus is remarkably broad, especially when compared with the width of the band on the earlier whorls, where it is much narrower than on the body-whorl. An example in the Geological Survey Collection, Edinburgh Museum, has part of the sinus intact, and it is similar in form, but not so well preserved. The specimens vary considerably in the height of the body-whorl: in some cases this may be partly the result of the manner of preservation, some being slightly compressed downward, while others are pressed upward. Members of the genus *Lophospira* are frequently characterized by irregularity in the coiling of the spire. This appears to be the species wholly, or in part, referred to as *Murchisonia gyrogonia*, M'Coy,[1] in the list of species published in the Scottish Survey Memoir, 'Silur. Rocks of Britain' vol. i (1899) p. 682. The specimen just mentioned from Balclatchie is thus named in the Museum. It differs, however, from *M. gyrogonia* in the whorls being less flat above and below the band, in the band not being flange-like; also the angle on the body-whorl is not so pronounced in the adult. *L. variabilis* resembles *Pleurotomaria Sybillina*, Billings,[2] from the Island of Anticosti, but is distinguished by its greater height and more numerous whorls. It is also somewhat like *L. tenuistriata*, Ulrich,[3] from the Utica Group, but differs in the greater convexity

[1] 'Brit. Palæoz. Foss.' 1855, p. 293 & pl. 1 K, fig. 43.
[2] Geol. Surv. Canada 'Catal. Sil. Foss. Anticosti' 1866, p. 54 & fig. 19.
[3] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 983 & pl. lxxii, figs. 48–50.

of the upper part of the body-whorl; moreover, the angularity below the band on the body-whorl is less pronounced, and the lines of growth, though varying in strength, are not lamellar and they do not recede and advance so strongly as represented in the figures of *L. tenuistriata*. This species evidently belongs to the Perangulata subsection of the Perangulata section of Ulrich.

Dimensions.—The crushed specimen figured in Pl. IX, fig. 9 consists of eight whorls in a length of 15·5 millimetres. That figured in Pl. IX, fig. 7, has about six whorls, measuring 13·5 mm. in length, and 8 mm. in width; the length of the sinus in its outer lip, if entire, would be about 4·5 mm., and would thus equal about one-fifth of the circumference of the last whorl.

Locality and Horizon.—Balclatchie (Ayrshire), in rocks of Llandeilo age [Lapworth].

Family PLEUROTOMARIIDÆ, d'Orbigny.

Genus *Pleurotomaria*, Defrance.

Subgenus PALÆOSCHISMA, nov.

Diagnosis.—Shell depressed-conical. Whorls few in number, flattened or slightly concave above, base convex. Band situated on the widest part of the whorl, near the middle of the body-whorl, low down on the earlier whorls, appearing just above the suture; lower margin coinciding with the periphery, concave, bounded on each side by a strong raised thread. Outer lip retreating with a moderate degree of obliquity above, oblique immediately below the band, and then forming a convex curve. Slit short, with parallel edges, about one-fifth the circumference of the body-whorl in length. Aperture probably subquadrate, but imperfectly known.

Type, *Palæoschisma girvanense*, sp. nov.

Remarks and Resemblances.—The characteristics of this subgenus do not exactly agree with those of any previously described genera or subgenera of the Pleurotomariidæ. It comes nearest to *Eotomaria*, Ulrich[1] in general form, and in possessing a concave band, bounded on each side by a strong thread situated on the apical side of the whorl; but it differs in having a distinct though short slit, instead of a sinus in the outer lip. The form of the slit greatly resembles that of *Trepospira sphærulata*[2] (Conrad), which species is figured by Ulrich as the type of his genus *Trepospira*. *Palæoschisma* is, however, distinguished in the band being visible above, instead of hidden by the suture on the earlier whorls, and in the absence of ornamenting nodes. It differs from *Schizolopha*,[3] the only Ordovician genus described by Ulrich with a slit in the outer lip, in the form of the shell and in the character and position of the band, this latter in *Schizolopha* being prominent

[1] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 954.
[2] *Ibid.* pp. 957 & 1081. [3] *Ibid.* p. 952.

and situated on the periphery. From *Ptychomphalina*, Bayle[1] it is separated by having less convex whorls, and in the slit probably being shorter. In *Bembexia*, Œhl.[2] the form is more turriculated, the band higher above the suture and situated on the periphery; also the lines of growth sweep backward to and forward from the band less obliquely. Though the umbilical region is imperfectly known, it does not appear to have the wide umbilicus of *Mourlonia*, de Kon.[3]

Dimensions.—The length of the type = 11 millimetres.

Range.—The only species at present known is from the Llandeilo Formation.

PALÆOSCHISMA GIRVANENSE, sp. nov. (Pl. IX, figs. 11 & 11 *a*.)

Diagnosis.—Shell depressed-conical, composed of more than four whorls. Whorls increasing rapidly, smooth, slightly angular at the periphery, flat or rather concave above, convex below. A fine thread immediately below the suture constitutes the only ornamentation. Band a little above the middle of the body-whorl, but very low down on the penultimate whorl, being about half its width above the suture, flat or slightly concave, bounded by a strong thread on each side, with another thread between, somewhat nearer the upper than the lower limit, and becoming much fainter on the latter half of the body-whorl, the lower margin coinciding with the periphery. Lines of growth sloping rather obliquely back above, forming crescents on the band, and advancing with a moderately convex curve below. Slit in the outer lip short. Base convex. Aperture imperfectly known. Umbilicus probably closed.

Remarks.—At present there is but one specimen known of this species, which is in the collection of Mrs. Gray. It is remarkable for being the earliest British representative of the Pleurotomariidæ with which I have met possessing the slit in the outer lip preserved, the end and greater part of the sides being intact.

Resemblances.—This species greatly resembles *Eotomaria labiosa*, Ulrich,[4] in form, but is distinctly separated from that species, and from all other members of the genus, by possessing a slit in the outer lip, and a thread near the middle of the band. It bears also a certain general likeness to figures of *Pleurotomaria elliptica*, His.[5] Prof. Lindström kindly lent me a specimen of that species from the

[1] P. Fischer, 'Man. de Conchyliologie' 1885, p. 850. After a vain search for the original description of this genus by Bayle, I wrote to ask Dr. H. Fischer whether he could throw any light on the subject. As far as he can tell, his father was the first to publish the description of the genus, the name of which was written in manuscript by Bayle on the labels of the following species in the École des Mines, Paris—*Pt. carinata*, Sow. (Visé), *Pt. conica*, Phill. (Visé), and *Pt. striata*, Sow. (Visé). The date of the genus given by Fischer is 1885, and that was the year in which p. 850 was published.

[2] Bull. Soc. Études Sci. Angers, 1887 (sep. cop.) p. 24.

[3] Ann. Mus. Roy. Hist. Nat. Belg. vol. viii, pt. iv (1883) p. 75.

[4] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 1003 & pl. lxix, figs. 15–17.

[5] 'Lethæa Suecica' 1837, p. 35 & pl. xi, fig. 1.

Upper Orthoceratite-Limestone of Lerkaka (Öland) for comparison. I find that *P. girvanense* differs in being much smaller, being about one third the size; the upper surface of the whorl is flatter and almost concave, while *Pleurotomaria elliptica* is slightly convex; below the band the base is more convex, while *Pl. elliptica* is flattened: the upper part of the body-whorl also appears longer in proportion; but the only known specimen is slightly flattened by pressure, so it cannot be accurately compared in this particular. The whorls are less angular at the periphery, the three keels forming the band on the penultimate whorl are nearly equal in strength, and the lower one coincides with the periphery; while in *Pl. elliptica* the central one appears the strongest and most prominent. They agree, however, in having the central thread of the band less developed on the latter part of the body-whorl. Both species are quite distinct from *Trochus ellipticus* of Portlock,[1] which latter is so much crushed that it would be difficult to compare other specimens with it accurately.

Dimensions.—The length = 11 millimetres, the width = 11 mm., and the length of the slit = about 5 mm.: if the lip were entire, it might possibly be longer. It equals about one-fifth of the circumference of the body-whorl.

Locality and Horizon.—Ardmillan Braes (Ayrshire), in rocks of Llandeilo age [Lapworth].

Family Turritellidæ, Lam.

Genus *Aclisina*, de Kon.[2]

Aclisina (?) obscura, sp. nov. (Pl. IX. fig. 12.)

Diagnosis.—Shell small, very elongated, turreted, composed of about thirteen whorls. Whorls increasing gradually, flat above, slightly convex below. There is a strong keel near the middle of the whorl, with two similar keels at equal distances apart below. and traces of a fine thread above them, and another thread immediately below the suture. Base convex, moderately produced. Apertures and lines of growth unknown.

Remarks and Resemblances.—There are but two examples of this species known, which are in Mrs. Gray's collection. As the aperture and lines of growth are not preserved on either of them, it is difficult to ascertain to which genus they should be referred. There does not appear to be any trace of a true sinual band, therefore they cannot be placed in *Murchisonia*. The elongated form and ornamenting keels resemble those of both *Ectomaria* and *Aclisina*, and more especially the latter, the keels being finer than is usually the case in *Ectomaria*. It reminds one forcibly of certain Carboniferous species of *Aclisina*; and should it prove really to

[1] 'Geol. Rep. Londonderry' 1843, p. 414 & pl. xxxi, fig. 1.
[2] This genus is fully described in Quart. Journ. Geol. Soc. vol. liv (1898) p. 45.

belong to this genus, it is the earliest known representative, for none older than the Devonian have been recorded previously.

Dimensions.—The length of the largest example = 14 millimetres, and the width = 5 mm. Its five upper whorls are merely represented by their impression left in the matrix. The smaller shell = about 9 mm. in length.

Locality and Horizon.—Woodland Point (Ayrshire), in beds of Middle Llandovery age [Lapworth].

EXPLANATION OF PLATES VII–IX.

PLATE VII.

Fig. 1. *Murchisonia (?) dudleyensis*, sp. nov. Wax-impression, × 1½. Dudley. Museum of Practical Geology, London.

Figs. 2–4. *Goniostropha (?) elegans* (Sollas). Wax-impressions. Fig. 2. Type, partly embedded, × 4; fig. 2*a*. Outline of whorl, × 6; Fig. 3. Specimen with band more nearly central, × 4. Rhymney Quarry, Cardiff. Bristol Museum. Fig. 4. Specimen with whorls more exsert, × 3. Tymaur Lane, Rhymney, Cardiff. Cardiff Museum.

5 & 6. *Cyrtostropha corallii* (Sow.). Fig. 5. Front view, embedded in coral (*Stenopora fibrosa* var. *incrustans*), × 2; fig. 5*a*. Portion of whorl, × 4. Grindrod Collection, University Museum, Oxford. Fig. 6. Wax-impression, back view, × 4. Lily Mere. Collection of the Rev. M. S. Donald.

7 & 8. *C. scitula*, subgen. et sp. nov. Fig. 7. Back view, partly embedded, × 2; fig. 7*a*. Portion of eighth whorl, × 6. Locality unknown. Grindrod Collection, University Museum, Oxford. Fig. 8. Young specimen, × 6. Chance's Pitch, Malvern. Worcester Museum.

9 & 10. *C. bicincta* (M'Coy). Fig. 9. Type, partly embedded in matrix, × 4. Fig. 9*a*. Portion of second whorl from base, × 12. Chair of Kildare. Museum of Science & Art, Dublin. Fig. 10. Sinistral variety, partly embedded, × 4. Chair of Kildare. Museum of Practical Geology, London.

Fig. 11. *Ectomaria girvanensis*, Don. Portion of body-whorl showing lines of growth, × 2. Minuntion (Ayrshire). Gray Collection.

PLATE VIII.

Fig. 1. *Cyrtostropha torquata* (M'Coy). Front view from wax-impression, × 4. Fig. 1*a*. Single whorl of another specimen, × 5. Lily Mere. Collection of the Rev. M. S. Donald. Fig. 1*b*, × 5. Kendal. Carlisle Museum.

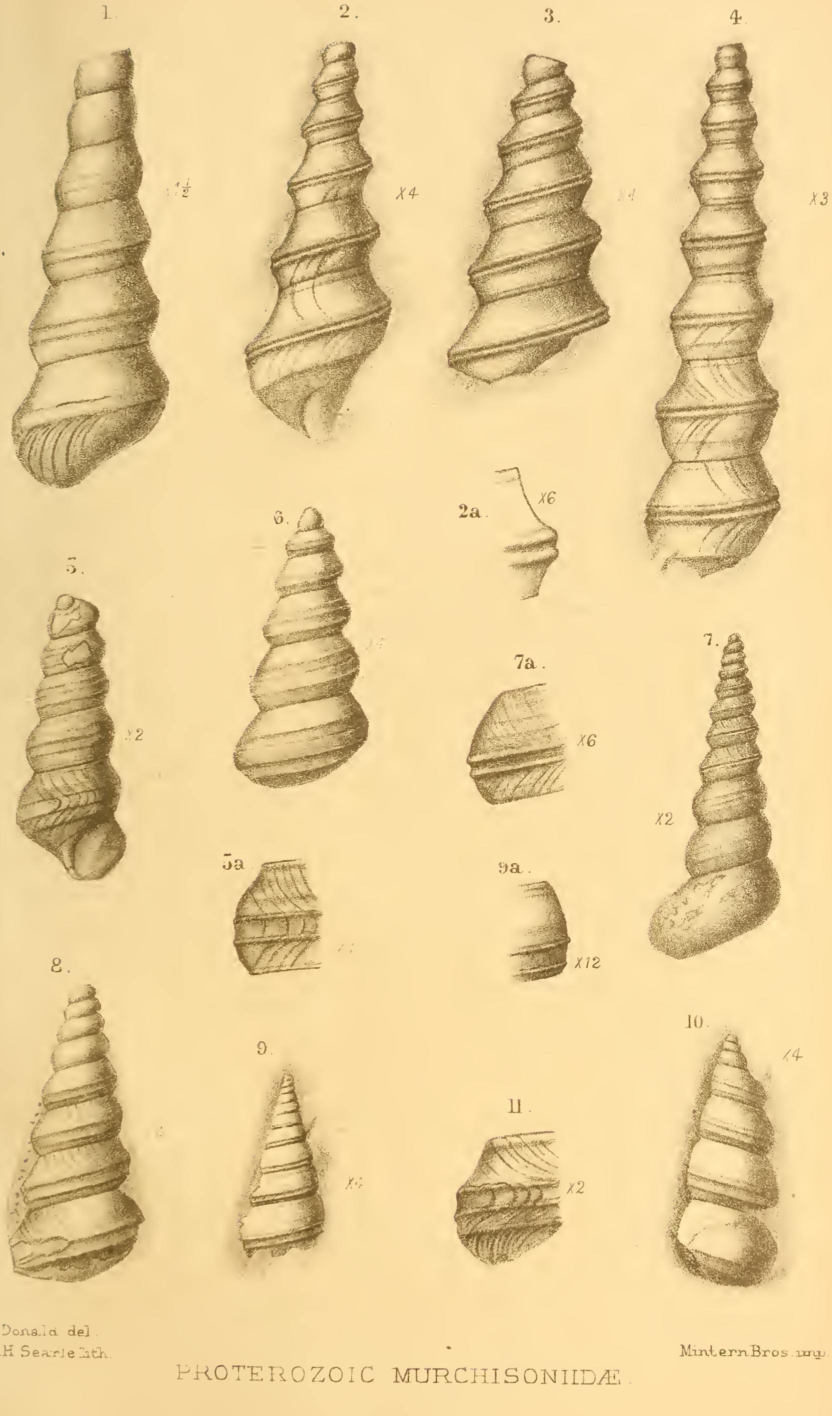
Figs. 2 & 3. *C. obscura* (Portl.). Fig. 2. Front view of type, greatly compressed, × 2; fig. 2*a*. Portion of a wax-impression of a whorl, taken from the cavity in the matrix made by part of fig 2, × 3. Fig. 3. Back view of another specimen, slightly compressed, × 2. Desertcreight. Museum of Practical Geology, London.

Fig. 4. *C. robusta*, subgen. et sp. nov. Front view of specimen, × 1½. Thraive Glen, Gray Collection. Drawn from a photograph.

5. *C. Ordovix*, subgen. et sp. nov., × 2. Fig. 5*a*. Portion of whorl, × 4. Shalloch Mill. Gray Collection.

6. *Goniospira filosa*, sp. nov., × 2. Fig. 6*a*. Body-whorl, × 3. Shalloch Mill. Gray Collection. Drawn from a photograph.

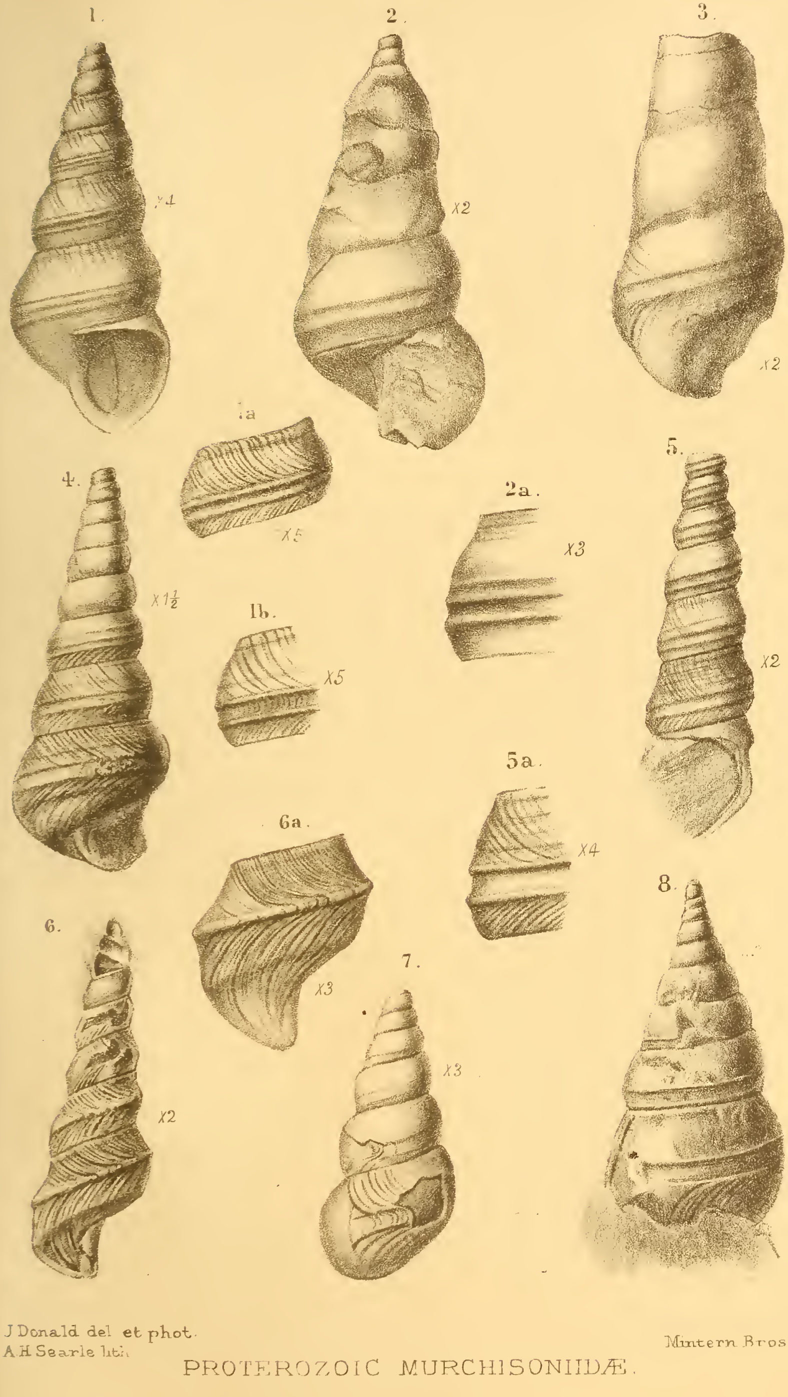
Figs. 7 & 8. *Turritoma (?) polita*, sp. nov. Fig. 7. Back view, slightly crushed, making the spiral angle appear rather wider, × 3. Fig. 8. Specimen embedded in matrix, × 3. Shalloch Mill. Gray Collection. Drawn from a photograph.



J. Donald del.
A. H. Searle lith.

Mintern Bros. imp.

PROTEROZOIC MURCHISONIIDÆ.



J Donald del et phot.
A.H. Searle lith.

Mintern Bros. imp.

PROTEROZOIC MURCHISONIIDÆ.

J. Donald del. et phot.
A. H. Searle lith.

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PROTEROZOIC MURCHISONIIDÆ, PLEUROTOMARIIDÆ, & TURRITELLIDÆ.

PLATE IX.

Figs. 1–3. *Turritoma (?) pinguis*, sp. nov. Fig. 1. Front view, × 2. Fig. 2. Single whorl showing lines of growth, × 3. Fig. 3. Young specimen, × 5. Thraive Glen. Gray Collection. Drawn from a photograph.

Fig. 4. *Lophospira (?) angulocincta* (Salt.), × 2. Fig. 4*a*. Portion of a whorl of another specimen, × 6. Durness. Museum of Practical Geology, London.

5. *L. borealis*, sp. nov. Front view, × 2. Durness. Geological Survey Collection, Edinburgh Museum.

6. *L. borealis*, var. (?), × 2. Durness. Geological Survey Collection, Edinburgh Museum.

Figs. 7–10. *L. variabilis*, sp. nov. Fig. 7. Side view showing sinus, × 3. Fig. 8. Front view, × 3. Fig. 9. Specimen crushed and embedded, but showing the apical whorls fairly well, × 3. Fig 10. Back view, × 3. Balclatchie. Gray Collection. All drawn from photographs.

Fig. 11. *Palæoschisma girvanense*, subgen. et sp. nov. Side view, showing slit in outer lip, × 3. Fig. 11*a*. Outline of portions of two whorls, × 3. Ardmillan Braes. Gray Collection. Drawn from a photograph.

12. *Aclisina (?) obscura*, sp. nov. × 3. Woodland Point. Gray Collection.

19. *The* WOOD'S POINT DYKE, VICTORIA (AUSTRALIA). By FREDERIC PHILIP MENNELL, Esq., F.G.S. (Read April 16th, 1902.)

[Abstract.]

THIS dyke is intrusive into a belt of Silurian (Upper Silurian) strata which strike in a direction somewhat west of north, and extend beyond Walhalla on the south. Wood's Point is about 75 miles east of Melbourne. It may be taken as typical of the intrusions associated with the Silurian rocks of the Victorian gold-fields. Brown, original, hornblende is the dominant constituent, but it is rarely idiomorphic; augite, three varieties of felspar, micro-pegmatite, and ilmenite are also present, in a microcrystalline or cryptocrystalline groundmass. The rock is called a hornblende-porphyrite. In certain varieties cordierite occurs, and is accounted for by derivation from the adjacent shales. The reefs in the Silurian and Ordovician rocks usually occur at or near the contact with intrusive rocks. At Wood's Point the reefs are nearly horizontal, traversing dykes and shales, the junction usually marking the occurrence of rich ore. The Author notes the 'almost invariable association of gold in this class of deposit with rocks containing original hornblende.'

20. *On the* Geological *and* Physical Development *of* Dominica; *with* Notes *on* Martinique, St. Lucia, St. Vincent, *and the* Grenadines. By Prof. Joseph William Winthrop Spencer, M.A., Ph.D., F.G.S. (Read December 18th, 1901.)

[Plate X—Map.]

Contents.

I. Introduction.

The features of this chain of islands form a striking repetition, or rather interrupted continuation, of the mountainous portions of Guadeloupe and Antigua—in a word, they are largely made up of old igneous formations, the surfaces of which have been greatly denuded, surmounted by the more recent volcanic accumulations, some of which rise into high mountain-peaks. The general geological and physical history, with local variations, is repeated to such an extent, that these islands can only be regarded as one physical unit.

The only paper that I have seen upon the geology of Dominica is that entitled 'Notes of a Visit to Dominica' by Mr. R. J. Lechmere Guppy.[1] There are also some scattered references to the late volcanic eruptions of the various islands; but this is not the subject of our investigations. Outside of Dominica, my personal observations were made at only a few points, where the older volcanic foundations alone were seen, modified by atmospheric agents; these showed, however, a repetition of the features of Guadeloupe and Dominica.

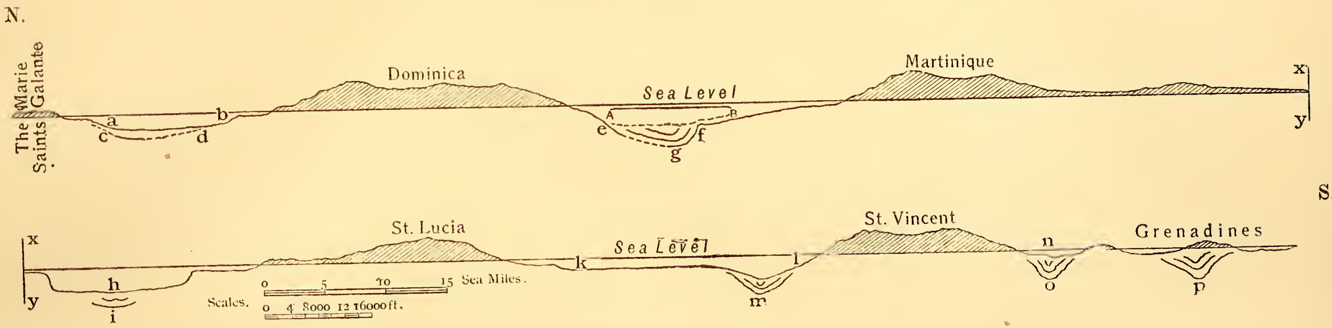
II. Situation and Hydrographical Characteristics.

Dominica is separated from the Guadeloupe archipelago by a depression in the Antillean plateau from 15 to 20 miles wide,[2] which is submerged to about 2100 feet (see map, Pl. X). This depression is indented by an embayment extending within the line connecting the western shores of Guadeloupe and Dominica, where even the few soundings reach 1200 feet deeper than those on the surface of the ridge. Martinique is 25 miles distant from the southern end of Dominica, but the submarine features already

[1] Proc. Sci. Assoc. Trinidad, Dec. 1869, pp. 377–92, with two plates.

[2] See U.S. Hydrographic Chart No. 40, or the British Admiralty equivalent.

Fig. 1.—*Section from Guadeloupe to the Grenadines.*



$a\,b$, $c\,f$, h, and $k\,l$ represent the floor of the submarine depression between the islands; $c\,d$, $e\,f$, and i sections through the indentations farther westward, but within the line connecting the islands. g, m, o, and p illustrate the deep valleys that dissect or indent the more gently sloping submarine plateau. A B represent the slightly submerged fragments of tableland at the head of the Dominica-Martinique embayment, which heads in two branches and continues to the cols on each side of the islands. The sections are continuous at $x\,y$.

discovered are more interesting, for here the higher part of the drowned plateau has a breadth of 35 miles. Its western margin is indented by a great amphitheatre or valley-like embayment, beginning at the col between the Atlantic and the Caribbean basins (which is 3300 feet below the surface of the sea), and extending to a depth of over 6000 feet; while the greater portion of the plateau is not submerged more than 2500 or 3000 feet (see Pl. X, and also fig. 1, p. 342). It should be further noted that on the eastern side of the plateau there are two elevated fragments of the drowned tableland (*A* and *B* in Pl. X), reaching to within 300 feet of the surface of the sea,—these being repetitions of the coastal plains of Antigua, Grand' Terre of Guadeloupe, and the outlying fragment which forms Barbados. About 60 miles east of Martinique is another slightly submerged remnant of the drowned Antillean plateau, about 12 miles long, and here named Madiana Banks.

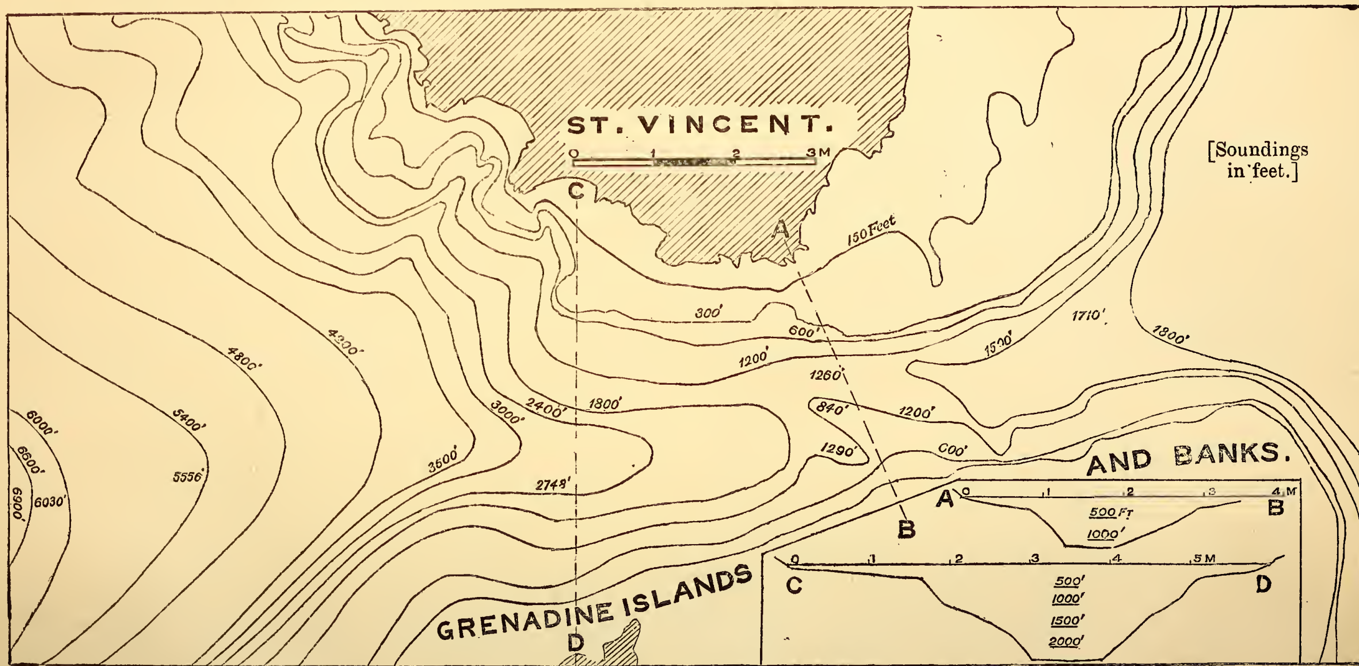
The channel between Martinique and St. Lucia is about 20 miles wide, with the higher portions not more than 3300 feet below sea-level. From the western side of the col, a valley descends rapidly to a depth increasing from 3600 to 6000 feet, and even to more than 7200 feet, as it widens out into a broad embayment, all within the line between the western shores of Martinique and St. Lucia. On the north-western edge of the St. Lucia mass is a remarkable cirque, 6624 feet deep, within the 600-foot submarine contour-line.

St. Vincent is about 25 miles distant from St. Lucia. The summit of the connecting ridge is not generally submerged more than 1200 feet; but near St. Vincent is a channel, less than 5 miles wide, which dissects the col to a depth of 1800 feet, thus showing a rather narrow valley across the submarine Antillean plateau, reaching to 3000 feet below sea-level. Towards the west this valley descends rapidly, and in a distance of 10 miles the soundings show a depth of 6000 feet. This rapid descent appears to be by steps, and even within 3 or 4 miles of its head one such step amounts to 2500 feet.

The submarine coastal plains of St. Vincent and the Grenadines are generally covered by 100 to 200 feet of water. In reality they form one plateau, dissected by a valley with precipitous walls, reduced to a breadth of 2 miles. The divide in this valley is about 1200 feet below the surface of the sea, or about 1000 feet below the submarine plateau. There are no soundings to show the development of the valley descending towards the east; but that to the westward is seen, reaching in a distance of 4 miles a depth of 2700 feet, and 5 miles farther on to 5500 feet, and still a little farther to 6900 feet, below the surface of the sea. This St. Vincent-Grenadine valley is one of the best-shown amphitheatre- or cirque-valleys that indent the submarine Antillean banks.[1] (See fig. 2, p. 344.)

[1] See U.S. Hydrographic Chart No. 1279, or the equivalent British Admiralty Chart.

Fig. 2.—*Map & sections of the submerged valley across the divide between St. Vincent and the Grenadines.*



Other large embayments indent the western margin of the Grenadines. By a careful study of the more complete chart,[1] the heads of several of the smaller amphitheatres, of a mile or less in breadth and a mile or two in length, are seen indenting the drowned plains to depths of 600 to 900 feet, such as that at Kingstown in St. Vincent and that south-east of Carriacou, one of the Grenadines.

Small channels are often observable on the surfaces of the submarine plains having depths of 50 to 100 feet, recording the late erosion when the marine banks formed land-features.

Such valley-like features are constantly recurring in the submarine plateau throughout the group. They are better shown on their western side than upon the eastern, where even the scantier soundings show that the descent is more precipitous. From a study of the indentations, which are the exact reproduction of the amphitheatres or cirques, or somewhat longer valleys, upon the margins of the tablelands of Mexico, one is impelled to the conclusion that these submarine features were modified, if not formed, by subaërial denudation, when the land stood as high as the valleys are now depressed—in other words, at least 6000 or 7000 feet higher than now; while the small channels seen on the surface of the banks were formed at a later date, when the land was not more than 200 feet or so above the sea.

III. Physical Characteristics.

Dominica.

This island has an elliptical form, with a maximum length of 34 miles and a breadth of 15. It is the most completely mountainous of all the islands, and consists of a mass of volcanic ridges dissected by deep gorges. The highest point is Morne Diablotin, 4747 feet, and the Trois Pitons reach to nearly the same altitude. The Grande Soufrière (3554 feet above sea-level) was in eruption in 1880. The flanks of the mountains are characterized by slopes caused by the tilting outward of great beds of stratified tuffs, which are dissected by deep valleys, between which are numerous isolated peaks. There are no coastal plains of importance, the only flat land being in the lower reaches of the short valleys, as that of the Layou River, or on fragments of low terraces. There is even no other submerged coastal plain, than a small fragment on the eastern or north-eastern side, which does not reach a width of 4 miles (see Pl. X). This margin is seen to be dissected by channels, one of which, south-east of Rosalie, reaches to a depth of 600 or 700 feet, where the shelf is covered by only 200 feet of water.

Among the mountains, many fragments of base-levels of erosion are observable, as at Bona Vista, at the head of the Roseau valley, and also at the divide along the road between Roseau and Geneva, at elevations of 1500 to 1700 feet. One at 500 feet above the sea was quite extensive, and another at an altitude of between

[1] U.S. Hydrographic Charts Nos. 1279 & 1640, etc.

700 and 900 feet was of importance. Morne Bruce, immediately behind the town of Roseau, at 400 feet, is a fine illustration. On each side of the Geneva-Roseau summit are grand gorges, reaching to depths of 400 and 600 feet, clothed with the lovely primeval tropical vegetation, such as tree-ferns, etc. Short ravines occur, commencing directly at the coast, and suggesting recent elevation of the land. But the larger valleys, such as that of Roseau, are much more open, and have had a longer and more varied history.

Martinique.

This island is somewhat larger than Dominica, with the highest point, la Montagne Pelée, in the north, reaching to an elevation of 4428 feet. The central part of the island is deeply indented by Fort-Royal Bay and the large valley behind it. The soundings show the remains of a considerable coastal plain, submerged about 200 feet, extending north-eastward from the island. From the higher mountain-ridges heavy tuff-beds are seen sloping seaward at angles varying between 10° and 20°. On the southern portion of the island are remains of base-levels of erosion, or modified tablelands.

St. Lucia.

This is a smaller island than Dominica. It consists of a central dome rising to a height of 4000 feet, and formed of late volcanic accumulations. The northern part of the island shows considerable antiquity, as its surface, composed of old igneous rocks, has been greatly modified by erosion. There is only the suggestion of a coastal plain in the fragment of a shelf, submerged to 200 feet, extending northward from the island. The peaks upon the south-western coast, called the Pitons, attract the main attention of travellers. They are simply the remains of a dissected volcanic crater, partly rising out of the sea.

St. Vincent.

This island is still smaller than St. Lucia. The highest cone has a summit reaching to 4048 feet, but the floor of the crater, covered by a lake, is only 1930 feet in altitude, and the rim varies from 3100 to 3600 feet. This volcano was in eruption in 1812, when great quantities of ash were carried to Barbados, more than 100 miles away. Extending from the interior mountains, are dissected sloping surfaces, as in the other islands, but the forms of the valleys are more mature than those of Dominica. South-east of the island is a considerable coastal plain, submerged to a depth of 200 feet and less.

The Grenadines.

These are simply the remnants of the erosion of the old volcanic formations, rising out of an extensive plain now submerged to between 100 and 200 feet. Grenada, about the size of St. Vincent, with one dome rising to 2749 feet, owes its generally greater elevation above the sea to more recent volcanic accumulations.

IV. The Volcanic Formations of Dominica.

The Basement.

In Antigua, a basement of igneous rocks underlies tufaceous deposits, in the upper portions of which are calcareous layers containing fossils belonging to the Oligocene or to the Eocene formations. These early Tertiary beds are succeeded only by late Pliocene or more recent deposits. In Dominica there is the same foundation of old igneous rocks, which, however, are not succeeded by calcareous beds, but by massive tuffs. These are overlain by Pleistocene or recent volcanic accumulations, which form the high ridges and domes. This contiguous occurrence of older and newer volcanic formations has popularly given rise to confusion. It is not easy to decipher the physical features of these islands, except by going beyond their mountainous portions into their calcareous zones, which are almost wanting in Dominica.

The sea has made encroachments upon the shore, south of Roseau and at Point Michel, 4 miles distant; the foundations of the cliffs are seen to consist of a dark-grey doleritic rock, much jointed and fractured, and overlain by a firmly-cemented volcanic breccia or conglomerate. The advantage of an examination at this point is that the rocks are worn away more rapidly by the waves than by decay, thus giving a clean section. But in the exposures of the interior of the island (observed to an elevation of about 1500 feet), where all the later accumulations have been removed, the older volcanic rocks are found to be decomposed and converted into a red clay to depths of 8 feet or more, in places disclosing residual boulders of decomposition, such as those on the road to Bona Vista, and eastward of the Belleville divide leading to Geneva. On account of their fundamental position and their long exposure (shown by the decayed surfaces), as well as by their similarity to the older rocks of Guadeloupe, which pass under Tertiary formations, it is probable that these rocks belong to a pre-Tertiary period. As before noticed, this basement-formation is succeeded by a very much disturbed accumulation of breccia.

In the higher valleys, an old volcanic tuff recurs, as seen to an altitude of 1300 feet on the road to the Belleville divide. The beds are stratified, the individual members being as much as 10 feet thick. In places they enclose coarse fragmental materials, and at times there are difficulties in distinguishing them from a newer tuff-deposit, but they are more widely distributed and their surfaces have been subjected to a greater amount of denudation. Their age cannot be conjectured with any approach to certainty: they may be the equivalent of the old Tertiary tuffs underlying the calcareous beds of Antigua and Guadeloupe, or perhaps they are the equivalent of some of the Tertiary calcareous beds of those islands.

The Roseau Tuffs.

These deposits have distinct characteristics, and are well exposed along the Roseau Valley and on the flanks of Morne Bruce, where they are shown to be over 400 feet thick. The tuff is a mixture of fine-grained gritty particles and small fragments of the same volcanic débris, with some waterworn pebbles varying from a few inches to a foot in diameter. The gravels often occur in layers ending abruptly, or the pebbles may be scattered throughout the mass. The tuffs are of a light cream-colour, due in part to the kaolinization of the felspar.

These beds only partly refill an older valley. The strata have since been raised, so that they dip seaward at an angle of about 10°, the slope being somewhat less than that of the surface of the land. While the Roseau River has cut through the formation, its surface still forms a well-marked sloping terrace, in contrast to the country underlain by the older tuffs previously mentioned. Furthermore, there has been no physical break in the succession of the beds, so great as that which preceded the submarine accumulation of the Roseau Tuffs: consequently one is forced to conclude that the deposit is of much more recent geological date than that of the older tuffs. Mr. Guppy recognized a conglomerate-formation overlying the older volcanic rock, but I do not know what he included in it.

V. The Gravel-Formations of Dominica.

Owing to the extension of the mountain-spurs towards the encroaching seashore, the various mechanical formations exposed along the coast-line become disconnected and show considerable variations, so that it is often difficult to identify their recurrence. There are two gravel-formations, which are separated by a great unconformity.

The Morne Daniel and the Grand Savanna Gravel-Series.—About 2 miles north of Roseau is an extensive exposure of rounded gravel in the lower part of the cliffs overhanging the sea, adjacent to the foot of Morne Daniel, where the upper portion is composed of a coral-rock along the margin of the cliffs, but landward of these the gravel rises to 150 feet or to even a greater elevation. In ascending to Bona Vista, about 2 miles north of this point, the gravel was seen up to a height of 300 feet. Higher up the valley, gravels were also observed to an elevation of 500 feet, though the identity of the two deposits was not apparent. A similar bed overlies the Roseau Tuffs, on the flanks of Morne Bruce, up to an altitude of 300 feet; but the Roseau Tuffs are in part absent from the locality where the gravels appear beneath the coral-bed on the seashore, below Morne Daniel. At other points to the northward, what were evidently the same gravels were seen in interrupted beds as far as Grand Savanna, the farthest point visited. This interruption was occasioned by the very great denudation, which first removed most of the deposit before the epoch of the coral-beds. In places, the gravels were seen resting upon lavas, but it is not certain whether these beds belong to the lower or to the upper Gravel-Series. In other places, they rest upon reddish-brown tuffs.

In front of Grand Savanna, the lower 20 feet of the bluffs are composed of yellowish gravel and sand showing wave-action, with some larger boulders. Upon the denuded surface of this deposit is another, of grey gravel, with some angular materials. This upper deposit, which has a thickness of 30 feet, may be called the Grand Savanna Series. It is succeeded by a homogeneous, vertically ointed, earthy deposit 15 feet thick.

Immediately north of Coullibistre, at the end of a mountain-spur, is a gravel composed of coarse and fine material showing wave-action; it includes some boulders 10 feet in diameter. Occupying denuded hollows in its surface is a coral-formation. The gravels were seen to an elevation of 200 feet; they belong to the lower series, as at Morne Daniel. The beds undulate and dip in various directions from horizontal to 15° or 20°, showing variable disturbances of the strata. The respective ages of the gravels will be considered after describing the coral-formation.

VI. On the Coral-Point Formation and the Age of the Gravels.

Occupying the little valleys, upon the surface of the gravels at the base of Morne Daniel, is a whitish marl, more or less filled with corals. The base of this coral-bed is 50 feet above the sea, and the deposit is 30 feet thick. At Check Hall, a mile to the north, is a small terrace, 40 feet high, composed of the same coral-marl. At a point another mile northward, filling a little valley about 50 feet wide, is a recurrence of this formation. In all these places the coral-bed rests upon denuded surfaces of gravel. So also the marl, made up of fragments of mechanical limestones, with some fossil remains, at Coullibistre, with a thickness of 30 feet, rests in the hollows of the gravels. The white marls sometimes become grey, from the admixture of volcanic sands or ashes: they also contain pebbles and boulders. The scattered fragments of this calcareous formation show its former extension, and the enormous denudation to which it has subsequently been subjected.

I obtained the following collections, the corals of which were kindly determined for me by Dr. T. Wayland Vaughan and the mollusca by Mr. Charles T. Simpson. Some echinoids also were found.

Corals.

Orbicella cavernosa, Linn.
O. acropora, Linn.
Colpophyllia gyrosa, Ell. & Sol.
Siderastræa siderea, Ell. & Sol.
Isopora muricata, Linn., forma *palmata*, Lam.

Mollusca.

Venus cancellata, Linn.
V. paphia, Linn.
Cardium subelongatum, Sow. (?).
Lucina aurantia, Desh. (?).
Glycimeris pectinata, Lam.
Gl. undata, Lam.
Lutricola interstriata, Say.
Tellina interrupta, Wood.
Pecten sp., seems to be identical with *subnodosus*, Sow., found only on the western side of Tropical America.
Pecten sp., 8 to 10 inches in diameter, could not be extracted from the rock. There is no species of this size now living in the adjacent sea.

The foregoing species are all recent, except perhaps the *Pecten*.

Mr. R. J. L. Guppy gave the following lists of corals and shells from one of these localities. They, too, are recent West-Indian species. He found also one or two unnamed species.[1]

CORALS.

Favia ananas, Lam.
F. coarctata, Mich. & Duch.
Eusmilia aspera.

MOLLUSCA.

Cypræa exanthema, Linn.
C. cinerea, Linn.
Cassis decussatus, Linn.
C. flammeus, Linn.
Purpura trapa, Bolt.
Ranella cubaniana, d'Orb.
Triton pilearis, Linn.
Dolium pennatum, Mart.
Pusio articulatus, Lam., var. (?) [perhaps a new species].
Natica mamilla, Linn.
N. canrena, Lam.
Neritina punctulata (?) Lam.
Turbo pica, Linn.
Conus testudinarius, Mart.
Spondylus coccineus, Lam.
Lucina tigria, Linn.
Tellina fausta, Sol.
T. interrupta, Wood.
Pectunculus angulatus, Lam.
Lithodomus cinnamomeus, Lam.
Petricola robusta, Sow.
Plicatella cristata, Lam.

These names have not been revised. Mr. Guppy classified the formation as Pliocene.

The coral-formation in Dominica has the same characteristics and about the same thickness as the Usine Beds at Pointe à Pitre (Guadeloupe), the upper marls of Anguilla, the limestones of Brimstone Hill (St. Kitts), and similar beds in Barbados, and also others in Sombrero. Owing to the modern aspect of the fauna, the age would appear to be Pleistocene, or not older than the close of the Pliocene, which last view may be favoured if measured by the subsequent great denudation to which the beds have been subjected.

These coral-beds rest unconformably upon the lower gravels, thus showing that those deposits are of considerable age and belong to a period preceding the early Pleistocene great elevation and denudation. This occurrence would cause them to be referred to the Lafayette Formation of the American continent. Where the upper gravels lie unconformably upon the lower, the marls must have been removed before the deposition of the latter. It would appear that the upper gravels and the tufaceous earths overlying them, at Grand Savanna, and like accumulations covering the coral-beds at Coral Point, occupy the same position in Dominica as similar deposits in the other islands which have been referred to stages of the Columbia Formation of the American continent, or a mid-Pleistocene Series. The lava underlies at least the upper gravels, pointing to renewed volcanic action in the Pleistocene Period.

VII. THE TERRACES.

Morne Bruce is a terrace on the southern side of the Roseau Valley, with an elevation of about 400 feet. On the northern side

[1] Proc. Sci. Assoc. Trinidad, Dec. 1869, pp. 390–91.

of the valley, its equivalent slopes at nearly 10° seaward. Here is also another sloping cut terrace, 60 feet below the upper one. Morne Bruce does not show the tilting, on account of the sea having formerly cut off its face parallel with the strike, and left only a fragment of the raised base-level plain. At an elevation of 70 feet above the sea is a somewhat broad terrace, which has been formed since the tilting of the sloping terraces. The lower delta is only 8 feet above the sea. From the Morne-Daniel coral-cliff an old base-level plain rises gradually towards the interior of the island, to an elevation of 1500 feet.

The special interest of these terraces, or old deformed plains, lies in the fact that they do not represent a general elevation of the region, but only a local uplift, due to the volcanic forces acting at a recent date,—the focus being in the interior of the island, and the deformation not extending much beyond its limits. The rising of the land may be still going on, as the streams have not yet cut their gorges far into the sloping terraces.

VIII. Notes on Phenomena repeated in the Islands South of Dominica.

In Martinique there is a repetition of tuff-beds similar to those of Dominica, and in places deposits of gravel occur. In the southern portion of the island the old and denuded volcanic formations may be seen, unobscured by the later volcanic accumulations characteristic of the northern part. Remnants of elevated base-level plains are also seen.

The northern part of St. Lucia seems to be entirely made up of the denuded remains of the basal igneous formation of dark doleritic rock, which is often decomposed to a depth of 20 feet. In the south-western part of the island the tuff-beds lie almost horizontal, but they are dissected by valleys. Out of a plain of this character rise the Pitons: these, as before mentioned (p. 346), are the remains of a crater, part of which has been carried away by the sea and the remainder dissected by atmospheric agents. The more recent volcanic deposits occur in the mountainous interior of the island, where the late volcanic activity is still shown in the boiling- and sulphur-springs.

In St. Vincent the old igneous basement is again seen, but the rocks are weathered to a depth of 20 feet or more near Kingstown. The more recent volcanic accumulations are in the interior of the island. On the western coast extensive beds of tuff were observed, some containing rounded pebbles. Beds of breccia were also seen. The erosion-features show more mature forms than in Dominica, as instanced by the gorges becoming more open valleys.

The Grenadines appear to be merely the fragmentary remnants of the ancient igneous formation, except the island of Grenada. Their more recent features, with coral-reefs accumulating upon the surface, are submerged.

IX. Summary and Conclusions.

From Dominica to Grenada the Windward Islands are underlain by a basement of trappean rocks, the same as in Guadeloupe and Antigua, where they occur beneath the early Tertiary formations. Upon this foundation the older igneous tuffs, accumulated below sea-level, may be seen. The volcanic ridges surmounting some of these deposits belong to a late period—Pleistocene, or not older than the late Pliocene; but volcanic activity has continued down to the present time. There are at least two formations of tuffs. The newer is derived from the débris of older beds, and contains waterworn gravels or boulders, with the bedding more or less disturbed. The lower series cannot be newer than the earlier part of the Tertiary Period. Upon their denuded surfaces are nearly horizontal beds of stratified waterworn gravels, which in turn have suffered great denudation. These occur up to an elevation of 300 feet, or perhaps more. From their geological relationship, they have been correlated with the Lafayette Formation of the American continent—provisionally assigned to the close of the Pliocene Period.

Lying in valleys excavated out of the surfaces of the older gravels is a calcareous marl, with some rounded pebbles, 30 feet thick, containing a fauna almost wholly, if not entirely, living at the present day, with only a suspicion of older types. This coral-limestone has been weathered away, except in protected places, showing the enormous denudation that has taken place since its elevation. It was not seen at more than 100 feet above the sea. The same formation recurs in Sombrero, Anguilla, St. Kitts, Guadeloupe, and Barbados.

Since the Coral Epoch, there has been another subsidence, with the accumulation of a second gravel-series, which often rests upon the lower gravels, or even lower deposits, where the coral- and the older gravel-beds have been washed away. This formation may be correlated with deposits in similar positions in other islands, and with some stages of the Columbia Series of the American continent. The overlying tufaceous earths represent another stage of the geological series.

The raised terraces or base-level plains dip outward from the mountain-mass, and are evidence of the local elevation, with deformation, which occurs immediately adjacent to the foci of recent volcanic activity, but does not extend beyond the mountain-districts.

So far as observations go, the phenomena of the islands to the south are similar to those of Dominica.

The coastal plains are represented in the islands by only traces, or the somewhat enlarged shelves, less than 200 feet below sea-level. From St. Vincent to the Grenadines the banks have a considerable breadth. Some 20 miles south-east of Dominica, and again some 60 miles east of Martinique, fragments of the submarine Antillean plateau rise to within 300 feet of the surface of the water: presumably these are remnants of ancient coastal plains, dating from before the

[Soundings are shown in feet.]

dissection of the plateau into what are now the various island-masses.

This portion of the Antillean chain records several epochs of denudation :—(1) That of the long Miocene-Pliocene time when the Antillean plateau was elevated to 3000 feet or more, and carved into several isolated tablelands now forming the various island-masses, with broad undulating depressions between them. The date has been determined from the evidence obtained in Antigua, Guadeloupe, Barbados, and other islands, and sustained in these. (2) After a subsidence, or probably two epochs of subsidence, at the close of the Pliocene Period the region was raised to its maximum height, shown within the area of the islands to have exceeded 7000 feet, though evidently it attained a still greater altitude. The erosion-feature of this epoch is that of very deep valleys, amphitheatres or cirques dissecting or indenting the late tablelands, but the time was not one of relatively long duration and belonged to the early Pleistocene Period. Then there was a subsidence in the Mid-Pleistocene Period, so that the islands were smaller than at present; followed by (3) a re-elevation which resulted in the islands being a little higher than now. The gorges and channels formed then have been partly submerged since that date. The subsequent minor changes of level need not be followed further at present.

It was during the great elevation of the early part of the Pleistocene Period that all the islands were united into a continental mass, thus allowing of the migration of the Pleistocene mammals to Guadeloupe and Anguilla. These, however, were exterminated by the subsequent almost complete submergence : since when there has been no land-connection between the islands and the adjacent continent. The elevation of the mountain-districts, in excess of the general movements of the Antillean plateau, is a phenomenon due to local plutonic forces, where recent volcanic activity has obtained ; although it is not to such causes that the various islands owe their separation one from the other, but to atmospheric erosion and changes of level.

EXPLANATION OF PLATE X.

Geological sketch-map of the Windward Islands, on the scale of about 35 miles to the inch. Soundings are shown in feet.

[For the Discussion, see p. 365.]

21. *On the* Geological *and* Physical Development *of* Barbados; *with* Notes *on* Trinidad.

By Prof. Joseph William Winthrop Spencer, M.A., Ph.D., F.G.S. (Read December 18th, 1901.)

Contents.

I. Introduction.

As there is an extensive literature on the geology of these islands, the chief object of the present paper is to record some newly-observed features, and to extend the studies which have been made by the writer on the other West Indian Islands. The most important contributions as yet made to the geology of Barbados are those of Prof. J. B. Harrison & Mr. A. J. Jukes-Browne,[1] supplemented by the studies of the fossil coral-fauna by Prof. J. W. Gregory.[2] In his 'Birds of Barbados,' Col. H. W. Feilden [3] anticipated some of the conclusions subsequently arrived at by the other writers. In the earlier part of the 19th century some notes by Count Schomburgk [4] appeared, and earlier still James D. Maycock [5] made the first geological map of the island.

The geological literature of Trinidad is still more voluminous, being especially represented by the numerous papers of Mr. R. J. Lechmere Guppy, and by the earlier Government reports on the 'Geology of Trinidad' by G. P. Wall & J. G. Sawkins (1860).

II. Hydrographical Relationships of Barbados.

Barbados is an outlying remnant of the dissected and submerged Antillean plateau. It occupies the same relationship to the main chain of islands, although separated from St. Vincent by 100 miles, as Grand' Terre does to Guadeloupe proper, from which it is divided by a strait only a few hundred feet wide, or as Marie Galante and The Saints do to Guadeloupe.

[1] 'Geology of Barbados' Quart. Journ. Geol. Soc. vol. xlvii (1891) pp. 197–250; & *ibid.* vol. xlviii (1892) pp. 170–226.

[2] 'Contrib. to Palæont. & Phys. Geol. West Indies' Quart. Journ. Geol. Soc. vol. li (1895) pp. 255–310.

[3] 'On the Birds of Barbados' Ibis, ser. 6, vol. i (1889) pp. 478–79.

[4] 'History of Barbados' 1847, pp. 546–57.

[5] 'Flora Barbadensis' London, 1830, pp. 15–17.

While Barbados has a length of little more than 20 miles, the soundings show that the submerged ridge extends for 110 miles, and is covered by from 3000 to 4500 feet of water. This ridge is abruptly terminated towards the south by a channel, where soundings attain a depth of 7200 feet, while on the north the indentation in the submarine plateau reaches to 9600 feet. Just north of it, a fragment of the plateau—the Madiana Banks—comes to within 300 feet of the surface of the sea. In a north-westerly direction, towards Martinique, the submarine plateau is somewhat more depressed (8000 feet or more). To the north of the summit of this Barbados-Martinique ridge its character has not been determined, except that between the outlying Madiana Banks and Martinique there is a depth of 9246 feet. South of the ridge is a hole or a valley reaching to a depth of 8958 feet, at a point west of Barbados. Elsewhere the embayment in the drowned plateau is not known to reach more than 7200 feet below sea-level. The amount of the depression here noted is in accord with that of the more confined valley-like indentations upon the western side of St. Lucia, St. Vincent, and the Grenadines. See the map (Pl. X) which accompanies the foregoing paper on Dominica, etc.

Seaward of the Scotland Valley, the incomplete soundings on the edge of the narrow shelf show the usual evidence of two or three amphitheatres or cirques indenting the submarine plateau.

III. Hydrographical Relationships of Trinidad.

These are continental, with a channel between the island and the mainland of only 36 feet in depth. The Gulf of Paria is nowhere more than 96 feet deep, except at its mouth, where there is a valley revealed to a depth of 924 feet, or more than 600 feet beneath the adjacent floor of the submerged coastal plain, which extends nearly 50 miles farther seaward. The greatest submergence of the summit of the ridge between Trinidad and the Grenadines appears to be only 750 feet, although there may be an adjacent narrow channel of greater depth, as here the soundings are few in number. From this point the drowned plains gradually descend westward, and on the line between the nearest point of Trinidad and the Grenada banks the depth reaches to 2286 feet; but this line is indented by several cirques. Tobago rests upon the north-easterly extension of the continental shelf (which supports Trinidad), here submerged to about 200 feet, though indented on its north-western side by a cirque, with a depth of 408 feet. A more deeply-submerged spur extends north-eastward from Tobago towards the Barbados ridge, thus enclosing the large valley in the submarine Antillean plateau, with the Grenadines, St. Vincent, St. Lucia, Martinique and the ridge therefrom to Barbados almost surrounding it, as already mentioned. (See map, Pl. X.) The character of this depression is best understood when studying the question of the drowned valleys as a whole. The continental shelf extends 70 miles east of Trinidad.[1]

[1] See U.S. Hydrographic Chart, No. 1010.

IV. Physical Characteristics and Erosion-Features of Barbados.

Barbados, as already mentioned (p. 355), is scarcely more than 20 miles long, with an area of 166 square miles. From the south and west the surface rises gently or in terraces, until an elevation of 1104 feet is attained near the north-eastern side of the island. Thence there is a more rapid descent towards the sea, which is encroaching upon this coast, undermining the softer formations and leaving great blocks of coral-limestone strewn along the shore. The surface of the island is covered and protected by White Limestones or 'raised coral-reefs,' except in the great valley descending from the height of land towards the north-eastern coast, where the underlying formations are the Scotland Sands and Oceanic Oozes, to be referred to again below.

The surface of the high country is the remnant of a base-level plain of erosion, with undulations of 25 to 40 feet. It is now a small zone, the margins of which (as on the Orizaba and Canefield Estates) are dissected by gullies from 50 to 100 feet wide, increasing in depth from almost nothing to 50 and 75 feet, and extending for distances of 300 to 500 yards to the floor of a lower terrace, 700 feet above the sea. In the intervening space, escarpments or sea-cliffs are carved out of the limestone-rocks. The ravine-features are repeated down to low levels, dissecting the edges of the terraces, but they diminish in size. At about 500 feet there are rather extensive terrace-plains. The terraces below the altitude of 400 feet (near St. Thomas's Church) are bounded by sea-cliffs—the faces of higher ones. The ravine-features, in contrast with the undulating plain of the summit, suggest the recent elevation of the land.

As the limestone-capping of the great Scotland Sands and the Oceanic Oozes on the highest part of the island is only about 25 feet thick, it is not surprising to find in the Scotland Valley a series of gigantic 'wash-outs,' or amphitheatres indenting the island to a distance of 3 miles inland, with a breadth increasing to 5 miles.

V. The Older Geological Formations of Barbados.

Hitherto the geological formations of the island have been divided into three groups—the Scotland Beds, the Oceanic Series, and the Raised Coral-Reefs—which have been comprehensively described by Prof. Harrison & Mr. Jukes-Browne.[1] The Scotland Beds consist of great thicknesses of stratified sands but slightly coherent, which nevertheless form some bold cliffs along the encroaching seashore. These are overlain by the Oceanic Oozes or marly clays of abysmal origin, the establishment of the character of which by Mr. Jukes-Browne is one of the most important contributions that have been made to West Indian geology, and indeed to the science, as showing the great changes of level of land and

[1] Quart. Journ. Geol. Soc. vol. xlvii (1891) pp. 197–250 & vol. xlviii (1892) pp. 170–226.

sea, which have occurred in comparatively late geological times; for these deposits originated at ocean-depths of perhaps 2 miles or more. Their age has not hitherto been exactly determined, as the Scotland Beds, beneath them, contained only very fragmentary palæontological evidence, and the limestones above were not differentiated into their component formations, all being designated 'Raised Coral-Reefs,' and regarded as of Pleistocene age. Accordingly, Mr. Jukes-Browne originally assigned the Oceanic Series to the Pliocene Period.

From the fragmentary evidence available, Mr. R. J. L. Guppy correlated the Scotland Sands with the Naparima Beds of Trinidad, on account of finding two fossils in common. At first he classified the Trinidad formation as Lower Miocene, but later as Eocene, which conclusion agrees with that of Prof. Gregory.[1] The changing physical conditions, which allowed at first of the accumulation of shore-deposits of sand, then of the oceanic oozes at abysmal depths, and finally of limestones, containing a littoral fauna, imply at least a long duration of time. The limestones overlying the Oceanic Beds are now found to belong to the Oligocene, not geologically very much more recent than the age assigned to the underlying Scotland Beds. On this account, without fuller evidence, I am inclined to think that the Scotland Beds are somewhat older than Mr. Guppy makes them; for the one period (Eocene) seems too short for the stupendous changes in physical conditions recorded in these various formations. Oceanic Beds occur in Cuba, beneath the White Limestones, as first shown by Prof. W. O. Crosby,[2] and subsequently by Mr. R. T. Hill.[3] From the fossils contained in the White Limestone of Cuba, Prof. W. H. Dall concluded that they belonged to the Lower Miocene Period, which he now classifies, however, as the Upper Oligocene. Oceanic Beds occur in Jamaica at what is supposed to be the same horizon as in Cuba.

The Scotland Beds and the Oceanic Series constitute the foundation of Barbados, lying unconformably beneath the limestones.

VI. The White Limestone or the Antigua Formation, and its Relationship.

Under the designation of 'Raised Coral-Reefs,' Mr. Jukes-Browne has given a description of the calcareous formations, to which he assigned a date no older than the Pleistocene Period. As the general characteristics of these rocks are alike, it was natural to correlate all of them under one series as had been previously done, and when large collections of fossils were obtained at a few localities, to assign their age to the whole calcareous cap. In Prof. Gregory's revision of the corals collected by Mr. Jukes-Browne and Mr. G. F. Franks,

[1] Quart. Journ. Geol. Soc. vol. li (1895) p. 298.

[2] See Messrs. Harrison & Jukes-Browne's paper, Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 236.

[3] 'Notes on the Geology of the Island of Cuba' Bull. Mus. Comp. Zool. Harv. vol. xvi (1895) pp. 243–88 with nine plates.

he found an admixture of species belonging to different horizons. The mollusca were from low levels, mostly lower than Ceres (70 feet), and were in a better state of preservation than those of higher levels, such as at 150 feet above the sea. The low-level shells may represent the fauna belonging to almost modern days, and even much later than the remains of recent species found at higher altitudes. It is a question of different horizons in apparently the same kind of rocks which needs consideration.

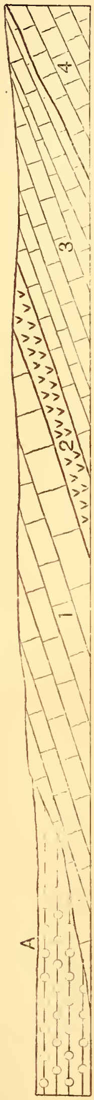


Fig. 1.—*Section near Ragged Point (Barbados).*

4 = Soft marly limestone, 20 feet exposed. 3 = Hard, massive, semicrystalline limestone, 40 feet. 2 = A bed containing masses of corals, 10 feet. 1 = A hard massive bed with eroded surface, 40 feet. [All of these beds dip 15° to 20° south-eastward. The strike of these beds continues to Three Houses, 2 miles inland.] A is a mechanical limestone, containing pebbles from 1 to 4 inches long, resting unconformably upon the lower beds: the position of this bed is horizontal, and its remaining thickness reaches to 6 feet.

The limestones are essentially white, with a texture sometimes soft and marly, while other layers are more compact. Generally the beds are devoid of organic remains, though in places casts of shells and corals are found; especially are the fragments of coral notable. But an overlying formation of the same materials at lower levels is rich in corals. The older limestones cover the higher parts of the island, and may be seen to dip at from 12° to 20° south-eastward, as at the estates of Chimborazo, Canefield, Mount Misery, etc., above 1000 feet in altitude; and from there at various points down to less than 100 feet above sea-level, near Ragged Point and Three Houses. At the higher points named, the limestones are only about 25 feet thick, resting unconformably upon the older eroded surfaces of the Oceanic Series. Near Ragged Point, Three Houses, and Bath, the inclined strata of this formation may be seen dipping and passing under other beds which rest unconformably on them in horizontal positions. Thus we find the accompanying section (fig. 1) in the railway-cutting and bluffs near Ragged Point. On the southern and western side of the island, one cannot be certain of distinguishing the older beds from the newer, unless the dip, unconformity, or fossils identify them. Near the Cathedral at Bridgetown I found *Stylophora* sp. and *Astrocœnia* sp. (the same corals as the Oligocene species of Antigua), which were kindly determined for me by Dr. T. W. Vaughan. These show that the old White Limestone passes much below the altitude of the horizontal 'raised coral-reefs,' and that the surfaces of both have been extensively denuded, so that the underlying limestones appear in places at the surface. Prof. Gregory [1] also contributes some knowledge of the corals of the higher levels, derived from the collections of Messrs. Jukes-Browne & Franks, found at Castle Grant (at an altitude of over 1000 feet) and at other points (at over 600 feet in elevation). Their low-level collections were from Ceres (70 to 90 feet above tidemark). Of the 13 species found at high levels, 7 occur not only in the 'low levels' of Jukes-Browne & Franks, but also in the terrace near Bath at an elevation of about 150 feet, where they were collected by the present writer. This important deposit will be described in its proper place.

My own high-level collections were rendered valueless by an accident, after I had brought them to Washington. As the fossils of the Bath terrace do not contain any admixture of older forms, they cannot date much farther back than the Pleistocene Period. I am inclined to explain the occurrence of the 7 identical species at the higher levels and at Bath, as having been obtained from remnants of the newer formation filling hollows in the eroded surface of the older high-level limestones. This feature may be seen in ascending the western side of the island, where pockets rich in corals form a contrast with the prevailing scarcity of organic remains of the older formation.

Of the remaining 6 species, out of the 13 mentioned, 3 are reported in both the high- and low-level collections. One of these —*Cyphastræa costata*, Duncan—is a West Indian Oligocene form. It may have been unconsciously obtained at Ceres, where the older limestones come to the surface, as is the case of my collection near the Cathedral. The remaining 3 species come from only the high-level deposits. Two of them are Oligocene types of the West Indies, and the third a new species suggestive of the same. The late Prof. Duncan has also described *Astræa barbadensis* from both Barbados and Antigua (Oligocene). In Nugent's collection from Antigua, which Duncan studied, there were some living forms. That admixture has led some writers to regard his conclusions with doubt. It may here be said that my collection of 15 species, several of which are new, has been found by Dr. Vaughan to consist entirely of ancient types referable to the Oligocene Period. My collections came from the older limestone-beds of Antigua, and I suspect that the recent forms found by Duncan came from beds of an upper series related to, or above, the Mechanical Marls of that island.

The amount of erosion which the lower limestones have suffered has been enormous, so that they have at various points been entirely removed before the formation of the overlying reefs, as shown near Bath. This will be referred to again. From the corals already known (the shells are mostly casts), from the physical characters here set forth, and from their counterparts in Antigua, Guadeloupe, Anguilla, etc., one is led to conclude that the White Limestone Series in the different islands are of the same age as that primarily

[1] Quart. Journ. Geol. Soc. vol. li (1895) p. 285.

determined in Antigua. In my papers on these islands,[1] I have collected evidence showing that the limestones belong to the Oligocene Period, or what was formerly called Lower Miocene, and are equivalent to certain Oligocene Beds of the South-eastern States of America.

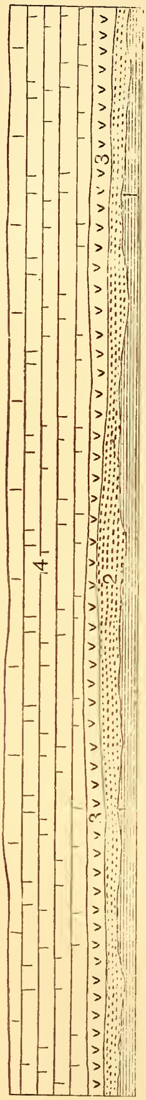


Fig. 2.—*Section about a mile north of Bath (Barbados).*

1 = Underlying Oceanic Series. 2 = Stratified sands (derived partly from the Scotland Series and partly from comminuted limestone) with rounded pebbles of the White Limestone and rolled masses of the Oceanic Clay, 4 to 5 feet. 3 = Bed of massive corals, 5 to 8 feet. 4 = Bed of branching corals, with the upper layers laminated, 30 feet.

Additional evidence of the age of the Antiguan beds has been mentioned by Prof. Gregory.[2] Since Duncan's studies of the Antiguan corals, the White Limestones in other islands have been frequently compared, in regard to age, with those of Antigua, and as we now know their equivalence on the American continent, whether in the typical island or in Barbados they may be appropriately called the Antigua Formation.

VII. The Ragged-Point Series.

After the deformation and elevation of the Antigua or old White-Limestone Series, there was an extensive denudation of its surface, when eventually the land stood for a long time at a low elevation above the base-level of erosion, so that the resulting outlines were broad undulating features. In places, this denudation left bare the underlying Oceanic Series. Upon the denuded surface of this formation a bed of mechanical limestone was accumulated, which now rests in an horizontal position. Remains of this, having a thickness of 6 feet, may be seen lying in the hollows of the eroded surface of the upturned beds of the older white limestones of Ragged Point, as shown in fig. 1 (p. 358). The material is a marl containing water-worn pebbles of the harder limestones. At other points, fragments of rolled Oceanic Clays were seen in this mechanical series. The only fossils observed were

[1] 'On Antigua, Guadeloupe, Anguilla, St. Martin, St. Christopher, etc.' Quart. Journ. Geol. Soc. vol. lvii (1901) pp. 490–544.

[2] *Ibid.* vol. li (1895) p. 295.

rolled fragments derived from the older formation. Between Three Houses and the 'Thicket,' remnants of the mechanical limestones were also seen, resting unconformably upon the Scotland Sands. At the foot of the terrace, north of Bath, where the Antigua Formation has been entirely removed, is an horizontal bed of sand containing small rounded pebbles of the harder old calcareous rocks and lumps of the Oceanic Clay. This stratum is succeeded by a coral-formation (fig. 2, p. 360).

Between the sea and St. Thomas's Church, at an elevation of 100 feet, the same mechanical accumulations overlie the older limestones. Here the thickness is from 4 to 8 feet. At Bridgetown, a laminated layer of marl, containing rounded pebbles, is shown in excavations to have a thickness of 3 feet. At many places, the formation was seen to a height of 100 feet. Wherever observed, the deposit formed only a remnant of what was once a widespread mass over the older limestones, which themselves have been farther carried away where the denuding agents have removed the covering. Thus this newer formation bears testimony to the vast amount of subsequent denudation. The Ragged-Point Series is only a repetition of similar accumulations overlying the eroded surfaces of the Antigua Limestone in other islands. It may be correlated with the Lafayette Series of the North American continent, provisionally placed at the close of the Pliocene Period.

VIII. The Bath-Reef Series, and more Recent Phenomena.

Along the eastern coast, both south and north of Bath, but here somewhat interrupted by an indentation, is a limestone-cliff, the surface of which is a terrace about 150 feet above the sea. South of Bath, the cliffs lately projected so as to allow of the sea undermining the hard upper beds, and consequently the shore-line is now strewn with great blocks. About a mile north of Bath a good section may be seen, as in fig. 2 (p. 360). The summit of this terrace is level in front, but it rises slightly to 165 feet. The strata are substantially horizontal, in contrast with the sloping beds of the Antigua Limestone upon the flank of the mountain behind it.

From two points on this terrace I collected a number of shells, all in the form of casts, and a quantity of corals, which last Dr. T. W. Vaughan kindly determined for me, as follows:—

1. *Dichocœnia Stokesi*, M.-Ed. & H.
2. *Eusmilia fastigiata*, Pallas.
3. *Orbicella cavernosa*, Linn.
4. *O. acropora*, Linn.
5. *Stephanocœnia intersepta*, Esper.
6. *Favia* sp.
7. *Isophyllia* sp.
8. *Platygyra viridis*, Le Sueur.
9. *Diploria labyrinthiformis*, Linn.
10. *Colpophyllia gyrosa*, Ell. & Sol.
11. *Isopora muricata*, Linn., forma *cervicornis*, Lam.
12. *Isopora muricata*, Linn., forma *palmata*, Lam.
13. *Porites porites*, Pallas.
14. *P.* (*Neoporites*) *astræoides*, Lam.

All these are living species, without any admixture of old forms. They are found in a stratum not resting on any calcareous foundation, so that this may be considered as typical of a series of the Pleistocene (?) Formation, which itself has suffered greatly from erosion. Remnants of this massive coral-rock occur in the Scotland Valley and at other points.

Without entering into the question of what terraces are due to marine erosion, leaving sea-cliffs in the rear of them, and what are constructional from the building-up of reefs, it may be said that these deposits of recent coral-species are widespread over the surface, not merely below the altitude of 165 feet, but possibly (in part at least) at the higher levels, where pockets of coral-masses containing recent species occur. Some of these, however, may belong to an even later epoch of the Pleistocene Period than the Bath Series.

As noticed at Bath, the series rests upon a mechanical foundation: although unconformity is suggested, it may possibly be its lowest member. At other points, at the same or lower levels, the overlying coral-formation is wanting where it should be found. This emphasizes the subsequent denudation. But in Dominica, the corresponding coral-formation rests in hollows upon the surface of gravels. At any rate, great denudation of the surface of the Bath Series occurred during the epoch of the elevation of the land, when the deep valleys and cirques indenting the margins of the Antillean Plateau were completed. These features are illustrated in a small degree in the Scotland Valley and adjacent off-shore soundings shown, though they could not be strongly marked by the incomplete soundings of the steep submarine slopes (almost without a fringe) of this outlying Barbadian remnant of the Antillean Plateau. But deep erosion-features are illustrated in the submerged ravines or cirques at the mouth of the Gulf of Paria, and between Trinidad and Tobago.

The study of the relationship of the Bath Coral-Reef and the mechanical deposits will help us to understand the whole West Indian Series, forming, as they do, mantles of similar thickness and characteristics in Grand' Terre (Guadeloupe), Anguilla, Tintamarre (near St. Martin), St. Kitts, Sombrero, and Dominica. Whether or not the coral-reefs in the various islands, with a similar fauna and development, be nearly as old as the Mechanical Marls, which are regarded as the equivalent of the Lafayette Formation of the North American continent (provisionally assigned to the close of the Pliocene Period), it is certain that they cannot be much older, if quite so old, as the early Pleistocene Period; yet they were anterior to the epoch of great elevation of the land, when the deep gorges and cirques were being completed. As there is no palæontological guide in separating the various episodes of the Pleistocene Period, one is quite prepared to learn that some of the coral-deposits, newer than the lower gravels, may belong to a little later date than the Bath Series. Thus some of the newer coral-accumulations were probably formed during the subsidence, when the waves carved out the sea-cliffs of the higher terraces of Barbados. This subsidence would correspond in time with that of the Columbia Formation of other islands and the North American continent. As the terraces are dissected by only youthful ravines, the re-elevation must have been comparatively recent.

But this rise of the land to over 1000 feet is greater than that traced in other islands. Indeed, the amplitude of all the more recent changes of land appears to have been greater in the south than in the north. The subject of the calcareous formations deserves still further investigation.

IX. Notes on the Physical Features of Trinidad.

The greater part of Trinidad consists of undulating plains rising to 200 feet above the sea, with some extensive swamps. Along the southern and the eastern coasts are a few isolated hills, as also a range of hills in the interior, whose summits reach more than 1000 feet above sea-level. But along the northern side of the island is a range of mountains containing crystalline schists, etc., which culminate in points 3100 feet above the sea. Various formations of sandstone, shales, and calcareous rocks, in more or less disturbed strata, have been described by Messrs. Wall, Sawkins, and Guppy, the last-named of whom places the highest of the series (Caroni) as the equivalent of the Lower Miocene of Jamaica,[1] now referred to the Oligocene Period. Accordingly, the entire topographic outlines of the lower country are due to the sculpturing of the surface during the Miocene-Pliocene Period, as it has been re-covered by newer formations to only a limited extent. At Matura Bay, on the eastern coast, Mr. Guppy found a deposit with shells, which he regarded as indicating a Newer Pliocene Period. I was unable to visit the locality, but I suspect that in some way this formation will be found to correspond in time with the Bath Series of Barbados —that is, the early Pleistocene Period.

Superficial gravel-deposits have been mentioned by previous writers. Some of these deposits I have visited: thus, behind St. Joseph are terraces at 110, 135, 185, and 210 feet above the sea. That at an elevation of 185 feet was covered by a layer containing numerous shells of *Strombus*, oysters, etc. These terraces are composed of loam and gravel, only part of which is rounded and part is subangular. The colour is reddish or brownish. The plains of the Caroni are covered with the same material, but contain few pebbles. Along Dry River (near Port-of-Spain), the surface is covered by 10 or 12 feet of red loam, overlying 3 or 4 feet of well-rounded gravel. South of San Fernando are extensive horizontal beds of sand and loam, with some pebbles, resting upon the upturned strata of the older formations. These have a thickness of 50 feet. They do not belong to the same formation as the terraces just mentioned. Mr. Wall classified them provisionally with the later deposits of a Tertiary formation, at the same time asking whether they were really such. In position they appear to be a post-Miocene-Pliocene accumulation, subsequent to the denudation of that long period. At the point where the Arima River leaves the northern mountains is an old base-level flat at 200 feet above the town, or about 400 feet above the sea. This flat is deeply dissected by the stream, in such

[1] In his earlier papers Mr. Guppy placed the Caroni Series in the Upper Miocene, Quart. Journ. Geol. Soc. vol. xxii (1866) p. 572.

a way as to suggest the recent elevation of the district, which view is supported by the occurrence of a neighbouring cataract 340 feet in height. These and other similar observations show that the old Miocene-Pliocene land-surfaces continued long in Trinidad, as in the West Indian Islands, and that they were subsequently covered by a thin mantle of mechanical deposits, which further observation would probably show to belong to two series, as on the North American continent.

X. Summary and Conclusions.

Except the crystalline schists of Trinidad, the oldest formations in both that island and Barbados are shore-accumulations, which have been referred to the Eocene Period, though possibly somewhat older. Then succeeds in both islands the Oceanic Series, deposited in oceanic abysses at perhaps depths of 2 miles or more. This great subsidence was followed by an elevation of the region, so that the subsequent denudation not only moulded the surface of the Oceanic Deposits, but in places cut through them; and upon this foundation the White-Limestone Series, or the Antigua Formation, was accumulated in comparatively shallow water. This widespread formation has been found to belong to the Oligocene Period. It was then elevated, so that throughout the long Miocene-Pliocene Period it formed the surface of the land—which stood at a high altitude at first, and later, at a lower one—when the broad undulating topographic features of the Antillean Plateau, now in part submerged to over 7000 feet, were produced. Then followed a subsidence which carried the land to 100 feet below the present level, when the Ragged-Point Series was accumulated unconformably upon the older formations, about the close of the Pliocene Period.

Upon the subsequent emergence, the land rose to such a height as to favour rapid and extensive denudation, so that the Ragged-Point mantle now remains only in protected places. The Bath-Reef Series (occurring at a height of 165 feet or more) shows another very great subsidence, subsequent to a post-Ragged-Point elevation, with the accumulation of fossils belonging to living species. Much of the great denudation of the Ragged-Point Series was subsequent to the Bath episode, for this series has also been dissected and very largely removed, so as to expose the lower mechanical formation. The great topographic features of this epoch are to be seen in the deep river-like valleys and cirques, such as now indent the margins of the drowned plateau; these, while scarcely observable in the scanty soundings on the steep submarine slopes of Barbados, may be traced to depths of 6000 or 7000 feet near St. Lucia and St. Vincent, and to a less degree at the mouth of the Gulf of Paria. Possibly the valley shown in the deep sounding of 8958 feet, west of Barbados, may have been produced at this time (see map, Pl. X).

The early Pleistocene elevation was succeeded by a depression of the region, so that Barbados sank to over 1000 feet lower than now, and formed only a little low islet, like Sombrero, lying alone far out in the ocean. During this episode of subsidence, some of the superficial coral-layers or pockets were probably formed upon the surfaces of what are now the raised White Limestones. It was during these mid-Pleistocene changes of level, carrying the island down to 1000 feet below the present altitude, and raising it again, that the waves cut out the sea-cliffs which now form the faces of terraces. Since their elevation small ravines have been formed, which dissect their edges. This late ravine-feature is mostly observable on the drowned coastal shelves of the northern islands, thus showing that the last movement of depression has not advanced so far in Barbados as it has in the north.

The question of local elevation due to volcanic forces in other islands is not involved in the study of Barbados, but only that relating to great regional movements. All the late minor changes have not been fully studied. While much is yet to be learned concerning the Antillean chain, the problem of the changes of level of Barbados and Trinidad cannot be solved by the investigation of these islands alone, but it must be studied in connection with those of the other islands. While there are occasional references to other islands, a correlation of the phenomena described in the series of papers of which this is the last, and in the paper of Prof. Cleve on the Virgin Islands, should be made, pointing out the development and modification of features in different localities, where the record of the geological history of the West Indian region may be found.

Discussion [on the two foregoing papers].

Prof. Hull expressed his gratification at being the channel of communication of these papers to the Society; though, as the Author was himself a Fellow, this was unnecessary. He understood that these papers completed the series in which Prof. Spencer had embodied the results of an elaborate survey of the great oscillations of level which the West Indian Islands had undergone in late Tertiary and post-Tertiary times, causing a connection, as he maintained, to be established between North and South America, and the formation of submerged valleys and embayments.

Dr. Blanford agreed with Prof. Hull in his appreciation of the value and importance of the Author's descriptions of West Indian geology. He especially called attention to the new light thrown on the Raised Coral-Reefs of Barbados, which, instead of being of one age, as they were described by Prof. Harrison & Mr. Jukes-Browne, are shown by both physical and palæontological characters to belong to two (or perhaps three) unconformable series of different ages. In one of the principal conclusions to which the Author had come—his view that the whole of the West Indian Islands formed a high plateau uniting North and South America in the Pleistocene Period—the speaker was unable to concur. The Author's principal evidence was derived from submarine troughs and valleys, which he regarded as proofs of subaërial erosion during a period of elevation, but the origin of these depressions is doubtful. On the European shores, the finest submarine valley known (the 'fosse du Cap Breton') corresponds to no river, and there is no submarine trough of any kind corresponding to the greatest river of Western Europe—the Rhine. Moreover, if the West Indies in Pleistocene times formed a bridge between North and South America, the fauna of the islands would testify to the fact. It does nothing of the kind, as was shown by Mr. G. F. Harris in 1895, with regard to the land-mollusca, in his remarks on Prof. Gregory's paper. The evidence regarding the mammals is, if possible, even more strongly opposed to the Author's views. There are no monkeys, carnivora, or ungulata even in the large West Indian Islands, but only bats, insectivora, and rodents. Omitting bats, the rodents and insectivora of Cuba, Hayti, and Jamaica have quite as strong affinities with African as with American forms. There are no insectivora in South America, and the North American genera are remote from the West Indian, the nearest allies of the latter being found in Madagascar. It is possible that the West Indian mammals entered the country when it was part of a land extending from South America to Africa, and since the immigration of these types, which must have been in the older Tertiary times, there is nothing to show that the West Indies as a whole have been united to either North or South America.

Prof. Sollas said that he could add but little to the weighty words of the last speaker; but it appeared to him that the more important part of these interesting papers lay in their study of stratigraphical correlations, which afforded fresh evidence of the wide-reaching character of the Oligocene transgression, and was a solid contribution to the geology of the Islands.

It was unfortunate that in the more theoretical part of the papers, terminology was employed which wholly begged the point at issue. Submarine depressions of various form existed, but no convincing evidence had been adduced to show that these were cirques and valleys. Without doubt the area had been subject to great tectonic changes, but these were not necessarily of the age nor of the nature assumed; if land-connections were required for the migration of terrestrial animals, they could be more economically obtained by bridging the gaps between the islands, and a subsequent fracturing and subsidence of the bridges might then be admitted.

Prof. Watts, by permission of the President, read the following remarks sent by Mr. A. J. Jukes-Browne:—

'I notice that the Author's paper on Barbados deals mainly with the Raised Coral-Reefs, and that his examination of these rocks has led him to find three distinct formations in what Prof. Harrison and I regarded as one continuous series. Apparently he only admits the two newer of these "formations" to be Pleistocene, and claims that the oldest beds contain an Oligocene fauna. On the strength of this he refers the Oceanic Series to the Eocene, and the Scotland Beds to a still earlier period.

'All this alteration in the classification of the Barbadian sequence appears to depend entirely on the identification of the corals which have been obtained from different levels, and on their comparison with Antiguan and American species. I understand, however, that the Author has not added much to the fauna of the high-level reefs, and that the beds which he would refer to the Oligocene occur at low levels near Bridgetown and at Ragged Point.

'Prof. Harrison and I have admitted that the oldest reef-rocks and the *Globigerina*-marls may be of Pliocene age; but it will need very strong evidence to prove that any parts of what we took to be low-level reefs are ancient limestones of Oligocene age. The evidence on which the Author relies is not given in the abstract of the paper, and when it appears it will be presumably such as only a coral-specialist can properly appreciate. He intimates, however, that the fauna is the same as that of his Antigua Formation, which Dr. T. W. Vaughan has pronounced to be of Oligocene age. I shall await the publication of this evidence with much interest.'

Postscript to Discussion.

[The Author, in reading over the proof, replies to Dr. Blanford's doubts as to the continental elevation of the islands, in addition to the evidence adduced from drowned valleys set forth in these and other papers, by calling attention to the fact that features similar to the 'fosse du Cap Breton' (not having a great river at its head) may be found dissecting the Central American plateaus where no great river enters them, as the *barrancas* cut out of nearly horizontal plains start from no surface-depression, and in the distance of a mile form gorges 500 feet or more in depth, with numerous tributaries. All of these continue, and sooner or later form great valleys. They are like great wash-outs. As for not finding the continuation of the Rhine or that of a Norwegian fjord, these valleys are more or less in the path of the ancient glaciations, and therefore their courses may have become concealed; while, on the other hand, similar great-river valleys in America are traced to the floor of the sea. Referring to the distribution of fauna not supporting the continental connection of the islands, he would point out that remains of *Amblyrhiza* and Elephants of Pleistocene age have been found in Anguilla and Guadeloupe. The great elevation is supposed to have been in the Early Pleistocene Period. Later, subsidence completely or almost completely submerged many of the islands—thus reducing Barbados to an island of probably less than a square mile in area, such as Sombrero is nowadays. And as there has been no subsequent connection of the islands and continent, large modern species could not be expected in the islands. The Author is quite prepared to accept an Atlantis theory such as Dr. Blanford seems to favour; but that would also involve a connection of the Windward Islands with the continent at a late date.

To reply to Prof. Sollas would involve too lengthy a discussion. But the evidence adduced from the submerged topographic forms is confirmed by the relationship with and repetition of land-features, best seen in high plateau-regions, such as Mexico and Central America, where the Author has just spent another winter (whence the delay in the appearance of this paper).

In reply to Mr. Jukes-Browne, the Author ventures to think that a perusal of the full paper will explain the situation. The different series, as shown by unconformities so pronounced, with the most elevated and oldest calcareous formation traceable as dipping-beds to the sea-level, as for instance near Ragged Point, furnish proof of different epochs (short or long) even without fossils; and this shows that the Barbadian series are in complete harmony with those of the other Antillean islands, which help to explain the changes in Barbados, while those in Barbados throw light upon the history of the other islands.—*April 28th*, 1902.]

22. NOTE *on a* PRELIMINARY EXAMINATION *of the* ASH *that fell on* BARBADOS *after the* ERUPTION *at* ST. VINCENT (WEST INDIES). By JOHN SMITH FLETT, M.A., D.Sc., F.R.S.E., F.G.S. *With a* CHEMICAL ANALYSIS *by* DR. WILLIAM POLLARD, M.A., F.G.S. (Read May 28th, 1902.)

Two samples of the material were sent by Dr. D. Morris, C.M.G., of the Imperial Agricultural Department for the West Indies, to Prof. Judd, who forwarded them to the Director of the Museum of Practical Geology. They consisted of a fine greyish-brown powder, not unlike 'flour-emery,' but somewhat coarser and distinctly gritty to the touch. This powder was passed through a set of sieves, and it was found that 69 per cent. passed a sieve of 90 meshes to the inch, and 95 per cent. passed one of 60 meshes. All passed 30 meshes to the inch.

The 'ash' contains plagioclase-felspar, hypersthene, monoclinic brownish augite, apatite, and magnetite, with fragments of a brown glass. The separated powders were all of much the same colour.

Plagioclase-felspar is the most abundant constituent, mostly in broken fragments of very irregular shape. It belongs largely to labradorite, but appears to include more than one variety. Perfect crystals are not uncommon. Glass-enclosures are very numerous, and are frequently rectangular in outline: they often contain very small stationary bubbles.

Many of the felspars have a thicker or thinner skin of glass adhering to their surfaces. This glass is brown, somewhat turbid, isotropic, with often many small rounded steam-cavities. The perfect crystals of felspar are often lozenge-shaped, as they lie on the broad flat brachypinacoid, being bounded by 001 and $\bar{2}01$.

Hypersthene is next in frequency. The larger crystals are strongly pleochroic in green and reddish-brown tints, as is usual in a volcanic hypersthene which is rich in iron. The enclosures are glass-cavities with bubbles, and are often bounded by regular prismatic outlines. Magnetite is sometimes also seen in sharply-formed little octahedra in the hypersthene. Monoclinic augite is less common; it is browner in colour, less pleochroic, and contains fewer enclosures than the hypersthene.

Both pyroxenes are often in perfect little crystals, showing prism-faces and both vertical pinacoids, and with roof-like terminations. Sometimes a little brown glass is adherent to their surfaces. Many of the hypersthenes are cross-twins.

Magnetite can be easily extracted in fair quantities from the powder by a weak magnet. Its octahedra are often perfect.

Apatite is undoubtedly present in rather large prisms; and there is another mineral, which appears to be zircon.

Fragments of glass are numerous, and mostly smaller than those of crystallized minerals. The very smallest are minute threads and broken fragments, with curved or concave surfaces, such as are common in the tuffs that exhibit 'aschen-structur.' The larger pieces of glass are grey or brownish in colour, turbid or spotted, full of very small steam-cavities, and between crossed nicols show sometimes small, elongated, doubly-refracting microliths. In most cases the larger pieces are of composite character, and consist of a fragment of felspar with more or less of adherent glass.

Among the finest débris there is much felspar in very minute angular chips, but pyroxene in this condition is less common.

The great preponderance of crystalline materials in this volcanic dust is one of its distinctive features, and shows that in the lava before the great eruption an early generation of crystals was developed in considerable perfection and abundance.

Another feature worth notice is the perfect crystalline form, not seldom exhibited by the felspar and the pyroxenes, and the very inconsiderable amount of glass that often surrounds them. At the time when the mass was projected into the air the glass must have been very fluid, and must have been to a large extent wiped off the surface of the crystals by friction with the atmosphere during its rapid passage.

Dr. Morris reports that 'the ash at first was of a brownish colour, then it became slightly redder,' while the final deposits consisted of a whitish-grey impalpable powder. This may be explained by supposing that the minerals of high specific gravity were first to fall. The magnetite and the pyroxenes would first subside, and appear black or dark-brown from adherent films of brown glass; thereafter the felspars, paler, but brownish for the same reason; and the last to fall would be the minute threads of glass and the smallest débris of felspar, which would form a whitish-grey impalpable powder.

A complete chemical analysis of this ash is appended, and as the state of the material offers considerable facilities for mineral separations, it is hoped that at a future time it may be possible to obtain separations and analyses of the constituents, more especially the felspars. The chemical analysis is as follows:—

	Per cent.
SiO_2	52·81
TiO_2	0·95
Al_2O_3	18·79
Fe_2O_3	3·28
FeO	4·58
MnO	0·28
(CoNi)O	0·07
CaO	9·58
MgO	5·19
K_2O	0·60
Na_2O	3·23
P_2O_5	0·15
SO_3	0·33
Cl	0·14
H_2O at 105° Cent.	0·20
H_2O above 105° Cent	0·17
Total	100·35

Discussion.

Mr. Teall called attention to the small quantity of potash revealed by the analysis, and thought that this might possibly be due to the glassy part having been mechanically separated from the crystalline minerals in the air, as the sample analysed consisted mainly of such minerals. Hence, if the area could be found where the glass fell, the discovery might prove important from the agricultural point of view. Nature would have been more bountiful if she had let all the glass fall on Barbados, and the minerals in the sea.

Prof. Johnston-Lavis pointed out the uselessness of such dust-analyses, except as applied to agricultural deductions at the actual spot where the material was collected. He had shown many years ago that, in studying a given volcanic deposit, its composition varied with the distance from the focus of eruption, owing to the winnowing effect of air-currents. In his paper on volcanic ejectamenta, he had shown that a volcanic dust may be quite different in composition from the initial explosive material that was the motive power of its ejection, so that it might be in part made up of the powder of quite different volcanic rocks, or even of sedimentary rocks forming the walls of the volcanic vent. Thus a volcanic dust might contain a large percentage of limestone or quartz of sedimentary origin. Only a careful selection of primary eruptive material near the vent, without any admixture of supplementary or accidental ejectamenta, could afford suitable material for an analysis that would throw any light on the nature of the magma of this eruption.

Prof. Sollas doubted whether the small proportion of potash contained in these ashes stood in any necessary connection with the winnowing-away of the glass, especially if this amounted to half the bulk of the rock, as might well have been the case. The general result of analyses which had hitherto been made, was to show that the chemical composition of the total phenocrysts of a glassy rock did not differ widely from that of the glass itself. No doubt there was a general increase in the ratio of potash to soda on passing from phenocrysts to glass, but it was on the whole trifling, and not sufficient to lead us to expect that the glass of this eruption should contain more than, say, an additional 1 per cent. of potash above that in the phenocrysts.

Mr. Prior said that he had examined the dust, and thought that it indicated the character of the lavas of eruption: they were probably hypersthene-augite-andesites, such as those of the Andean and Mexican chains. He had also examined the dust which fell on Barbados in 1812; this was finer in grain, but qualitatively of the same composition as the dust of 1902. The amount of light material (pumice), however, was much larger, and that of magnetite less. The older fall is said to have increased the fertility of Barbadian soils.

23. *The* CARLISLE EARTHQUAKES *of* JULY 9TH AND 11TH, 1901.

By CHARLES DAVISON, Sc.D., F.G.S. (Read April 16th, 1902.)

[Map on p. 372.]

THE chief title to interest possessed by the Carlisle earthquakes of 1901 is the light which they throw upon the structure of the region underlying the Lake District and the North of Cumberland —a structure which must clearly be very different from that manifested by the surface-rocks. The shocks were at least four in number. The first and strongest occurred on July 9th, at 4.23 P.M.; the second about three minutes later; the third on the same day at 4.45 P.M.; and the fourth on July 11th at about 11.10 P.M. In addition, there are records of four other shocks, depending on the authority of single observers. These are as follows:—

July 9th, about 3 P.M.: Loweswater. A slight shock.

July 10th, about 1.30 A.M.: Crosthwaite (near Keswick). A slight shock without sound.

July 12th, about 2 A.M.: Crosthwaite. The same.

July 14th, about 11 P.M.: Crosthwaite. The same.

a. July 9th, 4.23 P.M.

Intensity, 5 centre of isoseismal 5, lat. 54° 47·8′ N., long. 3° 0·4′ W. Number of records 267, from 155 places; and negative records from 50 places.

Isoseismal lines and disturbed area.—The two continuous curves in the map (p. 372) refer to this earthquake. The isoseismal 5 is very nearly a circle, 29 miles in diameter, and 660 square miles in area. Its centre is situated at a point 7 miles south-south-west of Carlisle.

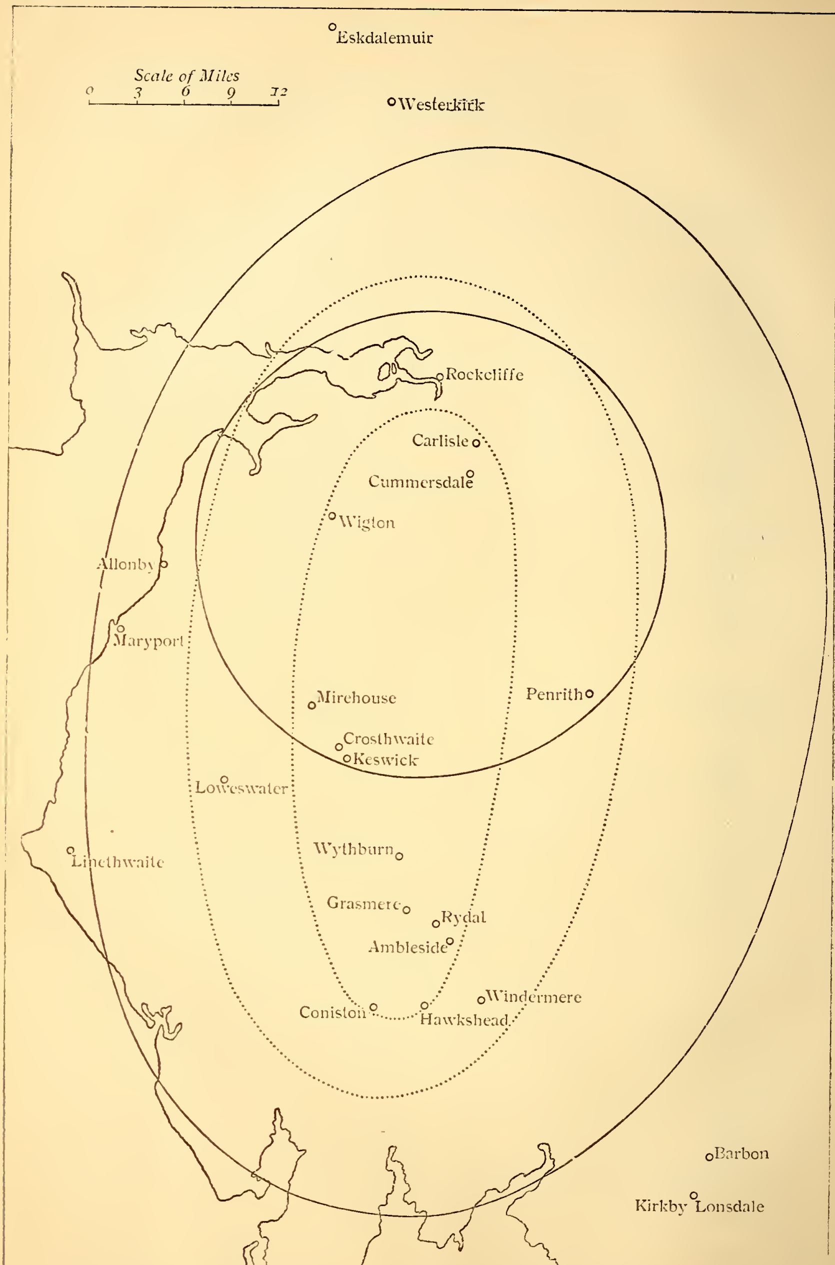
The isoseismal 4 is an elongated ellipse, 66 miles long, 46 miles wide, and 2390 square miles in area, its longer axis running N. 5° E., and S. 5° W. The distance between the isoseismals 5 and 4 is 5 miles on the west side and 10 miles on the east.

Outside this isoseismal, the shock was felt at Whitehaven, 2 miles to the west, Westerkirk and Eskdalemuir, respectively 4 and 9 miles to the north, and Barbon, near Kirkby Lonsdale, 5 miles to the south-east. Its disturbed area must therefore have contained more than 3000 square miles.

The excentricity of the isoseismal 5 with respect to the isoseismal 4 is the most peculiar feature of these lines. On the north, the distance between them is 10 miles, and on the south 27 miles, the distance between their centres being about 9 miles.

Nature of the shock.—In the central portion of the disturbed area, the shock consisted of a single continuous series of vibrations. The accounts as a rule are not very detailed, but

Map showing the area affected by the Carlisle Earthquakes.



[The inner continuous curve represents the isoseismal 5, and the outer continuous curve the isoseismal 4 of shock *a*. The inner dotted curve represents the isoseismal 4, and the outer dotted curve the isoseismal 3 of shock *c*.]

there were evidently two maxima of intensity, with intervening weaker motion and fainter sound. At no great distance from the longer axis, these intervening vibrations became imperceptible to many observers, and the shock consisted of two detached series of vibrations, separated by an interval of about 3 seconds' duration. This double series was perceived over an area the outer boundary of which coincides nearly with the boundary of the disturbed area of the third shock (indicated by the outer dotted line on the map), except that it is less elongated in form, extending 2 or 3 miles beyond it towards the east, and falling short of it by about the same distance towards the north and south. Towards the boundary of the disturbed area, the shock consisted once more of a single series, the weaker part of the shock apparently becoming imperceptible.

The continuity of the shock over a band extending from Carlisle to Coniston, implies a corresponding continuity in the focus. The disposition of the isoseismal lines, however, in conjunction with the observations on the shock, shows that within the focus there were two regions of initial maximum intensity. The principal region must have been near the centre of the isoseismal 5; the other appears to have been in the neighbourhood of Grasmere, for, in this district, there is evidence of a slight increase in the intensity of the shock. The records of the order of relative intensity of the two maxima or series are few in number; but it is probable that the slipping began at the northern end of the focus, and took place rapidly throughout its whole extent.

The average of forty-five estimates of the duration of the shock is 7·2 seconds, or, excluding eight estimates varying from $12\frac{1}{2}$ to 30 seconds, the average is 4·1 seconds.

Sound-phenomena.—The sound was heard all over the disturbed area, and by 90 per cent. of the observers. The percentage of audibility varies very slightly in different parts. Within the disturbed area of the third shock (the boundary of which is approximately an isoseismal of the first shock), the percentage is 90; outside it, it is $89\frac{1}{2}$: an uniformity which is probably due to the great depth of the focus. It is evident, however, from the descriptions, that the sound was by no means of uniform intensity. Comparisons in some places to very heavy waggons passing, to the crash of a steam-roller against the house, to dreadful explosions, etc., and in others to distant thunder (a very common expression), wind, or a distant explosion, show that there were two regions of maximum intensity, the boundaries of which are difficult to define. One of them lies within the isoseismal 5; the other includes such places as Ambleside, Coniston, Grasmere, Hawkshead, Rydal, and Wythburn, at several of which the intensity of the shock was greater than in the surrounding district.

The sound was compared to passing waggons (a passing motor-car appearing for the first time in such references) in 33 per cent. of the records, to thunder in 35 per cent., wind in 6, loads of stones falling in 4, the fall of a heavy body in 7, explosions in 8, and to miscellaneous sounds in 6 per cent.

The beginning of the sound preceded that of the shock in 60 per cent. of the records relating to this epoch, coincided with it in 36, and followed it in 4 per cent.; the epoch of maximum intensity of the sound preceded that of the shock in 25 per cent. of the records, and coincided with it in 75 per cent.; while the end of the sound preceded that of the shock in 11 per cent. of the records, coincided with it in 63, and followed it in 26 per cent. In 60 records, the time-relations of both terminal epochs are mentioned: in 48 per cent. of these, the duration of the sound is greater than that of the shock, in 35 per cent. equal to it, while in the remaining 17 per cent. the relative duration is doubtful.

b. July 9th, about 4.26 P.M.

Intensity, 4. Number of records 4, from 4 places.

This earthquake was observed at Carlisle, Cummersdale, Rockcliffe, and Wigton. The shock was slight, and lasted about 2 seconds. At Rockcliffe it was accompanied by a noise like that of a heavy body falling; and at Wigton by a sound which resembled that of a passing traction-engine. The focus of this shock was evidently close to the northern end of the focus of the first and principal shock.

c. July 9th, 4.45 P.M.

Intensity, 4; centre of disturbed area, lat. 54° 40·2′ N., long. 3° 2·4′ W. Number of records 64, from 44 places; and negative records from 59 places.

Isoseismal lines and disturbed area.—The two dotted lines in the map (p. 372) refer to this earthquake. The inner line represents the isoseismal 4, but the course of the line is doubtful towards both east and west. As drawn, it is an elongated oval, 37 miles long, 13 miles wide, and including about 380 square miles.

The outer line, which forms the boundary of the disturbed area, is more accurately drawn. It is 51 miles long, 28 miles wide, and contains an area of 1130 square miles. The longer axis runs N. 4° E., and S. 4° W., and the centre of the curve is 6 miles north-east of Keswick; but the epicentre probably lies a short distance farther west. The position of the boundary with regard to the isoseismal 4 of the first shock (the distance between them being 6 miles on the west, and 12 miles on the east, side) shows that it must coincide closely with an isoseismal of intensity slightly greater than 4 of that earthquake.

Nature of the shock.—The shock was simpler in character, as well as much slighter, than the first. In all parts, there was a single series of vibrations, which gradually increased in intensity and then died away. There is no evidence of any discontinuity in the shock, or of the existence of more than one maximum of intensity. The mean duration of the shock was 3·4 seconds.

Sound-phenomena. — The sound, though obviously much slighter than that which accompanied the first shock, was heard at four places outside the disturbed area—at Linethwaite and Allonby to the west, and Bentpath and Westerkirk to the north-west. This overlapping of the sound-area on the west confirms the conclusion already arrived at, that the originating fault must hade to the east.

The sound was heard by 86 per cent. of the observers; and it is worthy of notice that the percentage of audibility is the same outside, as within, the isoseismal 4 of this earthquake. Comparisons are made to passing waggons, etc., in 46 per cent. of the descriptions, to thunder in 33, explosions in 17, and to miscellaneous sounds in 4 per cent. The large percentage of references to the first type is no doubt due to the gradually increasing amount of slip from the northern and southern margins towards the central region of the focus. The sound is uniformly described as faint, with one exception. This occurred at Mungrisdale, which is on the minor axis of the disturbed area, and about 2 miles from the centre, and here the sound was evidently loud, for it was compared to terrific thunder.

Very few observations were made on the time-relations of the sound and shock. The beginning of the sound either preceded or followed that of the shock, while the end of the sound either coincided with or followed that of the shock, the number of records in each case being three.

d. July 11th, about 11.10 P.M.

Number of records 2, from 2 places.

A slight tremor was observed at Coniston and Mirehouse (near Keswick). It is probable that the focus was not far from the southern part of that of the first shock.

Origin of the Earthquakes.

The principal result to which the investigation of the Carlisle earthquakes has led, is the recognition of a deep-seated fault, the average direction of which is N. 5° E., and S. 5° W., and the hade throughout is to the east. In the surface-rocks there is no sign whatever of such a structure; but the study of two successive earthquakes points to the same conclusion, and I do not think that the evidence can be interpreted in any other way.

The movements along the fault which gave rise to these earthquakes were somewhat peculiar. In the first shock, the focus was of considerable length, and consisted of two principal portions the centres of which were about 23 miles apart, connected by a region wherein the slipping was continuous throughout, and much less in amount.

The northern part of the focus was smaller than the other, but was marked by a much stronger impulse. The stress in this portion of the fault was not, however, completely relieved by this displacement, for, 3 minutes afterwards, another slight slip occurred there. The third slip, about 20 minutes later still, was complementary to the first, for it appears to have occupied the whole of the region between the two principal portions of the first focus, and to have been greatest near the centre of that region and gradually diminishing towards both ends. A little more than two days later, a very slight movement occurred in or near the southern part of the first focus, and the series of movements, if we may rely on solitary observations, concluded with some small slips near the central part of the intermediate region of the fault.[1]

[For the Discussion, see p. 397.]

[1] The expenses incurred in investigating this earthquake were defrayed from a grant received from the Government Research Fund.

24. *The* Inverness Earthquake *of* September 18th, 1901, *and its* Accessory Shocks. By Charles Davison, Sc.D., F.G.S. (Read April 16th, 1902.)

[Plates XI & XII.]

I. Introduction.

The earthquakes of Inverness and Comrie, though never so strong as those of Essex and Hereford, bear, in their long trains of after-shocks, a far closer resemblance to the great earthquakes of other countries. Since the Comrie earthquake of October 23rd, 1839, which was followed by 330 tremors and earth-sounds within little more than two years,[1] no British earthquake has been attended by so many accessory shocks as that which occurred in the neighbourhood of Inverness on September 18th, 1901. The unusual intensity of the earthquake, its apparent connection with the great northern boundary-fault of the Highlands, and the possibility of tracing oscillations in successive centres of disturbance along the fault-surface, combined in rendering a detailed investigation desirable.[2] The names of all those who have assisted me are too numerous to mention here; but, in offering my best thanks to them collectively, I should like to acknowledge my special indebtedness to Mr. W. J. Watson, Rector of the Royal Academy, Inverness, Mr. A. S. Reid, F.G.S., of Trinity College, Glenalmond, Mr. S. Archibald of Dalarossie, and Miss Isabel Forbes of Teanassie, near Beauly, for the most useful series of accounts which they have kindly collected. Valuable records of after-shocks have also been communicated to me by the following gentlemen:—Mr. D. Forsyth (Inverness), Mr. James Fraser (Aldourie), Mr. John E. Fraser (Dores), Mr. P. Fraser (Holm, near Lentran), Mr. A. Grant (Drumälan, near Drumnadrochit), Mr. W. Grant (Invermoriston), Mr. R. Keillar (Lochend, Aldourie), Mr. W. Mackenzie (Bunchrew), Lieut.-Colonel L. D. Mackinnon and Mr. D. Munro (Dochgarroch), Lieut.-General F. W. Peile (Inverness), Mr. D. A. Rose (Abersky), and the Rev. T. Sinton (Dores); while Col. Mackinnon and Mr. D. Munro have furnished some interesting notes with regard to the fissure formed in the bank of the Caledonian Canal, near Dochgarroch.

In the following catalogue of earthquakes, I have included no records but those made by careful observers. A large number (41) of the shocks and earth-sounds rest on the authority of a single observer; but, while all are probably of seismic origin, I have distinguished by means of prefixed letters and more detailed descriptions, those (19 in number) that were noticed by several or many persons.

In estimating the intensity of the shocks, I have referred as usual

[1] J. Drummond, Phil. Mag. vol. xx (1842) pp. 240–47.

[2] The expenses of the investigation were defrayed from a grant received from the Government Research Fund.

to the Rossi-Forel scale, but have employed only one test for each degree.[1] At the head of the account of each earthquake, the position of the epicentre is given to the nearest tenth of a minute of latitude and longitude; and, in the account itself, I have stated the approximate position with reference to Dochgarroch, a place which lies close to the epicentres of nearly all the shocks. In the maps (Pls. XI & XII), the isoseismals are indicated by continuous lines when some confidence may be placed in their accuracy; and, in parts, by broken lines when their course is doubtful, owing to the scarcity or absence of observations.

As the principal earthquake occurred shortly after midnight, many of the observers were asleep when it began. In most cases, however, they were evidently awakened by the preliminary sound; for, according to those who were awake, the beginning of the sound preceded that of the shock in 72 per cent. of the records, coincided with it in 21, and followed it in 8 per cent. According to those who were asleep, the corresponding figures were 72, 20, and 9. In other respects, also, the two classes of observers differ but slightly; and the only point on which I have not availed myself of the evidence of those who were at first asleep, is the relative intensity of the two parts of the shock.

II. Faults of the Epicentral District.

With a few exceptions, the earthquakes originated beneath the district lying between Inverness and the north-eastern end of Loch Ness. The chief structural feature of this district, is the great boundary-fault which runs from Tarbat Ness along the eastern coast of Ross-shire, and follows the line of the Great Glen. The mean direction of this fault is about N. 35° E., and S. 35° W., and its hade is to the south-east. Its course within the epicentral district (for which I am indebted to Mr. J. Horne, F.R.S.) is shown in Pl. XII and the text-figure on p. 392.

Several of the after-shocks were observed only at Dalarossie and a few other places in the valley of the Findhorn; and it is probable that they were due to movements along a fault in this district. The seismic evidence is insufficient to determine the position of this fault, except that it may run along the line of the valley. Mr. Horne informs me that the ground there has not yet been surveyed, but that he has proved the existence of faults along the Findhorn Valley near Drynachan Lodge, which lies about 11 miles down the valley from Dalarossie.

III. Fore-Shocks.

The beginning of the series, which culminated in the earthquake of September 18th, seems to have occurred some time during the preceding summer months. No precise dates are available, but

[1] Phil. Mag. ser. 5, vol. l (1900) p. 51.

there is an isolated record of one in June at Aldourie, and of another in July at Dochgarroch. The first to attract general notice took place about thirty hours before the principal shock.

a. September 16th, 6.4 P.M.

Intensity, 4; epicentre, lat. 57° 24·9′ N., long. 4° 18·5′ W. Number of records 9, from 8 places (Pl. XII).

The disturbed area is roughly circular in form, about 12 miles in diameter, and contains about 108 square miles. Its centre lies about 1½ miles south of Dochgarroch, and three-quarters of a mile on the south-east side of the great fault. The shock was extremely slight, the vibrations being hardly perceptible, except at Dochgarroch. As a rule, the sound was also faint, though more prominent than the accompanying tremor. The approximate circularity of the disturbed area shows that the focus must have been small, an inference which is supported by the comparison of the sound with the discharge of cannon.[1]

September 17th, 11 P.M.: Inverness.—A quivering, lasting for 2 seconds.

September 18th, 1.15 A.M.: Dochgarroch.—A tremor, accompanied by sound.

IV. Principal Earthquake.

b. September 18th, 1.24 A.M.

Intensity, 8; centre of Isoseismal 8, lat. 57° 26·8′ N., long. 4° 15·8′ W. Number of records 710, from 381 places; and 77 negative records from 68 places.

Time of occurrence.—For the time of occurrence stated above, I am indebted to Dr. Alexander Ross, F.G.S., of Inverness. It seems to me the most reliable of all the estimates, for it was observed immediately and checked by time-ball (Greenwich mean-time) during the following morning. It differs little, moreover, from the records given by several station-masters in the immediate neighbourhood of Inverness.[2]

Effects of the shock.—In Inverness, the damage to buildings, though never serious, was by no means inconsiderable. One brick building used as a smithy collapsed, several chimneys, or parts of them, fell, and many chimney-pots were displaced or overthrown.

[1] On September 16th, at 9.30 P.M., a slight shock is said to have been felt at Edderton, Fortrose, and Tain. No details are given, and the places of observation are so far one from the other and from the main epicentral area, that it is impossible to establish the seismic character of the disturbance, or even to regard it as probable.

[2] The Rev. A. Henderson informs me that the shock was registered by the Ewing seismograph in the Coats Observatory at Paisley, but the time given ($1^h\ 21^m\ 35^s$ A.M.) appears to me too early. The seismographs at the Ben-Nevis and Fort-William observatories and at the Royal Observatory, near Edinburgh, were not affected by the shock.

At Dochgarroch, and other places within the epicentral district, walls were cracked, chimneys thrown down, and lintels loosened.

But, for this country, the most remarkable effect of the earthquake was a long crack in the northern bank of the Caledonian Canal, near Dochgarroch Locks. It was formed in the middle of the towing-path, and could be traced at intervals for a distance of 200 yards to the east of the Locks and 400 yards to the west, being often a mere thread, and in no place more than half an inch wide. Shortly after the earthquake, heavy showers of rain obliterated the fissure; but Col. Mackinnon informs me, on the authority of the engineer in charge of the canal, that there can be no doubt whatever that the crack was caused by the earthquake.

Epicentral area.—The district within which slight damage to buildings occurred is bounded by the isoseismal 8, the innermost line in Pl. XI (shown on a larger scale by the dotted line in Pl. XII). The curve is 12 miles long, 7 miles wide, and contains 67 square miles: its longer axis running N. 33° E., and S. 33° W. The centre of the curve is about $1\frac{1}{2}$ miles east-north-east of Dochgarroch, and three-quarters of a mile on the south-east side of the fault-line.

Isoseismal lines and disturbed area.—The isoseismal 8 is probably the only curve of the series that is accurately drawn throughout. In every other case, owing to the scarcity of observations in the West of Scotland, there are portions which must be regarded as doubtful.

Except towards the west, there are sufficient points to determine the course of the isoseismal 7. Its length is $53\frac{1}{2}$ miles, width 35 miles, and area 1500 square miles; the longer axis is directed N. 32° E., and S. 32° W., and is therefore nearly parallel to that of the isoseismal 8. The distance between the isoseismals is 9 miles on the north-west side, and 14 miles on the south-east side.

Records of intensity 6 were difficult to obtain, as most observers slept in darkened rooms. As drawn on the map in the position which appears to me most probable (Pl. XI), it includes a district 105 miles long, 87 miles wide, and containing 7300 square miles. The distance between the isoseismals 7 and 6 is $21\frac{1}{2}$ miles on the north-west, and 31 miles on the south-east side.

The path traced out for the isoseismal 5 is entitled to a greater degree of confidence. Its length is 157 miles, width 143 miles, and area about 17,000 square miles. The distance between the isoseismals 6 and 5 is $21\frac{1}{2}$ miles on the north-west, and $34\frac{1}{2}$ miles on the south-east side.

For the isoseismal 4, there are again but few determining points, and the curve could not have been drawn in the doubtful parts without reference to the preceding isoseismal. In the extreme North of Scotland, records come from Wick, Castletown, and other intermediate places. From the North-west of Sutherland and from Skye, observations are entirely wanting. The intensity was, however, equal to 4 at Tobermory, in the island of Mull. Towards the south, there are good accounts from Skelmorlie (in Ayrshire), Paisley, Belsyde (near Linlithgow), Gullane (near North Berwick), and Dunbar. So far as I know, the earthquake was not felt in either Edinburgh or Glasgow, but the isoseismal 4 clearly passes to the south of the line joining these cities. The distance between the isoseismals 5 and 4 is 20 miles on the north-west, and 35 miles on the south-east side.

Isoseismal 4 may be regarded as the boundary of the disturbed area, for no observations seem to have been made outside it. The disturbed area is thus 215 miles long from north-east to south-west, 198 miles wide, and includes about 33,000 square miles.

Position of the originating fault.—Despite the somewhat doubtful character of the three outer isoseismals, the other two furnish abundant evidence for determining the position of the originating fault. The direction of their longer axes shows that the average direction of the fault must be N. 33° E., and S. 33° W. As the distance between the isoseismals is greater on the south-east than on the north-west side, we may infer that the hade of the fault is to the south-east. Again, the intensity of the shock being greater on the side towards which the fault hades, it follows that the fault-line must lie a short distance (about a mile or so) on the north-west side of the centre of the isoseismal 8.

The correspondence between the positions of the great boundary-fault and of the fault inferred from the seismic evidence, is so close that there can be little, if any, doubt that the earthquake was due to a slip along this fault. It will be seen that the evidence of the after-shocks offers additional support to this conclusion.

Nature of the shock.—Contrary to the general rule, there was little variation in the nature of the shock throughout the disturbed area. This will be seen from the following accounts, which are selected as typical from among those written by observers who were awake when the shock began:—

Inverness.—A gentle movement, followed by an extraordinary quivering, which increased in force for 2 or 3 seconds, and then decreased for 2 or 3 seconds; just as the quivering was about to cease, there was a distinct lurch or heave, after which the vibration was much more severe than before, and lasted several seconds longer than the first part of the shock.

Dalarossie.—The first indication was a loud sound, as of an express train coming from the east, rushing along close to, and then under, the northern wall of the house; this lasted for a few seconds, and towards the end of it the house vibrated. Then succeeded an interval of quietness for about one second, followed by a terrific burst or crash, not unlike the crash of a loud thunder-peal of about 2 seconds' duration, during which the house distinctly heaved up once and then sank back. After another brief interval of quietness, there was a low rumble, somewhat like the sound of a dying peal of thunder.

Aberlour.—A noise, like that of a traction-engine, was first heard, and at the same time a vibration was felt, such as is generally associated with a traction-engine passing close at hand. Both noise and vibration ceased, and almost immediately there followed two or three heaves like a slight movement in a boat.

Aberdeen.—The shock consisted of two parts, the first a tremble, followed, after an interval of a few seconds, by a swinging movement of longer duration than the tremble.

Similar descriptions are given by observers in other parts of the disturbed area. If we divide the whole area into four quadrants by lines drawn through the epicentre parallel to the axes of the isoseismal 8, such records come, in the eastern quadrant, from Aberdeen, Aberlour, Dinnet, Duffus, Dyke, Forres, Huntly, Inverness, Monyruy, and Rothie-Norman: in the southern quadrant, from Aberfeldy, Blairgowrie, Dunbar, and Rothiemurchus: in the western quadrant, from Lochcarron: and along the line between the eastern and southern quadrants (that is, on the minor axis of the isoseismals), from Dalarossie and Montrose. Throughout the disturbed area, the shock thus consisted of two distinct parts, the second being of greater duration and intensity than the first, and consisting of vibrations of longer period. Near the epicentre there was no interval between the two parts; but, at a distance, the intermediate tremors were imperceptible, and the parts were separated by an interval of rest and quiet lasting 2 or 3 seconds.[1]

It follows that the two series of vibrations were produced by two distinct impulses, the stronger impulse succeeding the other after an interval of a few seconds. It is possible that the corresponding foci were nearly or quite detached, as in the twin earthquakes of Hereford in 1896 and Leicester in 1893; but it is more probable, I think, that the focus of the earlier impulse was overlapped by, or included within, that of the second.

Sound-phenomena.—Outside the isoseismal 5, there are but few records of the earthquake-sound; it was heard faintly, however, at Skelmorlie (in Ayrshire), Belsyde (near Linlithgow), and Gullane (near North Berwick). Towards the north, it was not observed beyond Wick and Watten (in Caithness). The extent of the sound-area must therefore have been about 27,000 square miles.

Throughout the whole disturbed area, 84 per cent. of the observers who describe the earthquake heard the accompanying sound. The percentage varies in different counties, from 93 in Inverness-shire to 77 in the counties of Perth and Aberdeen. In more distant regions, the records are too few to allow of the percentage of audibility being calculated; and the scarcity of observations in all but the south-eastern quadrant prevents, of course, the construction of isacoustic lines.

[1] According to 22 observers, who were awake when the earthquake began, there was only one series of vibrations, the places where they were situated being often close to those where the double series was observed. The duration of the shock is recorded by 13 of these observers, and their estimates give a mean duration of 2·8 seconds. As the average duration of the shock (according to 59 observers who were awake) was 4·7 seconds, it is therefore probable that these observers noticed only the second and more powerful series of vibrations.

The character of the sound is described by 394 observers; 39 per cent. of these compared it to passing waggons, traction-engines, etc., 25 per cent. to thunder, 14 to wind, 8 to loads of stones falling, 3 to the fall of heavy bodies, 4 to explosions or the firing of heavy guns, and 7 per cent. to miscellaneous sounds.[1]

There are the usual anomalies in the audibility and character of the sound, depending on the varying powers of the observers for hearing low sounds. This is especially noticeable in the case of the heavy crashes heard by some observers at the moment when the shock was strongest.

The variation in the sound throughout the sound-area was also normal. Its intensity gradually diminished outward from the epicentre, and most rapidly near the isoseismal 7, which bounds approximately the district in which the sound was very loud from that in which it was distinctly fainter. With one exception, the same curve includes all places at which the explosive crashes were heard with the strongest vibrations. Again, 34 per cent. of the observers within this line, and 44 per cent. of those outside it, compared the sound to passing vehicles, traction-engines, etc.; for thunder, the corresponding percentages are 34 and 18, for wind 8 and 19, for loads of stones falling 11 and 6, the fall of heavy bodies 2 and 4, explosions 7 and 3, and for miscellaneous sounds 5 and 5. Thus, with increasing distance from the centre, the sound became more uniform in character and intensity.

Time-relations of the sound and shock.—In the following table, the letters *p*, *c*, and *f* indicate the number of records per cent. in which any epoch of the sound preceded, coincided with, or followed, the corresponding epoch of the shock. In the last line, I have added the average percentages for three strong earthquakes: namely, the Pembroke earthquakes of 1892 and 1893, and the Hereford earthquake of 1896.

County.	Beginning.			Epoch of Maximum Intensity.			End.		
	p	*c*	*f*	*p*	*c*	*f*	*p*	*c*	*f*
Inverness	80	16	4	27	64	9	14	30	56
Ross	75	12	12	25	62	12	9	41	50
Nairn & Elgin	73	15	12	20	70	10	36	28	36
Banff	64	9	27	...	100	...	33	25	42
Aberdeen	19	67	14	...	100	...	...	60	40
Other counties	80	15	5	25	75	...	13	12	75
Whole sound-area	72	20	8	20	73	7	15	34	52
Average for strong shocks	78	14	8	25	67	8	20	23	57

[1] During the night of the earthquake, there was a strong wind in many parts of Scotland, which, however, generally subsided before the shock took place. Some of the observers may have mistaken a short gust for the earthquake-sound; but more than 60 per cent. of those who refer to this type record the time-relations of the sound and shock in such a manner as to leave no doubt on the subject.

Thus, as a general rule, the beginning of the sound preceded that of the shock, their epochs of maximum intensity coincided, while the end of the sound followed that of the shock. The most striking exception occurs in the case of Aberdeenshire, where, in the majority of cases, the three epochs coincided one with the other. This result is important in its bearing on the origin of the sound-vibrations, for most of the observations come from the south of the county, and the line joining this district to the epicentre is nearly perpendicular to the line of fault. Now, if the general precedence of the sound with respect to the shock were due to its superior velocity, the percentage of records in which the beginning of the sound preceded that of the shock would vary only with the distance, and not with the direction, from the origin. If, however, the sound-vibrations were to start simultaneously, or nearly so, from all parts of the focus, but especially from its marginal regions, then the three epochs of the sound and shock would coincide approximately at places near a line at right angles to the earthquake-fault. We may infer from the observed coincidence, and also from the fact that the sound generally followed the shock at distant stations, that the vibrations of every amplitude and period travelled outward with the same, or very nearly the same, velocity.

The time-relations of both terminal epochs are recorded by 180 observers, and from these we obtain the following table, in which are given the percentages of cases wherein the duration of the sound was greater than, equal to, or less than, that of the shock. The last line contains the corresponding average figures for the Pembroke earthquakes of 1892 and 1893, and the Hereford earthquake of 1896.

County.	Greater.	Equal.	Less.	Doubtful.
Inverness	75	10	1	14
Ross	67	11	8	14
Aberdeen	6	75	...	19
Whole sound-area	60	14	3	23
Average for strong shocks	57	18	5	20

Omitting doubtful records, we find that, in 78 per cent. of the cases, the duration of the sound was greater than, in 18 equal to, and in 4 per cent. less than, that of the shock. It is possible that the movements which produced the sound-vibrations lasted a longer time than those which produced the shock. But the more probable explanation is, that the area from which the sound-vibrations proceeded was larger than that whence the more prominent vibrations came, and extended beyond it at both ends; in other words, that the sounds heard before and after the shock came from the lateral margins of the focus.

V. After-Shocks.

In the following catalogue are supplied records of 46 shocks and 10 earth-sounds. Of these, 16 shocks and 1 earth-sound were noticed by several or many observers; the remainder depend on the evidence of one person alone. The list, however, is obviously far from being complete. Thus, on September 18th, between the two prominent after-shocks at 3.56 and 9 A.M., there is only one record given below; but Mr. D. Munro informs me that he felt 18 slight shocks at Dochgarroch within the same interval. Several shocks were also felt at Dores, and many earth-sounds were heard at Bunchrew, besides those contained in the register; while one observer at Lochend (Aldourie) estimates the total number of shocks up to October 23rd at about 70.

c. September 18th, about 1.35 A.M.

Intensity, about 4; epicentre, lat. 57° 24·9′ N., long. 4° 16·8′ W. Number of records 7, from 7 places (Pl. XII).

The boundary of the disturbed area is uncertain towards the west. It is probably, however, nearly circular in form, as represented in Pl. XII, being $10\frac{1}{2}$ or 11 miles in diameter, and containing about 88 square miles. Its centre is about $1\frac{3}{4}$ miles south-east of Dochgarroch, and $1\frac{1}{2}$ miles on the south-east side of the fault-line. The shock was very slight, and the sound a low rumble like distant thunder.

d. September 18th, about 2 A.M.

Number of records 2, from 1 place.

A slight shock, accompanied by a noise like distant thunder, was felt at Glenmazeran, near Dalarossie, in the valley of the Findhorn.

e. September 18th, about 2.30 A.M.

Number of records 2, from 2 places.

A slight tremor was felt at Inverness and Abersky, and at the latter place was accompanied by a noise like that of a passing vehicle.

f. September 18th, about 3 A.M.

Number of records 2, from 2 places.

A tremor only was observed by the engineer at the Inverness District Asylum (2 miles west-south-west of Inverness), and a slight rumbling at Aigas (near Beauly).

g. September 18th, 3.56 A.M.

Intensity, not less than 5; centre of isoseismal 5, lat. 57° 25·3′ N., long. 4° 15·9′ W. Number of records 90, from 43 places; also 6 doubtful records from 5 other places (Pl. XII).

This was clearly the strongest of the whole series of after-shocks, though it exceeded but slightly the shock felt twelve days later

(September 30th). The records are comparatively numerous, but many amount to little more than a statement that the shock was felt; and it is impossible to draw the isoseismal lines with any approach to accuracy. On the map (Pl. XII) the isoseismal 5 alone is shown, and even the course of this must be regarded as doubtful. Its length, as drawn, is 38 miles, width 25 miles, and the contained area about 750 square miles. The centre is situated 2 miles east-south-east of Dochgarroch, and 1·7 miles on the south-east side of the fault, and the longer axis is roughly parallel to the fault-line.

Outside this isoseismal, the shock was felt at Little Scatwell, Relugas, Dunphail, and Grantown, which are respectively 18, 24, 25, and 26 miles from the centre of the isoseismal 5. There are also records of its occurrence at Deskford, Ordiquhill, and Banff, places near to one another, and respectively 57, 59, and 67 miles from the centre; and at Comrie and Crieff, distant 73 and 76 miles. The absence of observations at intermediate localities makes these records somewhat doubtful, but there is nothing impossible in an after-shock of this intensity being felt so far from the epicentre.

The shock consisted of two or three distinct oscillations, the average of seven estimates of its duration being 2½ seconds. At Dochgarroch and Inverness, and in the immediate neighbourhood, these vibrations seemed to be nearly vertical.

The sound was certainly heard by 62 per cent. of the observers. It was compared to passing waggons, etc. by 14 per cent. of those who described it, to thunder by 43 per cent., wind by 14, the fall of a heavy body by 7, explosions by 14, and to miscellaneous sounds by 7 per cent. The beginning of the sound preceded that of the shock in 62 per cent. of the records, coincided with it in 25, and followed it in 12 per cent. The end of the sound coincided with that of the shock in 17 per cent., and followed it in 83 per cent., of the records. The duration of the sound was generally greater, and never less, than that of the shock.

The direction of the longer axis of the curve and the position of the centre favour the connection of this earthquake with the boundary-fault. Moreover, the sound was heard at two places—Garve and Little Scatwell—on the north-west side of the isoseismal 5, and respectively distant 7 and 6 miles from it. As the sound-vibrations from the upper margin of the focus would be more readily heard than those from the lower margin, this fact confirms the inference that the hade of the earthquake-fault must be to the south-east.

September 18th, about 6.25 A.M.: Inverness.—A noise was heard, but much slighter than that which accompanied the shock at 3.56 A.M.

h. September 18th, 9 A.M.

Intensity, 5; epicentre, lat. 57° 27·0′ N., long. 4° 15·1′ W. Number of records 26, from 18 places (Pl. XII).

The disturbed area of this shock is elliptical in form, and is

25 miles long, $12\frac{1}{2}$ miles wide, and 250 square miles in area. Its longer axis runs N. 36° E., and S. 36° W., and the centre is situated 2 miles east-north-east of Dochgarroch, and 1 mile to the south-east of the fault.

The shock consisted of a single series of vibrations, and was accompanied by a sound which is variously described as resembling a passing vehicle, thunder, or the discharge of cannon.

September 18th, 12 (noon): Inverness District Asylum.—A mere tremor, but strong enough to knock down some loose plaster which was lying on the joists of buildings.

September 18th, about 11.25 P.M.: Inverness.—A low, but distinct, rumble.

September 20th, 4 P.M.: Dores.—A slight shock.

September 21st, 10.45 A.M.: Holm (near Lentran).—A shock, direction west to east, accompanied by a noise like the discharge of cannon.

September 21st, 11.20 A.M.: Holm.—The same.

September 21st, 3.15 P.M.: Holm.—The same.

i. September 23rd, about 7.30 A.M.

Number of records 4, from 4 places.

The only records of this earthquake come from Dores, Holm, the Inverness District Asylum, and Kirkhill. The shock was very slight, of intensity probably less than 4. At Dores the sound resembled the rumbling of a coach, and at Holm the discharge of cannon. The epicentre lay probably in the neighbourhood of Dochgarroch.

September 22nd, 9 A.M.: Teanassie (near Beauly).—A shock felt and rumbling noise heard, the latter being the more noticeable.

September 24th, 5.15 A.M.: Holm.—A shock, the direction of which was from west to east, accompanied by a sound like the discharge of cannon.

September 24th, 7.10 A.M.: Holm.—The same.

September 24th, 4.20 P.M.: Holm.—The same.

September 26th, 8.8 A.M.: Holm.—The same.

September 26th, 9.25 A.M.: Holm.—The same.

j. September 26th, 11.40 A.M.

Intensity, 4. Number of records 3, from 3 places.

The shock was felt at Dores and Holm. At Drumälan (near Drumnadrochit) there was no tremor, and the sound was like that of a train gradually approaching, passing, and receding from the house.

September 26th, 9.39 P.M.: Holm.—A shock, of intensity less than 4, accompanied by a sound like that of distant cannon.

k. September 27th, 1.47 P.M.

Intensity, 5. Number of records 2, from 2 places.

The intensity of this shock was 5 at Holm, and probably 4 at Aigas (6 miles south-west of Beauly). The sound was heard at both places, and at Holm resembled that of distant cannon. Considering the intensity of the shock, it is remarkable that no more records are forthcoming; but there is no reason to doubt its genuineness.

l. September 28th, about 4 A.M.

Intensity, 5. Number of records 2, from 1 place.

A slight shock noticed in Inverness. There is no record of any sound.

September 28th, 11.50 A.M.: Glen Urquhart.—The exact position of the place of observation is uncertain, but it is probably near Loch Ness. Both shock and sound were extremely slight, the intensity of the former being less than 4.

September 28th, 1.40 P.M.: Loch Ness.—The observer of the preceding shock was in a boat on Loch Ness at 1.40 P.M. The boat moved distinctly, and a slight tremor was felt.

September 29th, about 4.30 A.M.: Inverness.—A slight shock, accompanied by a faint sound like distant thunder.

m. September 29th, 9.6 P.M.

Intensity, 4; epicentre, lat. 57° 26·1′ N., long. 4° 17·0′ W. Number of records 6, from 5 places (Pl. XII).

The places where this earthquake was observed lie within an area which is probably circular in form, about $8\frac{1}{2}$ miles in diameter, and including about 57 square miles. The centre is nearly 1 mile east of Dochgarroch and three-fifths of a mile south-east of the fault. (At 9.10 P.M. a sound, as of a carriage passing, with scarcely any accompanying tremor, was heard at Bridgend, 3 miles from Dalarossie and about 13 miles from the epicentre.) The shock was slight, and the sound faint and of brief duration, leading, in conjunction with the approximate circularity of the disturbed area, to the inference that the focus was very small.

September 29th, 11 P.M.: Aigas.—A rumbling sound heard.

September 29th–30th: Drumälan (Drumnadrochit).—During the night, two slight shocks were felt before the shock of September 30th, 3.39 A.M., by observers who were awake. One of these may be identical with the sound heard at Aigas at 11 P.M. on September 29th.

n. September 30th, 3.39 A.M.

Intensity, 7; epicentre, lat. 57° 24·5′ N., long. 4° 19·3′ W. Number of records 54, from 33 places (Pl. XII).

On the map (Pl. XII) are shown the isoseismal 5, part of the isoseismal 6, and the isoseismal 7 approximately. Outside the isoseismal 5, records of the shock are scanty; but the intensity was 4 as far as Lochluichart, which is 22 miles north-west of the epicentre and 13 miles from the isoseismal 5. A shock was also reported at about 4 A.M. from Crathes (Kincardineshire); but, as that locality is 74 miles from the epicentre, the connection between this disturbance and the earthquake under consideration is doubtful.

The isoseismal 7, which is only roughly drawn, is 5 miles long, 2½ miles wide, and contains about 10 square miles. Its centre is 2 miles south-by-west from Dochgarroch, and half a mile on the south-east side of the fault. The isoseismal 5 is 33 miles long, 23 miles wide, and 595 square miles in area: its longer axis running N. 34° E. and S. 34° W. The distance between the isoseismals 7 and 5 is 8 miles on the north-west, and 12½ miles on the south-east side. The originating fault must therefore run N. 34° E. and S. 34° W., and must hade to the south-east. The closeness of the epicentre to the line of fault shows that the depth of the seismic focus must have been very small; and the rapid decrease in the intensity of the vibrations as they radiated outward points to the same conclusion.

The shock, the mean duration of which was 3 seconds, differed in one respect from those that preceded it. The movement at Inchmore (Kirkhill) was distinctly more lateral, more undulating or swinging, than in the others. At Inverness one observer remarks that the movement was horizontal, as distinguished from the vertical or 'choppy-sea' motion of the principal shock.

The sound was heard by at least 80 per cent. of the observers. It was compared to passing waggons etc. in 25 per cent. of the records, to thunder in 50 per cent., wind in 4, loads of stones falling in 4, explosions in 8, and miscellaneous sounds in 8 per cent. The beginning of the sound preceded that of the shock in 61 per cent. and coincided with it in 39 per cent. of the records; while the end of the sound preceded that of the shock in 16 per cent. of the records, coincided with it in 28, and followed it in 56 per cent. The duration of the sound was greater than that of the shock in 64 per cent. of those records in which the time-relations of both terminal epochs are given, was equal to it in 18 per cent., while in the remaining 18 per cent. the relative duration of the sound and shock is doubtful.

September 30th, about 4.10 A.M.: Aldourie.—A slight shock.

o. October 1st, about 4.35 A.M.

Intensity, 5. Number of records 2, from 2 places.

A shock, preceded, accompanied, and followed by a sound like thunder, was felt at Dalarossie and Coignafuinternach.

October 1st, about 3 P.M.: Dalarossie.—A faint sound, like distant thunder, was heard, without any shock.

October 1st, 5.6 P.M.: Holm.—A shock of intensity less than 4, accompanied by a sound as of distant thunder.

October 2nd, 2.7 P.M.: Holm.—The same.

p. October 6th, 4.24 A.M.

Intensity, 5. Number of records 2, from 2 places.

At Dochgarroch two vibrations were felt (intensity 5), without any sound. The shock was also felt at Holm. It is probable that the epicentre was not far from Dochgarroch, and that the depth of the focus was small.

October 9th, 7.40 P.M.: Dalarossie.—A shock (intensity probably 5), preceded, accompanied, and followed by a sound like that of a light carriage passing.

October 12th, 8.40 A.M.: Dochgarroch.—A single vibration (intensity 5), accompanied by a rumbling sound.

October 12th, 12.56 P.M.: Holm.—A slight shock.

October 12th, about 4 P.M.: Inverness.—A shock, as if a heavy body fell against the house and was then dragged along the side of it.

October 13th, 12.30 P.M.: Dalarossie.—A slight sound, without any tremor.

q. October 13th, 4.24 P.M.

Intensity, probably 4; epicentre, lat. 57° 26·1′ N., long. 4° 18·0′ W. Number of records 7, from 5 places (Pl. XII).

The records are too few to determine the boundary of the disturbed area; but it is clearly elliptical in form, with its axis approximately parallel to those of the isoseismal lines of previous shocks. The length of the curve, as drawn (Pl. XII), is 8 miles, the width 5½ miles, and the area contained by it about 35 square miles. The centre is about a quarter of a mile south-east of Dochgarroch, and a tenth of a mile from the fault-line. The shock consisted of two or three vibrations, and was accompanied by a loud report, compared by an observer near Dochgarroch to a shot from a gun, followed by a sound as of the ball passing through the air. At Muirtown, which is near Inverness and close to the line of fault, the sound resembled that of a heavy vehicle approaching. The focus was about 2 miles in length, and lay at a very small depth.

October 13th, about 5.30 P.M.: Holm.—A very distinct shock.

October 14th, 1 A.M.: Inverness.—A shake, preceded by a sound like the soughing of the wind through trees.

October 14th, 5 P.M.: Dochgarroch Locks.—A shock (intensity less than 4), accompanied by a sound like that of a heavily-loaded lorry running on a country-road.

October 22nd, 5.30 A.M.: Drumnadrochit.—A distinct tremor.

r. October 22nd, about 10.15 A.M.

Number of records 2, from 2 places.

The only records of this earthquake come from Aldourie and Drumnadrochit. At Aldourie, eight or nine sounds were heard between 9.45 A.M. and noon. The sound here at about 10.15 A.M. was very distinct, and resembled the roar of a furnace when the door is open, or of an underground train; it lasted 2 or 3 seconds, and seemed to travel eastward. No distinct shock was felt, but there was evidently a very weak tremor. At Drumnadrochit only a sound was heard, like distant thunder, growing louder and dying away. The focus lay probably beneath Loch Ness.

October 22nd, 12.55 P.M.: Drumnadrochit. — A sound, like distant thunder, without any accompanying tremor.

October 22nd, 8.20 P.M.: Bunchrew.—A slight tremor, accompanied by a rumbling sound.

October 22nd, 8.25 P.M.: Bunchrew.—A rumbling sound.

November 5th, 12.12 A.M.: Dalarossie.—A rumbling sound, like thunder, not loud, lasting about 4 or 5 seconds, without any sensible shock.

s. November 15th, about noon.

An underground rumbling sound was heard by several persons at Dochgarroch.

November 15th: near the end of Loch Ness.—An underground rumbling sound was heard during the night.

November 21st: Dochgarroch.—A slight vibration and rumbling sound were observed during the night.

Sound-Phenomena of the After-Shocks.

Many accounts of the after-shocks are little more than mere records of their occurrence. If we exclude these, the percentage of audibility of all the after-shocks is 77. That of the shock of September 18th, 3.56 A.M., is 62; and of the shock of September 30th, 80. Omitting these shocks, the percentage is 85, showing that the sound, though much fainter than that which accompanied the principal earthquake, was nevertheless a comparatively important feature.

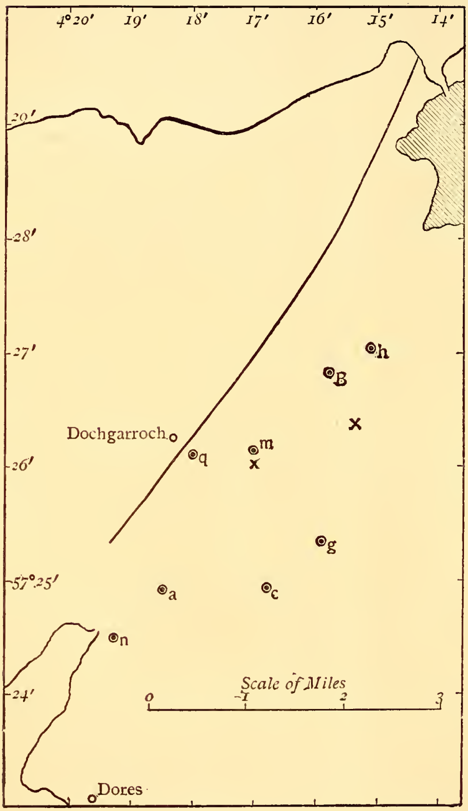
Taking all the after-shocks together, the comparisons of the sound to passing waggons, etc., occur in 26 per cent. of the records, to thunder in 43, wind in 7, loads of stones falling in 2, the fall of a heavy body in 2, explosions, etc., in 17, and miscellaneous sounds in 3 per cent. Omitting the two strongest after-shocks on September 18th and 30th, the corresponding figures are: passing waggons, etc. 33, thunder 33, wind 5, and explosions 28. These are about the proportions met with in slight earthquakes, and indicate that, as a rule, the foci of the after-shocks were of small linear dimensions.

VI. Origin of the Earthquakes.

In the absence of a definite fault-scarp,[1] it would be difficult to obtain clearer evidence than that given above of the connection between several of the Inverness earthquakes and the great boundary-fault. The axes of the isoseismal lines are parallel to the mean direction of the fault; the epicentres, or the centres of the inner isoseismals (see text-figure) lie a short distance to the south-east of the fault, that is, on the side to which the fault hades; and most of them lie within a band which is nearly parallel to the fault-line and the centre of which is less than a mile south-east of Dochgarroch.

The dots in the figure mark only the centres of the epicentral areas. In many earthquakes, the focus was no doubt small (possibly less than a mile in length); but in the principal earthquake and in the after-shocks of September 18th, 3.56 and 9 A.M., and September 30th, 3.39 A.M. (denoted by the letters *g*, *h*, and *n*), its length must have amounted to several miles.

Centres of the epicentral areas of the Inverness earthquakes.



a = Fore-shock *a* (p. 379).
B = Principal earthquake (p. 379).
c = After-shock *c* (p. 385).
g = After-shock *g* (p. 385).
h = After-shock *h* (p. 386).
m = After-shock *m* (p. 388).
n = After-shock *n* (p. 388).
q = After-shock *q* (p. 390).

[1] The absence of a fault-scarp is sometimes felt as an objection to the fault-slip theory; but, when the slip within the focal area is small (perhaps, in this case, only a fraction of an inch), it would die out before reaching the surface.

Earthquakes of 1890.—The last strong earthquake in the Inverness district occurred on November 15th, 1890.[1] It seems to have been preceded by several slight earth-sounds, and was followed by not less than ten after-shocks, the series ending on December 14th. The epicentre of the principal earthquake was situated in lat. 57° 25·0′ N., long. 4° 10·8′ W., or $4\frac{1}{2}$ miles S. 21° E. of Inverness, and $4\frac{1}{3}$ miles from the fault-line. As the longer axes of the isoseismal lines ran from N. 48° E. to S. 48° W., it seemed to me probable that this shock was caused by a slip along a fault passing through a point about 1 mile south-east of Daviot, inclined at an angle of 13° to the boundary-fault, and hading to the north-west. I have re-examined the evidence on which this conclusion was founded; and, though I am unable to interpret it otherwise, I think it possible that a larger series of records might have led to a different result.

The epicentre of this earthquake lies outside the area represented in the map on p. 392; but a line drawn through it at right angles to the fault-line would pass very nearly through the centre of the principal earthquake of 1901. The small crosses (×) mark the epicentres of two of the after-shocks in 1890, those of November 15th, 6.15 P.M., and December 14th, 3.30 A.M.: the latter being quite close to the epicentres of two after-shocks (*m* and *q*) of the recent series.[2] If the principal earthquake were due to a slip along the boundary-fault, there is thus an evident displacement of the focus in subsequent shocks towards the south-west.

Fore-shocks of 1901.—Between December 14th, 1890, and the summer of 1901, no earthquakes, so far as I am aware, were felt in the Inverness district. The stresses tending to produce slipping were clearly increasing along the whole portion of the fault between Loch Ness and the sea. Here and there, however, were certain small areas of the fault-surface in which the resistance to slipping was greater than elsewhere; and this resistance had to be overcome before any general movement could take place. One of these areas was situated about half a mile north-east of the end of Loch Ness, and the slip here gave rise to the first shock which attracted general observation. Two others, if we may rely on solitary records, existed farther to the north-east, where the resistance gave way within three hours of the occurrence of the principal shock.

Principal earthquake of 1901.—The removal of these small obstructions helped to equalize the effective stress along several miles of the fault; so that the next displacement, which resulted in the principal shock, took place over a region extending

[1] Quart. Journ. Geol. Soc. vol. xlvii (1891) pp. 618–32.
[2] The epicentre of another shock of the 1890 series (November 16th, 8.30 P.M.) lies about half a mile west of Dochgarroch. This point is on the north-west side of the fault, and may be incorrectly determined owing to the scantiness of the evidence.

nearly from Loch Ness to Inverness. There were two distinct slips in rapid succession, with continuous slight motion between them, the second being greater in amount and extending over an area which probably overlapped, even if it did not entirely include, that within which the first took place.

After-shocks of 1901.—The immediate result of this displacement was a change of stress over a great extent of the fault-surface—a decrease, for the most part, near the centre of the principal focus, and an increase within and near its marginal regions. In places, the augmented stress produced secondary slips, each of which resulted in further changes of stress, and as a rule in decreasing slips, until the stresses were everywhere reduced below the maximum resistance capable of being offered to movement.

The sequence of events is rendered clearer if, for the present, we disregard the very small slips (some of which may have been due to merely local variations of stress), and confine our attention to the six chief after-slips, three of which were of much greater importance than the rest, and affected several miles of the fault-surface.

An interval of only 10 minutes separated the principal earthquake and its first successor. This was caused by a small slip (*c*, p. 385) near the south-western margin of the principal focus. After $2\frac{1}{4}$ hours, the chief after-slip (*g*, p. 385) occurred; its centre migrated about half a mile to the north-east, but, as the focus was several miles in length, its south-western margin extended some distance beyond that of the principal focus. The seat of action was then transferred to the other side of that focus, a long slip (*h*, p. 386) taking place after the lapse of about 5 hours; its centre was approximately half a mile north-east of the principal centre, and its focus probably extended a little beyond the north-eastern margin of the principal focus. During the next $11\frac{1}{2}$ days there were no important movements; but at the end of that time a small slip (*m*, p. 388) occurred about 1 mile to the south-west of the principal centre, and close to Dochgarroch. This was followed, in $6\frac{1}{2}$ hours, by the third long after-slip (*n*, p. 388), the centre of which lay to the south-west of the principal focus, and the slip itself must have extended 2 or 3 miles beneath Loch Ness. Again, after a further lapse of $13\frac{1}{2}$ days, there was a slip (*q*, p. 390), about 2 miles long, in the immediate neighbourhood of Dochgarroch.

Thus, of the six chief after-shocks, one originated within the region of the fault lying to the north-east of the principal centre, and the rest within that to the south-west.

There remain eleven after-shocks recorded by more than one observer. Two of these had no connection with the boundary-fault; the epicentres of four are undetermined; of the others, the focus of one lay to the north-east, and the foci of four to the south-west, of the principal centre.

Further light is thrown on the nature of the fault-movements by the numerous tremors and earth-sounds recorded by single observers [1]; for, in such slight disturbances, the epicentres must have been close to the places of observation. The numbers recorded in different districts near the boundary-fault are as follows:—

Inverness and Bunchrew	8
Dochgarroch and Holm	16
Dores, Aldourie, etc.	3
Drumnadrochit, etc................	6

Thus, 8 probably originated on the north-east side of the principal centre, and 25 on the south-west side.

To sum up. The great slip, which caused the principal shock, reached nearly from Loch Ness to Inverness, and was greatest at a point about halfway between. The three chief after-slips resulted in an extension of this area of principal displacement in both directions along the fault-surface, the extension towards the north-east being small (probably less than half a mile), while that towards the south-west amounted to 6 miles or more. The smaller after-slips (some of them mere creeps) were most numerous in three regions—one lying about a mile south-west of the principal centre, the others near Inverness and Drumnadrochit, which lie near the extremities of the displaced area of the fault, while in the intermediate regions they were apparently less frequent.

In addition to the migration of the focus in the direction of the fault, there was also, in the six principal after-shocks, a continuous decrease in the depth of the focus, for the distances of the epicentres of these shocks from the fault-line are respectively 1·5, 1·7,[2] 1·0, 0·6, 0·5, and 0·1 mile.[3]

Sympathetic earthquakes.—In the list of after-shocks, there are records of six shocks or earth-sounds observed only in the valley of the Findhorn, which lies 13 or 14 miles to the south-east of the boundary-fault. The times at which they occurred are: September 18th, about 2 A.M.; October 1st, about 4.35 A.M. and 3 P.M.; October 9th, 7.40 P.M.; October 13th, 12.30 P.M.; and November 5th, 12.12 A.M.: the first two shocks being recorded by more than one observer. As one of these shocks was of intensity 5,

[1] It should be remembered that some of these may not have been of seismic origin.

[2] In this case (*g*) the distance refers to the centre of the isoseismal 5, which would be somewhat farther to the south-east than the true epicentre.

[3] It is interesting to notice that similar laws governed the distribution of the after-shocks of the great Japanese earthquake of 1891. In that case, the area of displacement was 70 miles or more in length, and the after-slips affected for the most part a nearly central region (in which they were exceedingly numerous), and two more or less isolated districts near or surrounding the extremities of the fault. After the lapse of some months, the latter districts became practically inactive, and there was a gradual but oscillating withdrawal of the after-slips to a more or less central district; while, at the same time, the depth at which the slips occurred continually diminished. See Quart. Journ. Geol. Soc. vol. liii (1897) pp. 1–15 & Geogr. Journ. vol. xvii (1901) pp. 635–55.

and another not much, if at all, weaker, it is clear that, if they had been due to slips along the boundary-fault, they could not have escaped notice by one or more of the watchful observers at Dochgarroch, Dores, Drumnadrochit, Holm, and Inverness. They must therefore have been of local origin. Mr. S. Archibald, to whose careful observations and enquiries we are indebted for the knowledge of these after-shocks, informs me that he has on several previous occasions heard mysterious rumbling noises at Dalarossie; but the occurrence of the recent shocks and sounds in such close succession to the principal Inverness earthquake shows, I think, that the great slip on September 18th was responsible for the precipitation of the movements in the Findhorn Valley.[1]

Conclusion.—The region which lies between Loch Ness and the sea appears to be in a stage of more rapid development than any other in the British Islands. In all probability, the earthquakes of 1816, 1888, and 1890 originated within it, as well as many of the minor shocks that followed them. That the earthquake of August 13th, 1816, was the strongest of the series is evident from the damage which it caused to buildings in Inverness and from the large area that it disturbed. Its series of after-shocks, of which no doubt only the more important were recorded, lasted until November 10th, 1818; and it is worthy of notice that, so far as we can judge from the scanty materials that have come down to us, the foci of some of these after-shocks lay beneath the north-eastern end of Loch Ness. The earthquake of February 2nd, 1888, was probably also attended by a train of after-shocks; but no accounts of them seem to have been published. After the earthquake of November 15th, 1890, the foci of the minor shocks showed a tendency, though with some oscillations, to recede in a south-westerly direction towards Loch Ness; while in 1901 this tendency, as we have seen, was revealed in a very striking manner.

The earthquakes provide no evidence with regard to the direction of the displacement along the boundary-fault; they do not tell us whether the rock on the south-east side of the fault was elevated or depressed with reference to that on the north-west side. There can be little doubt, however, that Loch Ness is still growing; but, without instrumental observations continued for many years, it can hardly be decided whether the lake is now contracting in area, or whether it is gradually, though very slowly, pushing its way outward to the sea.

[1] The shock and sounds observed at Teanassie on September 22nd, and Aigas on September 29th, may have had a similar origin. These places are both 8 miles to the north-west of the boundary-fault.

Immediately after the Japanese earthquake of 1891, there was a great and sudden increase of seismic activity in two detached regions, one 45 miles north-east, and the other 55 miles south-west of the meizoseismal area. See Geol. Mag. 1897, pp. 23–27 & Geogr. Journ. vol. xvii (1901) p. 653.

EXPLANATION OF PLATES XI & XII.

Plate XI.

Map showing the isoseismals 4, 5, 6, 7, & 8 of the principal Inverness earthquake, on the scale of 30 miles to the inch.

Plate XII.

Map illustrating the area affected by the accessory shocks of the Inverness earthquake, on the scale of 6 miles to the inch.

Discussion (on the two foregoing papers).

Prof. Judd said that everyone must be struck by the conjunction of two earthquakes with such dissimilar features. The movement in Cumberland was probably not of long continuance nor originating from a very old disturbance; moreover, it seemed to take place along a fault of which there was no evidence at the surface. In the Loch-Ness district, however, the fault-line was plainly apparent at the surface, and there was evidence that the recent disturbance was the continuation of movements that have been going on for ages. He expressed his gratitude to the Author for the care that he had taken in bringing the facts together.

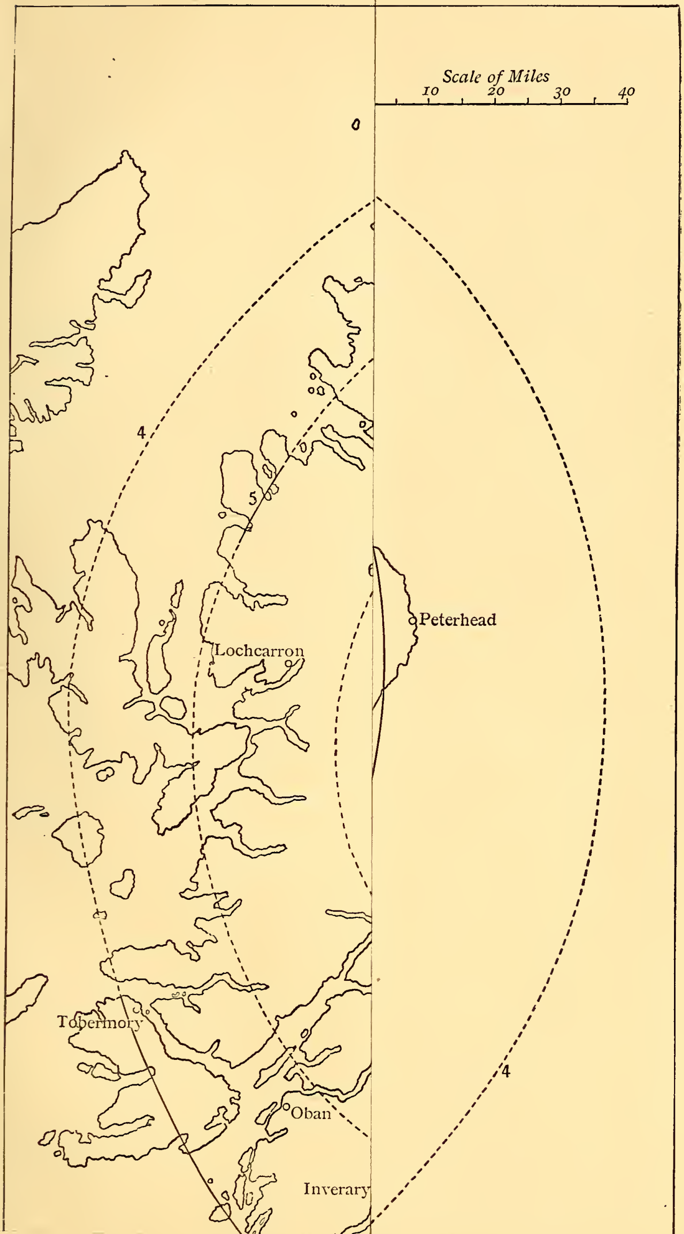
The Rev. Edwin Hill expressed admiration of the Author's work. Referring to the Carlisle paper, he asked whether the words 'in the surface-rocks there is no sign' of such a fault, meant that these rocks were not faulted. If so, did this imply that stress had been accumulating through geological periods, or that a cause of stress had after such periods been renewed? The latter was easier to imagine. He had heard that a recent earthquake in New Zealand had been followed by frequent movements through many weeks, and expressed a hope that there had been some worker on the spot as enthusiastic as the Author.

Mr. Gibson cited instances from North Staffordshire and Nottinghamshire of great faults affecting the Coal-Measures, now buried beneath the undisturbed Trias. Such faults might be revealed by earthquakes.

The President referred to the great geological importance of the Author's researches into the phenomena and distribution of British earthquakes in general; and pointed out how greatly he had enlarged our previous ideas as to their frequency in what we very naturally regard as a comparatively stable region. The painstaking manner in which he collected his materials, and the cautious way in which he drew his conclusions, inspired one with confidence in his results. He was especially to be congratulated on the advance that he had made in our knowledge of the subject as a whole, by his demonstration that most, if not all, the British earthquakes are due to slipping movements along fault-planes; by the discovery of twin earthquakes, and of the fact that the trends of the various earthquake-sliplines are more or less coincident with the four recognizable trends of crust-folding in the country. The Carlisle earthquake appeared exceptional, at first sight, in the fact that the direction of the presumed deep-seated fault-line ran almost meridionally, or from north to south, instead of diagonally, or from north-east to south-west, which is the strike of the deep-seated rocks of the Lake District. But it behoved us to remember that this meridional or Malvernian trend is practically that of the neighbouring Pennine Chain as a whole, and of the typical portion of its great Craven Fault.

In regard to the Inverness earthquakes, it was most significant to notice that where, as in this case, the fault-plane is of very great length, the earthquake-movement is of proportionate magnitude. While the oscillation-earthquakes along the fault-line itself might be due to the gradual and intermittent adjustment of the parts upon the opposite walls of the fault-fissure, it was not unlikely that the sympathetic earthquakes of the Findhorn, etc. might be owing to those broader areas of the earth-crust which extend for many miles from the fault-plane also slowly settling down into equilibrium with the new conditions of crust-strain brought about by the main earthquake. As respects the view that Loch Ness was still growing, the Author's idea seemed to be in harmony with the speaker's own suggestion made many years since, that the Loch-Ness depression in general is an 'intermont valley' the sides of which are gradually approximating because of crust-creep. If so, the lake is deepening, but not necessarily increasing proportionately in length.

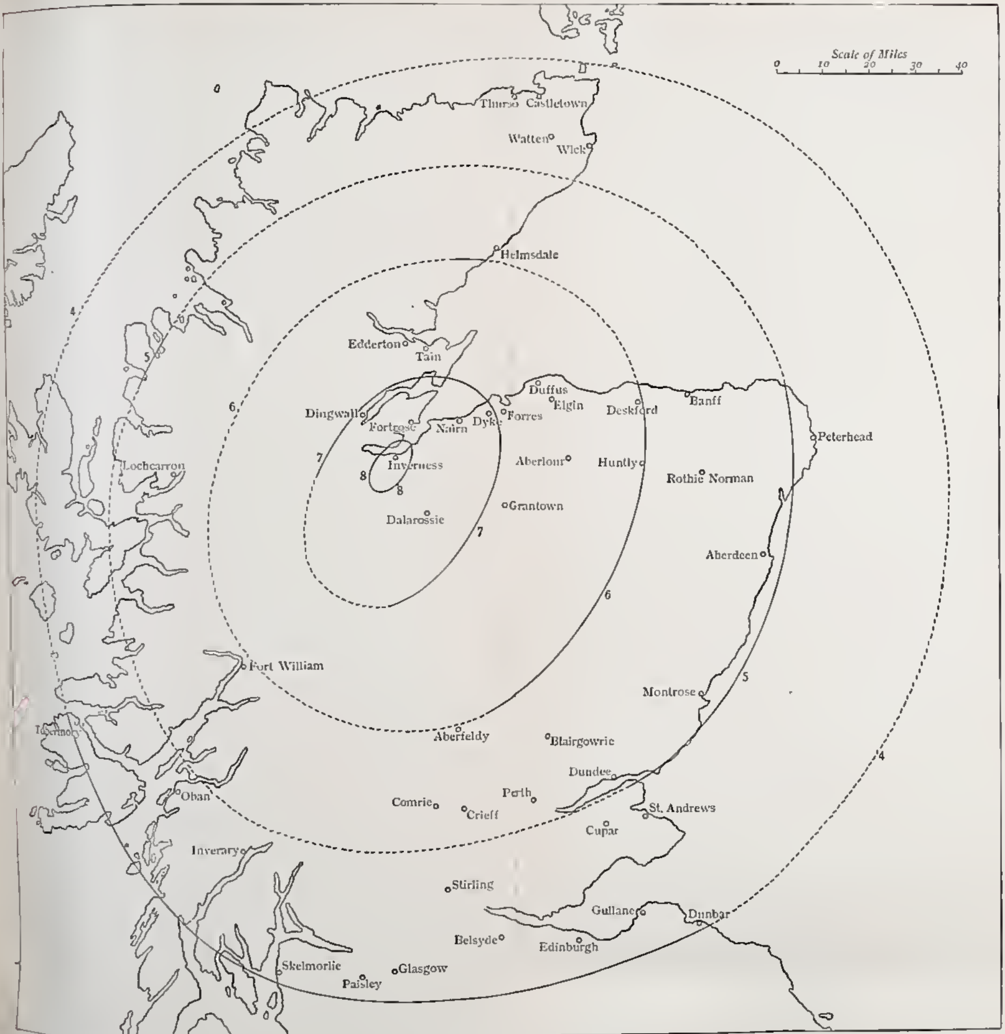
MAP SHOWING THEARTHQUAKE.



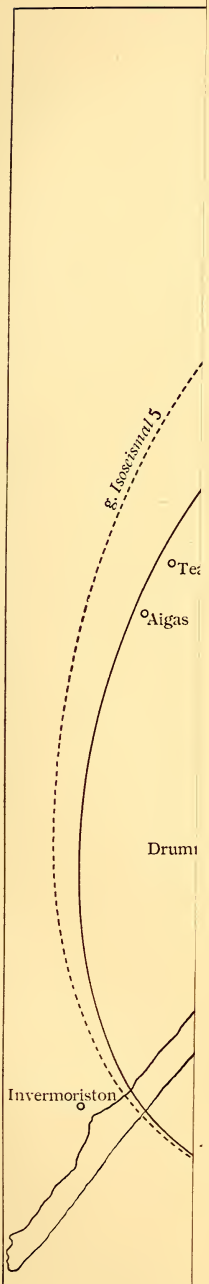
g = Afte

h = Afte

MAP SHOWING THE ISOSEISMALS 4, 5, 6, 7, & 8 OF THE PRINCIPAL INVERNESS EARTHQUAKE.

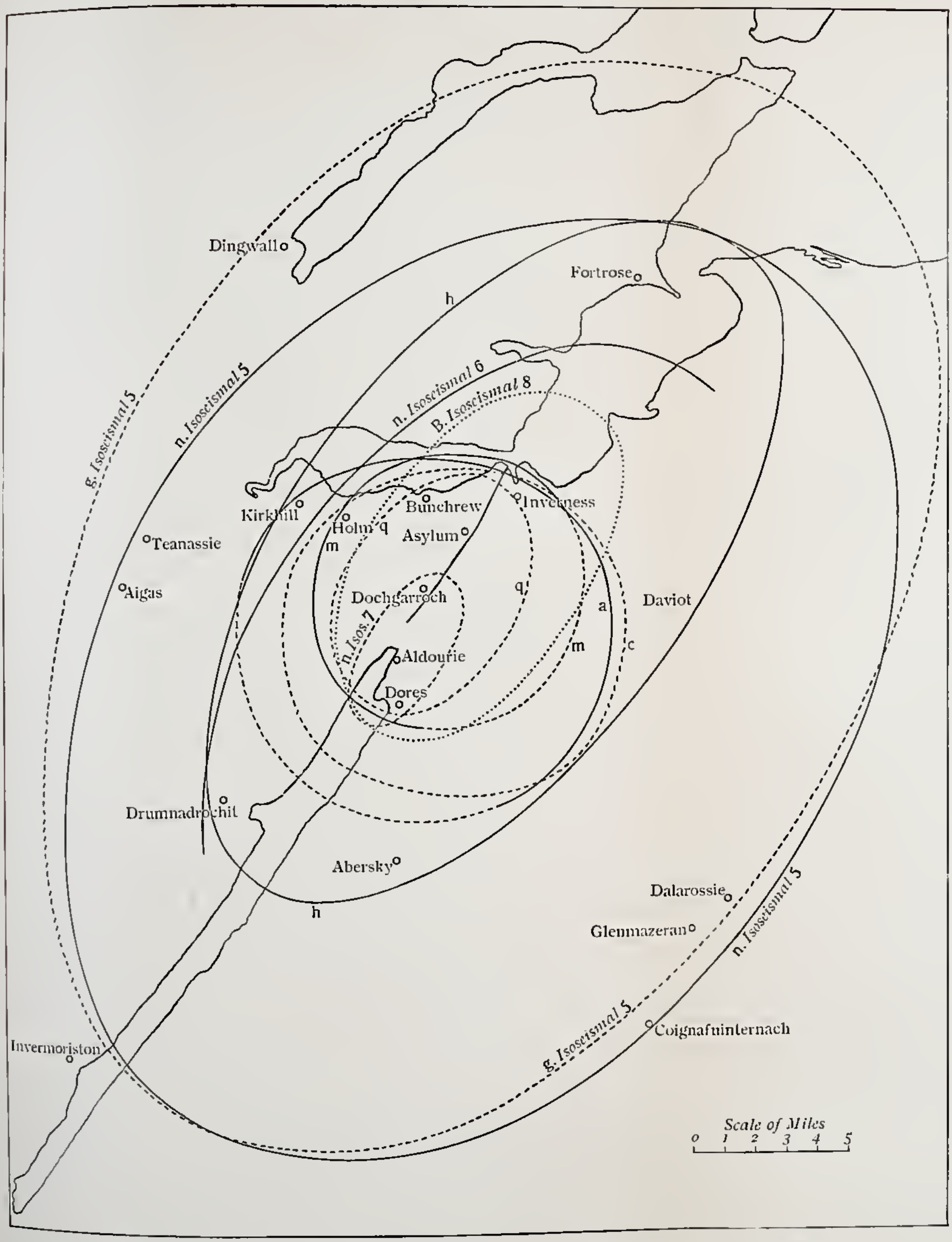


MAP ILLUSTRA



a = Fore
c = Afte
g = Afte
h = Afte

MAP ILLUSTRATING THE AREA AFFECTED BY THE ACCESSORY SHOCKS OF THE INVERNESS EARTHQUAKE.



a = Fore-shock *a* (p. 379).
c = After-shock *c* (p. 385).
g = After-shock *g* (p. 385).
h = After-shock *h* (p. 386).
m = After-shock *m* (p. 388).
n = After-shock *n* (p. 388).
q = After-shock *q* (p. 390).

25. *The* Crystalline Limestones *of* Ceylon.

By Ananda K. Coomáraswámy, Esq., B.Sc., F.L.S., F.G.S. (Read March 12th, 1902.)

[Plates XIII & XIV.]

Contents.

I. Introduction.

In 1860 Baron Ferdinand von Richthofen[1] recorded the occurrence of limestones in Ceylon. He observed the intimate associations of 'gneiss' and granular limestone, and the transitions between the two.

Mr. A. C. Dixon[2] has given a short account of the beds of limestone as follows:—The

'beds run through the gneiss in a somewhat parallel direction, striking generally north-west by north to north, and having various angles of dip, from 10° to 40°.'

He refers to five bands.

'The first is one which outcrops a few miles this side of Balangoda, and runs north-north-west, occurring again at Hunuwala. The second runs through Dolosbage and Maskeliya; probably the bed occurring at Bilhul Oya is continuous with this. The third outcrops under the Great Western [Mountain] on the Great Western Estate, and is continuous to the north-north-west with the Wattegoda and Medakumbura dolomites, and probably also with the beds at Gampola and Kurunegala. A subsidiary bed—or it may be an outlier of this—occurs near the Pussellawa rest-house. The fourth bed outcrops largely at Wilson's Bungalow, Glen Devon, Dumbara, and Matale. The fifth occurs in the Badulla District.' (*Op. cit.* pp. 42–43.)

I may say that the identity of these bands over such considerable distances requires confirmation.

Under the name of cipolin, Prof. A. Lacroix[3] has described some specimens of crystalline limestone from Ceylon, which form part of the De Bournon collection belonging to the Collège de France and that of Leschenault de la Tour in the Muséum d'Histoire Naturelle, Paris. The specimens were chiefly collected 7 leagues east of Kandy among acid gneisses. The minerals calcite, dolomite, blue apatite, phlogopite, spinel, pyrrhotine, and chondrodite were

[1] 'Bemerkungen über Ceylon' Zeitschr. Deutsch. Geol. Gesellsch. vol. xii (1860) p. 523.

[2] Journ. Roy. Asiat. Soc. Ceylon Branch, vol. vi (1880) p. 39.

[3] 'Contributions à l'Etude des Gneiss à Pyroxène et des Roches à Wernerite,' Bull. Soc. franç. Minéral. vol. xii (1889) pp. 336–44.

noted. Other cipolins from Cornegal (Kurunegala) were examined, and consisted largely of yellow calcite. They contained elliptical masses, reaching a foot in length, made up of a mixture of various minerals. One such was formed of calcite, oligoclase, green pyroxene, pyrite, quartz, and sphene; another of green amphibole, calcite, scapolite, sphene, oligoclase, pyrite, and zoisite. These nodules thus present a composition not altogether unlike that of the pyroxenic gneisses of the same districts.

In 1898 Dr. Max Diersche[1] examined a specimen of limestone from 'Queen's Palace' (Anuradhapura?) which Prof. Zirkel had collected; he found in it calcite, dolomite, olivine, phlogopite, and rutile.

In 1900 Dr. E. Ch. Schiffer[2] described in some detail a granular limestone from Wattegama, from the railway-cutting near the level-crossing, giving analyses of dolomite, apatite, phlogopite, hydrophlogopite, green serpentine (probably derived from forsterite), and white serpentine, recording also spinel, pyrite, and magnetite.

In the same year the present writer[3] noted the occurrence of limestones at Hakgala, Kandy, etc., referring especially to large pyroxenic masses with much blue apatite, occurring in the Hakgala limestone.[4]

Mr. John Parkinson[5] has described a section exposed in a railway-cutting near Matale, showing crystalline limestone in which occurs a band of rock resembling pyroxene-granulite which he (I think, rightly) supposes to be an intrusion in the limestone (see p. 408). He suggests also that limestone-material has been absorbed by the igneous rock.

Prof. E. Weinschenk[6] refers to the occurrence of these coarse-grained dolomites and cipolins, and regards the forsterite, chondrodite, phlogopite, and spinel which they contain as contact-minerals. He associates these rocks with the peculiar andalusite-, sillimanite-, and corundum-bearing rocks described by Prof. Lacroix, and considers that they represent beds of unknown age into which the rocks forming the Granulitic or Charnockite Series were intruded, producing widespread contact-metamorphism.

Dr. Fr. Grünling,[7] who collected the specimens of limestone described by Schiffer, in a general account of the results of his expedition to Ceylon, suggests that the corundum and spinel found

[1] 'Beitrag zur Kenntniss der Gesteine u. Graphitvorkommnisse Ceylons' Jahrb. d. k.-k. Geol. Reichsanst. vol. xlviii (1898) p. 271.

[2] 'Chemische Untersuchungen eines körnigen Dolomits aus dem Gneiss von Wattegama in Ceylon' Inaug.-Diss. Munich, 1900.

[3] 'Ceylon Rocks & Graphite' Quart. Journ. Geol. Soc. vol. lvi (1900) p. 600.

[4] This is the locality 'near Newara Eliya' referred to by Prof. A. H. Church in 'Nature' vol. lxiii (1901) p. 464.

[5] 'Notes on the Geology of South-Central Ceylon' Quart. Journ. Geol. Soc. vol. lvii (1901) pp. 204–206.

[6] 'Zur Kenntniss der Graphitlagerstätten: III. Die Graphitlagerstätten der Insel Ceylon' Abh. k.-bayerisch. Akad. Wissensch. vol. xxi (1901) pp. 286–90. See also review in Geol. Mag. 1901, pp. 175–76.

[7] 'Ueber die Mineralvorkommen von Ceylon' Zeitschr. für Krystallogr. vol. xxxiii (1900) pp. 233, 235.

in the river-gravels are derived from the dolomitic limestones; and, further, he saw in Colombo a specimen of calcite containing rather large crystals of zircon. I have never found corundum or zircon in the limestones, though spinel is very commonly seen in them.

The object of the present paper is to give a somewhat more complete account than has yet been attempted of the crystalline limestones and their relation to the (igneous) granulites (Charnockite Series) among which they are found. It is based on observations made in Ceylon in 1901, and refers especially to the Kandy and Hakgala districts, while limestones from Matale and farther north are referred to, and also some from Balangoda and Rakwane.

The crystalline rocks of Ceylon may be classified as follows:—

(1) Older Gneisses (orthogneisses).—These have suffered from earth-movements to a considerable extent, previous to the introduction of the extensive Granulite or Charnockite Series.

(2) Crystalline Limestones (cipolins of French authors).—These occur in bands or beds of very various width, the boundaries of which are parallel to the foliation (mineral banding) of the granulitic igneous rocks with which they are associated.

(3) Charnockite Series or Granulites.—These constitute the mountain-massif of South-Central Ceylon, and are probably intrusive in the older gneisses. (Dykes of a rock which may be connected with the Charnockite Series are clearly intrusive in the older gneiss at Ambalangoda.) These rocks are specially characterized by mineral banding and variation in chemical and mineralogical composition. They are all transitions from pure pyroxene-rocks to pure quartz-rocks. The limestones are interbanded with these rocks, and almost inseparably connected with them. The rocks of the Point de Galle Group must be included in the Charnockite Series, and form a subdivision thereof. This group includes granulitic rocks, in part largely composed of pyroxene, wollastonite, and scapolite, and in part resembling types of rock more usual in Ceylon.

The rocks included in Divisions (2) and (3) have, since their final consolidation, remained almost unaffected by deforming earth-movements.

With regard to terminology, I have adopted the name Charnockite Series for the granulitic igneous rocks of Ceylon, on account of the convenience of employing a definite name for them, and because they resemble, more than they differ from, the Indian rocks to which this name has been applied by Mr. T. H. Holland. So far is this the case, that any considerable series of rock-specimens from the Nilghiri Hills, the Shevaroy Hills, or from near Madras and from near Madura, could only with difficulty be distinguished from such a collection from Ceylon. There are of course varieties forming part of this series in India that have not been matched in Ceylon, and *vice versa*. I feel, however, that there is some ambiguity in using the one term Charnockite for the whole series, and also for a special type of rock very characteristic of the series. Despite this objection, it seems more important to emphasize the resemblances between Ceylon and Indian rocks than to propose a new term.

I desire to thank Prof. T. G. Bonney, F.R.S., and Mr. G. T. Prior, M.A., for occasional assistance and kind advice, and the latter for his analysis of forsterite. I am indebted to Prof. Miers's kindness for crystal-measurements which were made by Mr. Graham at Oxford, and to Mr. Herbert Smith for measurements of clinohumite. In Ceylon I have to thank Mr. Shand (Rakwane) and Mr. Holland (Balangoda) for their hospitality; and also Mr. and Mrs. Nock, who rendered my stay in the new bungalow at Hakgala very pleasant. Mr. W. C. Hancock, B.A., has taken an interest in some of the chemical analyses, which he has made with great care.

II. General Description of the Limestones.

The crystalline limestones form beds, the boundaries and foliation of which are parallel to the foliation (mineral banding) of the neighbouring granulites (fig. 2, p. 406). The outcrops vary in width from a few feet to more than a quarter of a mile. The most general strike is from north to north-west, and it is sometimes quite constant for many miles.

The narrower bands of limestone are occasionally more intimately interbedded with the granulites than can be shown in the maps which illustrate this paper. The foliation of the limestone is marked by variation in coarseness of grain, in structure, and in mineral composition. Thus there are alternations of bands rich and poor in accessory minerals. The latter on the whole are more abundant near the contact with the granulite, but this difference is not always marked. Bands in which occur parallel intergrowths of dolomite and calcite may alternate with others in which ramifying intergrowths are found, or in which there is merely a granular mixture of carbonates, or dolomite or calcite alone. Calcite seems to predominate where accessory minerals most abound. The following accessory minerals are very characteristic: olivine, diopside, phlogopite, blue apatite, spinel, pyrite, and graphite; less common are amphibole, clinohumite, magnetite, scapolite, sphene, and orthoclase. I have never met with garnet or wollastonite associated with the limestones.

The limestones often contain nodular masses of silicates, recalling those that occur in the Glenelg Limestone.[1] These knots or nodules weather out of the limestone, with which they are often connected by only a small neck, so that they are easily detached. They vary from less than an inch up to several yards in diameter, and their constitution is various.[2] Many are white, and consist entirely of

[1] C. T. Clough & W. Pollard, 'On Spinel & Forsterite from the Glenelg Limestone' Quart. Journ. Geol. Soc. vol. lv (1899) p. 372.

[2] Here only those mineral-aggregates are referred to, that consist of accessory minerals characteristic of the limestones. It is not always possible, however, to draw a sharp line between these aggregates and inclusions of pyroxene-granulite in the limestone, which are peripherally rich in lime-silicates, diopside, phlogopite, and scapolite.

diopside; a variety common in the Hakgala district consists of diopside, blue apatite, and mica. The blue apatite 'from a locality near Newara Eliya'[1] (actually Lower Albion, near Hakgala, see map, Pl. XIV) occurs in a mass of this kind several yards in diameter, slightly quarried in the hope of obtaining mica of value. Carbonates are, as a rule, nearly or quite absent from these aggregates. The associations met with include:—Pure diopside (the commonest type); diopside, phlogopite, blue apatite (common); diopside, phlogopite, blue spinel (near Tataluoya); tremolite, calcite, blue apatite, colourless phlogopite (two-fifths of a mile south-south-west of Ulisna Muduna trigonometrical station, Pl. XIII); tremolite alone (36 miles north of Kandy); clinohumite (near Gettembe); olivine (Harakgama, Pl. XIV); olivine, green spinel, calcite, pale phlogopite (Mount Olive, Pl. XIV); olivine, pale phlogopite, pink spinel, tremolite, calcite, graphite, blue apatite, pyrite, rutile (disused middle quarry at Gettembe); phlogopite alone (several localities).

The limestones vary much in coarseness of grain. The finer varieties are saccharoidal; the coarsest-grained consist of individuals measuring over 4 inches along the rhombohedral edge. This exceptionally coarse variety forms a thin band of limestone, exposed by the roadside about a third of a mile east-south-east of Talatuoya Bridge. Speaking generally, the limestones are distinctly coarse-grained, and the individual accessory minerals are always clearly visible to the naked eye.

The limestones vary as much in purity; almost pure varieties have a specific gravity of 2·76 to 2·78; in very impure varieties (rich in olivine) the specific gravity may reach 2·92, and that of the silicate-aggregates is, of course, still higher.

Sometimes the carbonate-individuals are not uniform in size, but there are porphyritic crystals embedded in a finer matrix. In one case examined the larger crystals consisted of dolomite, the smaller of dolomite and calcite mixed, and intergrown. These porphyritic limestones occur at several points in the Hakgala district. Neither in them nor elsewhere are the carbonate-crystals idiomorphic.

The proportion of calcite and dolomite present varies considerably. It is always posssible to separate the two carbonates by means of the Lemberg[2] stain, which may be applied either to a thin section or to a smoothed surface of rock. The only other distinctions between the carbonates of which I have made use in microscopic work, are the difference of refractive index and the twinning, which is usually, but not quite invariably, characteristic of the calcite only.

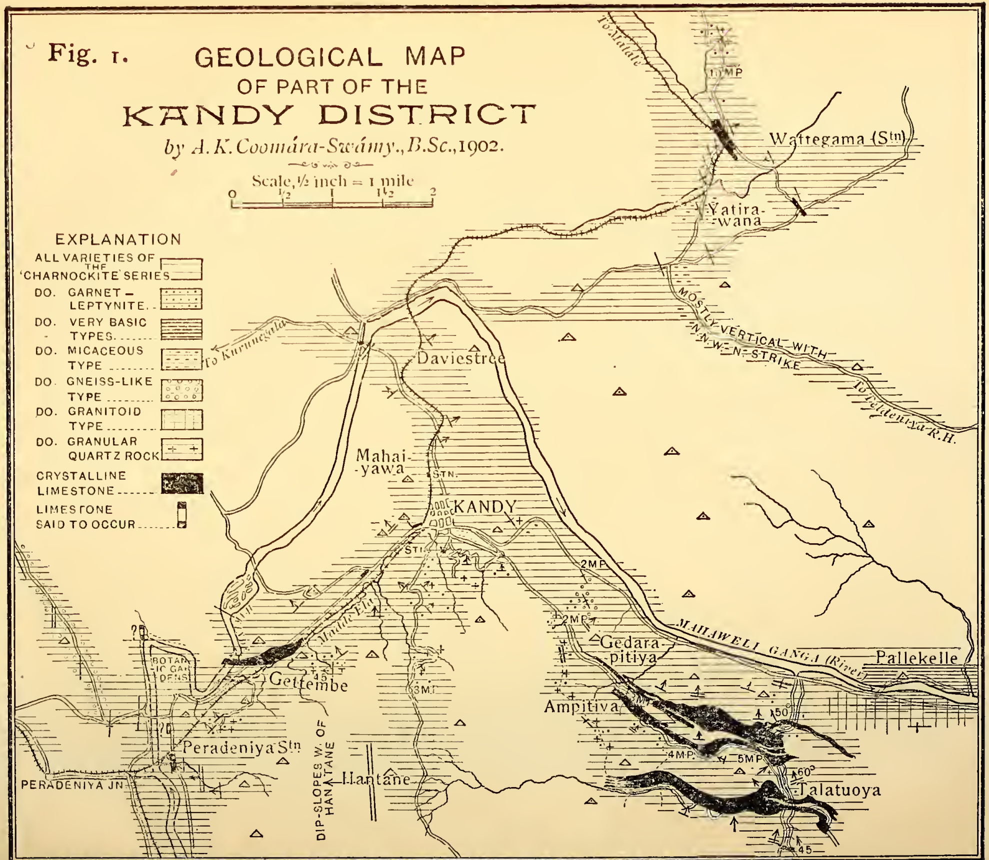
Microscopic examination of the limestones shows that they have not suffered from deforming earth-movements since the development of the accessory minerals that characterize them.[3] In one case curved

[1] A. H. Church, 'Nature' vol. lxiii (1901) p. 464.

[2] 'Zur mikroskopischen Untersuchung von Calcit, Dolomit u. Predazzit' Zeitschr. Deutsch. Geol. Gesellsch. vol. xl (1888) p. 357.

[3] It will be gathered that I am inclined to regard all these accessory minerals as *original*, that is, as contemporaneous with the carbonate rock-constituents.

Fig. 1.


GEOLOGICAL MAP
OF PART OF THE
KANDY DISTRICT
by A. K. Coomára-Swámy., B.Sc., 1902.
Scale, ½ inch = 1 mile
0 ½ 1 1½ 2
EXPLANATION
ALL VARIETIES OF THE 'CHARNOCKITE' SERIES
DO. GARNET – LEPTYNITE
DO. VERY BASIC TYPES
DO. MICACEOUS TYPE
DO. GNEISS-LIKE TYPE
DO. GRANITOID TYPE
DO. GRANULAR QUARTZ ROCK
CRYSTALLINE LIMESTONE
LIMESTONE SAID TO OCCUR
To Matale
Wattegama (Stn)
Yatira-wana
MOSTLY VERTICAL WITH N.N.W.-N. STRIKE
To Teldeniya R.H.
To Kurunegala
Daviestree
Mahai-yawa
STN.
KANDY
STN.
2MP
MAHAWELI GANGA (River)
Pallekelle
Gedara-pitiya
Ampitiya
4MP
5MP
50°
60°
Talatuoya
45
3MP
Gettembe
BOTANIC GARDENS
Peradeniya Stn
PERADENIYA JN
Hantane
DIP-SLOPES W. OF HANTANE

cleavage-faces were noted on the carbonate-crystals (Herimitigala). For a case of slickensided limestone, see below.

In the field, the various bands of limestone crop out with considerable regularity. Variations of dip are more frequent than changes of strike, which are always gradual, with one exception referred to below. It must be emphasized also, from this point of view, that the limestones cannot be considered apart from the granulites (Charnockite Series in Ceylon), and that these do not appear to have suffered from earth-movements since their consolidation, so far as microscopic work and the greater part of my field-work go.

In one case, however, a difficulty was met with in the field-work. On the Hakgala-Bandarawela road, near the 56th mile-post, the limestone strikes in a west-south-westerly direction; a furlong farther on the limestone is much slickensided and sheared (the only case observed by me in Ceylon), and in the stream just beyond this point the granulites are clearly seen striking in a north-westerly direction; the limestone-boundary near by has the same direction. Appearances of shearing and crushing are found in the granulitic rocks south-west of this point also. The areas north-east of it are somewhat inaccessible, being overgrown with lantana. Some uncertainty was felt also in mapping the area north of the Padinawela wood (Pl. XIV). Farther west, in the Mount-Olive area, limestones and granulites behave quite normally, possessing a common strike, a little north of west. A fault has been inserted in the map, in order to call attention to the existence of these phenomena; but in all probability it does not represent accurately the state of affairs.

It will be seen, from the maps which illustrate this paper, that the limestones and granulites together have probably been thrown into gentle folds; work in the field, however, impresses one with the comparatively uniform structure of very considerable areas.

III. Relations between the Crystalline Limestones and the Charnockite Series.

With the exception of Mr. Parkinson's description of a section near Matale, to be referred to later, no account has been given of these relations. As stated above, the limestones and granulitic (igneous) rocks exhibit a common foliation, the direction of which is parallel to the boundary between the two rocks. The junction is often very easy to follow on the ground, though not often clearly enough exposed for detailed examination. The actual boundary seems never, or very rarely, to be abrupt; but there is either a zone of green rocks in which greenish diopside is the most prominent constituent, other minerals including greenish and brown micas and amphibole, green spinel, iron-ores, and sometimes calcite—separating the limestones from the ordinary granulitic rocks,—or there is a gradual transition between the latter and the limestones, marked by the gradual appearance of calcite, accompanied by scapolite and sphene.

About 300 yards or so north of Talatuoya, on the Gurudeniya minor road, the road-cutting on the east side of the road exposes a series of normal granulites, among which a band of limestone 8 feet wide is intercalated, there being a northerly dip of about 50°. A transition-zone $1\frac{1}{2}$ to 2 feet wide is seen on the north side, the southern boundary being less clearly exposed. North of this zone are normal granulites; south of it the rather rotten, coarsely crystalline limestone, dotted with dark pyroxene. Sections from the outer part of the transition-zone show a rock much like an ordinary, rather acid, pyroxene-granulite with quite fresh felspars (plagioclase and orthoclase very finely microperthitic), elongated quartz, pale-green augite, and iron-ores, but with also a varying proportion of calcite, scapolite, sphene (individuals of the latter reaching 3 millimetres in diameter), and graphite: these minerals being evidently essential parts of the rock, and original constituents thereof. A small part of the calcite is probably secondary. A section much nearer to the limestone consists mainly of scapolite, calcite, and augite, but orthoclase-microperthite, plagioclase, quartz, sphene, and iron-ores are also present.

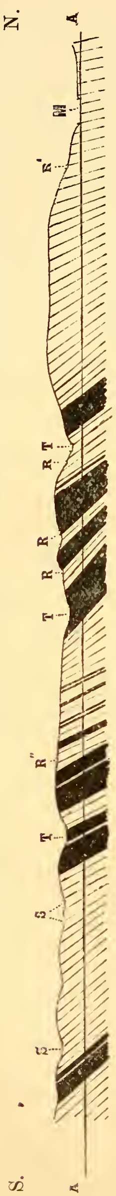


Fig. 2.—*Section along AB in Pl. XIII: from the Mahaweli Ganga to south of Talatuoya.*

[Horizontal scale: $2\frac{1}{2}$ inches=1 mile.]

AA = Approximate level of the bed of the Mahaweli Ganga.

M = Mahaweli Ganga. T = Talatuoya River. SS = Streams.

R = Talatuoya-Gurudeniya road. R′ = Kandy-Badulla road. R″ = Kandy-Talatuoya road.

The limestones are shown as black bands amid the (stripe l) granular quartz-rock, leptynite, pyroxene-granulite, pyroxenite, etc.

A similar case was noted at Rakwane, where on the Allerton Estate, near a now abandoned mica-pit, some masses of limestone crop out. In the lower part of a large mass a junction with a dark pyroxene-granulite is seen, and patches and flecks of pyroxenic rock are scattered through the limestone and weather out from it. The limestone consists of calcite with diopside, orthoclase, scapolite, pyrite, phlogopite, and graphite and apatite as accessory minerals. In a section through a small pyroxenic patch, these accessory minerals were seen to be much more abundant. A section of a specimen next to the limestone at the junction referred to showed much green augite and scapolite, with calcite (partly secondary), pyrite, little felspar, sphene. What is probably the same limestone is seen again in the Rakwane Ganga, Rangweltenne Estate, near by, and though very impure it has there been burnt for lime.

Fallen blocks below the Herimitigala Rock, on the estate of the same name near Balangoda, show a beautiful, coarsely crystalline limestone, with abundant crystals of diopside, scapolite, and some also of sphene. Some individuals of calcite measure more than $3 \times 1{\cdot}5$ centimetres. There are gradual passages from this rock to a handsome green and white scapolite-augite rock, strongly recalling certain varieties of rock occurring at Galle. The country-rocks here are granitoid in aspect, and more coarsely crystalline than usual.

Cases in which a zone of green rocks is found are also common. In the stream-bed, north of the bridge at Talatuoya, it may be seen that a band of impure limestone is in contact with a wide zone of heavy green rocks in which the minerals diopside, biotite, greenish-brown hornblende and green spinel predominate (specific gravity=3·25, 3·31); sometimes calcite is present, associated with many large spinels. Similar rocks are seen on the Kandy-Talatuoya road, about $3\frac{3}{4}$ miles from Kandy at the top of the hill (see fig. 1, p. 404), also $3\frac{1}{2}$ miles from Kandy south of the limestone-band; and again south of the limestone-band at the little bridge over the Mahaoya, south of the Peradeniya level-crossing, where a specimen (of specific gravity 3·27) consisted of diopside, brown mica, and green spinel, the latter rendered nearly opaque by granules of iron-ore.

Near the boundaries of limestone-beds, thin bands of limestone and granulite are sometimes found to alternate, as at Gangapitiya, where in the moonstone-pit the impure limestone-bands are usually separated from the beds of acid granulite by successive zones of diopside alone, and of diopside, serendibite, and spinel (with sometimes scapolite or plagioclase), each from 2·5 to 5 centimetres broad.

Moreover, it is often found that the limestones themselves become very impure near the junction with the granulitic rocks. Bands rich in mica, diopside, and spinel appear, as may be seen on the Kandy-Talatuoya road, about $5\frac{1}{4}$ miles from Kandy, and at Wattegama, east of the level-crossing, where some house-foundations afforded a section. Accessory minerals may, however, be quite as abundant in the main mass of the limestone, though here olivine (forsterite) is more characteristic.

It is not unusual to find in the limestones bands of pyroxenic rock, identical with the pyroxene-granulites, running parallel to the general foliation, and of various widths up to several yards. These bands are, as it were, s i l l s of pyroxene-granulite in the limestone. When quite narrow, such rocks occasionally form irregular snaky twists and flecks in the limestone; a quite chaotic mixture is sometimes thus produced. The patches weather out from the limestone, and look like masses of rotten ferruginous sandstone. A specimen of such a snaky twist had a specific gravity of 2·95, and consisted of a granular mixture of augite, potash, and felspar, with small quantities of scapolite, sphene, iron-ore, biotite, and calcite.

The granular structure of these masses, especially if there is slight decomposition, causes them to shatter at a light touch of the hammer, so that it is sometimes difficult to collect specimens for slicing.

There are also occasionally to be found in the limestones, quite isolated, inclusions of pyroxene-granulite a few feet or yards in width; and it may happen that the foliation of the limestone bends around them, suggesting flow-structure. Such occur, for example, on the Bandarawela road, beside the road, between the 56½ and 57 milestones, and elsewhere in the Hakgala district (Pl. XIV).

Sections from the central portions of the bands and masses here mentioned possess the usual characters of the pyroxene-granulites, the minerals augite, plagioclase, orthoclase, quartz (one case only), amphibole, brown mica, magnetite, pyrite, and sometimes sphene and scapolite, being noted.

Inclusions of quartz-rock, similar to that commonly occurring among the granulites, are exceedingly rarely met with. In one or two cases, strips of quartz an inch or two wide were noted in association with, or forming part of, the pyroxenic inclusions. Bands of quartz-rock (with also a negligible quantity of pyroxene) an inch or two wide were noted in limestone in the bed of the Talatuoya, four-fifths of a mile north of the bridge at Talatuoya.

On the Hakgala map (Pl. XIV) it will be seen that some large ellipsoidal masses of rock belonging to the Charnockite Series are completely included in the limestone-bands, and there are others smaller. In several cases these consist of a coarse quartzofelspathic rock: in other cases ordinary acid granulites enter into the composition of these masses, which I regard as masses of intrusive rock in the limestone, less flattened laterally than is usually the case.

The exposure described by Mr. Parkinson[1] is seen in the railway-cutting south of the level-crossing, south of Matale railway-station. I have visited the section, and am in complete agreement with him (except that I cannot find here or elsewhere in Ceylon clear evidence of an augite possessing the pleochroism of hypersthene, my own sections of the 'band' exhibiting only the usual green augite). The cutting shows a horizontal band of pyroxene-granulite, with crystalline limestone above and below it. The band becomes laterally very rich in pyroxene, and is not sharply separated from the limestone. It is probable that there has been, as Mr. Parkinson supposes, some absorption of calcareous material at the junction.

It will be useful to refer in greater detail to two other localities in which bands of acid granulite or pyroxenic granulite are found in the limestone.

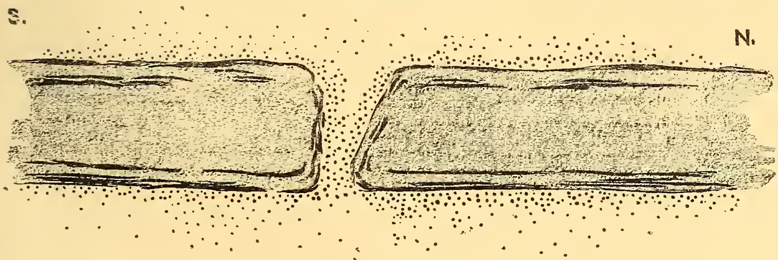
(1) Near the north-western corner of the Albion Estate, but a little north of the belt of acacias, and above and west of the Hakgala footpath, is a small section showing crystalline limestone with a

[1] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 204.

band of acid granulite therein: the limestones and included 'sill' being nearly horizontal. The band of granulite (specific gravity = 2·63) is of a very usual type, composed mainly of elongated quartz, orthoclase, microperthite, and plagioclase, with some green augite, magnetite, and abundant prisms of apatite. There are also brownish fibrous pseudomorphs, perhaps after rhombic pyroxene. This band of granulite, 2 feet wide, is separated from the limestone above and below by a zone of heavy, hard, dark rock, 3 to 6 inches thick (specific gravity = 3·2 to 3·28), composed mainly of greenish-brown hornblende, with more or less colourless diopside, brown mica, green spinel, and scapolite. The limestone near the top junction contains much colourless diopside, and a little olivine, besides calcite and some pale phlogopite. A less pure band in the limestone was composed of phlogopite, diopside, calcite, and bluish-green spinel, the plates of phlogopite being slightly distorted as if by pressure. There are also elongated silicate-lenticles in the limestone, consisting of dark heavy rock (specific gravity = 3·09, 3·31), similar in mineralogical composition to the contact-rock bordering the band of granulite. One measures about 2 feet by 6 inches, and consists of diopside, hornblende, and green spinel; in another phlogopite is abundant, in addition to these minerals.

(2) A small quarry, on the right-hand side of the Kandy-Anuradhapura Road, just south of the 32¾-milestone, is of much interest.

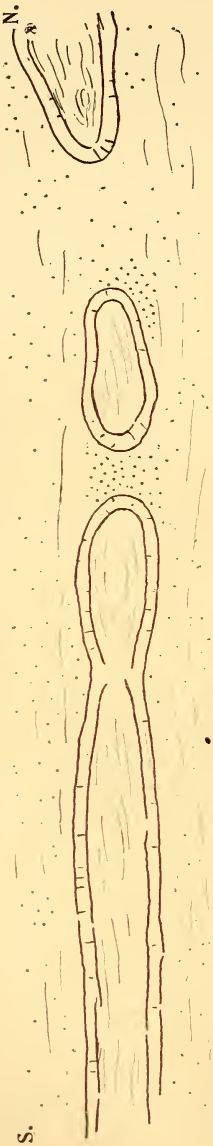
Fig. 3.—*Interrupted sill of pyroxene-granulite in limestone, near Nalanda.*



[A length of about 5 feet is shown.]

The quarry has been opened in a wide band of crystalline limestone along and over which the road runs. The limestone is of ordinary type, in part comparatively pure (specific gravity = 2·83), with calcite, dolomite, and not very abundant olivine. Impure varieties, from which knots of rusty rock weather out, are also present. These contain diopside, pale phlogopite, calcite, olivine, and green spinel (specific gravity = 2·85, 2·97). There are in the limestone two bands of granulite, striking north and south parallel to the general foliation and to each other.

The first appears as a dark band about a foot wide (fig. 3), centrally hard and compact, and resembling a pyroxene-granulite, but laterally more micaceous. A thin slice from the central part (sp.gr. = 2·96) shows much augite (very pale green to bright green), often with dark rod-like inclusions, and an equal amount of zoned plagioclase, most basic internally. Magnetite is abundant, and some pyrite is also present. Quartz is rare or absent, with the exception of a streak 2 millimetres wide, parallel to the foliation, consisting of elongated quartz-individuals. Scapolite appears to occur. Other minerals present in quite small quantity are hypersthene, biotite, and apatite. Without the scapolite, the rock would be an ordinary pyroxene-granulite. Another slice from a specimen nearer the edge of the band (sp.gr. = 2·99) contains much brown mica and hornblende, with green augite and plagioclase less abundant than before, and limpid scapolite tending to occur in plates moulding the other minerals. A third slice from the micaceous edge of this band (sp.gr. = 3·16) is composed of diopside, phlogopite, pyrite, and scapolite. The diopside is partly in graphic forms standing out against the scapolite. The limestone at the junction (which is not abrupt) contains calcite, olivine, very little diopside, green spinel (black macroscopically), and much pyrite, the last confined to a zone 2·5 to 5 centimetres wide next to the pyroxene-granulite band. The last-named band, however, is not quite continuous, but is interrupted by a tongue of limestone a few inches wide, which crosses it, connecting the limestone on the east with that on the west of the band. This limestone-tongue forms thus a sort of dyke crossing the band of pyroxene-granulite.



[A length of about 2 yards is shown.]

Fig. 4.—*Band of acid granulite in limestone, separated from it by a 1-inch zone of diopside-rock, and passing into lenticles of corresponding character.*

In the second case a band of white acid granulite is seen in the limestone (fig. 4), 2 yards west of the darker band just described. Here the acid granulite (possessing the usual characters) is separated from the limestone by a zone of hard, compact, greenish-grey rock, 1 to $1\frac{1}{2}$ inches wide, which borders it like a shell. This greenish zone (specific gravity $=3{\cdot}12$, $3{\cdot}25$) is composed almost entirely of compact granular diopside, with some green spinel in parts, and peripherally a little interstitial calcite. Where the calcite is more abundant, the diopside and spinel are idiomorphic. After running for some yards as such, the band is continued as a series of lenticles, the structure of which is identical with that of the band. The band of acid granulite is thus, as it were, interrupted by transverse dykes of limestone. A specimen of acid granulite from the interior of one of the lenticles contained augen-orthoclase, measuring as much as 23×13 millimetres. A thin slice showed a fine-grained granular mosaic of orthoclase-microperthite, traversed by strings of individuals of elongated quartz, and containing irregular porphyritic individuals of microperthite which appear strained and perhaps fractured. The band and lenticles can be traced for quite 15 yards, appearing again beside the road, north of the exposure in the shallow quarry.

It is exceedingly interesting to compare these broken sills of granulite in limestone with the broken dykes of nepheline-syenite in the limestone of Alnö (described by Prof. A. G. Högbom),[1] the peculiar characters of which seem to correspond closely with those of the cases just described.

Before leaving this part of the subject, it may be useful to point out that the various bands of granulite met with in the limestones occur *always as sills, and never as transverse dykes*. If we suppose the granulite to be intrusive in the limestone, we must regard this parallelism as the result of injection accompanied by lateral pressure.

IV. Intergrowths of Calcite and Dolomite.

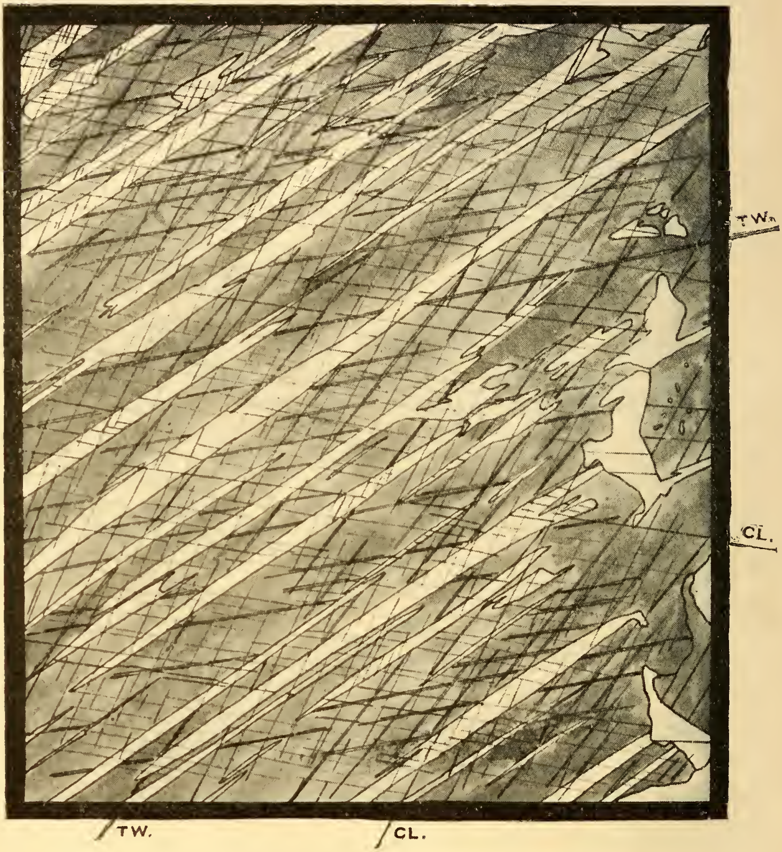
These are very characteristic of the crystalline limestones, especially in the Kandy and Matale districts, though rather unusual in the neighbourhood of Hakgala. Such intergrowths produce characteristic appearances on weathered surfaces.

Parallel intergrowths (fig. 5, p. 412).—It is very usual for the white carbonate-crystals composing the limestone to show a curious banding, well brought out on weathered surfaces. In such cases, there is a series of narrow parallel bands running across the crystal, diagonal to the cleavage, and alternately standing out and depressed. In the coarsest variety found, there were 15 upstanding bands to the half-centimetre. There are all transitions from this type to bandings of microscopic dimensions. Thin sections show that this appearance is caused by a parallel intergrowth of calcite and dolomite, in alternating planes parallel to the basal plane $c\,(001)$.

[1] Geol. Fören. Stockholm Förhandl. vol. xvii (1895) pp. 100, 214.

Sections prepared parallel to the plane of intergrowth yield a negative uniaxial interference-figure in convergent polarized light. In most cases the calcite and dolomite have an identical optical orientation, in others the alternating bands show a slightly differing orientation.

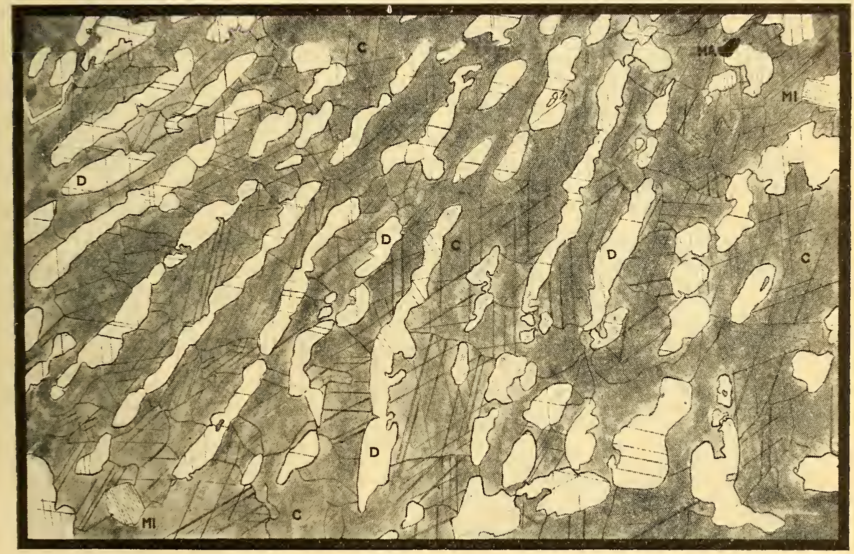
Fig. 5.—*Parallel intergrowth of calcite (dark) and dolomite.* ×20.



[The shading represents the effect of staining with Lemberg's solution. This applies also to fig. 6. TW=Twinning; CL=Cleavage.]

Ramifying (graphic) intergrowths (fig. 6, p. 413).—On the weathered surfaces of other varieties of limestone, a vermicular tracery is often seen, frequently appearing to radiate from several centres. Fractured surfaces of such specimens present a 'lustre-mottled' appearance. Thin sections show that these phenomena are due to ramifying intergrowths of calcite and dolomite. The radiating 'fingers' consist of dolomite, with a common optical orientation; the calcite-individuals are numerous and variously oriented, but each is large enough to enclose portions of more than one 'finger' of dolomite: Fig. 6 is from a specimen in which the intergrowth is less fine-grained than usual; it often sinks to quite microscopic dimensions, and such examples have been described by Prof. Lacroix [1] and Mr. Parkinson,[2] though without explanation.

Fig. 6.—*Ramifying or graphic intergrowth of calcite* (C) *and dolomite* (D). $\times 9{\cdot}4$.



[MA=Magnetite; MI=Mica.]

In many of the parallel intergrowths the calcite and dolomite are of equal relative importance; in others, and in most of the ramifying intergrowths, we usually find that calcite predominates, and should speak of the dolomite as forming parallel or ramifying inclusions in the calcite; it is exceedingly rare to meet with a reverse relation.

A conspicuous feature is the limitation of twinning to the calcite, the twinning-bands in it ceasing at the junction with dolomite, even when the two have a common optical orientation. Very seldom traces of twinning are found in the dolomite, and it seems perhaps to be not quite invariably present in the calcite, though usually so.

The distinctness of the intergrowths, even on a very small scale, shows probably that the carbonates consist of pure dolomite or pure calcite, and that intermediate types are absent.

[1] Bull. Soc. franç. Minéral. vol. xii (1889) p. 337 & fig. 60.
[2] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 205.

The finest examples of these intergrowths were obtained at a point three-quarters of a mile west of Ulisna Muduna trigonometrical station, along the footpath that descends the slope in a south-westerly direction (see map, Pl. XIII).

V. Notes on the Accessory and Contact-Minerals.

(1) Diopside.—Colourless monoclinic pyroxenes associated with the limestones and their contacts with the granulites are referred to as diopside. The monoclinic pyroxene of the pyroxene-granulites possesses always a green colour, though sometimes pale, and it is referred to as augite. The diopside of the green-rock contact-zones has sometimes also a pale-green colour.[1] Much diopside is present as the sole constituent of some white silicate-aggregates, or associated in them with other minerals, such as blue apatite and mica; it is also occasionally present as a constituent of the limestone-rock, with or without accompanying olivine.

(2) Olivine (forsterite).—Colourless olivine in crystals almost always clearly visible macroscopically (and even reaching 1 inch in length) is very commonly met with. Very often the limestone carrying olivine has a grey or dark-grey coloration, owing to the deposition of granules of iron-ore along the irregular cracks in the olivine. Alteration to serpentine is not very common, the crystals being very fresh.

Alternations of pure and olivine-bearing limestones give the effect of a white-and-grey banding. Such bandings are always parallel to the general strike. Olivine-bearing dolomites are well seen at Ampitiya, in quarries north-east of Ketawala trigonometrical station, and along the roadside west of the same point (Pl. XIII). An analysis of olivine from Ampitiya is quoted on p. 415. Olivine is unusually abundant in, and gives quite a dark colour to, limestones exposed on the Ambewela-Hakgala road, near the bridge over it, and near the 4th milestone.

Another case may be referred to in greater detail. Limestone occurs in a patch of jungle near the Hakgala Gardens, near the remains of an old kiln, where lime was formerly burnt (Pl. XIV). The limestone forms a sort of cave; it is doubtless a continuation of one of the bands which slope up from Harakgama. The minerals present are calcite, dolomite, olivine, phlogopite, pyrite, and pink spinel. The olivine in some specimens appears grey, in others yellowish; but these colours merely result from very slight quantities of iron-ore deposited along the cleavage-cracks. Grains treated for some hours with dilute hydrochloric acid become quite colourless. Such treatment serves to isolate the olivine, and seems to attack it very little or not at all. The grains obtained consist of separate flattened crystals, averaging 2 to 3 millimetres in length, and of more irregular aggregates. The flattened grains show in convergent

[1] In one case a quite dark green pyroxene occurred in limestone (at Herimitigala) associated with scapolite. This pyroxene resembles the Tiree 'coccolite,' and probably belongs to the hedenbergite group.

polarized light the emergence of an obtuse bisectrix. The optic axial plane is at right angles to the elongation of the crystals, which are thus elongated in the direction of the vertical axis, and flattened parallel to *b* (010).

CHEMICAL ANALYSES OF FORSTERITE AND SERPENTINE FROM CEYLON.

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	42·55	41·16	42·8	39·25	39·88
Al_2O_3	0·23	...	...	1·78	3·18
Fe_2O_3	...	2·58	...	...	...
FeO	2·36	...	2·6	...	...
CaO	1·43	...	...	1·84	1·75
MgO	51·97	52·60	55·4	39·00	38·64
Loss on ignition	1·68	H_2O (hygroscopic) 0·6 H_2O (combined) 3·2	...	(H_2O) 18·13	16·55
	100·22	100·14	100·8	100·00	100·00
Sp. gr.	3·14	3·13			

I. Analysis of forsterite from Hakgala, by Mr. G. T. Prior, M.A.
II. Analysis of forsterite from Ampitiya, by Mr. W. C. Hancock.
III. Analysis of forsterite from Kandy, by M. H. Arsandaux, Bull. Soc. franç. Minéral. vol. xxiv (1901) p. 475.
IV. } V. } Analyses of green and white serpentine from limestone, Wattegama level-crossing, by Dr. Schiffer, Inaug.-Dissert. Munich, 1900.

It is noteworthy that the olivine does not occur specially near junctions with the granulites, as does diopside, but is more common than the latter in the main masses of limestone.

(3) Mica.—Colourless to golden-brown micas, less often pale-greenish, are everywhere commonly found either scattered through the limestone (and then more or less idiomorphic), or accompanying malacolite, apatite, spinel, etc. in silicate-aggregates which weather out on the surface of the limestone. The most usual types have the colour and pleochroism of phlogopite, but are very pale, often colourless in thin section if not macroscopically. Greenish-brown micas, with the optical characters of phlogopite, are sometimes characteristic of impure bands in limestone near junctions with the granulites.

A dark-brown mica was found with hornblende in limestone at Wariapola.

Near Talatuoya several diggings for mica have been made; and it is probable that this mica occurs in connection with the junctions of limestone and granulite. It belongs chiefly to phlogopite, with various warm brown shades. The crystals are often idiomorphic, and not often more than 6 or 8 inches in diameter. Some have curious, flattened, black, lath-shaped inclusions, arranged parallel and perpendicular to the rays of the percussion-figure.

Quite dark greenish-brown or green micas (nearly uniaxial) occur with diopside, amphibole, and spinel in the heavy green rocks sometimes found between the limestones and granulites (Talatuoya).

(4) Spinel.—Pink and violet-pink spinels are very common

scattered through the limestone, for example, in the neighbourhood of Talatuoya, and also at Hakgala. The crystals are often well-shaped octahedra; sometimes, as at Hakgala Limekiln, combinations of the forms (111) and (101) are found. The largest crystals obtained *in situ* reached about 5 millimetres in diameter; but I have received much larger specimens, with the locality of which I am not acquainted, although they probably occurred in limestone.

Blue spinel was noted as forming, with olivine and pale phlogopite, a small mineral-aggregate in limestone near Talatuoya. Pink spinel occurs in a micaceous mineral-aggregate in limestone in the middle disused quarry at Gettembe. Green spinels (green or black macroscopically, often nearly colourless in thin sections) are common in the dark patches and mineral-aggregates in the limestones, and associated with diopside or amphibole in contact-zones, and with green diopside, amphibole, and mica in the heavy green rocks which are sometimes found between the limestones and the typical granulites (Talatuoya, etc.). Green spinels are rarely found scattered through the limestone, but seem to occur more definitely as a contact-mineral. Some varieties of limestone rich in green spinel are, however, to be met with, as at Talatuoya in the stream north of the bridge.

The presence of spinel as a contact-mineral seems to result from the appropriation of silica in the formation of lime- and magnesia-silicates.

(5) Apatite.—Blue apatite is everywhere common as an accessory mineral in the limestones, and associated with malacolite and phlogopite in mineral-aggregates in the limestone, as at Lower Albion, Hakgala. In the limestones it is present in the form of prismatic crystals, with rounded outlines, always big enough to attract attention. Isolated grains show (as was noted by Mr. Parkinson) a clear pleochroism, namely, for rays vibrating parallel to c sky-blue, for rays vibrating perpendicular to c' pale claret (nearly colourless). In thin sections the blue apatite appears colourless.

Dr. Schiffer has analysed a blue apatite from Wattegama, his results giving the calculated formula $(PO_4)_3(FlCl)Ca_5$. Prof. Church has also investigated the blue apatite of Ceylon.[1]

(6) Amphibole.—The amphiboles associated with the crystalline limestones are not especially abundant, but have been noted in several localities occurring as contact-minerals, silicate-aggregates, or scattered through the limestone.

Fibrous crystals of colourless tremolite, with an extinction-angle on (110) of about 17°, form a white silicate-aggregate in limestone not far from the 36th milestone on the Kandy-Anuradhapura road.

Colourless glassy amphibole occurs in nodular silicate-masses (with colourless mica and blue apatite) in limestone two-fifths of a mile south-south-west of Ulisna Muduna trigonometrical station (Pl. XIII). A variety has a very faint greenish tinge, and some glassy crystals scattered through the limestone itself are of a clear pale-green.

[1] 'Nature' vol. lxiii (1901) p. 464.

On a small pale-green individual, weathered out, Mr. Graham has determined the forms (011) (110) (010).

Mr. W. C. Hancock has analysed the colourless variety from this locality, with the following result:—

	Per cent.
C (graphite)	0·30
H_2O (combined)	0·60
SiO_2	47·04
Al_2O_3 (with a trace of iron-peroxide)	13·76
CaO	13·39
MgO	21·26
Na_2O	4.01
	100·36

The presence of so much soda and alumina, presumably introduced from the granulites, is interesting.

Specific gravity = 2·92

A dark-brown amphibole occurs in lumps of limestone with brown mica, in a field east of the railway near Wariapola, near Matale. The crystals are frequently idiomorphic. Mr. Graham has determined the forms (100) (010) (110) (310) (011) ($\bar{1}$01). In thin sections this amphibole is quite colourless. Cleavage-flakes show an extinction-angle of about 21° on *m* (110).

Many varieties are quite colourless, even macroscopically; others are pale-green, greenish-brown, or dark-brown, but colourless or pale in thin sections. Others, especially those occurring definitely as contact-minerals, show colour in the slides and have a normal pleochroism, not so strong, however, as that of the amphiboles which occur in the pyroxene-granulites themselves. Amphibole darker than any of those referred to above, and resembling the amphibole of the pyroxene-granulites, is found with green diopside, dark mica, and dark-green spinel, in the heavy green rocks which seem to separate the limestones from the granulites in some localities.

(7) Scapolite is quite unusual as an accessory mineral in the limestones themselves. It may also be met with in mineral-aggregates in limestone, as for example in an inclusion measuring 7 × 3 × 4 inches from Palugama (Pl. XIV), consisting of diopside, phlogopite, plagioclase, scapolite, and calcite. Another aggregate consisted of diopside partly granular, partly intergrown in beautiful graphic fashion with scapolite and a few individuals of orthoclase. Probably such aggregates correspond to inclusions of pyroxene-granulite, which being small have been much modified by the formation of lime-silicates. Hence they are not included in the list of mineral-aggregates on p. 403, which refers rather to aggregates of minerals especially characteristic of the limestones themselves.

Scapolite is, however, very characteristic of the peripheral parts of sills and inclusions of pyroxene-granulite in the limestones, where it is usually accompanied by sphene. Thus the peripheral portion of the pyroxene-granulite sill described on p. 409 consists of diopside, phlogopite, pyrite, and scapolite; while the rock in contact with the Herimitigala limestone, as seen in fallen blocks, is a fine scapolite-augite rock. Many other localities could be named. In such cases the scapolite is sometimes granular, but more often it forms plates enclosing the other minerals which sometimes assume graphic forms. Sometimes there are numerous elongated inclusions arranged parallel to the vertical axis.[1]

Fig. 7.—*Intergrowth of diopside (square and rectangular outlines) and scapolite, Lower Albion, Hakgala.* × *120.*

[The section is perpendicular to the vertical axes.]

(8) Iron-Ores.—Pyrite in small quantity is a common accessory mineral in the limestones; and is sometimes abundant also in the mineral-aggregates, but it is not usually characteristic of these. It may occur as a definite contact-mineral, as in the quarry 2 miles north of Nalanda.

Magnetite is occasionally met with; it was noted in some quantity in a variety of limestone from the western quarry at Gettembe.

Dr. Schiffer's examination of pyrite from Wattegama[2] showed its composition to be pure FeS_2, and he noted the forms (111) and (210).

(9) Clinohumite was found at Gettembe, 3 miles west of Kandy, and at Ampitiya, 3 miles east of Kandy. At Ampitiya yellow granules of clinohumite were found in coarsely crystalline limestone about a fifth of a mile north-west of Ketawala trigonometrical station. At Gettembe three pits have been opened for lime-burning, north of the road and below the hill ('Primrose Hill'). The middle pit is disused and small. Yellow clinohumite is very abundant in one

[1] See Lacroix, Bull. Soc. franç. Minéral. vol. xii (1889) p. 99 & fig. 6.

[2] 'Chemische Untersuchungen eines körnigen Dolomits aus dem Gneiss von Wattegama in Ceylon' Inaug.-Dissert. Munich, 1900.

variety of limestone occurring in the western pit, forming a handsome dolomite-clinohumite rock: other minerals present in small quantity are olivine (?) and blue spinel. Other varieties of limestone in the same pit are quite without clinohumite, and have different accessory minerals, or none. The clinohumite forms large crystals with some approach to crystalline form, reaching 1 inch in longest diameter; smaller granular crystals are abundant. These are very diminutive, but have sometimes numerous well-developed crystalline faces. The grains are about twice as long as broad and slightly flattened. Examined between crossed nicols, they are found to extinguish always parallel to their length, whether lying on one side or on the other, whence it follows that they are elongated in the direction of the orthodiagonal axis $\bar{b}$. In thin sections, it can be clearly seen that the axial plane is parallel to the elongation. The pleochroism is 𝔞 fine orange-yellow, 𝔠 pale chrome-yellow, and 𝔟 like 𝔠 or very slightly darker. Absorption $\mathfrak{a} > \mathfrak{b} \geq \mathfrak{c}$. In thin sections, basal cleavage is seen parallel to the elongation; isolated grains are also occasionally seamed by irregular cracks, more or less transverse to their length.

Mr. G. F. Herbert Smith has kindly measured one of the tiny crystals from Gettembe,[1] and identified the forms

$c(001)e_2(107)e_3(103)e_4(101)n_3(113)i_2(014)i_3(012)r_4(129)r_5(\bar{1}27)r_6(125)r_8(121)$

The measurements are quoted in the following table:—

Form.		Observed.				Calculated (Dana, 6th ed.).			
		Azimuth.		Distance.		Azimuth.		Distance.	
		°	′	°	′	°	′	°	′
e_4	101	0	0	79	15	0	0	79	11½
		,,	,,	79	7	,,	,,	,,	,,
		,,	,,	79	9	,,	,,	,,	,,
		,,	,,	79	17	,,	,,	,,	,,
e_3	103	,,	,,	60	6	,,	,,	60	12
		,,	,,	60	7	,,	,,	,,	,,
e_2	107	,,	,,	46	11	,,	,,	46	20
n_3	113	47	40	68	30	47	13	68	44½
r_4	129	65	17	54	9	65	10	54	11
		65	7	53	59	,,	,,	,,	,,
r_6	125	65	17	68	8	,,	,,	68	9
r_8	121	65	7	85	15	,,	,,	85	25
		65	17	85	22	,,	,,	,,	,,
r_5	$\bar{1}27$	65	6	60	45	,,	,,	60	42
		64	58	61	0	,,	,,	,,	,,
i_3	012	90	11	70	37	90	0	70	32
		90	2	70	30	,,	,,	,,	,,
i_2	014	90	11	54	40	,,	,,	54	45

[1] The determination of the mineral as clinohumite depends on the crystal-measurements referred to. Without these it would have been necessary to speak vaguely of 'chondrodite.' The mineral which occurs sparingly at Ampitiya is probably identical with the Gettembe clinohumite.

Mr. G. F. Herbert Smith says that

'besides these faces there are a large number (more than a hundred) of others, mostly very small. Some of these might, on calculation, be found to have simple indices. Most of them, however, have very complex indices and would be due to etching. It would seem as if, in this case, some of the original faces were still left unaltered.'

Mr. W. C. Hancock has analysed the clinohumite from Gettembe, with the following results :—

	Per cent.
SiO_2	37·52
Fe_2O_3 (with a trace of alumina) ...	9·00
MgO	49·75
Na_2O	1·44
F	1·02
H_2O (hygroscopic)	0·50
H_2O (combined)	1·00
	100·23

Yellow clinohumite was also found in the limestone in the bed of the Madde Ela near Gettembe, associated with what may be a colourless variety. In a thin section, one case of twinning was observed; in the material from the limestone-pit no twins were found. A colourless variety of chondrodite from limestone from Ceylon has been described and figured by Prof. Lacroix[1]; the figure is, however, very suggestive of olivine.

(10) Graphite.—Flakes of graphite occur commonly in some varieties of limestone, though quite absent in others. The flakes are often more or less hexagonal in outline, and have a seemingly basal cleavage corresponding to that of mica.

(11) Sphene was only noted as an accessory mineral in the Herimitigala limestone, but is common accompanying scapolite, calcite, etc., in the peripheral parts of pyroxene-granulites which show endomorphic modification in contact with limestone.

(12) Orthoclase was noted as an accessory mineral in limestone, on Allerton Estate, Rakwane; and once or twice in mineral-aggregates in limestone, in the Hakgala district.

(13) Tourmaline occurs very sparingly in joints in the nodular serendibite-diopside rock-bands, and still more rarely in the intrusive granulite, at Gangapitiya. Tourmaline from river-gravels is one of the commonest semiprecious gems of Ceylon, but localities where it occurs *in situ* are unknown.[2]

(14) Serendibite.—This name has been given by Mr. Prior and myself[3] to a mineral occurring at the Gangapitiya moonstone-pits,

[1] Bull. Soc. franç. Minéral. vol. xii (1889) p. 338 & fig. 60.

[2] For crystallographic details of Ceylon tourmaline, see V. von Worobiev 'Krystallographische Studien über Turmalin von Ceylon u. einigen anderen Vorkommen' Zeitschr. für Krystallogr. vol. xxxiii (1900) pp. 263–454 & pls. viii–xiv.

[3] Paper read before the Mineralogical Society on February 4th, 1902 abstract in 'Nature' vol. lxv (1902) p. 383.

about 12 miles east of Kandy. To reach the spot the Kandy-Badulla riverside road is taken as far as the Pallekelle ferry, which is crossed, and proceeding along the road to the Teldeniya rest-house, the village of Ambakotte is reached. Immediately after passing this village, a road must be followed which turns to the right across the 'Ambakotte' and 'Ambakotte New' Estates. The pits are on the farther side of the latter, some 2 miles distant from the main road. Several bands of limestone and granulite are passed on the way. Limestones are well exposed near a pond about halfway between the road and the pits.

The pits show intimately interbanded acid granulite and impure limestone. The bands do not exceed a few feet in width, but are usually thinner. This is probably a case of 'lit-par-lit' injection in the outer part of a band of limestone which is crossed before the pits are reached. The acid granulite is of the usual type, with much elongated quartz, and a tendency to graphic structure. The minerals are orthoclase-microperthite, orthoclase, quartz, and plagioclase. Large augen-orthoclases provide the moonstone, to obtain which the pits were dug. Individuals may reach a size of $12{\cdot}5 \times 10$ centimetres.

The granulite-bands are separated from the limestone by a contact-zone, first of compact granular diopside 2·5 to 5 centimetres wide next to the limestone, and secondly of diopside, serendibite, green spinel, sometimes scapolite and plagioclase, 1·25 to 2·5 centimetres wide. Similar lime-silicate rock occurs in thin nodular bands which alternate with the granulite, corresponding to bands of limestone so thin as to have been completely altered to silicate-rock. This type of contact-action (formation of diopside, etc.) recalls the cases described on pp. 409, 410. Alternate bands of acid granulite and limestone were noted also in another moonstone-pit near Talatuoya.

The serendibite has a dark bluish-green colour in the rock, and with the spinel gives it a similar hue. It rarely occurs in easily recognizable crystals, but is usually much mixed and intergrown with the diopside. In thin sections, it is rendered very conspicuous by its remarkable pleochroism from very pale yellowish-green [1] to deep indigo-blue, and by the multiple twinning which is as characteristic as in a triclinic felspar. The crystals are somewhat flattened and elongated, and the twin-plane is parallel to the elongation. Crystal-faces parallel to the elongation are fairly well seen, terminal faces are rarer. The crystals have sometimes an ophitic habit, so that several portions not in contact extinguish simultaneously.

Other characters may be summarized as follows:—Optically biaxial, probably triclinic, perhaps monoclinic. Cleavage none; hardness = about 7; specific gravity = 3·42. Refractive index nearly equal to that of diopside, double refraction weak.

[1] In thin slices the spinel and serendibite are indistinguishable for some positions of the lower nicol.

Mr. G. T. Prior's analysis gave the following results :—

	Per cent.
SiO_2	25·33
Al_2O_3	34·96
FeO	4·17
CaO	14·56
MgO	14·91
K_2O	0·22
Na_2O, Li_2O	0·51
P_2O_5	0·48
Loss by ignition	0·69
F	trace
B_2O_3	(4·17) by difference.
	100·00

The corresponding formula is

$$10\,(Fe, Ca, Mg)O \,.\, 5Al_2O_3 \,.\, 6SiO_2 \,.\, B_2O_3.$$

(15) Rutile.—A brownish-yellow mineral with high refractive index, occurring with olivine, phlogopite, spinel, tremolite, etc. in a mineral-aggregate in limestones at Gettembe, is probably rutile.

(16) Zoisite is recorded by Prof. Lacroix[1] as occurring in a mineral-aggregate in limestone from Kurumegala.

Garnet and wollastonite: the total absence of these minerals from the limestones and contact-modified granulites is noteworthy.

Corundum has not been found in the crystalline limestones as yet, although it occurs thus in Burma; and Dr. Grünling[2] has suggested that the Ceylon corundum may occur in the limestone.

EXPLANATION OF PLATES XIII & XIV.

Plate XIII.

Geological map of the country between Kandy and Talatuoya, on the scale of 3 inches to the mile.

Plate XIV.

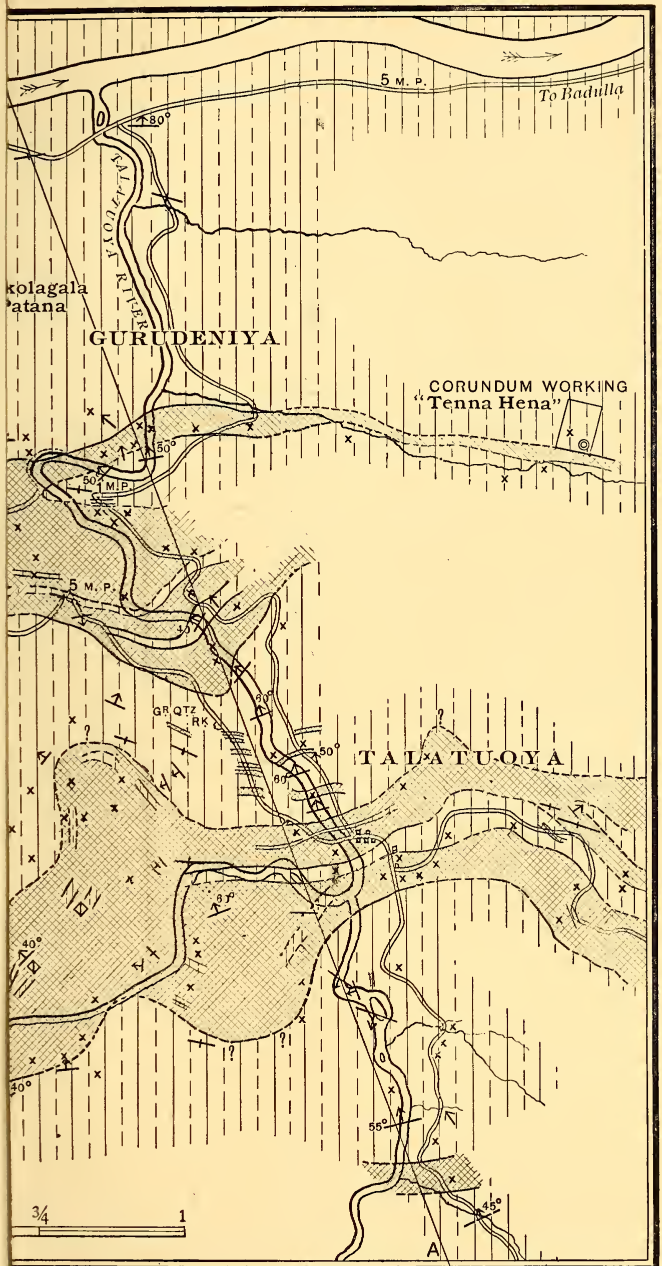
Geological map and sections of the district lying south-east of Hakgala, on the scale of 3 inches to the mile.

Discussion.

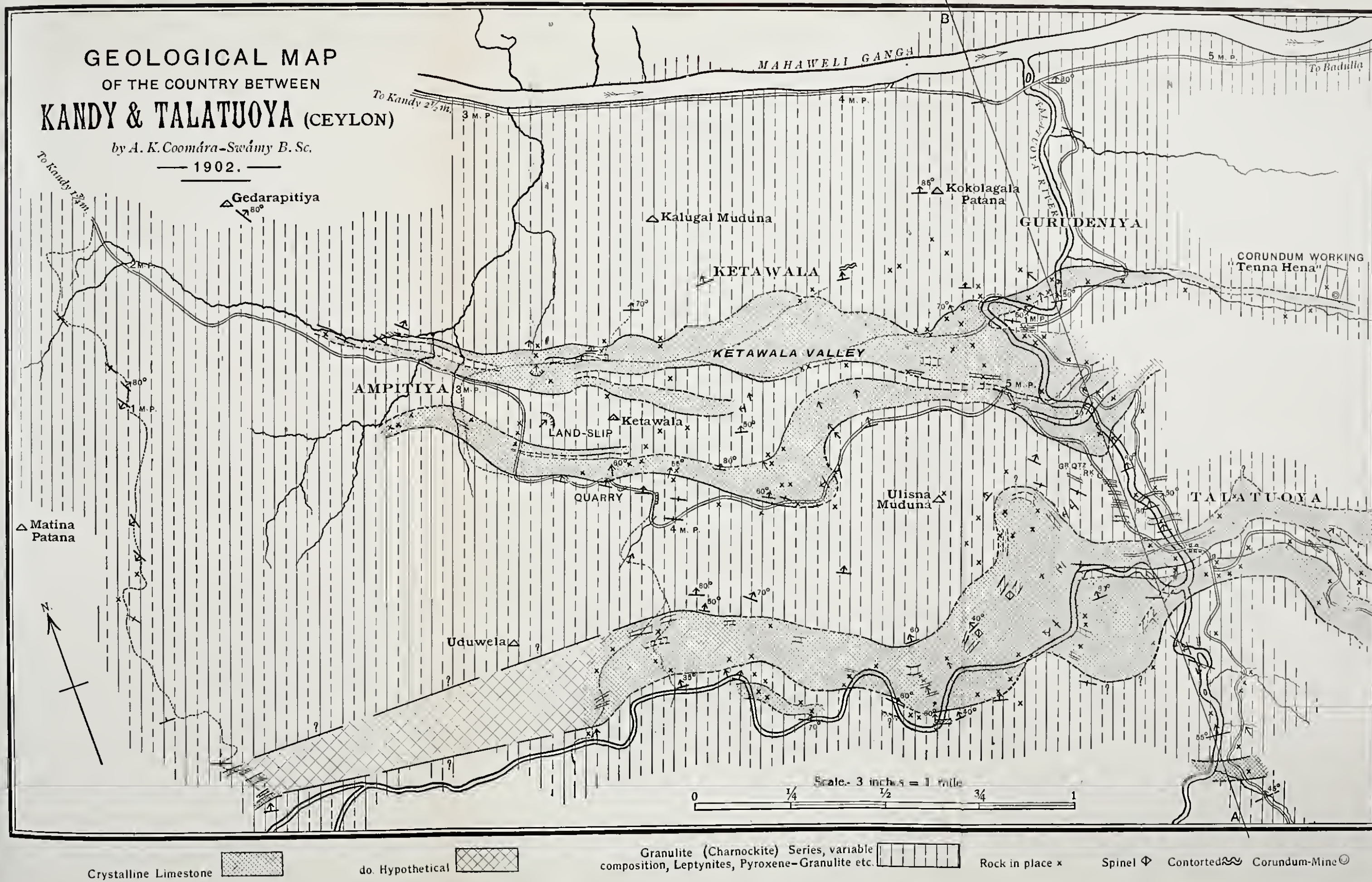
Mr. Parkinson, after expressing his sense of the value of the paper and the care and elaboration with which the details had been worked out, described the contact of granulite and limestone which he had seen near Matale, and remarked that he believed that this section proved, firstly, that the granulite was intrusive, and, secondly, that the intrusion had been attended by absorption of the limestone, which had locally modified greatly the composition of the granulitic

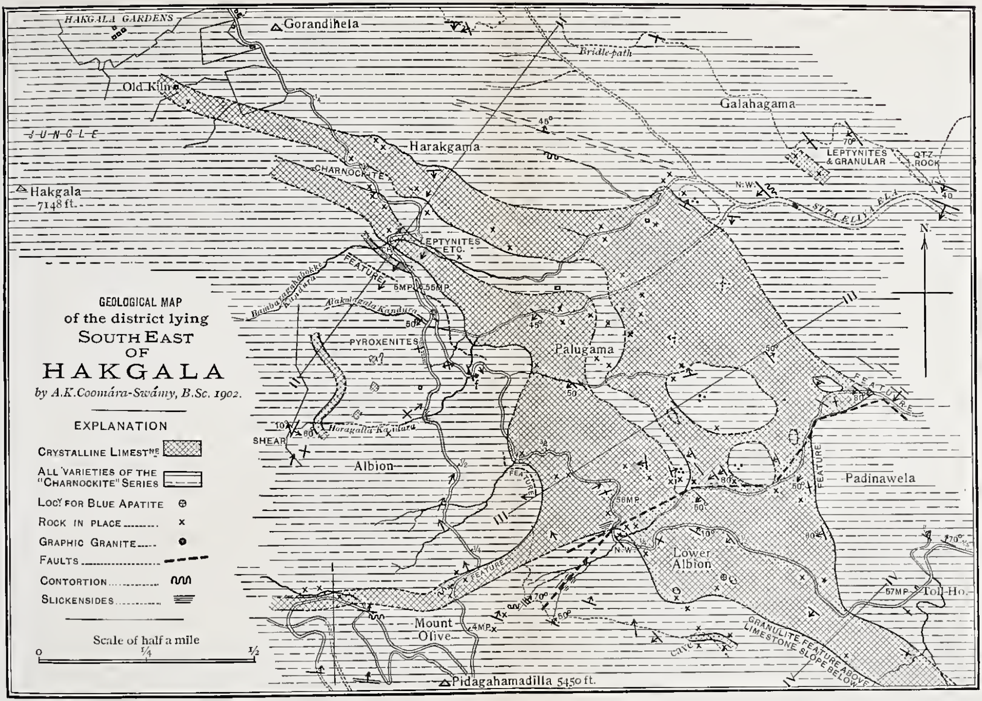
[1] Bull. Soc. franç. Minéral. vol. xii (1889) p. 344.

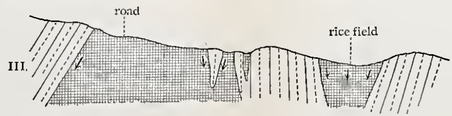
[2] 'Ueber die Mineralvorkommen von Ceylon' Zeitschr. für Krystallogr. vol. xxxiii (1900) p. 233.



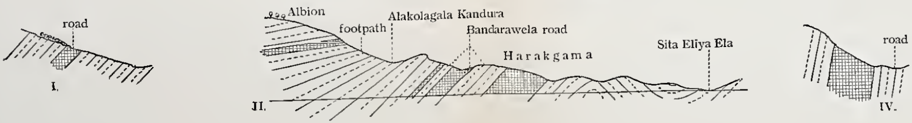
Rock in place × Spinel ◊ Contorted Corundum-Mine ◎


GEOLOGICAL MAP
OF THE COUNTRY BETWEEN
KANDY & TALATUOYA (CEYLON)
by A. K. Coomára-Swámy B. Sc.
1902.
MAHAWELI GANGA
To Kandy 2½ m.
To Kandy 1½ m.
To Badulla
Gedarapitiya
Kalugal Muduna
Kokolagala Patana
GURUDENIYA
KETAWALA
KETAWALA VALLEY
CORUNDUM WORKING "Tenna Hena"
AMPITIYA
LAND-SLIP
Ketawala
QUARRY
Ulisna Muduna
TALATUOYA
TALATUOYA RIVER
Matina Patana
Uduwela
N.
Scale.- 3 inches = 1 mile
0 ¼ ½ ¾ 1
Crystalline Limestone
do. Hypothetical
Granulite (Charnockite) Series, variable composition, Leptynites, Pyroxene-Granulite etc.
Rock in place ×
Spinel
Contorted
Corundum-Mine





Sections along lines I, II, III, & IV in the above map, on the scale of 3 inches to the mile (horizontal).



magma. As to the original nature of the limestones, he could say nothing; the interrupted sills and isolated masses of the granulite which had been described were very puzzling facts, and he inclined to the opinion that the Author's contention that 'the two rocks in their present condition are essentially contemporaneous' was the hypothesis most nearly in accord with the facts.

Mr. Holland thought that the Author's self-imposed task of attacking the crystalline problems of Ceylon deserved the highest commendation of the Society, and the additional facts now published formed a great advance on previous work in that area. But he considered that the evidence offered was utterly insufficient to establish the Author's contention that the crystalline limestones had behaved as igneous rocks, and formed part of the magma which gave rise to the associated Charnockite Series. He (the speaker) had described primary and original calcite in a nepheline-syenite from Southern India, as Adams had done for Ontario and Högbom for Alnö; and though he was convinced that calcite might be dissolved without decomposition, and subsequently separated from a nepheline-syenite magma, in which there was no free silica and an excess of electropositive alkali, it would be impossible for a limestone and charnockite to come into igneous contact without a chemical reaction which would result in the alteration of both rocks. The phenomena described by the Author were precisely those which would be expected theoretically from the intrusion of a charnockite into a pre-existing limestone. The limestones had been as a whole raised to a high temperature, and (as he had previously suggested from other evidence) had been brought to a condition probably akin to fusion, in which condition there would be a sufficient freedom of molecular movement to account for all their structural peculiarities—the intergrowths of calcite and dolomite, the flow-structures, and the occurrence of large phenocrysts of accessory minerals, which did not indicate an igneous condition any more than the large chiastolites of chiastolite-slates. The absence of cataclastic structures did not indicate freedom from deformation after solidification, as Adams and Nicolson had proved that marble, under differential pressure and at a temperature no higher than 400° C., could be made to flow like glacial ice without the production of cataclastic structures. The plasticity of the limestone at temperatures well below the fusing-point of any rock was sufficient to account for the stream-like disposition of the inclusions, as well as the dislocation of the charnockite-sills without internal deformation. In India are seen corresponding contact-phenomena where the charnockites invade aluminous rocks (the khondalites of Walker) and siliceous rocks (quartzites of various kinds), and these, like the limestones, have their nearest chemical equivalents among known sediments. In places these paraschists and paragneisses predominate over the orthogneisses; while in the south, where denudation has proceeded to greater relative depths, they are subordinate in quantity, and in Ceylon the limestones now exposed are apparently mere inclusions in the Charnockite Series.

Prof. JUDD expressed his gratitude to the Author for bringing forward a description of a district so interesting to geologists. The rocks described were similar to those of Burma, except in the remarkable absence of certain minerals, such as corundum and its derivatives. He found great difficulty, as the Author did, in realizing that the charnockites could be intrusive in the limestones. In Burma and Ceylon alike, whatever might be the case in Southern India, the limestones were remarkably subordinate to the silicate-rocks, instead of the reverse being the case (as we should expect, if the latter were intrusive in the former). He agreed with the previous speaker as to the difficulty of imagining the limestones to have behaved as igneous rocks, and yet their relations with the igneous rocks were puzzling in the extreme. He referred to the occurrences of Glenelg and Tiree as affording fine illustrations of the part played in such a complex by calciphyres.

Mr. GREENLY remarked that in the Hebridian Gneisses of the North-west of Scotland there was also a great preponderance of igneous over what appeared to be sedimentary material. The Loch-Maree Group was now generally regarded as sedimentary, but it was a comparatively narrow zone, while from Loch Maree to Cape Wrath all appeared to be igneous. Limestones were a conspicuous feature of the Loch-Maree Group, but they were accompanied by graphite-schists, mica-schists, and other probably sedimentary rocks.

The AUTHOR, in reply to Mr. Holland, said that no doubt in most cases crystalline limestones were a result of the recrystallization of calcareous rocks under pressure; behaviour as a plastic medium did not involve a very high temperature, as had been proved by the work of Adams and Nicolson. But the limestones of Ceylon possessed a number of peculiar characters which, taken together, suggested to him that they had existed in 'a state akin to fusion.' With regard to the interrupted sills, if this phenomenon was due to 'pinching' while both rocks were in a solid state (as Mr. Holland had suggested), why did the narrow lime-silicate contact-zones completely surround the lenticles, instead of occurring only on two sides of the granulite, as in the sill itself? Moreover, the accessory minerals in the limestones would show some trace of deformation if such powerful earth-movements had affected their matrix.

In reply to Mr. Greenly, the Author said that rocks composed mainly of biotite and garnet, which could be regarded as of sedimentary origin, were scarce; no rocks with kyanite, andalusite, or sillimanite were known *in situ*. Even if such exist, and are the remains of sedimentary rocks, the igneous rocks must greatly exceed them in amount. No graphitic schists had been found. Finally, the Author said that he had no wish to lay great stress on his 'igneous' theory, and he regarded the descriptive portion of his paper as of much more importance than the theoretical.

26. *The* Origin *and* Associations *of the* Jaspers *of* South-eastern Anglesey.

By Edward Greenly, Esq., F.G.S. (Read April 30th, 1902.)

[Plates XV & XVI.]

Contents.

I. Introduction.

One of the most singular and striking rocks in that region of Anglesey which lies to the south-east of the principal mass of Carboniferous rocks, is a bright red jasper. Though never in masses of large size, it is widely distributed, occurring in three distinct areas, which may be called the Newborough, the Pentraeth, and the Beaumaris areas. The character, mode of occurrence, and associations of this jasper throw much light on its origin; they are so remarkable, and present such singular analogies with those of groups of rocks which have lately been described in different parts of the world, as to be, I think, matter of general interest, as well as important to workers among the older rocks of Britain. The object, therefore, of this paper is to describe the rocks and their relations in the districts where they have escaped the effects of the movements that have modified most of the region.

Their geological age, and, in particular, their relations to the crystalline schists of the region, cannot, in my opinion, be regarded as settled, some of the evidence being conflicting. But as questions of the greatest interest regarding metamorphism are involved, I propose, in the fourth part of this paper, to set forth this evidence as briefly as is consistent with clearness. I am the less unwilling to do so, because the problem is so closely allied in its nature to those that are still under discussion at the margins of several other metamorphic areas, as to be in itself, I think, interesting to geologists who are investigating questions of metamorphism.

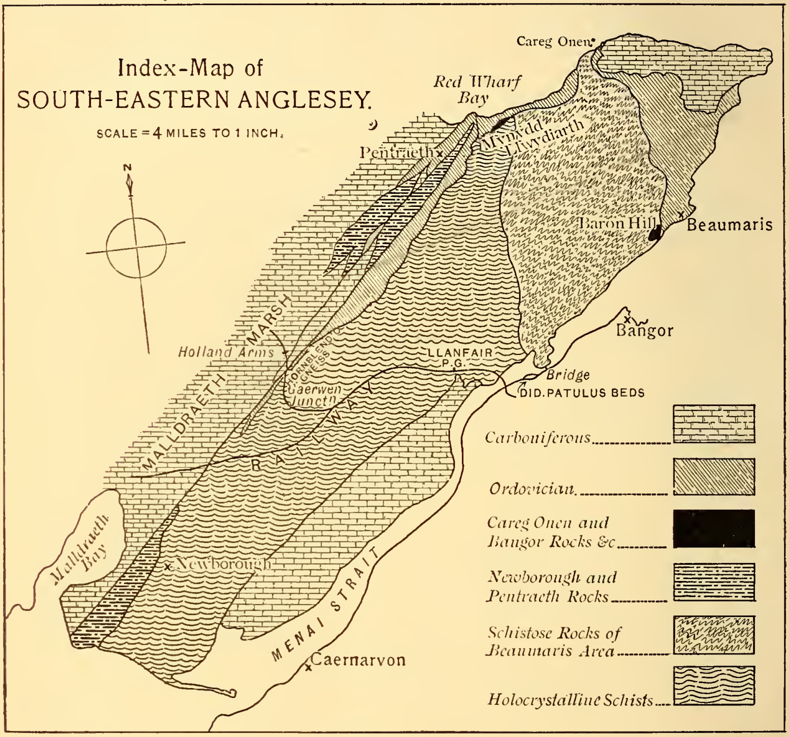
II. Description of the Rocks.

The principal associates of the jaspers are certain basic igneous rocks, limestones, and grits, the most important being the igneous rocks. Some fine shaly material, called elsewhere jaspery phyllite, will be described along with the jaspers.

Besides these, there are large quantities of a breccia which appears to be cataclastic, and also of various schistose rocks, the masses which retain original characters occupying comparatively small parts of the areas described, except in the Newborough district.

(i). The typical jasper is a very hard, brittle, bright blood-red rock, compact, and with irregular fracture, and often traversed by a large number of small quartz-veins. It possesses often a mottled texture, which gives, under the hand-lens, an appearance strongly suggestive of the presence of organic remains. But nothing certainly organic has yet been found in it. Some specimens have the

Fig. 1.



[The outcrop of Careg Onen Rocks at Careg Onen itself and the outcrops of the jaspers occupy areas of too limited an extent to permit of their being shown in the above map.]

aspect of red breccias, cemented by clear quartz. Many are definitely spherulitic. A thin slice shows a mosaic of quartz-grains which at first appear to have rather evenly rounded outlines, but on careful scrutiny between crossed nicols they show re-entering curves along which the grains interlock with each other. The mottling visible with the hand-lens is seen to be due to aggregations of hæmatite-dust, round about which the quartz is clear and nearly free from inclusions. Each of the aggregates is situated in the middle of a quartz-grain, and is thus confined to the limits of what is a crystalline or optical unit. The mottled texture is therefore, now, a mineral and not an organic structure; but it is of course quite possible that it may have been originally due to the presence of organic bodies the outlines of which have become obliterated. (See Pl. XV, fig 1.)

The spherulitic varieties, when best developed, are composed of red spherulites, 2 to 3 millimetres in diameter, in a darker matrix. The spherulites have colourless, granular cores, around which is the pale red body, with radial structure, giving a dark cross between crossed nicols. The intervening matter is very dark with iron-ores, often sufficiently well crystallized to show definite flakes of 'eisenglimmer,' and evidently much altered. No organic bodies have been found in the cores of the spherulites.

The texture of the ordinary jaspers varies considerably within the limits even of a microscopic slide, some parts being rather coarser, and some more free from hæmatite than others. Numerous veins of quartz traverse the rock in all directions. These are of much coarser texture than the fine mosaic of the main body, and are also generally much more free from inclusions. A slide from Fferam-gorniog, near Pentraeth, contains also some curious groups of small doubly-terminated crystals of quartz. Well-formed rhombs of calcite or dolomite are not uncommon in the fine mosaic, and to a less extent also in the quartz-veins.

The jaspery phyllites have the same general appearance as the jaspers, but have a parallel structure and a duller surface. In thin sections they appear, like the jaspers, to be composed chiefly of very fine granular quartz, and hæmatite, but there are also present numerous minute clastic grains of white mica, and also of quartz: and the general texture is that of a fine ferruginous shale or mud, and unmistakably sedimentary. (See Pl. XV, fig. 2.)

(ii). The igneous rocks are diabases and serpentines.

The serpentines are of small size, and have only been observed in one or two places in the Pentraeth area. Though the fact of their existence is of considerable interest, no petrological detail concerning them is necessary for the present subject.

The rest of the igneous rocks are more or less altered dolerites or basalts, generally fine-grained, and, from their lightish tint when weathered, evidently not very basic in composition. They are generally of a dull green, but when slightly deformed are often reddish, and their schistose parts can then be easily mistaken for the red phyllites associated with the jaspers. Thin slides show a fine meshwork of slender lath-felspars, with some iron-ores, and sometimes (in the Newborough district) cores of augite still remaining. Generally, however, the pyroxenes have been replaced by the usual green alteration-products. Sometimes a tendency to a sheaf-like or radial aggregation of the felspars is well marked. (See Pl. XVI, fig. 1.)

But the most remarkable characteristic of these rocks is their structure on the large scale. In the field they are seen to be

Fig. 2.—*Diabase with pillowy structure ; south-west of Bryn Llwyd, Newborough sand-hills, looking east-north-eastward.*

Fig. 3.—*Jasper filling interspaces of pillowy diabase ; Cerig Mawr, Newborough sand-hills, looking northward.*

[The handle of the hammer rests against a mass of jasper. For the photographs from which the above figures are reproduced, I am indebted to Mr. J. Trevor-Owen, Headmaster of the Grammar School, Swansea.]

composed of ellipsoidal or spheroidal masses, piled and pressed upon one another, as if they had been rolled over and over in a semi-consolidated condition (figs. 2 & 3, p. 428). Sometimes between the masses are small interspaces; sometimes smaller ellipsoidal or pillowy masses fit into gentle re-entering curves in the sides of larger ones, suggesting very vividly, hard though they now are, the rolling and pressing against each other of pasty, yet individualized bodies.[1] A graphic description of their aspect will be found in the Rev. J. F. Blake's 'Monian System'.[2] This structure is here dwelt upon, on account of its close resemblance to, in fact identity with, the 'pillowy' structure of the basic lavas of the South of Scotland and other localities. Figs. 2 & 3 will at once recall the frontispiece in the Geological Survey Memoir on that district,[3] and also the rocks of Mullion Island at the Lizard, and Point Bonita in California.[4]

The pillowy masses are of two types—a larger and a smaller; and though they occur together, yet one or the other usually predominates in any one section. The larger (about 4 feet long) is ellipsoidal, the smaller being, as a rule, more nearly spherical. The middle axis of the ellipsoid is generally vertical, and the longest lies north-east and south-west: the ellipsoidal 'pillows' therefore stand 'on edge.' No marked difference of crystalline texture has been observed between the inner and outer parts of the 'pillows,' but a concentric shell-structure is common, which becomes sometimes almost a concentric fissility. Small spherical amygdules are not uncommon, but they are not a marked feature of the rocks. The general microscopic character agrees with that of the Scottish and other pillowy rocks. This pillowy structure is seen at Tan y Graig in the Pentraeth area; but it is much better displayed among the Newborough sand-hills, where the great bosses of volcanic-looking, dark-green rock, rising from beneath great drifts of sand, have a most singular, and somewhat forbidding aspect; and as they are, besides, kept bare of vegetation by the incessant sweep of the sand-blast, the whole aspect of the scenery has a desert-like look that one does not expect to see in Britain.

It is in these pillowy diabases that the variolite first observed by the Rev. J. F. Blake,[5] and afterwards described by Prof. Grenville Cole,[6] occurs. Prof. Cole has moreover been so kind as to write for me the following description of a variolite which occurs in the pillowy rock of Tan y Graig, Pentraeth:—

'No. 5, 1899.—The large spherulite from which this is cut clearly enveloped a previously banded and spherulitic mass, just as the large spherulites in acid

[1] Rocks of this kind have been referred to as 'spheroidal,' but the structure is evidently distinct from ordinary spheroidal jointing produced after consolidation: see Platania, 'Geology of Acireale' in Dr. Johnston-Lavis's 'South Italian Volcanoes' 1891, pp. 41–43.

[2] Quart. Journ. Geol. Soc. vol. xliv (1888) pp. 510–11.

[3] 'Silur. Rocks of Britain' vol. i (1899) pl. i.

[4] Trans. Roy. Geol. Soc. Cornwall, vol. xi (1893) p. 565; 'Eruptive Rocks of Pt. Bonita' Bull. Departm. Geol. Univ. Calif. vol. i (1893) pl. vii, p. 78.

[5] 'Older Rocks of Anglesey' Brit. Assoc. Rep. 1888 (Bath Meetg.) p. 410.

[6] Sci. Proc. Roy. Dublin Soc. n. s. vol. vii (1891) p. 112.

lavas often arise as local "knots" during the latest consolidation of the rock, and include the pre-existing structures. The brown tachylyte between the bands of small spherulites is in places distinctly perlitic, and its vitreous character is well preserved. The rock is generally more glassy than crystalline; but the more lithoidal bands show the tufted aggregates of microlites, and even the "pseudo-crystallites" that are so characteristic of true variolite.' (See Pl. XVI, fig. 2.)

'No. 4, 1899.—This rock also has retained its glassy characters far better than is the case in typical variolites. In this, it resembles the selvage of the variolite of Annalong (Co. Down). It has been brecciated during its viscid flow, like the obsidian of the Rocche Rosse at Lipari, and spherulitic matter has collected from the matrix in which the consolidated angular fragments of brown glass were carried onward. Banded structure, often very delicate, resulted from the movement of the mingled mass; and then the whole lava was again broken up, perhaps by earth-movement. The interstices between the fragments that were thus formed are now filled by chlorite, and what appear to be minute radial aggregates of chalcedony.

'The angular patches that look like pseudomorphs after olivine, occurring in the original glass and in the larger spherulitic aggregations, are of puzzling nature, since they seem identical with the minute spherulites that were developed at an early stage of the consolidation; every intermediate type, judging by outline, occurs between the tiny rounded spherulites and the angular little bodies that look like crystals. Even the latter are isotropic, and I fancy that they are spherulites actually passing into crystalline granules, but of what nature I cannot determine. Such an occurrence is a rare one, but is paralleled by the outlines assumed, before complete differentiation of the crystalline matter from the matrix, by the "spots" in some "spotted slates" produced by contact-metamorphism.

'This rock has, I take it, a complex history, the first brecciation occurring while it was still a viscid mass, and a certain blending thus occurring between the firmer glass-fragments and the new material that gathered from the matrix round them. The second brecciation affected both the old fragments and the matrix, which by this time had consolidated against them.'

In the Newborough sand-hills, the variolite is apt to occur in zones which are approximately parallel, and generally near to the margin of the 'pillows,' though in some of the smaller spheroidal bodies varioles are pretty evenly distributed throughout. This is the mode of occurrence of the famous variolite of Mont Genèvre,[1] where the diabase has pillowy structure of the same kind. Variolite has also been found in the Point-Bonita rock.[2]

(iii). The limestones have been described by Dr. Callaway, Prof. Bonney, the Rev. J. F. Blake, and others,[3] and no further petrological details are needed for the purpose of this paper.

(iv). The grits are of importance, chiefly in connection with the question of the age of the rocks; and a detailed description is not necessary here. They are moderate to very fine in grain, the finer beds passing gradually into shale. Bedding is seen in many places, and very clearly in the Newborough district, where it is rapidly

[1] Cole & Gregory, Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 295.

[2] Ransome, Bull. Departm. Geol. Univ. Calif. vol. i (1893) p. 99. The variolites of the Lleyn, described by Miss Raisin in Quart. Journ. Geol. Soc. vol. xlix (1893) p. 145, belong, no doubt, to the same series as those of Anglesey.

[3] Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 236; Brit. Assoc. Rep. 1888 (Bath Meetg.) p. 389.

contorted. Cleavage, though general in the finer beds, is never very strong. The rocks are generally red or green, and full of volcanic débris: broken felspars, fragments of andesites and diabases and pink felsite, and lapilli blackened with iron-ores, being often abundant. Indeed they bear a strong resemblance to the ashy grits of Bangor; a fact which must be of the highest importance in considering their age and that of the jaspers.

(v). Cataclastic and schistose rocks. It is no part of the purpose of this paper to describe these rocks, the history of which belongs to that of the earth-movements and metamorphism which have affected the district; but without some reference to them, no connected picture of the general field-relations of the jasper-bearing group as a whole could be presented.

The least altered are breccias, generally more or less schistose. The more altered are for the most part dull greenish and reddish schists, the two being intimately connected. The jaspers, limestones, and diabases are all found as fragments in the breccias, which are clearly cataclastic (' crush-conglomerate '). I have not, indeed, been able to satisfy myself of the pyroclastic origin of any rocks in the district, except two small bands among the pillowy diabases, and these appear to be true tuffs. The grits, too, can be seen in the act of breaking up into breccia. The rocks of the jasper-bearing group occur as lenticles in the dull green schists, of all sizes, from the smallest discernible with a lens to masses a mile or two in length. In the Newborough district, original, and in the Pentraeth district, schistose matter appears to predominate: the undeformed masses float, so far as can be ascertained, in a schistose matrix, the whole forming a kind of gigantic crush-conglomerate.

In the Beaumaris area the jaspers and limestones lie among schists; but as an important metamorphic question comes in here, this district will only be touched upon in the latter part of the paper.

III. Relations and Origin of the Jaspers.

We may now deal with those relations of the jaspers to the diabases and limestones, especially to the diabases, the consideration of which is the principal purpose of this paper.

The jaspers are found in the limestones and diabases in innumerable lumps and seams, generally small. One or two are some yards long, but these are exceptional, and they are seldom more than a foot or two in any dimension. Many have no regular shape, but there is one mode of occurrence that is evidently original. This is when the interspaces between the ellipsoids and spheroids of the pillowy diabase are filled in with jasper (see fig. 3, p. 428). Where the pillowy structure is strongly developed, this is the typical mode of occurrence of the jasper, and it is admirably exposed in many of the great bosses of the Newborough sand-hills.

Now, in a paper on 'Greenstones associated with Radiolarian Cherts,'[1] and also in the Geological Survey Memoir on the 'Silurian Rocks of Britain' vol. i (1899) pp. 85–87, Mr. Teall has pointed out that lavas exhibiting this peculiar pillowy structure have been found associated with radiolarian cherts in several parts of Britain, in Saxony, and in California, and at several horizons, those in California being as late as the Cretaceous.[2]

Further, it is known that, in the Southern Uplands of Scotland, the radiolarian cherts occasionally pass into the condition of jasper, and that this jasper is accordingly, like the chert, associated with the pillowy diabase.

Again, on the South-eastern border of the Scottish Highlands, jaspers and cherts are found[3] in association with highly-sheared rocks of basic igneous origin, though here original structures have been for the most part effaced. Radiolaria have been found in some of these rocks. I have examined specimens of jaspers from both these districts, and could not have distinguished them from those of Anglesey. Indeed, I ought to say that, whereas I had been disposed, for some time after going to Anglesey, to regard the jaspers as siliceous substitution-products [a view which I find was also taken by Prof. G. A. J. Cole[4]], the view taken in this paper was first suggested to me in 1898 by the fact that my friend, Mr. Barrow, at once recognized them as identical in character with those on the border of the Highlands.

If we now compare the photograph (fig. 3, p. 428) with pl. vi, p. 431, in the Geological Survey Memoir already quoted, we shall see that the jasper at Newborough is not merely associated with, but fills the interspaces of, a pillowy diabase in precisely the same way as does the radiolarian chert in the Girvan area. Further, Mr. Teall permits me to add that, without knowing anything at all of the associations of the rock, he wrote to me in 1898 concerning a slide which I sent him of a rock from the Pentraeth area: 'It reminds me of some of the diabasic lavas associated with radiolarian chert in the Southern Uplands.' This rock (Pl. XVI, fig. 1) showed the sheaf-like and radial grouping of felspar-laths like that figured by Dr. Ransome[5] in the Cretaceous diabase of Point Bonita, and in several other papers on variolite-bearing pillowy rocks. Finally, in the very fine 'jaspery phyllites' minute clastic micas can be made out, which could not be the case if they were siliceous substitution-products.

No radiolaria, indeed, have been actually found. But the rocks are so much jasperized, even in the most promising localities, that

[1] Trans. Roy. Geol. Soc. Cornwall, vol. xi (1893) p. 560.

[2] In the face of an association so world-wide, it seems difficult to avoid the conclusion (as suggested by Mr. Teall) that there is a causal connection.

[3] G. Barrow, Quart. Journ. Geol. Soc. vol. lvii (1901) p. 333.

[4] Sci. Proc. Roy. Dublin Soc. n. s. vol. vii (1891) p. 114. May not the silica which has penetrated the diabase have been derived from adjacent, and pre-existing, jasper?

[5] Bull. Departm. Geol. Univ. Calif. vol. i (1893) fig. 6, p. 85.

I fear there is not much hope that any organisms existing therein can have escaped effacement.

The indirect evidence here set forth, however, seems to me so strong as to leave little doubt that the jaspers of Anglesey are of organic origin, and that they are really altered radiolarian cherts.

That jaspers, whether associated with igneous rocks or not, should occur in connection with limestones, is only to be expected: and in the limestones, accordingly, we constantly find them, in all the three areas here described. As before remarked, they occur here generally in small irregular aggregates; but in a limestone north-east of Garth Ferry, on the Beaumaris road, there is a thin bed of jasper some yards long. Both these forms are, as is well known, characteristic of chert and flint in the Carboniferous Limestone and the Chalk. It is interesting to recall that, so long ago as 1888, the Rev. J. F. Blake wrote in his 'Monian System'[1] of limestones in the central region of the Island:—

'There are bands and isolated pieces of red jasper, which behave towards the limestones exactly as flint does to chalk, and a similar origin is at least suggested.'

I have not yet visited the spot referred to, but the rocks described are clearly the same as those of the south-east. In that remark, therefore, written 14 years ago, the Rev. J. F. Blake has anticipated the most important result arrived at in this paper.

To recapitulate: radiolarian cherts, sometimes altered to jasper, are intimately associated with, and fill interspaces in, pillowy diabase-lavas in the South of Scotland. The same association has been observed in several other parts of the world, and at horizons ranging from the Lower Ordovician to the Cretaceous.

The mode of occurrence of the Anglesey jaspers is similar, even in small details, to that of the cherts of the South of Scotland,[2] and it seems reasonable, therefore, to regard them as of similar origin.

Variolite, in the typical locality of Mont Genèvre, occurs in a diabase with the same pillowy structure as that possessed by the rocks so frequently associated with jaspers and cherts. It has actually been found in such at Point Bonita, but is there very rare. The Anglesey phenomena are therefore remarkably well developed; and the occurrence here of limestone also, completes, in a certain sense, the circle of associations.

IV. Age and External Relations.

This part of the subject falls under two heads:—(1) The relation of the group to the fossiliferous rocks; and (2) Its relation to the crystalline schists of the district.

[1] Quart. Journ. Geol. Soc. vol. xliv (1888) p. 489.

[2] The only direct evidence that the Anglesey diabases are true lavas is the occurrence of the thin tuffs. But the infillings of jasper could hardly find their way into an intrusive rock, until after considerable denudation.

On neither of these points is the evidence conclusive; but on the first, though imperfect, it is not contradictory, and I will therefore discuss this part of the subject before approaching the more complicated matter of the second.

(1) Relation to fossiliferous rocks.—The analogies with the rocks of the South of Scotland naturally suggest that the jasper-bearing group of Anglesey is, like the Scottish cherts, of Arenig age. And it is true that Ordovician rocks do occur in juxtaposition with the group in the Pentraeth area, although in the Beaumaris area the jaspers and limestones occur quite away from any fossiliferous rocks at all.

But at Pentraeth the known Ordovician rocks (probably Llandeilo-Caradoc) are of a different type, and also in a different condition. The Ordovician rocks are here, as all over the South-east of Anglesey (including the *Didymograptus-patulus* Beds at the Straits), a very uniform series of black shales and dark grits, and always unaltered, often not even cleaved. The jasper-bearing group, on the other hand, is extremely varied, cut up into lenticles by powerful earth-movements, and to a great extent schistose. The very scenery of the two groups is sharply contrasted. The same contrast has lately been remarked by Mr. Matley in the Lleyn Peninsula,[1] and there the fossiliferous rocks are of Lower Arenig age.

Further, it may be observed that in the mountainous areas of Snowdon and of the Harlech anticline, where the whole Ordovician Series is exposed from the Bala Beds downward, even into the Cambrian, in numerous sections, this jasper-bearing group has never been recorded.

It will thus be seen that there is no positive evidence to connect the jaspers of Anglesey with the Arenig Beds, and some negative evidence to disconnect them. Moreover, it must not be forgotten that the very association of jaspers and pillowy diabases, which furnishes the principal argument of this paper, is by no means confined to the Arenig Beds, but occurs at several different and widely separated horizons. We may therefore expect to find cases of this association in rocks of any period.

(2) Relation to the crystalline schists.—This is the most difficult part of the whole subject, for it is here that the conflict of evidence to which I have referred comes in.

The schists which are here meant are those of the region called by the Rev. J. F. Blake 'The Eastern Region' of the island, extending from the coast south of Newborough to the neighbourhood of Beaumaris and Llanddona. That part of this tract which lies to the east of a line running from the shore of the Straits a little west of the Menai Bridge to Coch y Mieri in Mynydd Llywdiarth, is composed of schists which are for the most part but minutely crystalline, and contain many lenticles of original clastic

[1] Geol. Mag. 1902, p. 122.

matter[1]; whereas the part to the west of this line consists of holocrystalline mica-schist in which no such original structures can be discerned. To discuss the origin of these rocks is no part of the purpose of this paper, and would open up large and far-reaching questions. I shall therefore describe their phenomena only so far as is necessary to a discussion of their relation to the jaspers.

There are two chains of evidence, and they had better be considered separately.

a.—The jasper-bearing group at Pentraeth and Newborough, either adjoins the crystalline schists of the western and most completely altered area, or is separated from them only by a narrow belt of Ordovician shales; and they are very different in condition. Nowhere in the jasper-bearing group in these areas, however highly sheared and altered they may be, are there any rocks the minerals of which indicate a very high temperature or very deep-seated conditions, except the micas in some of the schistose material, which do indeed appear to be authigenetic. The basic igneous rocks never pass beyond the stage of chloritic and epidotic schists: no hornblende has been observed in them; whereas the basic rocks of the adjacent complex are always true hornblende-schists, sometimes even hornblendic gneisses. Certainly it would seem extremely unlikely that there could be any connection between rocks at once so near together and so different in crystalline condition.

Moreover, a slide of one of the ashy grits of the Pentraeth area contains two fragments of a thoroughly crystalline mica-schist of the type most prevalent in the adjacent complex. The condition of the grit, and the mode of occurrence of the fragments, put a cataclastic origin out of the question. This grit must, therefore, be later than the crystallization of the mica-schists. It is associated with the jasper-bearing group, and if contemporaneous, that group must also be later than the crystallization of the schists in question.

b.—The second chain of evidence is as follows. The jaspers and limestones are found not only in the Pentraeth and Newborough areas, but also in the eastern part of the Eastern Schistose Region, that is, east of the line from the Menai Bridge to Mynydd Llwydiarth. They occur there as lenticles in the schists, and in such a way as to make it almost incredible that the structures of the enveloping rocks have not been developed since the jaspers and limestones became incorporated in them.[2] In Baron-Hill woods, lenticles of jasper, not more than 3 to 5 millimetres thick, are wrapped round by the folia of the fine schistose rocks exactly as any other phacoidal masses in them are. At Crymlyn, in the heart of the plateau, a jaspery limestone occurs in the schistose rocks, and a ravine some 30 feet deep has been cut through it and them. There is a very

[1] E. Greenly, Geol. Mag. 1896, p. 551.

[2] This would still be true, even if the rocks of this region were, as they very possibly may be, a complex of material of different ages.

strong resemblance between the prevalent types of this area and much of the material of the Pentraeth[1] and Newborough districts. Indeed, I can see no difference at all in some cases, either macro- or microscopically.

Now, along the line above mentioned, the schistose rocks of the eastern part of the Eastern Region appear to pass, by a perfectly gradual transition, into the holocrystalline schists of the portion to the west. Excellent sections are to be seen at a point in Mynydd Llwydiarth, 400 feet east-south-east of Hafod Leucu, and on the shore of the Straits below Cartrefle, the two ends of the line. The change of character affects not only the great body of acidic material, but the basic rocks contained in it. The rocks of the region, on both sides of the line, appear, therefore, to be a metamorphic unit; and there is nothing to show that on the east side we have structures of later date than on the west.

From this, consequently, it would follow that the crystallization of the whole region, including its most highly altered members, which are undoubted holocrystalline schists, is later than the jaspers, and than their incorporation in the schistose rocks of the eastern part of the area.

These two lines of argument lead thus to opposite conclusions; and the second is of such a nature as to call for great caution in its acceptance, because of the principles involved in it. For my own part, I do not think that there is a sufficient preponderance of evidence on either side to justify the pronouncement of a conclusion in this paper: and my aim is, rather to put each case, if it may be so spoken of, as strongly as possible.

The alternatives are, briefly, these:—

If the grits of Pentraeth can be shown to be contemporaneous with, or not later than, the jaspers, then the supposed unity of, and gradual transition in, the Eastern Region must be in some way deceptive. If the transition really exists, and the schistose complex of the region be a metamorphic unit, then the grits of Pentraeth must be of later date than the jasper-bearing group with which they are associated.

I hope that other parts of the island, the mapping of which I have not yet completed, may afford evidence that will finally decide which alternative must be adopted.

V. Summary.

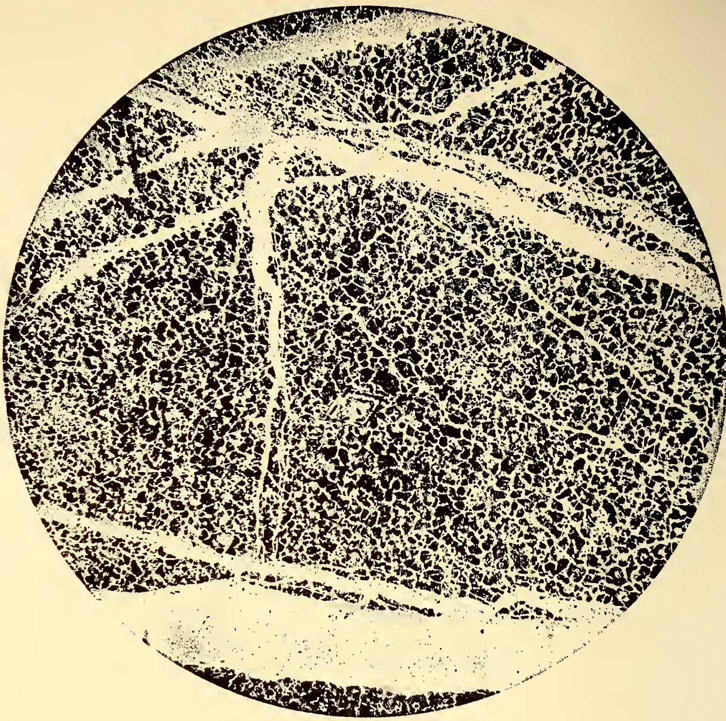
It may conduce to lucidity to summarize briefly the principal conclusions and results contained in this paper.

A red jasper, with the fine shaly material called jaspery phyllite, is widely distributed in the southern and south-eastern parts of Anglesey, occurring in the districts of Newborough, Pentraeth, and Beaumaris.

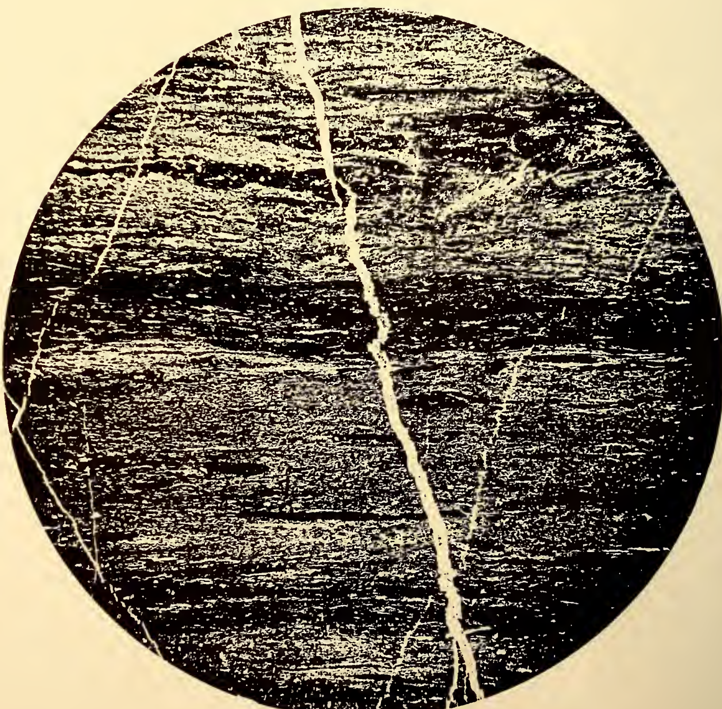
Its associates are a varied group of rocks, comprising limestones, diabases, and serpentines, with grits and shales. They have been much modified by powerful earth-movements, which have produced

[1] J. F. Blake, Quart. Journ. Geol. Soc. vol. xliv (1888) p. 509.

1. *Jasper* × 36.



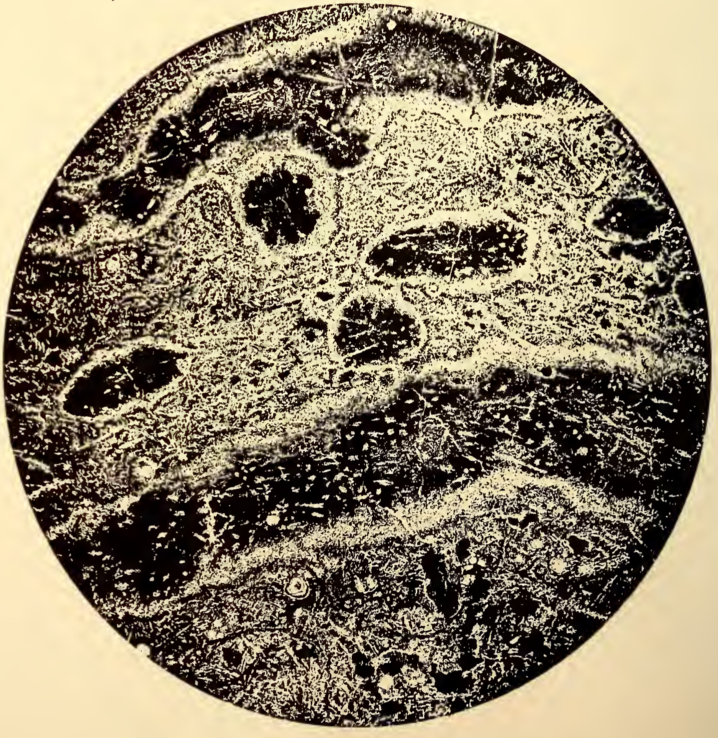
2. *Jaspery Phyllite* × 36.



ANGLESEY ROCKS.

1. *Diabase* ×36.

2. *Variolite* ×36.



ANGLESEY ROCKS.

brecciated and schistose structures through large parts of the areas, but original structures have survived in many places, and here the true relations of the rocks can often be seen.

The associations of the jaspers with the limestones, and especially with the diabases, are of the most intimate nature.

The diabases have the same characters, both in the field and under the microscope, as those basic lavas possessing the so-called 'pillowy' structure (often also variolitic), which have been found to be associated with radiolarian cherts and jaspers in several different parts of the world, and at several different geological horizons. Moreover, the relation of the jaspers to the igneous rocks here, is the same as that of the radiolarian chert in the South of Scotland to the accompanying igneous rocks.

On this ground, and also from the occurrence of jaspery phyllite with evident clastic texture, it is inferred that the jaspers of Anglesey are of organic origin, and must be regarded as altered radiolarian cherts.

The evidence for the age of the group is much less satisfactory. There is not sufficient to refer it to the Arenig Series, and it is possible that it belongs to a different period altogether.

Its relation to the crystalline schists of the region is obscured by conflicting evidence, which cannot yet be reconciled: one chain of evidence leading to the view that the group is older than, and has been involved in, the metamorphism of the adjacent schists, while another gives strong reason to suppose that it is altogether later.

EXPLANATION OF PLATES XV & XVI.

Plate XV.

Fig. 1 [No. 6, 1899] Jasper, from 200 yards west of Bryn Hyfryd, Llansadwrn. The minerals shown are quartz, hæmatite, and a carbonate. Most of the hæmatite is in fine dust, but there are many flakes of definite eisenglimmer. The aggregates of hæmatite-dust which produce the mottled appearance are contained within single optical individuals of the quartz-mosaic. In the middle of the field is a rhombic section of a carbonate, with a zone of opaque hæmatite and a crystal of eisenglimmer. The light parts are quartz-veins. (× 36.)

2 [91 a] Jaspery phyllite, from Bryn Mawr, south-south-west of Pentraeth.—The rock consists of a remarkably transparent matrix full of hæmatite-dust. The small clastic grains seen are quartz and white mica. Thin quartz-veins cross the field. (× 36.)

Plate XVI.

Fig. 1 [55 a] Diabase, from Fferam-gorniog, Pentraeth.—The only minerals shown are felspar and hæmatite-dust. The felspars have a sheaf-like or imperfectly radial arrangement. This rock contains small oval amygdules. (× 36.)

2 [No. 5, 1899] Variolite, from Taw y Graig, south-west of Pentraeth.—The only well-defined mineral is a felspar. The groundmass, though green with alteration-products, remains almost dark between crossed nicols. (× 36.)

[Fig. 1 in Pl. XV and fig. 2 in Pl. XVI are reproduced from slides kindly lent by Mr. George Barrow. He had them cut from specimens collected on the occasion of his visiting the ground with me, and they are now in his private collection. Fig. 2 in Pl. XV and fig. 1 in Pl. XVI are from slides in my own collection.]

Discussion.

Mr. G. Barrow said that he was interested in the group of rocks described by the Author, as they were the same group as the supposed Silurian rocks along the Border of the Southern Highlands. They here occurred in two different ways. First, along the least crystalline margin of the Anglesey schists; and again, faulted in some way against a highly crystalline portion of these schists. The second area showed that the condition of the jaspers, etc. remained the same in both areas, and it was not credible that the pillowy lavas and variolites could be of the same age as the hornblende-schists and hornblende-gneisses comparatively close by. Still more important, however, was the fact that small fragments of the well-crystallized schist occurred in the ashy grits associated with the lavas. It did not seem reasonable to suppose that these grits were of a totally different age from the lavas, and it seemed clear that the Anglesey schists were crystallized before the grits, lavas, and jaspers were formed.

The other (Beaumaris) area was of importance, as showing that on the outer edge of the aureole of crystallization in Anglesey these jaspers and green rocks again occur, in a manner suggesting their original association with the older rocks that pass into well-crystallized schists. But in all cases here, the junction of the jasper with the adjacent rock can be clearly seen to be due to movement, and not an original one. The evidence already given, however, shows unmistakably that the apparent identity in age has been produced by these movements, and, as in the Forfarshire area, it is a deception. The evidence from Anglesey certainly suggests that these jaspers and green rocks may be older than the speaker had supposed.

Prof. Bonney said that he agreed with the previous speaker in thinking that the apparent passage from the holocrystalline schists into the schistose rocks was more probably due to the crushing of a holocrystalline and a sedimentary group near their junction. Also, he did not see why a radiolarian chert should be associated over any wide area with a peculiar form of basic lava, having a structure which was likely to occur towards the outside of a mass of lava. Though doubtful about some details, he fully appreciated the value of the paper.

The Rev. J. F. Blake said that he was glad that the Author had visited the district near Newborough, which, though so inaccessible, was the most interesting in all Anglesey to a geologist. The present paper, however, dealt with only a few of the points of interest. Although the description of jaspers and pillowy lavas was taken from Malldraeth Marsh, the arguments for their age was taken from Pentraeth, where the ground was so broken that the relations of neighbouring rocks were by no means clear. He doubted whether the material filling the interstices of the pillowy lavas, or the folia in the crystalline schists which had been exhibited, had the same origin as true nodular jaspers, such as did occur in Anglesey at Cerrig Ceinwen and elsewhere, and showed appearances which might be taken for the relics of obliterated organisms. In these cases they were not associated with igneous rocks, but with limestones and umber; and these associates occurred in every district among the Monian schists, which were overlain at no great distance by basal Cambro-Silurian conglomerates and shales in an unmetamorphosed condition, and without a sign of any such materials as limestone, umber, or jasper. There could be no doubt as to their age.

The 'jaspers' described by the Author seemed to be of more than one kind. There was not, so far as the speaker could learn, anything to connect them with radiolaria or with the Arenig rocks.

Prof. Sollas observed that cherts should not be accepted as radiolarian, unless they contained undoubted remains of radiolaria. He was far from inferring a necessary connection between radiolarian ooze and deep-sea deposits, but here we were asked to believe that such ooze occurred in the heart of igneous rocks. The necessary relationship between this occurrence and the pillowy structure of the diabase required to be proved. The slide which was said to represent radiolarian chert seemed to him very like ordinary spherulitic rhyolite. He congratulated the Author on the admirable, painstaking work which he had accomplished.

Mr. Coomáraswámy said that radiolarian remains did not *necessarily* imply a deep-sea origin for the formation in which they occurred. He had recently found radiolarian remains in the porcellanous plant-bearing shales of Upper Gondwána age, which occurred at Sripermatur, near Madras.

Dr. Flett stated that, in the supposed Arenig rocks on the southern border of the Scottish Highlands, many of the difficulties with which the Author had met in Anglesey were repeated. While in certain sections it was clear that there was a break between the supposed Arenigs and the Highland Schists to the north of them, in others there seemed to be no evidence of any interruption. At Aberfoyle some of the Highland rocks were as little metamorphosed as any of the supposed Arenigs.

The President agreed with the previous speakers in their appreciation of the value of the detailed geological work which the Author was doing in Anglesey, and welcomed this fresh instalment of the publication of his results. It was only by detailed work like this, that problems of such complexity as those presented by Anglesey would ever be solved. It was indeed most interesting to find here another example of that peculiar association of certain characteristic sediments and igneous rocks which had already been described from Southern Cornwall, Southern Scotland, and the Southern Highlands and elsewhere; and the same apparent geographical, lithological, and structural gradation from unaltered, through altered, into acknowledged metamorphic rocks. He had himself held the opinion that this peculiar association and gradation would ultimately be found to be due partly to the physical conditions of such an area at the time when its later recognizable sediments were being deposited; and partly to the effects of the intense crust-creep to which the area itself had afterwards been subjected. Consider, for example, such an area as originally forming part of a slightly submerged continental shelf, or coastal platform, with volcanic and archipelagic conditions, and overlooking (say) to the south-eastward a broad and deeper sea. Suppose, further, the platform itself floored by rocks already metamorphosed, and that this platform remains covered by shallow waters for an extended period of geological time, while the sea-floor in front of it is continually deepening. Under these conditions, only such mechanical, volcanic, or organic material could become accumulated as rock-layers on the submerged platform, as by their original nature or rapid cementation were incapable of being swept off by the waves and currents of the shallow waters into the open and deepening sea beyond. Such rock-formations as would be accumulated on the platform would necessarily be thin, but would be lithologically varied and peculiar; while those laid down in the deepening sea outside would be of relatively enormous thickness, but would be lithologically monotonous. If, later on, the two regions became intensely folded, compacted, and overthrust by crust-creep, and the crests of some of the fold-ridges on the platform were worn down by denudation, so as to expose their cores formed of the original basement-floor of metamorphic rocks, most of the puzzling field-phenomena presented by Anglesey and North Wales, and the peculiar areas of similar character found elsewhere, might be expected to follow as a natural consequence.

The Author felt that, at that late hour, it was impossible to reply to the interesting points that had been raised in the discussion. He did not, of course, claim, in the absence of recognizable radiolaria, to have made a true demonstration of the organic origin of these jaspers; but he did submit that three converging lines of indirect evidence established a very strong probability. He laid especial stress upon the fine clastic nature of the jaspery phyllites. With regard to the relations of the jasper-bearing group to the crystalline schists, nothing that he could then add would better illustrate the peculiar perplexities of this problem than the remarks of Dr. Flett upon the rocks of the Highland Border. The interest that had been evinced by the Fellows of the Society would be a great encouragement in the work that still lay before him in the remaining parts of the island. He wished, in conclusion, to draw attention to the photographic reproductions by the process of contact, for which he was indebted to the kindness of Mr. J. H. Player, F.G.S.

27. Revision *of the* Phyllocarida *from the* Chemung *and* Waverly Groups *of* Pennsylvania. By Prof. Charles Emerson Beecher, Ph.D., F.C.G.S. (Read April 30th, 1902.)

[Plates XVII–XIX.]

It is now eighteen years since I prepared a memoir for the Second Geological Survey of Pennsylvania, describing the species of Phyllocarida then known from the Chemung (Upper Devonian) and Waverly (Lower Carboniferous) Groups in that State. Subsequent collecting at the original locality has yielded a quantity of material which further elucidates the characters of the original species, and also adds two distinctly new forms to the fauna of the Waverly Group.

The specimens described in the present paper, as well as those on which the original descriptions were based, were all obtained in the vicinity of Warren (Pennsylvania). The chief horizon is in the shale-beds of the Upper Chemung Group, about 50 feet above mean water-level in the Alleghany River. At this level, crustacean remains are fairly abundant, and constitute a conspicuous element of the contained fauna. On this account, the deposits have been called by me 'the Phyllocarid-Beds.' The species thus far secured from the horizon are *Echinocaris socialis*, *Tropidocaris bicarinata*, and *Elymocaris siliqua*. Other forms are much less abundant, and occur in a sporadic manner in the higher strata.

The following notes on the genera and species are to be considered, not as complete descriptions, but as additions and emendations to the original diagnoses.

Echinocaris socialis. (Pl. XVII & Pl. XVIII, figs. 1–7.)

Echinocaris socialis, Beecher, 'Ceratiocaridæ from the Chemung & Waverly Groups of Pennsylvania' 2nd Geol. Surv. Penn. vol. PPP (1884) p. 10; Hall & Clarke, 'Palæont. of N. Y.' vol. vii (1888) p. 174.

The new material representing this species, consisting of more than a hundred individuals, presents a greater range in size than was originally observed, and permits of a more exact description of the postabdomen, the ornamentation of the somites, and the number of lobes in the cephalic areas. In addition, the position and character of the mandibles can now be determined.

The telson has the form of an abdominal somite, with a carinated extension behind, forming the spine (Pl. XVIII, fig. 3). The rows of spiniform nodes so characteristic of the other somites are absent. On each side of the base of the telson-spine are the articular faces for the cercopods, the dorsal pivotal points being marked by a node. The cercopods are about one-fourth longer than the telson-spine, and have a groove on their inner side, probably for the insertion of a row of setæ, as in *Mesothyra oceani*, Hall & Clarke.[1]

[1] 'Palæont. of N. Y.' vol. vii (1888) p. 187.

Many of the specimens seem to have suffered little or no compression in the sediments, and therefore the form and ornamentation of the separate somites can be accurately determined. One of the middle somites is represented in Pl. XVIII, figs. 4–6. The dorsal side (fig. 4) shows a transverse row of three nodes across the middle, with two additional ones on the latera. The posterior edge has five nodes occupying a space equal to the three just in front. The ventral side (fig. 5) shows an obsolescence of the transverse row, and a diminution to three in the number of nodes on the posterior edge. An anterior-end view of this somite (fig. 6) is broadly elliptical in outline, and has two nodular elevations at the ends of the long axis, serving as pivots for the flexing of the somite. The large straight abdomen of the individual represented in Pl. XVII has the somites in contact at the latera only, with a slight gaping on the dorsum. During life, these spaces were covered by the inter-articular membrane. The somites are more uniform in length than in *E. punctata*, Hall, the ultimate abdominal segment being of about the same length as the penultimate. There is a gradual shortening forward to the proximal segment, which is also without the central row of nodes.

The lobation of the cephalic area differs somewhat, according to the size and preservation of the individuals. A large rounded node occupies most of the cephalic area in each valve, and carries the pitted optic node on its posterior side. Between this large node and the dorsal line there are often, in mature examples, three more or less well-developed smaller nodes. One adjacent to the nuchal furrow is always present, and is usually quite prominent. In some specimens, this node has the appearance of being double. Anterior to this, there is generally a smaller node, and a third one occupying the anterior dorsal angle. In an attempt to construe these characters in terms of the appendages, the largest cephalic lobe, as will be shown presently, would correspond to the mandibles. The anterior dorsal node may be taken as representing the first antennal segment; the small one just behind, as the second antennal segment; while the somewhat larger and occasionally double node next to the nuchal furrow may indicate the position of the two maxillæ.

The mandibles in this species (Pl. XVIII, fig. 7) are quadrate in outline, the oblique side forming a masticatory surface without cusps. Several examples show the mandibles protruding in front of the carapace, their inner ends being concealed by the valves (Pl. XVIII, figs. 1 & 2). From the size and position of the mandibles in these and other specimens, it may be inferred that the large cephalic lobes represent hollows on the ventral side, in which the mandibles were situated.

The largest carapace observed has a length of 27 millimetres, and a width of 17 mm. across one valve. The smallest carapace measures 6 millimetres in length.

This ornate and beautiful species is now quite as well known as any *Echinocaris*, and is a very characteristic representative of the genus.

Echinocaris Randallii, sp. nov. (Pl. XVIII, fig. 8.)

Three right valves represent this species in the present collection. Two are preserved in a fine-grained sandstone, while a third is from an arenaceous and micaceous shale. One of the sandstone-specimens is taken as the type. The valve is broadly ovate, widest in front, moderately convex, width more than half the length. Hinge-line about equal to the width of the valve. The nuchal furrow starts near the middle of the hinge-line, curving outward and forward to the margin. Cephalic area marked by a node (the maxillar?) adjacent to the hinge, with triangular base, a much larger lobe (the mandibular), about four times the size of the smaller one, occupying the remainder of the area. One of the specimens has two minute lobes (the antennal) in front, at the inner extremity of the mandibular lobe.

The thoracic region has two subequal transverse lobes adjacent to the nuchal furrow, between the hinge and the carina. The carina starts near the anterior ventral angle and makes a sigmoid curve, extending along the ventral border; then, following parallel to the posterior margin, it turns forward over the middle of the valve, and becomes obsolete before reaching the lobes.

The surface of the cephalic and thoracic lobes is marked by minute pustules, and the summit of the carina has one or two rows of similar pustules. The border of the valve is somewhat thickened and reflexed, but is apparently without ornamentation.

Abdomen and postabdomen unknown.

The type-specimen, consisting of a right valve, has a length of 13 millimetres and a width of 9 mm.

Distribution.—In the sandstones and shales of the Waverly Group of the Lower Carboniferous, near Warren (Pennsylvania).

This species much resembles the Devonian *E. socialis*, but may be readily distinguished by the form and arrangement of the nodes and carina, and by its less highly ornamented surface. The specific name is given in honour of the veteran geologist of Warren County, Mr. F. A. Randall.

Echinocaris Clarkii, sp. nov. (Pl. XVIII, fig. 9.)

The only specimen of this species thus far obtained is a nearly complete individual, with the carapace, abdomen, and postabdomen connected. The valves seem to have been quite tenuous, except along the margin, and have suffered from compression, so that the precise number and form of the nodes cannot be determined.

The valves are nearly elliptical in outline, with the margins considerably thickened, reflexed, and angulated. The outer margin is denticulate around the entire free edges of the valves, and there are also minute nodes along the angulation in the posterior and anterior regions. A nodose carina extends nearly parallel to the ventral border, and a row of granules is present in the mid-thoracic area.

The abdominal segments are not well preserved, but apparently did not differ much in length, and were without conspicuous ornamentation. The telson and cercopods were evidently quite similar to the same structures in *E. socialis* from the Chemung Group (Devonian).

The type-specimen has a length of 25 millimetres, of which about 6 mm. pertain to the postabdomen, 9 mm. to the abdomen, and 10 millimetres to the cephalothorax.

Distribution.—In the shales of the Waverly Group, Lower Carboniferous, near Warren (Pennsylvania).

The denticulate border of the valves at once distinguishes this form from any other that belongs to the genus *Echinocaris*. In this character, it is exceeded by the curious *Pephricaris horripilata* of Clarke,[1] which also has a postabdomen of entirely different form, and is without the curved sigmoid carina so characteristic of *Echinocaris*. This species is dedicated to Dr. John M. Clarke, State Palæontologist of New York, who has contributed so much to a knowledge of the American fossil Phyllocarids.

Tropidocaris.

Since the present material affords a number of structures hitherto lacking, and necessary for a consideration of the relations and affinities of *Tropidocaris* with other genera, it is now possible to define this genus quite fully.

The valves of the carapace are obliquely truncate behind, marked by one or more longitudinal carinæ, separated by a median lanceolate plate along the thoracic region, and by an elongate rostral plate in the cephalic region. Cephalic area not strongly marked, but generally indicated by indistinct rounded elevations, or by a difference in convexity from the remainder of the valve; ocular node usually at the end of a short carina, and with a minute pit at the summit. Abdomen with two exposed segments, cylindrical in form. Caudal plate short, with telson-spine shorter than the cercopods.

Type, *Tropidocaris bicarinata*, Beecher.

Hall & Clarke[2] first showed the existence of a rostral plate in *Tropidocaris*, and this, together with the recent discovery of the median lanceolate plate, necessitates the removal of the genus from the Echinocaridæ. The same structures are here shown in *Elymocaris*; hence this, too, will have to be placed with *Tropidocaris* in another family. In Eastman-Zittel's 'Text-Book of Palæontology' (1900) p. 657, Clarke established the suborder Rhinocarina for Phyllocarida possessed of these distinctive features. The single family of this suborder, the Rhinocaridæ (Clarke), was made to comprise the genera *Rhinocaris*, Clarke, and *Mesothyra*, Hall &

[1] 'Notes on some Crustaceans from the Chemung Group of New York' N.Y. State Mus. 49th Ann. Rep. 1895, vol. ii [1898] pp. 731–33.

[2] 'Palæont. of N. Y.' vol. vii (1888) p. 184.

Clarke, and, as at present constituted, may also include both *Tropidocaris* and *Elymocaris*.

Thus far, each discovery of additional characters for the genera now grouped in the Rhinocaridæ has resulted in strengthening their likenesses and eliminating their differences; and it may be reasonably questioned whether they are all morphologically distinct. The structural elements of the cephalothorax are the same, and the genera seem to differ chiefly in the presence or absence of carinæ, the number of these, the character of the truncation of the posterior ends of the valves, and the number of exposed abdominal segments. It is not within the proper scope of this paper to attempt a revision of the generic and specific synonymy of both American and European forms. A brief review of the literature, in connection with the study of a considerable collection representing a large part of the Hamilton and Chemung species, leads to the conclusion that there are distinct groups of species to which most of the existing generic names may be applied. A number of characters, however, such as the presence of the rostrum and the median lanceolate plate, hitherto serving for generic distinction, must now be considered as of patronymic or subordinal value.

Dithyrocaris has been shown by Jones & Woodward[1] to have a median dorsal ridge, consisting of a carinate narrow plate apparently superimposed over the inner edges of the valves. No rostral plate has yet been discovered, though it is quite evident that this genus should be included in any discussion of the members of the family Rhinocaridæ.

TROPIDOCARIS BICARINATA. (Pl. XIX, figs. 1–5.)

Tropidocaris bicarinata, Beecher, 'Ceratiocaridæ from the Chemung & Waverly Groups of Pennsylvania' 2nd Geol. Surv. Penn. vol. PPP (1884) p. 16; Hall & Clarke, 'Palæont. of N. Y.' vol. vii (1888) p. 184.

The new features to be added to this species are of considerable interest and morphological value. First among these may be mentioned a small node or spot in each valve, a little behind the so-called optic node, from which a number of vascular lines extend backward radially over the surface. One line curves inward, meeting the hinge near the posterior end; while the others seem to be confined between the two principal carinæ, and occasionally are branched at their ends. A similar vascular marking has been observed by Clarke[2] in *Rhinocaris columbina*, var. *livonensis*, Clarke, from the salt-shaft at Livonia (N.Y.), and is also present in specimens collected by me from the Cayuga-Lake section. They show the lines originating near the hinge, a little dorsal to the optic node. Obviously, these vascular markings are indicative of some important internal organ. Their position posterior to, and outside of, the cephalic area, with their point of origin at or near the line of attachment of the abdomen with the carapace, is precisely the same

[1] Monogr. Pal. Soc. 'British Palæozoic Phyllopoda' pt. iii (1898) p. 131.

[2] 'Devon. Phyllocarida fr. New York' [No. 3 of 'Notes on Palæoz. Crustac.'] N.Y. State Mus. Rep. State Pal. for 1900 (1901) App. iii, p. 100 & pl. iv, fig. 14.

as that of the shell-gland or renal organ of *Apus*. It seems safe to offer this suggested homology, since it invests an external character with some definite physiological meaning, instead of allowing it to stand as a fortuitous feature of little or no significance.

In this connection, an enquiry may be made as to the nature of the so-called optic nodes. It may be stated that they are most strongly developed in members of the family Rhinocaridæ, and are well shown in the species under discussion. Their position is at the posterior end of the short carina lying anteriorly between the two great carinæ. The summit of the node has a minute pit, called the optic pit. No positive information is as yet attainable as to whether or not these nodes are real visual organs. It is the most natural conclusion to reach, but, as the living *Nebalia* (which is analogous in many points of structure with these fossil rostrate forms) possesses independent stalked eyes in front of the first pair of antennæ, it is possible that another interpretation should be given. As a mere postulate, I would suggest that they are infolded points of the test to form muscular fulcra or apodemes for attachment of the muscles moving the mandibles.

Besides the two nodes already discussed, there is still a third and much larger one lying outside the shell-gland, and bisected by the large submedian carina of each valve. I can suggest no obvious homology for this lobe, although it doubtless corresponds with some large organ or ventral appendage.

As already noted, Hall & Clarke[1] proved the existence of the rostrum in this species. It is a narrow lancet-shaped plate, with a strong carina along the middle. The presence of a median lanceolate plate is now determined, as shown in Pl. XIX, fig. 5. It extends from as far forward as the optic nodes to the posterior end of the hinge, and is widest across the anterior fourth. Like the rostrum, it is marked by a strong longitudinal carina, and has a chevroned ornamentation, with the lines pointing backward.

The only specimen yet found that preserves the abdomen in connection with the carapace is represented in Pl. XIX, fig. 3. In this example, only a part of the ultimate abdominal segment is exposed, together with the telson and cercopods. Detached abdominal portions have been found, showing two segments in front of the telson, and this probably represents the number capable of extension beyond the carapace, the others being unprotected by a strong chitinous test. The ultimate segment is about twice as long as the one in front, and is marked by a chevron-pattern, as shown in Pl. XIX, figs. 1 & 2. On the dorsal side, the direction of the lines is forward; while, on the ventral side, they point backward, and are considerably finer and more numerous.

The youngest examples possess valves measuring about 6 millimetres in length. They are proportionately wider than in fully adult individuals, but clearly preserve their specific features. The surface of the valves is covered with fine, wavy, discontinuous, raised lines.

[1] 'Palæont. of N. Y.' vol. vii (1888) p 184.

The three characteristic nodes are present, though as yet there are no vascular lines developed from the one homologized with the crustacean shell-gland. The largest carapace measures 35 millimetres in length.

TROPIDOCARIS ALTERNATA. (Pl. XIX, fig. 6.)

Tropidocaris alternata, Beecher, 'Ceratiocaridæ from the Chemung & Waverly Groups of Pennsylvania' 2nd Geol. Surv. Penn. vol. PPP (1884) p. 19; Hall & Clarke, 'Palæont. of N. Y.' vol. vii (1888) p. 186.

When this species was originally described, but two imperfect valves were known, and the diagnostic features consisted mainly in the considerable number of strong alternating carinæ. A single, though quite perfect, left valve has since been found, which gives the complete outline of the valve, as well as the number of carinæ. The general proportions and outline are not unlike those in *Tr. bicarinata*, but from the ventral half of the posterior margin there are two sharp spiniform extensions, the dorsal one being somewhat the larger. These spines are in line with the fourth and sixth carinæ, as counted from the hinge. There are seven carinæ running nearly the whole length of the valve, the fifth one extending to the anterior apex or prora. Of these seven, three are much stronger than the others, and are marked by a double row of minute pits along their summits. In the cephalic region, there are four or five short interpolated carinæ, and, on the anterior ventral border, there are two more, becoming obsolescent before reaching the posterior end of the valve. The number and arrangement of the nodes in the cephalic area are not easily made out, though, in their main features, they apparently agree with *Tr. bicarinata.*

The specimen here described measures 34 millimetres in length along the dorsum, and 13 mm. in width across the middle. It has thus far proved to be a rare species in the sandstones of the Waverly Group at Warren (Pennsylvania), and has not been noticed elsewhere.

ELYMOCARIS.

In this genus, as in *Tropidocaris*, the cephalothorax is now known to be made up of four parts—the two valves, the median lanceolate plate, and the rostrum. The abdomen has two exposed segments, and three or four others are concealed beneath the carapace.

Type, *Elymocaris siliqua*, Beecher.

ELYMOCARIS SILIQUA. (Pl. XIX, figs. 7 & 8.)

Elymocaris siliqua, Beecher, 'Ceratiocaridæ from the Chemung & Waverly Groups of Pennsylvania' 2nd Geol. Surv. Penn. vol. PPP (1884) p. 13; Hall & Clarke, 'Palæont. of N. Y.' vol. vii (1888) p. 182.

The new material shows the detailed characters of the rostrum and median lanceolate plate in a very satisfactory manner. The rostrum projects slightly beyond the points of the valves, extends backward as far as the optic nodes, and is widest at about the posterior third of its length; surface with two longitudinal carinæ, one on each side of the middle. The median lanceolate plate is widest just in front of the mid-length, and has a single carina ornamented with a chevron-pattern of oblique striæ directed forward.

The specimen illustrated in Pl. XIX, fig. 7, has the abdomen detached, and lying along the ventral border of the carapace. The distal somites are those which are normally exposed, the others in front being considerably shorter, with a progressively thinner test. Altogether, there are six somites preserved in front of the post-abdomen. The four anterior somites have a single, deep, lateral, longitudinal groove, which is not produced by compression as is a similar appearance shown on the two posterior segments. On the ventral side, there are thickenings and infoldings of the test, probably for the attachment and support of muscles.

The mandibles, or gastric teeth, are short, triangular, and without cusps, closely resembling those in *Echinocaris socialis*.

The valves range in length from 8 to 33 millimetres.

Distribution.—All the known specimens have been obtained from the Phyllocarid-Beds of the Chemung Group (Upper Devonian), at Warren (Pennsylvania).

EXPLANATION OF PLATES XVII–XIX.

[The specimens illustrated in these plates are in the collections of the Yale University Museum, New Haven, Conn.]

Plate XVII.

Echinocaris socialis, Beecher.

A large and nearly entire individual: showing the form and ornamentation of the carapace, the six abdominal somites, with the telson and right cercopod. Enlarged 2 diameters. Chemung Group, Upper Devonian. Warren (Pennsylvania).

Plate XVIII.

Echinocaris socialis, Beecher.

Fig. 1. A specimen preserving the carapace and abdomen entire: showing the mandibles projecting in front. Enlarged 2 diameters.
2. A similar example, with the mandibles also exposed. Enlarged 2 diameters.
3. The postabdomen, with one abdominal somite: showing the form and length of the telson and cercopods. Enlarged 2 diameters.
4. The dorsal side of a single somite. Enlarged 4 diameters.
5. The ventral side of the same.
6. Anterior-end view of the same.
7. The mandibles, as found on the underside of a carapace. Enlarged 4 diameters.

Chemung Group, Upper Devonian. Warren (Pennsylvania).

Echinocaris Randallii, sp. nov.

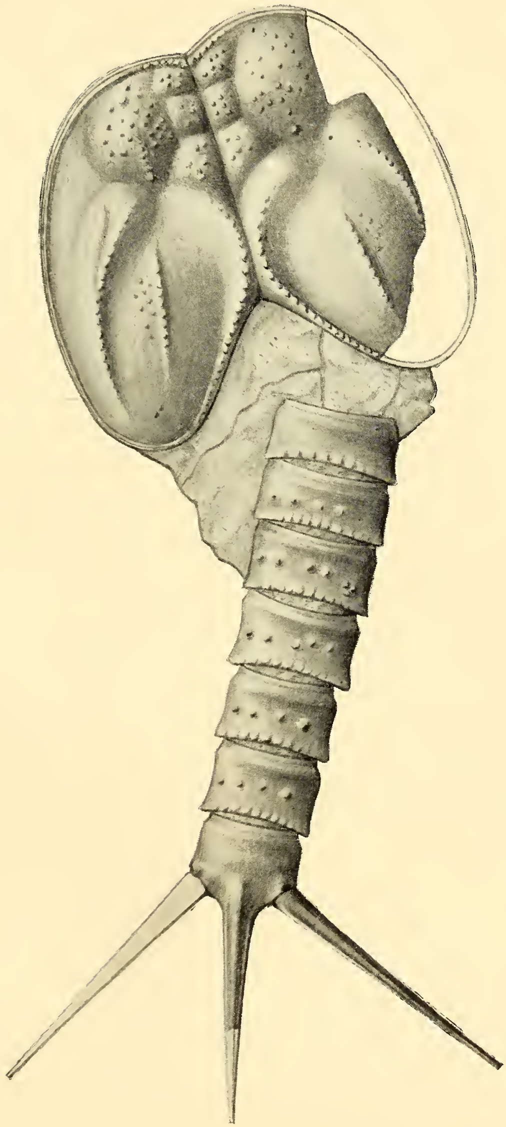
Fig. 8. The right valve: showing the form and disposition of the nodes and carina. Enlarged 2 diameters.

Waverly Group, Lower Carboniferous. Warren (Pennsylvania).

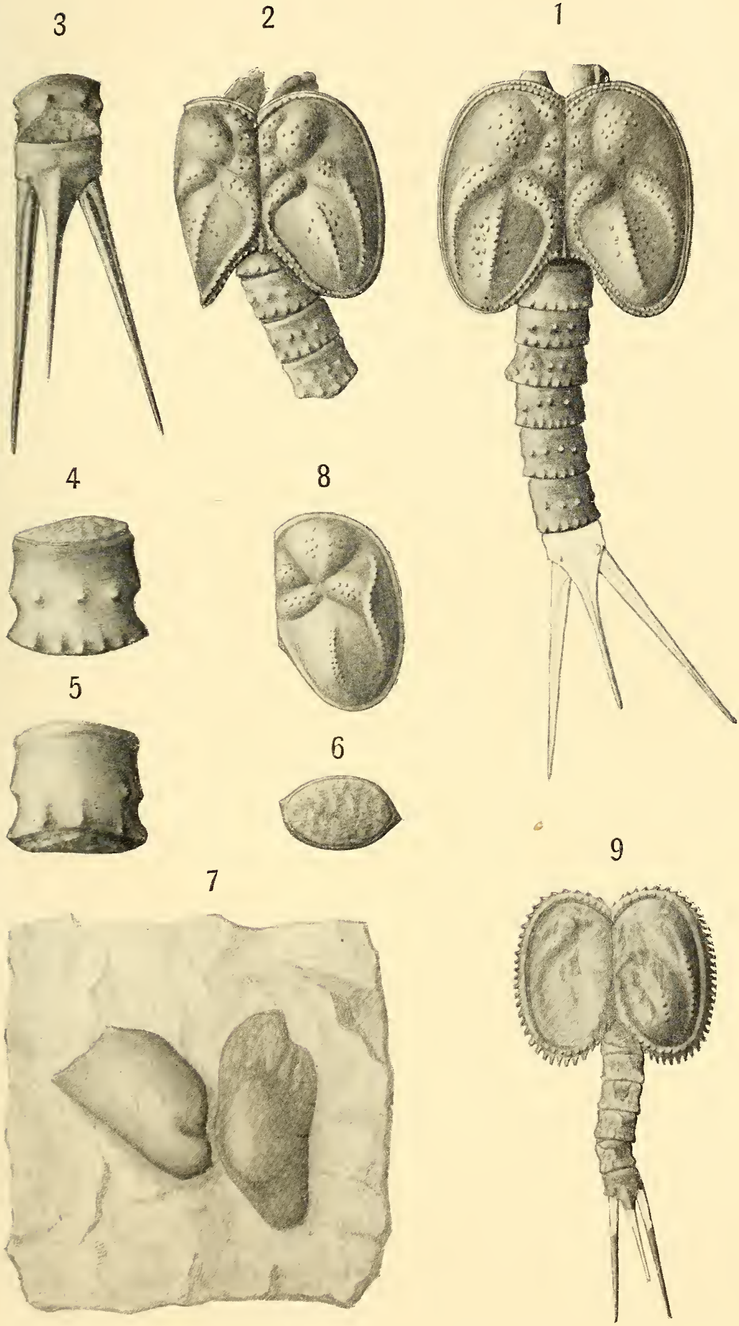
Echinocaris Clarkii, sp. nov.

Fig. 9. The type-specimen: showing the general form and proportions. Enlarged a little more than 2 diameters.

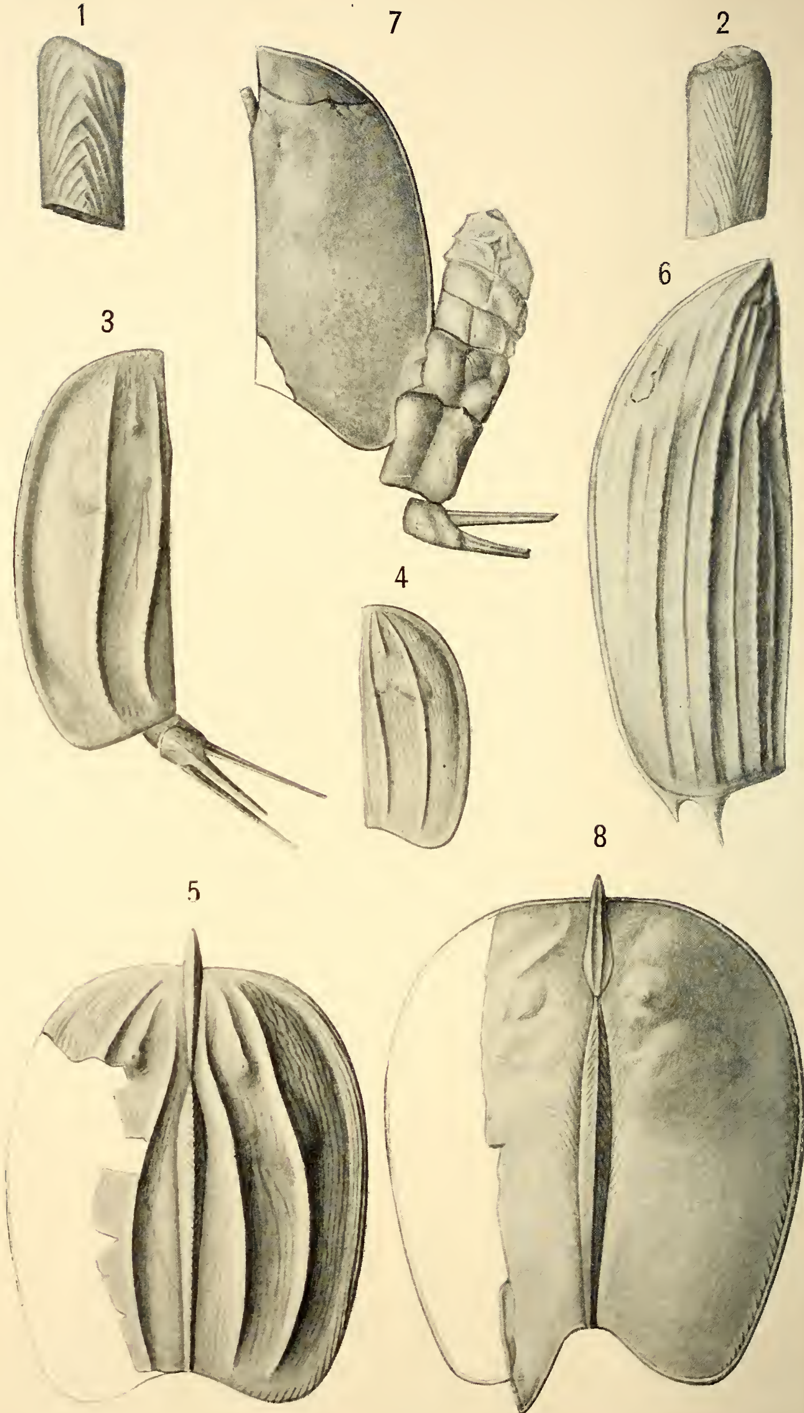
Waverly Group, Lower Carboniferous. Warren (Pennsylvania).



ECHINOCARIS SOCIALIS.



ECHINOCARIS SOCIALIS (figs. 1-7); E. RANDALLII (fig. 8); E. CLARKII (fig. 9).



TROPIDOCARIS AND ELYMOCARIS.

Plate XIX.

Tropidocaris bicarinata, Beecher.

Fig. 1. The dorsal side of the ultimate abdominal segment: showing the chevron-arrangement of the lines. Enlarged 4 diameters.
2. The ventral side of the same.
3. An individual with the abdomen and postabdomen in position: showing the carinæ on the carapace, the optic node, and the vascular lines radiating from the supposed shell-gland. Enlarged 2 diameters.
4. The right valve of a young individual. Enlarged 4 diameters.
5. The cephalothorax: showing the same features on the valves as the preceding, and, in addition, the rostrum and the median lanceolate plate. Enlarged 2 diameters.

Chemung Group, Upper Devonian. Warren (Pennsylvania).

Tropidocaris alternata, Beecher.

Fig. 6. An entire left valve: showing the numerous alternating carinæ and posterior spiniform extensions. Enlarged 2 diameters.

Waverly Group, Lower Carboniferous. Warren (Pennsylvania).

Elymocaris siliqua, Beecher.

Fig. 7. A specimen with the valves closed and the abdomen detached. Enlarged 2 diameters.
8. A specimen with the valves open: showing the rostrum and median lanceolate plate in position. Enlarged 2 diameters.

Chemung Group, Upper Devonian. Warren (Pennsylvania).

28. *On* Pliocene Glacio-Fluviatile Conglomerates *in* Subalpine France *and* Switzerland. By Charles S. Du Riche Preller, M.A., Ph.D., A.M.I.C.E., M.I.E.E., F.R.S.E., F.G.S. (Read May 14th, 1902.)

Contents.

I. Introductory.

In a paper read before this Society in the year 1896,[1] I described a series of Glacio-Fluviatile deposits which, occurring at varying altitudes in the Limmat Valley above, near, and below Zurich, and being the indirect product of the first general advance of Alpine glaciers in Upper Pliocene times, appeared to show that, at the time of their formation, not only the great Alpine but also the principal Subalpine river-valleys of Switzerland had already been eroded approximately to their present depth, while the lake-basins came into existence at a later period.

The study of a large number of other deposits in the lower parts of the Limmat and Aare Valleys, and along the Rhine above and below its junction with the Aare, and, further, of various deposits of so-called 'alluvion ancienne' in the Rhône Valley between Lausanne and Lyons, have, however, led me to modify my conclusions with respect to the configuration of Subalpine Switzerland and France towards the end of Tertiary times; and the object of the present paper is to lay briefly before the Society the further evidence that I have thus collected, together with some conclusions which it tends to warrant.

II. Deposits in the Limmat, Aare, and Rhine Valleys. (Figs. 1–5.)

(1) In the paper already quoted, I showed that, as regards the district immediately above and below Zurich, the deposits of the conglomerate now generally known as 'Deckenschotter' form a chain along the summit-line of the range of hills on the left of the present Limmat Valley.[2] Beginning at the base of the

[1] Quart. Journ. Geol. Soc. vol. lii, pp. 556 *et seqq.*

[2] In that paper I mentioned, among others, several low-level deposits embedded in the Limmat Valley, which, from the partial or surface-cementation of the gravel to a loose Nagelfluh conglomerate, appeared to be Deckenschotter, but which recent comparison with more extensive and conclusive exposures similarly embedded in the lower parts of the Limmat, Aare, and Rhine Valleys, now leads me to assign to the terrace-gravels of the two younger or Pleistocene glaciations. This applies to the deposits near Baden and Wettingen, close to the river-level (*op. cit.* pp. 560 & 563), near Höngg and Küssnacht (p. 565), and in the Au peninsula on the Lake of Zurich (p. 567).

Alps, the first links in that chain are the extensive deposits of the Lorze Valley near Zug, of the Sihl Valley between the Zug and Zurich lake-basins, and of Altschloss and Gehren near Wädenswil, on the hills flanking the Lake of Zurich. All these three deposits lie in a synclinal fold or zonal subsidence which occurred subsequently to their formation, and to which the lake-basins along the base of the Alps owe their existence.

The next links in the chain are the deposits on the Albis range of hills flanking the Lake of Zurich, including the classic deposit on the summit of the Uetliberg; and upon these follow the deposits on the Heitersberg hills, of Teufelskeller and Baldegg near Baden, and of the Gebensdorfer Horn near Turgi. Of these last-named three deposits, that of Teufelskeller again lies in a synclinal fold of the Molasse, which occurred subsequently to the formation of that deposit, that is, at the time of the raising of the Jurassic Lägern ridge as the result of the last thrusting and folding of the Jura range, of which the Lägern is an offshoot crossing the Limmat Valley almost at right-angles.

It is a noteworthy fact that, of all these deposits of Deckenschotter, only those of the Lorze Valley, of the Albis, and of the Uetliberg rest upon moraine, while those from the Uetliberg downward to the Gebensdorfer Horn rest directly upon Molasse; thus showing that the Pliocene glaciation in that district probably did not extend beyond the Uetliberg.[1]

(2) Having thus given a short summary of the Deckenschotter deposits already dealt with in my previous paper, I now pass to the deposits which I have more recently examined. In briefly reviewing these, I need not recapitulate the leading characteristics of the Deckenschotter or Pliocene conglomerate, as distinguished from the Miocene Nagelfluh on the one hand, and the Pleistocene gravels and loose conglomerates on the other, since these characteristics were fully described in my previous papers.[2]

(3) At the confluence of the rivers Aare, Reuss, and Limmat, near Brugg and Turgi, there occur, opposite the Gebensdorfer Horn, which forms a wedge between the Reuss and the Limmat, two extensive Deckenschotter deposits—one on the Bruggerberg, on the left of the Aare, and the other on the Siggenberg, on the right of the Limmat. In both cases the Deckenschotter, from 30 to 50 metres[3] in depth, and overlain by moraine, rests directly upon

[1] Prof. Mühlberg, of Aarau, mentions a deposit of old Glacial gravel in the valley of the Wyna, an affluent of the Aare, on a cliff called the 'Wandfluh, near Zezwyl, the conglomerate resting upon Molasse and being overlain by moraine at an altitude of 700 metres (Festschrift, Aarau, 1869, p. 96). This deposit, which I have examined, occurs in a line with the Uetliberg Deckenschotter, and is probably of the same age as the latter.

[2] Quart. Journ. Geol. Soc. vol. li (1895) pp. 369 *et seqq.*, & vol. lii (1896) pp. 556 *et seqq.*

[3] The depths of the various deposits and all the altitudes in the present paper are given in metres, as they correspond with the Swiss contour-map on the 1 : 25,000 scale.

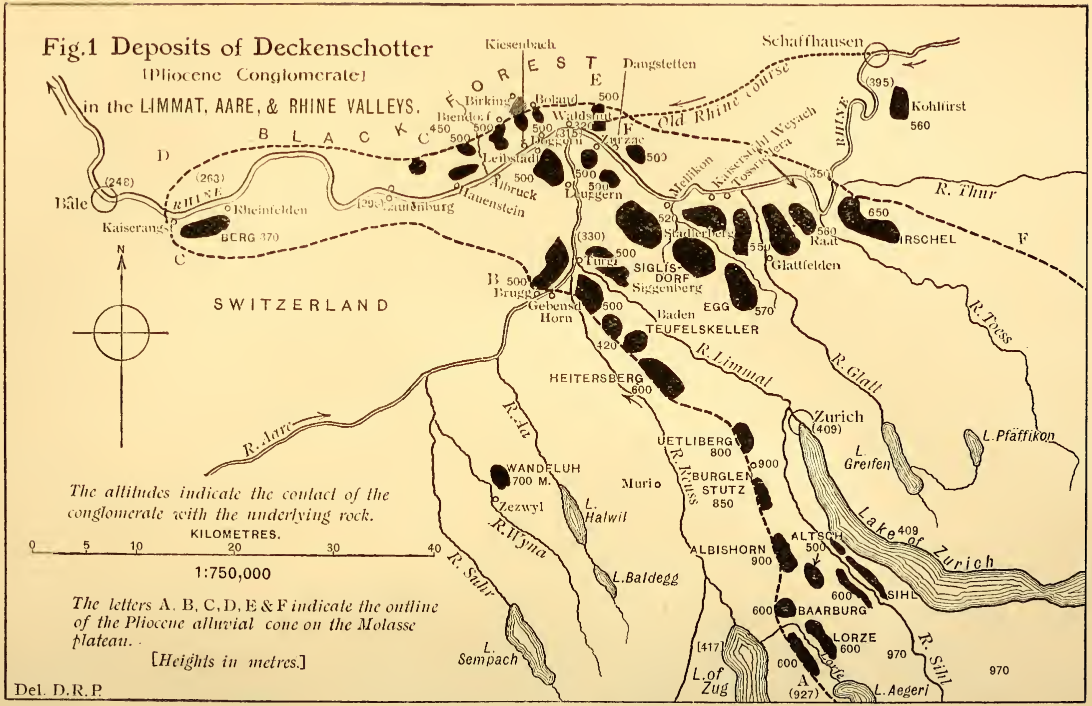


Fig. 1 Deposits of Deckenschotter
[Pliocene Conglomerate]
in the LIMMAT, AARE, & RHINE VALLEYS.

The altitudes indicate the contact of the conglomerate with the underlying rock.

The letters A, B, C, D, E & F *indicate the outline of the Pliocene alluvial cone on the Molasse plateau.*

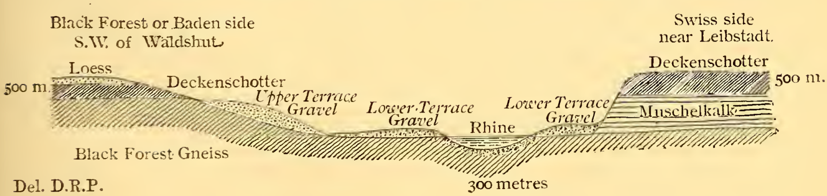
[*Heights in metres.*]

[*For* 'Zurzac' *read* Zurzach.']

Molasse at about the same contour as the precisely similar deposit on the Gebensdorfer Horn, that is, at the 500-metre contour, or, roughly, about 200 metres above the present river-level. About 6 miles farther down the Aare Valley, between the villages of Leuggern and Leibstadt, not far from the junction of the Aare and the Rhine opposite Waldshut, there occurs, again on the left of the Aare, another considerable deposit of Deckenschotter, about 30 metres in depth, which rests directly upon Muschelkalk and Keuper, the contact with the underlying rock being, as in the other cases just mentioned, at about the 500-metre contour.

(4) Passing from the confluence up the Rhine Valley, we find, in a distance of less than 20 miles, and chiefly on the left of the river, a whole series of hills capped by more or less extensive deposits of Deckenschotter. Among these are more especially noteworthy the deposits near Zurzach, near Siglisdorf, the large deposit on the flat, dome-shaped hill called Egg, about 5 miles south of the Rhine; again, the deposits near Kaiserstuhl, on the Stadlerberg, on the heights near Weyach and Glattfelden; and, lastly, the large deposit which caps Mount Irschel, a conspicuous hill on the left bank of the Rhine, about 13 miles south of Schaffhausen.[1] In all these cases the Deckenschotter, composed of Alpine material, and in some cases overlain by moraine, rests directly upon Molasse at contours gradually rising from 500 to 650 metres, the maximum being that of Mount Irschel. The conglomerate has a fairly uniform thickness of 20 to 30 metres, with the exception of the Zurzach deposit in the wedge between the Rhine and the Aare, where the Deckenschotter rests upon Dogger, and has been denuded down to

Fig. 2.—*Section across the Rhine Valley, south-west of Waldshut.*



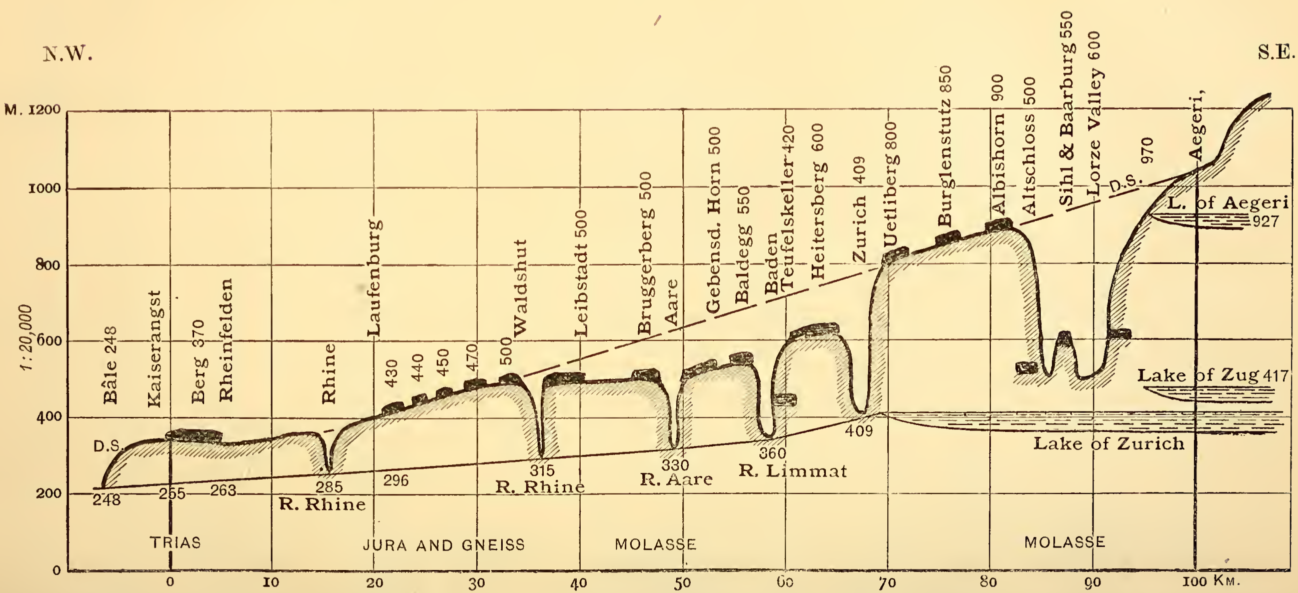
Del. D.R.P.

about 10 metres in depth. The average height of the contact of all these deposits with the underlying rock is about 200 metres, and, in the case of Mount Irschel, about 350 metres above the present level of the Rhine.

(5) Several Deckenschotter-deposits, from 15 to 25 metres thick, also occur on the right bank, or Black-Forest side of the Rhine,

[1] The Kohlfirst, a hill immediately south of Schaffhausen (see fig. 1, p. 452), is also capped by Deckenschotter, the contact with the underlying rock being at about the 570-metre contour.

Fig. 3.—*Section of Deckenschotter-deposits, from Bâle to the Alps.*



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[The fall of the Deckenschotter-cone=6 metres per kilometre, or about 32 feet per mile. The altitudes above the deposits denote the contact with the underlying rock.]

between Waldshut and Laufenburg, near Doggern, Kiesbach, Albbruck, and Hauenstein, the contact of the Deckenschotter with the underlying Triassic rock and Black-Forest gneiss varying from contour 500 near Waldshut down to 430 metres near Laufenburg.[1] That is, they occur at practically the same altitude as the corresponding Deckenschotter-deposit near Leibstadt and Leuggern, on the left or Swiss side of the valley, as is shown in the cross-section (fig. 2, p. 453). The Aarberg, a hill immediately east of Waldshut, is also capped by Deckenschotter resting upon Triassic rock; and still farther east, near Dangstetten, there is another similar deposit. The geological maps of the district designate those deposits roughly as 'Glacial,' without discriminating between them and the younger gravels at lower altitudes; but their position, as well as the fact of their being composed of Alpine material—chiefly grey limestone, diorite, and quartzite,—leaves no doubt as to their connection with the Deckenschotter-deposits on the left, or Swiss, side of the valley. It is only in the deposits nearest Laufenburg and towards Rheinfelden that Black-Forest material, easily recognizable by the considerably larger size of the pebbles, begins to be extensively mixed with Alpine material on both sides of the valley. A notable instance on the Swiss side is an extensive Deckenschotter-deposit on the Berg, a hill between Rheinfelden and Kaiserangst, about 10 miles east of Bâle, where the Deckenschotter (which is overlain by moraine) rests upon Triassic rock at about contours 360 to 370 metres, or 100 metres above the present river-level (263 metres).

(6) The evidence thus furnished by the various deposits points to the following conclusions:—

(i) The deposits indicate, in an almost unbroken outline, the former existence of a Deckenschotter-cone extending, at the time of the Upper Pliocene glaciation, from the base of the Alps in a north-westerly direction over a distance of about 60 miles, and radiating from an ice-sheet the maximum extension of which probably did not reach beyond a line drawn from the Uetliberg to Mount Irschel.

(ii) The Deckenschotter-cone, largely composed of retransported material derived from Miocene Nagelfluh, had a fall of about 6 metres per kilometre (say 32 feet per mile), and was formed by the waters of the western branch of the Rhine Glacier then emerging through the Walensee defile, and reinforced by the Linth, Sihl, and Lorze Glaciers.[2]

[1] An interesting monograph on the Rapids of the Rhine at Laufenburg, showing a former cañon of the river at some distance from the present bed, has recently been published by Dr. H. Walter ('Stromschnelle von Laufenburg' Abhandl. Naturf. Gesellsch. Zurich, 1902, pp. 232 *et seqq.*).

[2] The Lorze, descending from the Rossberg, formed at a later period part of the Reuss drainage-area.

(iii) The fact that the oldest Deckenschotter-deposits *in situ*—with the exception of two deposits now lying in a synclinal fold — invariably and uniformly crown the Molasse-ranges and isolated hills of the district, warrants the inference that the Glacio-Fluviatile material was

Fig. 4.—*Section of Deckenschotter-deposits, from Bruggerberg to Mount Irschel.*

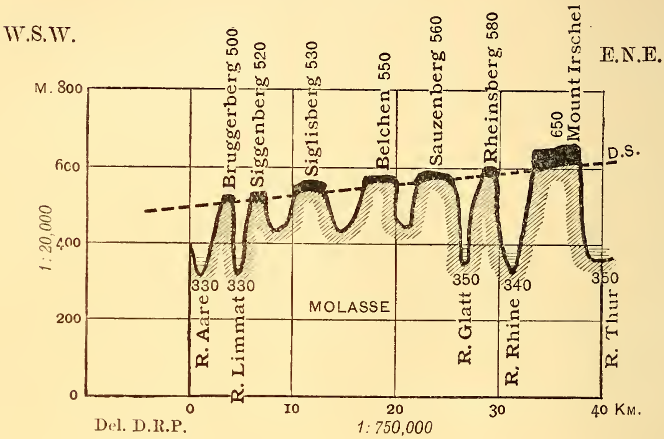
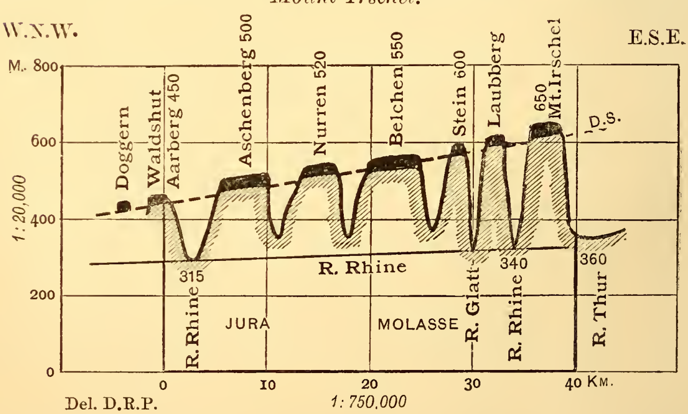


Fig. 5.—*Section of Deckenschotter-deposits, from Doggern to Mount Irschel.*



deposited on a Subalpine plateau, which, being inclined north-westward, determined the direction of flow of the masses of water descending from the glaciers and their drainage-areas.

(iv) The fact that the Deckenschotter-deposits occur on both sides of the Aare Valley, at Brugg, Turgi, and near the junction of the Aare with the Rhine, as well as on both sides of the latter river, warrants the further inference that, towards the end of the Pliocene Period, when the Deckenschotter was deposited, the Subalpine valleys of the Rhine, Aare, Limmat, and Reuss could not have existed in their present form and depth: the less so, when it is considered that the contact of the Deckenschotter with the underlying rock at those points is at about the 500-metre contour, while the present Lakes of Zurich, Zug, Lucerne, and Neuchâtel are respectively at contours 409, 417, 437, and 435 metres. Even the Lake of Thun lies only at the 560-metre contour, that is, at a level which, to give a minimum ratio of fall from Thun to Turgi of 1 metre per kilometre (or $5\frac{1}{4}$ feet per mile), should be at least 230 metres higher.[1] The same holds good with regard to the Lake of Constance, in relation to the deposits of Deckenschotter on both sides of the Rhine between Waldshut, Laufenburg, and Rheinfelden, where the contact of the conglomerate with the underlying rock varies between the 450- and 370-metre contours, while the lake-level is only at the 398-metre contour. The ratio of fall is thus totally inadequate: even according to the average fall of the present river,[2] the difference of level should be at least 140 metres.

III. Deposits in the Rhône Valley. (Figs. 6–12.)

(1) In the Rhône Valley, the enormous accumulations of Glacial, Glacio-Fluviatile, and inter-Glacial material render the distinction between the products of the three glaciations much more complicated and difficult than in the North of Switzerland; the more so as, both in France and Switzerland, the geological maps still designate all the Glacial deposits indiscriminately as 'Quaternary' or 'Diluvium.' It is due to French geologists, notably to F. Fontannes[3] and Fr. Delafond,[4] that the gravels and allied alluvia of South-eastern France were classified in 'alluvions anciennes' or 'des plateaux' (which were, however, regarded as pre-Glacial), 'alluvions des terrasses,' and 'alluvions des vallées'; a classification which, provided the Glacial or Glacio-Fluviatile origin of the 'alluvion ancienne' be accepted, corresponds to the Deckenschotter, Upper- and Lower-Terrace Gravels, respectively, of Northern Switzerland.

(2) About 5 miles north-east of Lausanne,[5] not far from the road

[1] The present fall = 230 metres in about 220 kilometres.
[2] The present fall = 140 metres in about 150 kilometres.
[3] Bull. Soc. Géol. France, ser. 3, vol. xiii (1884–85) pp. 59 *et seqq.*
[4] *Ibid.* ser. 3, vol. xv (1886–87) pp. 65 *et seqq.*
[5] See footnote ([1]) p. 459.

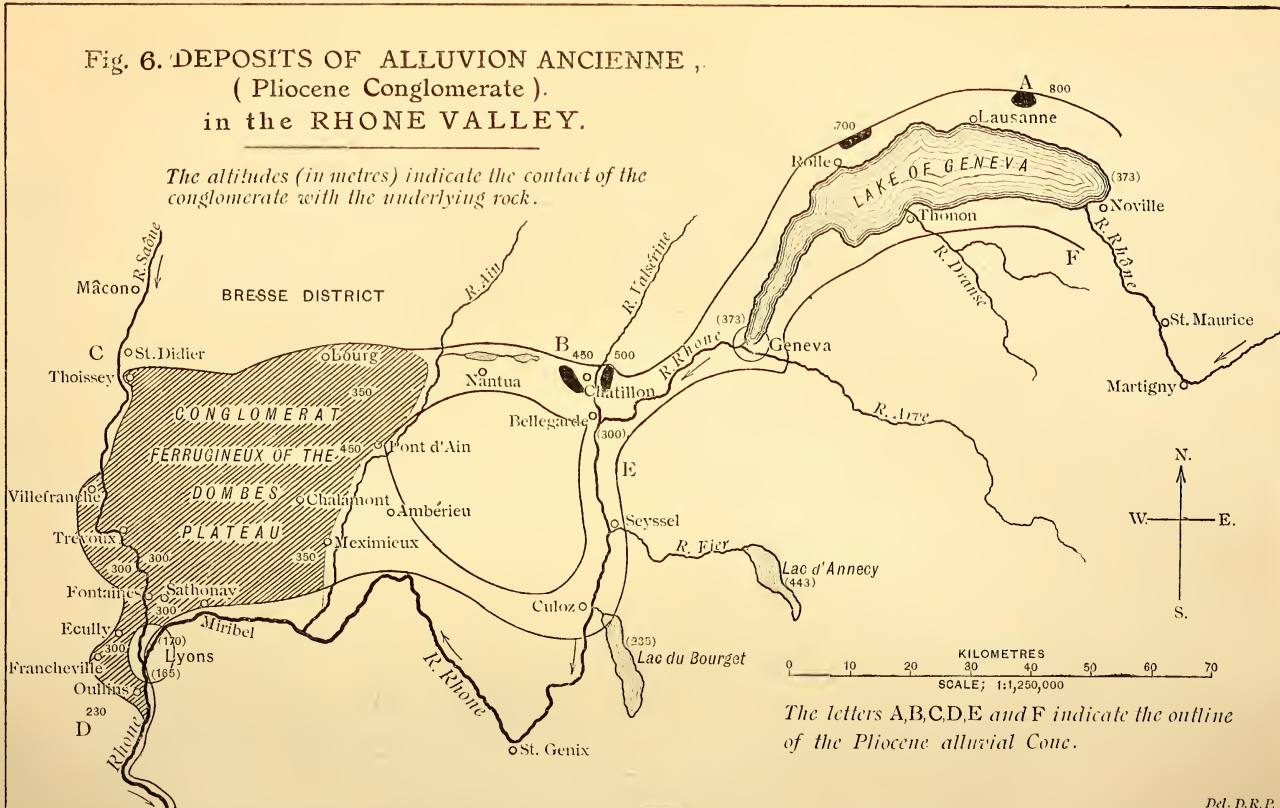


Fig. 6. DEPOSITS OF ALLUVION ANCIENNE, (Pliocene Conglomerate). in the RHONE VALLEY.

The altitudes (in metres) indicate the contact of the conglomerate with the underlying rock.

The letters A,B,C,D,E *and* F *indicate the outline of the Pliocene alluvial Cone.*

to Savigny, and about 300 yards south of a group of houses called 'les Cases,' there is a quarried exposure of Deckenschotter conglomerate about 20 metres in depth and at about the 800-metre contour, that is, practically on the plateau. This deposit is probably part of a much more extensive occurrence of Deckenschotter *in situ*, and derives special interest and importance from the fact that it is met with at an altitude of fully 400 metres, or about 1300 feet above the present Lake of Geneva.

The next important exposure of Deckenschotter occurs about 4 miles north-east of Rolle,[1] immediately below the Trigonometrical Survey point called Signal de Bougy (709 metres above sea-level). There a cliff of Deckenschotter, varying from 20 to 30 metres in thickness, and resting upon Molasse, extends for some distance at about the 650-metre contour, or 300 metres above the present lake-level.

These two deposits exhibit all the characteristics of Deckenschotter, and their occurrence at practically the same elevation above sea- and lake-level as the Albis and Uetliberg deposits near Zurich invests them with special significance.

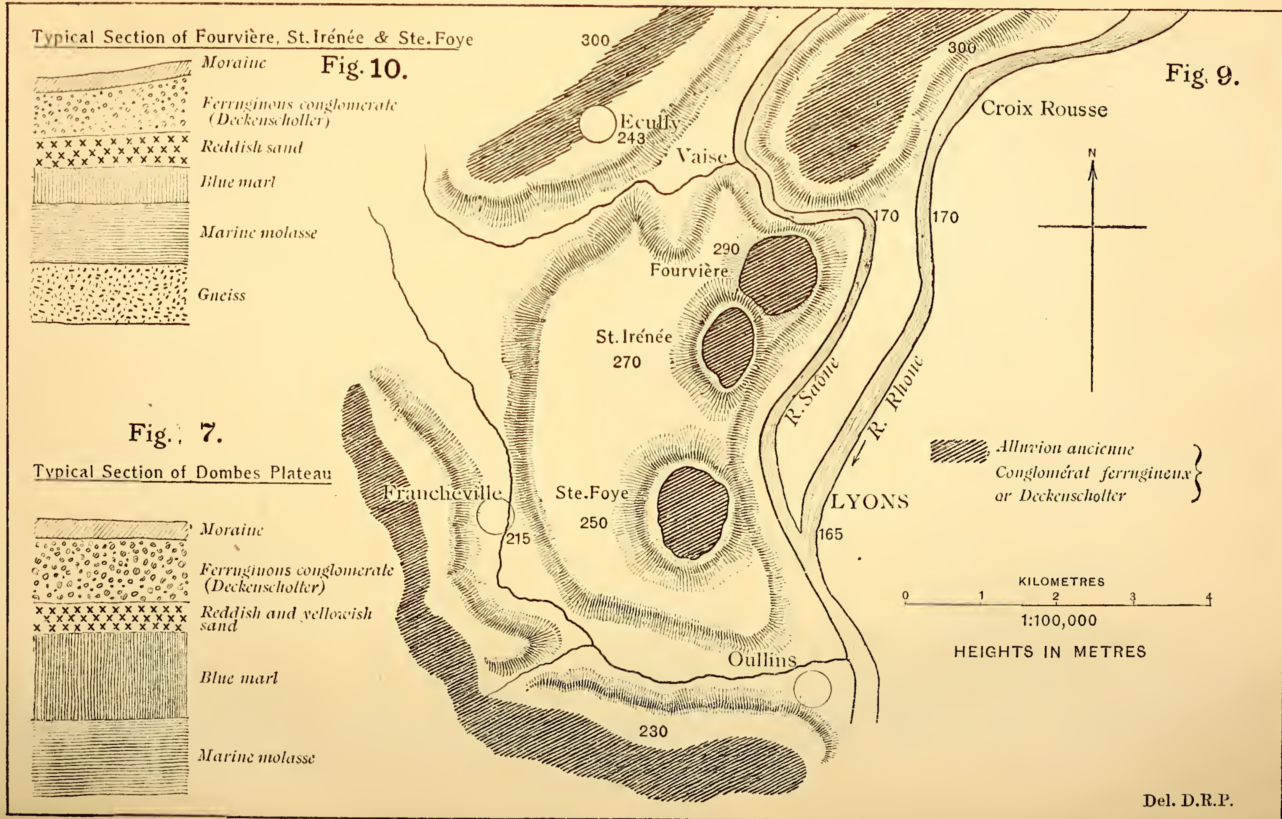
(3) On the heights above Bellegarde[1] (right bank of the Rhône), near Châtillon, there occur, at contour 450 to 500, that is about 200 metres above the present valley-floor,[2] extensive deposits of Deckenschotter-conglomerate similar to that of Lausanne and Rolle. These deposits thus appear to constitute the link between the Lausanne deposits and those of the Dombes district east of Lyons.

(4) The plateau of the Dombes, forming an irregular quadrangle between Lyons, Thoissey, Bourg, and Meximieux, and extending to a distance of about 25 miles north and east of Lyons, is composed of blue marine marl of Middle Pliocene age, which is covered by a sheet of reddish conglomerate about 20 metres thick, generally passing into and resting upon sand of the same colour, and overlain by clayey morainic, and, therefore, more or less

[1] My attention was first drawn to these deposits by Prof. Renevier, of Lausanne, who, however, was then disposed to regard them as either inter-Glacial or pre-Glacial. The extensive gravel-bank of the Bois de la Bâtie, near the junction of the Rhône and Aare at Geneva, is, in my view, inter-Glacial; and the same applies to the Dranse deposit near Thonon, both being at low altitudes and overlain by moraine of the third glaciation. A. Favre describes the former as 'pre-Glacial' ('alluvion acqueuse') and the latter as 'Glacial' in his 'Recherches Géol. Savoie' vol. i (1867) pp. 89 & 78.

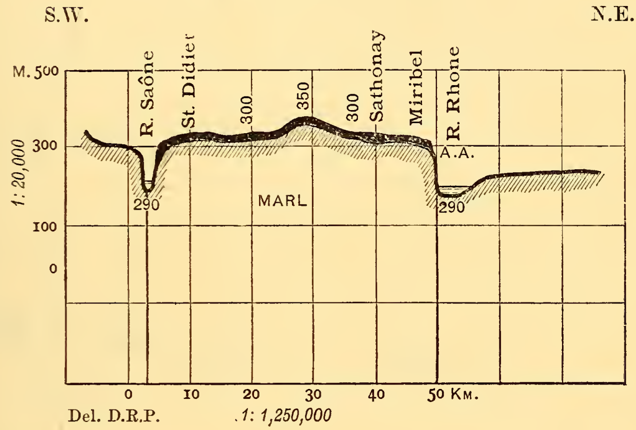
[2] It is interesting to note that, as early as 1859, Venetz (Soc. Helv. Sci. Nat. Nouv. Mém. vol. xviii) endeavoured to show that the Rhône Glacier had advanced three times. The first advance (in Pleistocene times) was beyond the Jura, when the Bellegarde Valley was, according to his estimate, at least 200 metres higher than now; the second, to the foot of the Jura, as far as Soleure; and the third, as far as Noville, at the head of the present Lake of Geneva. A fourth local advance occurred, in his opinion, towards the end of prehistoric times, as far as Obergestelen, in the Upper Rhône Valley.

Map and sections illustrating the deposits of Alluvion Ancienne at and around Lyons.



impermeable surface-soil.[1] It is in that 'conglomérat ferrugineux' of the Dombes that *Elephas meridionalis* and *Mastodon arvernensis* were found by Fontannes,[2] to whom thus belongs the merit of having fixed the Upper Pliocene age of that conglomerate, and thereby, although unwittingly, that of the first glaciation of the Alps of which that conglomerate is the indirect product—although he regarded it as pre-Glacial, and others (for example, A. Falsan and E. Chantre)[3] classed it with the Quaternary Glacial alluvia.

Fig. 8.—*Section of Alluvion Ancienne across the Dombes plateau, from the Saône to the Rhône.*



There are a good many fairly uniform exposures of the conglomerate along the vine-clad slopes of the Saône and Rhône Valleys, and also in the Valley of the Ain, the conglomerate appearing generally about the 300-metre contour, although on the diagonal divide of the Rhône and Saône watersheds, running in a line from Lyons to Pont d'Ain, it reaches occasionally the 350- to 400-metre contour. The section taken by myself at a point near Fontaines, on the left of the Saône, about 6 miles north of Lyons, between Fontaines and Sathonay (fig. 7, p. 460), does not differ materially from the section, between Meximieux and the Rhône, given by Delafond.[4] At Lyons itself, the conglomerate reaches to the high-level Croix-Rousse quarter in the wedge between the Rhône and the Saône,

[1] The Dombes is often considered as part of the Bresse district: hence Élie de Beaumont called the Dombes conglomerate 'conglomérat bressan.' The Bresse district, north of the Dombes, is, however, a distinct and somewhat lower plateau (about the 200-metre contour), much more intersected and eroded by watercourses, but otherwise of similar structure and composition, the conglomerate being chiefly composed of Vosges material.

[2] Bull. Soc. Géol. France, ser. 3, vol. xiii (1884–85) p. 60.

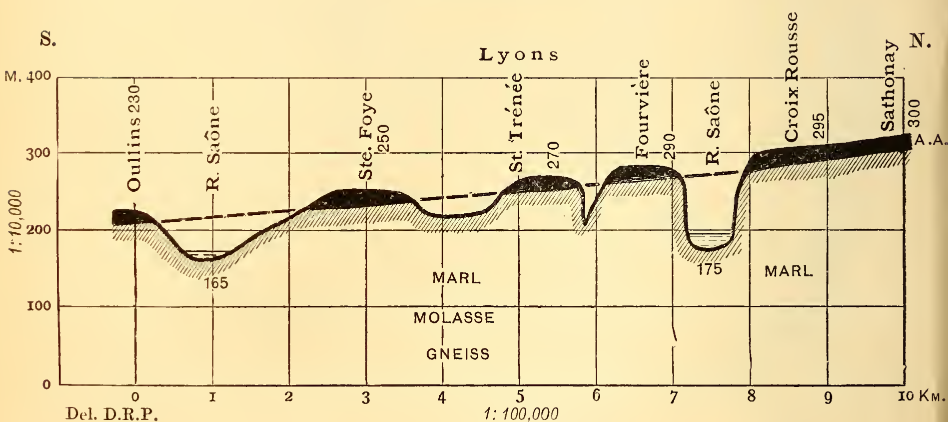
[3] 'Monogr. géol. des Anciens Glaciers' vol. ii (1880) pp. 65 *et seqq.*

[4] Bull. Soc. Géol. France, ser. 3, vol. xv (1886–87) p. 63.

about 130 metres above the present level of those rivers, which is at the 170-metre contour.[1]

(5) But the most noteworthy and significant feature as bearing on the subject of this paper, consists in the fact that extensive deposits of the same conglomerate occur not only on the left of the Saône, but also on the hills crowning the right bank of that river and of the Rhône in the immediate vicinity of Lyons. It occurs in extensive deposits on the upper flanks of Mont d'Or, immediately north of Lyons; it overlies the gneiss of the well-known hills of Lyons itself, that is, of Fourvière, St. Irénée, and Ste. Foye, to a depth of about 20 metres, being overlain, in its turn, by 20 to 30 metres of moraine; and it is also met with west of Fourvière, on the heights of Ecully, whence it extends to the heights above Oullins, on the Rhône, below the junction of the

Fig. 11.—*Section of Alluvion Ancienne, from Oullins to Sathonay, near Lyons.*



two rivers.[2] The contour at which these deposits of the 'alluvion ancienne' appear is somewhat lower than that of the deposits of Croix Rousse and of the Dombes—namely, 230 to 290 metres. The material of all the deposits, both near Lausanne and near Lyons, is derived from the Alps, that of the Dombes and Lyons deposits being considerably more decomposed: hence the predominance of quartzite.

[1] The moraine of Croix Rousse and Sathonay, which overlies the conglomerate, abounds in Alpine blocks of enormous size, many of the excavated blocks reaching 10 cubic metres, or 25 tons in weight.

[2] A branch, if not the whole of the Rhône and Saône, formerly passed west of Fourvière, that hill, together with St. Irénée and Ste. Foye, forming then an island. The confluence of the two rivers appears to have been at one time considerably above, at another time considerably below the present junction at Lyons.

(6) The Rhône-Valley deposits of Deckenschotter which I have thus briefly described point to the following conclusions :—

(i) The deposits indicate the existence, during and immediately after the Pliocene glaciation, of an extensive alluvial cone of Glacio-Fluviatile material, extending from Lausanne to Bellegarde, the Dombes district, and Lyons, that is, over a distance of about 160 kilometres (100 miles), and reaching to the right banks of the present Saône and Rhône Valleys.

(ii) The cone was deposited on a plateau the altitude of which was about 800 metres near Lausanne, 450 to 500 metres near Bellegarde, and 300 metres near Lyons. It had thus a fall of about 3 metres per kilometre (or, roughly, 16 feet per mile),[1] and was formed by the waters of the Rhône and Arve Glaciers, the maximum extension of which probably did not reach beyond the present confluence of those rivers at Geneva.

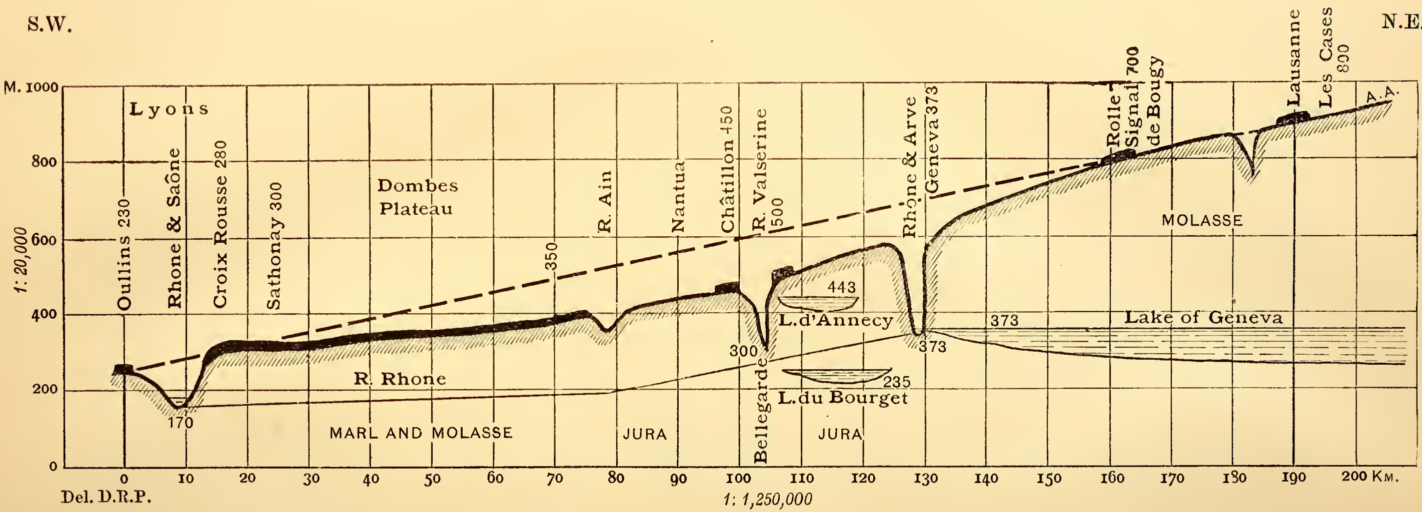
(iii) The fact that the deposits occur on the heights of both banks of the Saône and of the right bank of the Rhône, even below the junction of the two rivers, affords proof that, at the time of the formation of the alluvial cone, the valleys of those rivers could not have existed in their present form and depth. The contour of 300 metres, at which the conglomerate appears both on the Dombes plateau and at Lyons, further tends to prove that neither the basin of the Lake of Geneva, nor that of the Lac du Bourget, whose present altitudes are 373 and 235 metres respectively, could have existed in their present form and at their present level, the minimum ratio of fall requiring that their level should be at least 200 metres higher. The same applies even to the basin of the Lake of Annecy, the present level of which is at 443 metres, while the deposits near Bellegarde and Châtillon appear at contours 450 to 500, and near Seyssel (the junction of the River Fier with the Rhône) would be about 440 metres, the fall being thus altogether insufficient.

IV. General Conclusions.

(1) If the evidence of the two precisely analogous and contemporaneous phenomena of extensive Pliocene Glacio-Fluviatile alluvia deposited on the Subalpine plateaux of North-western Switzerland, and of the Rhône Valley between Lausanne and Lyons, is conclusive, it follows that at the advent of, and immediately after, the Pliocene glaciation, the principal river-valleys of

[1] It will be noticed that the inclination of this Deckenschotter-cone is only half of that of North-western Switzerland. Yet it is considerably steeper than the general inclination of younger alluvial cones, and is, in this respect, characteristic of Deckenschotter. The mean fall of the present Rhône from the Lake of Geneva to Lyons (200 kilom.) is 1 metre per kilometre, or $5\frac{1}{4}$ feet per mile.

Fig. 12.—*Section of Alluvion Ancienne, from Lausanne to Lyons.*



[The fall of the Alluvion Ancienne=3 metres per kilometre, or about 16 feet per mile.]

Subalpine France and Switzerland, including the lake-basins, could not have been already eroded to their present depth, but were as yet in their initial stage of formation as shallow depressions, the valley-floors being in the lowlands from 100 to 200 metres, and in the upper parts as much as 400 metres higher than in our own day. It follows, further, that a very long inter-Glacial period of erosion must have elapsed between the Upper Pliocene and the Middle Pleistocene or maximum glaciations, the latter of which found the valleys excavated, as is evidenced by the products of that glaciation which cover and fringe the slopes of, and are embedded in, the valleys. This last-named point is of decisive importance; for if it be assumed that, towards the end of the Pliocene Period, the valleys had already acquired their present outline and depth, it would follow that they must have been filled with the products of the Pliocene glaciation, to a depth of 100 to 400 metres—a theory which is untenable in face of the now recognized fact that all the upper-terrace and valley-gravels are the products of the two younger glaciations.

(2) True it is that the lowering of the valley-floor of the Zurich and Geneva lake-basins by 400 metres (or 1300 feet) in the course of, possibly even later than, the Ice-Age, is a startling phenomenon. But it must be borne in mind that, apart from the greater volume and, owing to the greater fall, the enhanced erosive power of the then Alpine rivers as compared with those of our own day, the lake-basins *per se*, as they appear at present, were formed not only by fluviatile erosion, and by subsequent banking-up at their lower ends, but by a zonal subsidence or settling along the base of the Alps, which followed upon the raising of the latter as a mechanical process. As is well known, this theory of a subsidence or 'flexure,' computed at about 400 metres on the northern side of the Alps, was first propounded by Prof. Heim [1] on the evidence of the reverse-dip of the Molasse-terraces of erosion on both sides of the Lake of Zurich. It is further demonstrated by the fact that the Molasse-floor of the valley itself exhibits a considerable reverse dip which, beginning near Baden, about 15 miles below Zurich, extends up the valley and the greater part of the lake: so much so, that, at the outlet of the lake at Zurich, the deepest borings have failed to reach the Molasse, and that, towards the upper end and at the deepest point of the present basin, the old Molasse-floor is not reached even at a depth of 140 metres (460 feet), and is, indeed, buried below lake-deposits at an unknown depth. And further proof is afforded by the considerable folding of the Molasse in the low hills between the Lakes of Zurich and Zug subsequent to the deposition of the Deckenschotter, which now appears at a level from 300 to 400 metres lower than the deposits on the original plateau of the Albis or Uetli range (see fig. 3, p. 454).

[1] Beiträge z. geol. Karte d. Schweiz, vol. xxv (1891) pp. 475 & 476.

(3) Even if the lowering of the Pliocene valley-floor near Zurich and Lausanne by about 400 metres had been solely effected by the agency of fluviatile erosion, denudation, and wastage, there would be nothing extraordinary in such a phenomenon, when it is considered that the Miocene material to be removed in the course of the two inter-Glacial Periods, of which the first at least is now commonly recognized to have been of very long duration, was, in the main, soft Molasse, clay, and gravel. Moreover, the apparently considerable depth of 400 metres represents barely one-twentieth of the width of the two, even now essentially shallow valleys; while other valleys, as for example that of the Rhine near Bregenz, of the Aare near Berne, of the Reuss in its lower course, and of the Inn near Innsbruck, are all of about similar depth and width, and therefore give similar cross-sections:—

	Mean width. Kilo-metres.	*Approx. Depth.* Metres.	*Cross-Section.* Square metres.	*Mean flow per second.* Cubic metres.
Rhine Valley, near Bregenz ...	13·5	400	5,400,000	250
Aare Valley, near Berne	8·5	400	3,400,000	200
Reuss Valley, near Muri	7·0	400	2,800,000	150
Inn Valley, near Innsbruck ...	4·0	400	1,600,000	160
Limmat Valley, near Zurich ...	5·5	400	2,200,000	100
Rhône Valley, near Geneva ...	6·0	400	2,400,000	270

(4) With reference to the altitude of 800 metres of the Pliocene Subalpine plateaux at Zurich and Lausanne, it may be asked, how does that elevation correspond with the then valley-floors in the Alps proper? And further, would not a subsequent zonal subsidence along the edge of the Alps of 400 metres (or 1300 feet) raise the mean temperature, whereas the Pleistocene glaciations require a lowering of the same?

The answer to the first question would be that, given the altitude of the Pliocene Subalpine plateaux as stated, that is, 400 metres above the present Lakes of Zurich and Geneva, the fjord-like Alpine valleys of the Rhine and the Linth (say at Sargans, Chur, and Glarus) and of the Rhône (say at Martigny and Sion) must of necessity have been correspondingly, that is, at least 400 metres, higher than at present. As regards Northern Switzerland, this is confirmed by the significant fact that certain characteristic rocks of the older Alpine series, such as Julier and Puntaiglas granite of the Rhine drainage-area, and more especially the well-known Sernifite or red sandstone of the Glarner Alps or Linth watershed, are entirely absent in the Miocene Nagelfluh, and extremely rare in the Pliocene Deckenschotter. They abound, on the other hand, in the Pleistocene gravels, thus showing that in the middle and at the end of the Tertiary Age, erosion and denudation in the Alps had not as yet reached those lower rock-formations.

To the second question the answer would be that a zonal subsidence of 400 metres (or 1300 feet) is, after all, but a small fraction, that is, less than one-tenth of the maximum elevation of the Alps;

and that the rise of temperature corresponding to that subsidence would not be more than 2° Cent. or 3·6° Fahr., which is about equal to the difference between the present mean Subalpine temperature north and south of the Alps,[1] for example between Zurich and Lugano (9° and 11° Cent. respectively), and would be insufficient to affect materially the conditions under which a general advance of the ice might take place. Whether the zonal subsidence, and, with it, the formation of the present lake-basins, must be assigned to the first or second inter-Glacial Period, or to a yet later date, is still an open question with which I propose to deal in a future paper.

(5) So far as the immediate scope of the present paper is concerned, I hope to have shown conclusively that the pre-Glacial existence of the principal river-valleys and lake-basins of Subalpine France and Switzerland, in their present form and depth, can no longer be maintained in face of the evidence of the extensive Molasse-plateaux upon which the fluviatile products of the Pliocene glaciation were deposited. Equally untenable appears, in face of that evidence, the view that the Rhône-Valley conglomerate known as 'alluvion ancienne' is either pre-Glacial or Quaternary. Deposits of such Pliocene Glacio-Fluviatile alluvia abound in the whole region between the Jura and the Cevennes above Lyons, in the Rhône Valley below Lyons, between the Dauphinese Alps and the Cevennes, in the Valley of the Po and elsewhere at the base of the Alps; and it may safely be averred that the more they are studied, the more will the formerly accepted views with regard to their character and origin, and to the contour of Alpine and Subalpine valleys towards the end of Tertiary times, come to be modified.

Discussion.

Prof. Bonney expressed his regret at the absence of the Author, for the paper required a more detailed explanation than could be conveyed by an abstract, necessarily condensed. So, as he knew the ground, he would venture to state to the Fellows, in a slightly different form, the problem which this paper attempted to solve,—a problem which, in the speaker's opinion, was one of the most difficult presented by the later geology of the Alps. Having done this, he said that the hypothesis, though rather startling in the magnitude of the denudation assigned to a single interval in the glaciation of the Alps, did remove some difficulties which hitherto had been most perplexing. But he thought it possible that some of the patches of Deckenschotter might be newer than others, and that denudation and deposition might have gone on *pari passu* prior to the second advance of the ice. If any part of the Höngg gravel

[1] Or the difference between the present mean temperature of districts on the same side of the Alps: for example Geneva, Bâle, and Lucerne (9·5° Cent.), Berne (8·3° Cent.), and St. Gall (7·5° Cent.).

was Deckenschotter, as it was said to be when he saw it, this must be so. In any case, he was disposed to look upon the formation of the actual lake-basin of Zurich as a yet later phenomenon than the second glaciation, for he did not see how the gravels below the town could be formed, if the lake existed, unless they were all attributed to the Sihl, which he thought improbable. The amount of zonal subsidence required by the Author, though large, was not impossible, but it meant that the valley-systems above the lake would be higher than their present elevation by 1300 feet, and probably more. They proceed, however, from a rather low part of the Alps, and this elevation-hypothesis explains some difficulties—among others, the change from excavating to filling-up the main valleys like those of the Limmat and Rhine. He thought it probable that this paper, which abandoned one very important position taken up in the former one, might require modification in the future; but it was, nevertheless, valuable as supplying an explanation of some very perplexing problems.

The Rev. Edwin Hill also regretted the Author's absence. He would have liked to learn his views on the age of the diversion of the Sihl channel from the Lake of Zurich, as to which his former paper gave such interesting particulars.

Mr. H. W. Monckton said that he had some hesitation in criticizing a paper of which he had only heard a comparatively short abstract. He considered the Deckenschotter of the Uetliberg, alluded to by the previous speakers, a very difficult deposit to explain. The underlying glacial bed seemed to show the presence of large glaciers, and he thought it possible that the Deckenschotter itself might be more or less of glacial origin, and suggested the possibility that the valley of the Lake of Zurich might have been full of ice at the time of its deposition.

Prof. Sollas enquired whether some of the difficulties of the Author's explanation might not be met on the supposition that the Lake of Zurich and the Valley of the Limmat were already in existence before the deposition of the Deckenschotter, but filled with ice during this deposition. The presence of 'grundmoräne' below the Deckenschotter pointed to the existence of a considerable body of ice, the intra- and infra-morainic material of which would become converted, as the ice melted away, into pebbles. The esker-material, as seen in Ireland, showed that large quantities of rounded pebbles might be formed during the melting of glaciers and before their final disappearance.

Prof. Bonney, in reply to a request from the President, said that as, when he had visited a country, he retained in his memory what he had seen better than what he had read, he could not undertake to say at the moment how far the Author was in accordance with, or differed from, the Swiss geologists. In regard to remarks which had been made, he said that he did not think that the 'first moraine' required the ice to have been thick above it, and that the Deckenschotter had but little resemblance to the materials of an esker. It was true fluviatile gravel, not at all unlike that now filling the bed of the Limmat Valley, as indeed was proved by the difficulties of distinguishing them at Höngg and Baden. It had once been much more extensive, the isolated patches on the map having been, in many cases at least, formerly continuous.

Postscript to Discussion.

[The Author, in regretting his unavoidable absence, and thanking Prof. Bonney for his kindness in more fully explaining the subject of the paper to the meeting, observes that, no doubt, during the long inter-Glacial (Upper Pleistocene) Period which followed upon the first glaciation, erosion and denudation on the one hand, and deposition on the other, went on *pari passu*, the plateau-gravel being thus, by re-transport, gradually carried farther out and deposited in the lowland valleys as these were being deepened. In that sense, the Glacial, Glacio-Fluviatile, and inter-Glacial gravels, deposited in the interval between two glaciations, may be said to form groups, rather than constitute one single formation. With regard to Prof. Bonney's view that the present Zurich lake-basin may have been formed after, and not before, the second glaciation, there are, in the Author's view, various reasons for and against it; he proposes to revert to the very complex question of the age of the Subalpine lake-basins in a future paper.

In reply to the Rev. E. Hill's inquiry as to the age of the deflection of the River Sihl (by a moraine-wall) from its original outlet into the Linth (or Zurich Lake) Valley, the Author holds that the present Sihl Valley, running parallel to the present lake from the point of deflection to its junction with the Limmat below Zurich, is post-Glacial, and affords an instructive instance of the remarkable erosive power of a comparatively small river, which has already cut its new bed in moraine, gravel, and Molasse to a depth of more than 100 metres, and is chiefly responsible for the rapid denudation of the Uetli range.

In reply to Mr. Monckton's and Prof. Sollas's remarks, the Author observes that if the evidence adduced by him of the existence of a Subalpine Molasse-plateau at the advent of the first glaciation is correct, the Limmat Valley could not have been filled with ice at the time when the Uetli Deckenschotter was deposited. He agrees with Prof. Bonney that the moraine underlying the Uetliberg Deckenschotter does not point to the presence of a large body of ice, such as the glaciers of the second or maximum glaciation which filled the then excavated valleys and, passing in many places over the Deckenschotter-cliffs, left large masses of moraine overlying the same.[1]

With reference to the views of Swiss geologists on the subject of

[1] As, for example, in Northern Switzerland on Albis, Heitersberg (depth of overlying moraine = 150 to 300 feet), Bruggerberg, Siggenberg, Mount Irschel, and Berg, near Rheinfelden; and in the Rhône Valley generally, throughout its whole length from Lausanne to Lyons.

Deckenschotter, as to which some of the speakers enquired, the Author observes that the more recent writers on 'Cavernous Nagelfluh,' as it is locally called, are the late Dr. Wettstein,[1] Prof. Mühlberg,[2] the late Dr. L. Du Pasquier,[3] and Dr. Æppli.[4] The first of these regarded the Uetli deposits, and generally all the compact or loose conglomerates of the Zurich district which exhibit cementation, as Glacial, but without reference to a Pliocene glaciation. Prof. Mühlberg's investigations bear exclusively on the gravels of the Canton of Aargau, and, with a leaning to the latest views of Prof. Penck and Prof. Brückner, he assumes five glaciations. The late Dr. Du Pasquier examined more especially the alluvia of the Aare and Rhine Valleys between Aarau and Bâle, dividing them into Deckenschotter, Upper- and Lower-Terrace Gravels in relation to the three glaciations; and Dr. Æppli adopts the same division for the gravel-deposits of the Limmat Valley and round the Lake of Zurich. Thus each of these writers confines himself, in the main, to a separate, more or less prescribed local area. So far as the Author is aware, his paper is the first attempt to deal comprehensively with the subject, by drawing conclusions from an examination of the whole Subalpine region extending from the base of the Alps to the Rhine near Bâle, and the same applies to the Rhône Valley from Lausanne to Bellegarde and Lyons.—*May 31st, 1902.*]

[1] 'Geologie von Zurich' 1885.

[2] 'Erratische Bildungen im Aargau' Mitth. d. Aarg. naturforsch. Gesellsch. 1869, 1878, & 1885.

[3] Beiträge zur Geol. Karte d. Schweiz, vol. xxxi (1891).

[4] *Ibid.* vol. xxxiv (1894).

29. *A* System *of* Glacier-Lakes *in the* Cleveland Hills. By Percy Fry Kendall, Esq., F.G.S., Lecturer on Geology at the Yorkshire College, Leeds. (Read January 8th, 1902.)

[Plates XX–XXVIII.]

Contents.

I. Introductory.

It is now 8 years since I commenced observations upon the Glacial phenomena of the Cleveland area—using the term in its broadest sense as including the whole of the Jurassic mass of North-eastern Yorkshire, but no results were attained in the first 5 years. The investigation, however, of a tract of country on the western edge of the Vale of York familiarized me with many of the more patent signs of old glacier-lakes, especially the phenomena of abandoned overflows, and this experience enabled me to recognize the great Newton-Dale valley as belonging to this category. Following this clue backward, I discovered the great system of lakes and related phenomena now to be described.

The progress of the investigation of the area west of the Ouse has been briefly recorded in papers submitted to the British Association,[1] and on various occasions has been communicated to the Yorkshire Geological & Polytechnic Society.[2] A new stimulus to these studies was given by Prof. W. M. Davis, who accompanied me

[1] Rep. Brit. Assoc. 1896 (Liverpool) p. 801, & *ibid.* 1899 (Dover) p. 743.

[2] Proc. York. Geol. & Polyt. Soc. n.s. vol. xii (1893) pp. 306–18, & *ibid.* vol. xiii (1895) pp. 89–91.

in the examination of a tract of country round Knaresborough, where an extra-morainic diversion of the River Nidd and some other lake-overflows are well displayed. Prof. Davis on that occasion mentioned some work of a like nature which was engaging the attention of Prof. G. K. Gilbert; and I am impelled to mention the fact, as this statement of Prof. Gilbert's views undoubtedly aided me, to how great an extent I am unable to say.

II. Modern extra-Morainic Lakes.

Whenever a glacier or ice-sheet advances against or across the general slope of a country which is not occupied by ice, there will be a tendency to impound the natural drainage and to produce lakes. Such lakes, from their position, have been termed extra-morainic lakes,[1]—a term not wholly free from objection, as some ice-masses are not margined by any recognizable moraine; and, again, some such lakes lie between the lobes or ridges of a moraine. But, with a reservation to cover all these cases, the term may be conveniently adopted.

The Alps furnish few examples of these lakes, as they are best developed where the relief of the country is low and the ice-streams are large. The Märjelen See is the best known, though not the only, glacier-lakelet of the Alps. It has been admirably described by many writers, the best description in English being that given by Dr. Du Riche Preller.[2] The present writer has also published some notes upon the lakelet and its floor-deposits.[3]

Norway, with its more extensive ice-fields, furnishes more numerous and varied examples, such as the Dæmmevand described by Capt. A. F. Mockler Ferryman[4] and Dr. P. A. Œyen.[5] It is, however, to the gigantic 'piedmont' glaciers of Arctic America and the ice-sheet of Greenland that we must look for our best illustrations of this class of phenomena. These great ice-floods must, in the nature of things, more frequently oppose and impound the drainage of the ice-free country than could be the case with greatly-crevassed glaciers flowing for a few miles down steep mountain-valleys.

The chain of lakes held up in the Chaix Hills by the ice-stress of the Malaspina Glacier are of great interest, and geologists will welcome a fuller description of them than that contained in Prof. I. C. Russell's masterly memoir.[6]

The great ice-sheet of Grinnell Land sustains marginal lakes of large size, described by Gen. Greely in his 'Three Years of Arctic Service'; but around the lobes of the Greenlandic ice-cap they are to be found in the greatest number and perfection.[7] I would

[1] Carvill Lewis, Rep. Brit. Assoc. 1887 (Manchester) p. 691.
[2] Geol. Mag. 1896, p. 97.
[3] Glac. Mag. vol. iii (1895) pp. 127–28.
[4] Geogr. Journ. vol. iv (1894) p. 524.
[5] Bergens Museums Aarbog (1894–95) no. iii.
[6] 'Glaciers of North America' Boston, 1897, pp. 118–21.
[7] T. C. Chamberlin, 'Glacial Studies in Greenland' Journ. of Geol. vols. ii, iii, & iv (1894–96).

refer especially to Prof. R. S. Tarr's brief but highly interesting account of the lakelets that fringe the Cornell Glacier on the Nugsuak Peninsula.[1] Prof. Tarr furnishes a description of the deltas and floor-deposits of these lakelets, which will be found of great value for comparison with the relics of similar lakelets in Britain.

III. Pleistocene Lakes, and the Criteria for their Recognition.

It might have been predicted that proofs would be forthcoming that extra-morainic lakes of Pleistocene age had prevailed over areas extensive in proportion to the great magnitude of the ice-sheets. Traces of several such lakes have been recognized, the most important of which is, undoubtedly, the gigantic Lake Agassiz, the waters of which covered half a million square miles in North America. This lake has a claim to consideration, apart from its mere magnitude, as it appears to have been first in order of discovery as well as in point of size. Keating inferred the presence of a lake on this site so long ago as 1823, but probably to Gen. Warren should belong the credit of clearly demonstrating its existence. A noteworthy series of lesser lakes in the neighbourhood of Rochester (N.Y.), has been well described by Mr. H. L. Fairchild,[2] and the investigations of Prof. G. K. Gilbert upon a similar series have been referred to. Many other examples in North America have been described. The only lakes having such an origin that have been recognized in this country, so far as I am aware, are:—a lake enclosed in the valley of the Black Cart, behind (south of) Glasgow, identified by my lamented friend the late Mr. Dugald Bell of Glasgow,[3] and independently by Prof. James Geikie[4]; another in the valley of the Tweed, also discovered by Prof. Geikie[5]; the Glen-Roy Lakes, the lacustrine nature of which was first conclusively shown by Mr. T. F. Jamieson[6]; a great lake in the Vale of Pickering, postulated upon very inconclusive grounds by Phillips and other writers, but demonstrated in a very clear and convincing manner by Mr. C. Fox-Strangways[7]; and a great series of extra-morainic lakes described by the late Prof. Carvill Lewis.[8]

The criteria by which ancient extra-morainic lakes can be recognized are mainly four:—(1) beaches; (2) deltas; (3) floor-deposits; and (4) overflow-channels. But to these might be added the *a priori* arguments of Prof. Carvill Lewis, who considered that the existence of lakes could be deduced from the ascertained position of the ice-front, a process of deduction upon which I have never relied, except when reinforced by the direct testimony of one or more

[1] Amer. Geol. vol. xx (1897) pp. 150 *et seqq.*
[2] Am. Journ. Sci. ser. 4, vol. vii (1899) pp. 249–63.
[3] Trans. Geol. Soc. Glasgow, vol. iv (1874) p. 66.
[4] 'Great Ice Age' 1st ed. (1874) pp. 186 *et seqq.*
[5] *Ibid.* 2nd ed. (1877) p. 144.
[6] Quart. Journ. Geol. Soc. vol. xix (1863) p. 235.
[7] Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. i (1892) p. 423.
[8] Rep. Brit. Assoc. 1887 (Manchester) p. 692.

of the phenomena mentioned above. Mr. Warren Upham, in his masterly monograph upon the glacial Lake Agassiz,[1] has reviewed these criteria with his customary clearness; but, although his descriptions may be confidently recommended for study by British geologists, they deal with phenomena upon a scale of magnitude so far transcending that upon which such features are developed in Britain, that I am constrained to furnish a brief account more applicable to experience in this country. Moreover, Mr. Upham addresses a scientific public which is practically unanimous in accepting his premises of great confluent glaciers, and in rejecting the suggestion of marine action as a cause of the bulk of the Pleistocene deposits, whereas, in Britain, these views have not as yet received unanimous sanction.

(1) Beaches.—The occurrence of beach-lines, whether consisting of detrital accumulations or of mere shore-scarps, is clear proof of the former presence of static waters; but no absolute proof, apart from included organisms, can be adduced to show whether sea- or fresh-water was the agent.

The little Märjelen See is margined by an excellently defined beach, consisting for the most part of an arrested talus of large angular blocks which have rolled or crept down the adjacent mountain-sides, with some blocks rafted out by floating ice. The upper level of the beach coincides with that of the col across which the overflow takes place, or did formerly take place (that is, before the great drainage-tunnel was made by the Cantonal authorities). The series of lakes in the Glen-Roy district was recognized solely by the evidence of such beaches, which form a series of sensibly horizontal benches along the mountain-sides, so conspicuous as to have become the subject of a popular legend. Mr. Jamieson demonstrated that they were the strand-lines of ice-dammed lakes, chiefly by the evidence of the coincidence of their respective altitudes with those of the cols across which drainage could have occurred. The beaches of Lake Agassiz are upon a vast scale, and show a noteworthy deformation in a vertical sense: they do not consist of arrested talus merely, but are composed of sand and well-rolled shingle. Mr. Fox-Strangways found few signs of the beaches of his Lake Pickering; and I am unable to cite a single well-marked example in the Cleveland area, where, if the conditions had been favourable, there should be hundreds, each representing either a separate lake or a separate phase of a particular lake. Shore-scarps are quite common, but they are (with two or three exceptions) impersistent. I have seen in several places sections in these scarps, and these will be mentioned in the sequel. Some show well-bedded dirty gravel, and in others a rubble of angular and rounded fragments of local rock with some foreign stones, all resting against a greatly-shattered face of sandstone. Occasionally the hillsides are seen to be furrowed by many scarps half-obliterated by weathering or by the action of the plough,

[1] Monogr. U.S. Geol. Surv. vol. xxv (1896).

and running at different levels for 1 or 2 furlongs. The reason for this general absence or imperfect development of beach-lines in the Cleveland area admits of a very simple and natural explanation. For their production, stability of the water-level during a considerable period is one of the great requisites, abundance of beach-forming material the other. The occurrence of successive sea-beaches round the coasts of Scotland and Norway does not imply that the land rose *per saltum*, but rather that there were protracted periods of comparative repose and beach-formation, followed by periods of movement, slow, yet sufficiently rapid to prevent the accumulation of a recognizable beach. Again, the beaches are not horizontally continuous, but are interrupted where the supply of beach-making material was deficient.

In the case of a glacier-lake, the stability of the level will be determined by the constancy of the position and altitude of the ice-dam, and the rate of erosion of the channel by which the overflow takes place. The former factor cannot in the generality of cases be evaluated, but the latter is much more easily determined. It will depend upon the volume of water to be carried, the fall, and the nature of the rock at the overflow. In the cases of both the Märjelen See and the Glen-Roy Lakes, the overflow takes place (or took place) over hard crystalline rock, which is very slowly eroded, and consequently the lake-levels were very stable and the beaches are large and well-defined. The overflows of the Cleveland Lakes were over Jurassic rocks, for the most part soft shales ; hence they were cut down rapidly, and little or no beach-formation resulted. In a few cases the sills were cut down on to hard beds of grit; and it is at levels coincident with these that the best-defined strand-lines occur.

(2) Deltas.—When a stream carrying sand or gravel enters standing water, the detrital materials are cast down in the form of a fan, the surface of which is just below the highwater or flood-level. If debouching into the sea, the fan shelves off into the deep with a continuous slope, while a lake-delta usually terminates with an abrupt face.

Mr. Jamieson, and observers who preceded him, found that the deltas of streams flowing into the Glen-Roy Lakes were very well-defined at the point where they coalesced with the beaches. In the Cleveland area such deltas are rarely seen, but some examples exist, especially in the valley of the Esk. They occasionally exhibit the fanlike form and steep scarp of lacustrine deltas, but more often they are simply patches of current-bedded sand and gravel occurring isolated at the beach-level where some stream has debouched, generally the overflow from another lake.

(3) Floor-deposits.—The late Mr. Dugald Bell and Prof. James Geikie have alluded to the deposits which accumulated upon the floor of the Black-Cart Lake ; and the late Prof. Carvill Lewis made reference to the nature of the deposits accumulated in

the extra-morainic lakes identified by him. I shall endeavour to show that he was correct in the ascription of the Warp-clays of the Vale of Pickering to a lacustrine origin as well as the older Warps of the Vale of York. On the other hand, I was impelled, some years ago,[1] to dissent from his identification of the great Chalky Boulder-Clay with lacustrine deposits, an opinion which he shared with the Rev. Edwin Hill. Recent experience has greatly strengthened my conviction that that remarkable deposit was laid down by the direct agency of land-ice. Mr. Fox-Strangways expressed the opinion that the Warp and other alluvium of the Vale of Pickering was either of lacustrine or estuarine origin.

It will be seen that, in this country, considerable uncertainty prevails regarding the materials which might be accumulated under lacustrine conditions; and I may well at this stage define my own position upon the question, with specific reference to the accumulations in glacier-lakes.

I have had the opportunity of examining the deposits of two well-known lakelets held up by glacier-ice in the Alps, namely, the Gorner See and the Märjelen See. The former of these is mainly super-glacial in position: it lay in 1894 in the angle formed by the confluence of the Grenz and Monte Rosa Glaciers, tributaries of the Gorner, and its floor was composed chiefly of ice, though along one of its free sides it abutted upon a spur of Monte Rosa, and the right lateral moraine and rock-train of the Grenz Glacier descended beneath the water. The waters of the lake are prone to rapid lowering of level at very irregular intervals, dependent upon the production of the crevasses by which they are drawn off. I have at one season seen the shallow basin filled almost to the point at which it would flow off over the ice, and at another season have found the icy bed almost completely exposed, with large blocks of ice lying stranded near the old margin. On both occasions I observed that, besides the large masses of rock from the rock-train which were strewn promiscuously about, the deserted bed was covered with a deposit of very fine mud, perhaps glacier-meal washed in by a stream flowing beside the Grenz Glacier.

At the time of my visit to the Märjelen See, the lakelet was approaching the condition of repletion which would bring into action the new artificial drain, but there was still a large area of its floor exposed. This was mainly composed of a bouldery-rubble covered with a film of fine mud, but in some hollows I found a gritty clay with stones, resembling ordinary moraine-stuff.

Thus far only extends my personal experience of the deposits of *modern* glacier-lakes; but Prof. Chamberlin, in his valuable papers on the Greenlandic glaciers, and Prof. Tarr, in his description of the Cornell Glacier of the Nugsuak Peninsula, have furnished data of the greatest value relative to the floor-deposits of some of the countless glacier-dammed lakes of the Arctic regions. Reference

[1] 'Man & the Glacial Period,' by G. F. Wright, Internat. Sci. Series, 1892, p. 159.

must also be made to the fjord-muds so well described by Rink and others, for these muds, though accumulated under tidal conditions, must have many features in common with the deposits of glacier-lakes.

The study of lacustrine formations other than those of glacier-lakes is also germane to the present enquiry, for the differences will be only in the details, and especially in two of them—the amount and character of the mud, and the presence and character of included organic remains. Reference may therefore be made to the extensive literature of limnology, and especially to Prof. F. A. Forel's monograph 'Le Léman' vol. i (1892) pp. 101–139; Dr. H. R. Mill's valuable description of the English Lakes[1]; and Mr. Upham's monograph on Lake Agassiz.[2]

The Lake of Geneva, which differs from the largest of British Pleistocene lakes chiefly in the absence of any direct contact with the glaciers that feed it, might be taken as a typical area of lacustrine accumulation, and a general description of its floor-deposits will be helpful to our understanding of the general conditions of deposition.

At the point where the Rhône debouches into the lake, near Villeneuve and Bouverie, the river casts down its great load of shingle, and is gradually pushing its mouth forward into the lake. Beyond the gravel, finer materials are cast down within a short distance of the mouth of the river; and beyond this again the fine glacier-mud, with which the Rhône is so heavily charged, is wafted on and laid down over a wide area as a deposit of impalpable mud of exceeding fineness. The seasonal and diurnal augmentations of volume which affect the Rhône, must carry sediments of a different grade out to the regions of finest sediment, and so it might be anticipated that the fine clays would show interlaminations of coarser material. Interlaminations of materials differing more in colour than in texture must also occur. The bed of the Lake of Geneva is not sufficiently well exposed to enable me to support these generalities by actual observation, but fine laminated muds have been found in the exploration of lake-dwellings in seasons of exceptional dryness, when the lake-levels were lowered.

If the Lake of Geneva were held up by an ice-dam, as the Märjelen See is, we might expect to find stony clays, resembling those of the Märjelen See, and perhaps actual moraine, accumulating near the ice; while farther away laminated clays might be expected to prevail, and to contain occasional stones, large and small, which had been rafted out by bergs breaking off from the ice-front or by shore-ice. Such sporadic boulders and pebbles do occur sparsely in some of the Warps of Yorkshire.

Some means of distinguishing, however, between the flood-alluvium of rivers and these lacustrine deposits seems to be a desideratum, and as the result of the examination of a large number of sections of river-silt in the magnificent exposures opened in the excavation

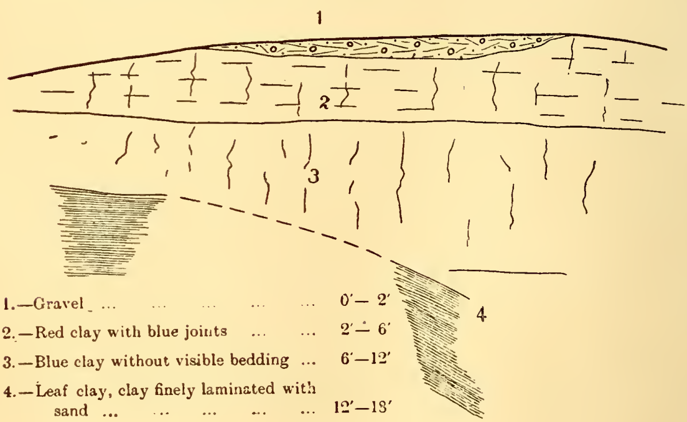
[1] Geogr. Journ. vol. iv (1894) p. 237.
[2] Monogr. U.S. Geol. Surv. vol. xxv (1896).

of the Manchester Ship-Canal, and the comparison of the materials with the Warps of Yorkshire, I have obtained, as I believe, a means of discrimination.

Flood-alluvia are cast down upon meadows through which the streams meander, and consequently the area occupied by them presents very little relief: hence upon our geological maps we find these flat meadows marked as alluvium, the boundaries following the feature against which the deposits halt. The flood-alluvium is cast upon a surface well covered with herbage, and consequently any bedding which it may display is irregular, and is liable to obliteration by penetration of roots and by other agencies.

Take, now, the case of a lacustrine deposit—it is dropped over the whole floor of the lake, which may have a greatly diversified and undulating surface, upon which the mud will lie as a nearly uniform mantle. There may be absolutely no vegetation upon the lake-bottom, either to produce any original irregularity, or to efface eventually the laminations; consequently such limnal muds may be expected frequently to display close and regular laminations, which, being parallel to the subjacent surface, may be highly inclined.[1]

Fig. 1.—*Section at Danby Brick-and-Tile Works.*

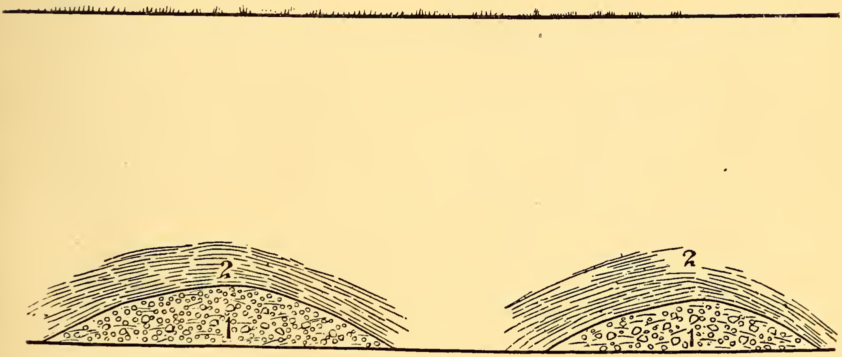


Anyone who has studied the ancient Warps of Yorkshire will know how generally these characters, which I have regarded as indicative of lacustrine origin, are present. The late Canon Atkinson in his fascinating book, 'Forty Years in a Moorland Parish,' describes a sort of prophetic vision of a great lake in Upper Eskdale (where, as I shall show in the sequel, a glacier-lake of large dimensions probably existed); and he justifies his vaticinations by one piece of geological evidence, the exceedingly close and regular laminations of the Warp-clays of the district. The exposure to which he refers certainly furnishes me with my clearest and best illustration. This section is exposed in a pit at Danby Brick-and-Tile Works (fig. 1, p. 478).

The red and blue clays display no visible bedding, but the leaf-clay (that to which Canon Atkinson referred) contains interlaminations of exceedingly fine sand. He mentions between 24 and 30 alternations in 4 inches, but this is an underestimate. A specimen which I took shows 24 coarser layers to the inch, and each of these includes about 8 finer laminæ, making in all about 200 laminæ to the inch. The laminations at one side of the section show a high north-easterly dip. Occasional stones, flat, and 'as large as a tile,' are said to occur. One such large stone yielded, when broken up, about half a cartload of fragments. The leaf-clay unfortunately has not been penetrated by the excavation; and at the Tile-Works in Little Fryup, a boring was put down 60 feet in laminated clay without reaching the Lias.[1]

A section (fig. 2) in the brickyards at Dringhouses, west of York, gives an instructive view of similar beds with the underlying deposits. The section was drawn in my notebook in 1895, before I had recognized its significance. The brickyard is situated between the reticulated northern series of morainic hills, and the single sharply-defined moraine-ridge that is so conspicuous a feature for 4 or 5 miles to the westward of York.

Fig. 2.—*Section in the brickyard at Dringhouses, York.*



[1=Gravel; 2=Laminated clay (Warp).]

My notes state that the laminations are parallel to the surface of the gravel, to the height of 10 or 12 feet above it. A visit paid to the section a few days before the reading of this paper, showed that the gravel-mound had been cut away to the floor-level of the pit, but the steeply-inclined laminæ of the Warp could be observed dipping into the face of the section.

[1] Mem. Geol. Surv. 'Eskdale & Rosedale' 1885, p. 51. It is important to observe that this is mapped as Boulder-Clay, no doubt because of the absence of alluvial features.

(4) Overflow-channels.—The overflows of glacier-lakes have attracted but little attention in this country. Those of the Glen-Roy Lakes, so far as can be gathered from descriptions, present no marked features of eroded channels, but are merely scoured cols which have been swept fairly clean by the effluents of the lakes. Nevertheless I think that one or two of them show features of particular interest, judging by the maps and the behaviour of some streams related to them. Dugald Bell appears to have been the first geologist to have recognized that an ancient lake might be postulated from its overflow with as great certainty as by any other sign ; and as I have already remarked, he described [1] a lake-overflow at Dalry, enforcing his conclusion by the evidence of floor-deposits. Prof. James Geikie made similar observations quite independently.[2]

In America such phenomena are among the regular data of glacialists. The most noteworthy in the whole continent is no doubt the great overflow of Lake Agassiz, known as the Warren River, which is described at length by Mr. Upham in his monograph already cited. Mr. Upham, in allusion to these phenomena, says that he regards them as evidences of glacial lakes 'the most invariably recognizable and the most definite in their testimony,' an opinion which I most cordially endorse.

As these features are but little known to British geologists, and my experience of them extends to over three hundred examples, chiefly in Yorkshire, but also in Northumberland, Westmoreland, Lancashire, Cheshire, and Lincolnshire, it seems desirable that I should describe the general characters with some care, the more so as I have placed my chief reliance upon them in the identification of the series of lakes which form the subject of this paper.

When an ice-sheet or glacier obstructs the drainage of a country, the water is impounded so as to form a lake, which will find an escape either through, or over, the ice ; or, by overflowing, by some col or spur in the surrounding watershed.

In the former case, the evidence remaining to the geologist after the disappearance of the glacier will consist solely of beaches, deltas, and lacustrine deposits ; but in the latter, and in such a country as ours, the more common case, of overflow across a col, or spur, the water proceeds to cut for itself a channel. The deepening of this channel may be swift or slow according to local conditions. Upon the withdrawal of the ice, it may be that a morainic obstruction may be left across the valley of such a height that a lake may persist for a considerable period, until, in fact, the overflow has cut far enough down to drain it, and then remains as the permanent course of the drainage. Or the overflow-channel may have cut

[1] Trans. Geol. Soc. Glasgow, vol. iv (1874) p. 66.

[2] 'Great Ice Age' 2nd ed. (1877) p. 146. I ought, however, to point out that a consideration of the peculiar conditions prevailing in the Clyde area at the close of the Glacial Period seems to forbid the ascription of any considerable part of the excavation of the valley in question to a lake-overflow of the same date as the deposits.

down during the persistence of the ice-barrier; and when this happens, we find the events recorded in the form of a river-gorge of a breadth disproportionately small as compared with the magnitude of the stream, and an abandoned valley of a normal form obstructed near the deviation by the moraine.

Such a gorge is that of the River Nidd near Knaresborough, described by me in a paper presented to the British Association in 1896.[1] In other cases, it may happen that upon the retreat of the obstructing ice the drainage may be resumed upon the original lines, though perhaps over a raised floor of Drift. When this is the case, the temporary overflow-channel will be abandoned, and will thereafter carry only such small amount of drainage as belongs to its own very limited catchment, sometimes even none at all.

Here now are two distinct types of anomaly in valleys both bearing the cañon-like aspect that tells of rapid erosion: but in one case the valley is narrow out of proportion to the stream that occupies it; in the other the stream, if stream there be, is disproportionately small for the valley. In every district in which I have found these evidences, both types occur; often, where a chain of parallel lakes existed draining one into another, the two types of valleys occur in rough alternation, as in the country between the Ure and the Wharfe from Hackfall to Tadcaster.

The anomalous valleys which at present constitute the main drainage-channels of Cleveland, present no special features to which I need devote attention here. Their recognition is easy, and their characters simple; but the deserted channels, having remained practically unchanged from the time of the departure of the ice, with all their characteristics unimpaired, are of singular interest and demand careful consideration. They appeal to me as perhaps the most impressive memorials of the Ice-Age that our country contains.

IV. General Character of the Abandoned Channels.

These valleys conform to four principal types in regard to position.

(1) Direct overflows.—Those which trench the main watershed of a country so that the overflow is directly away from the ice—these may for convenience of reference be termed *direct overflows*. The finest example in the Cleveland area is Newton Dale. Direct overflows are usually found to trench only the lowest cols of a given watershed, except where the obstructing ice has approached very near to the watershed. They generally occur singly, one overflow serving for the drainage of a considerable area of the iceward side of the country; but when the watershed is very uniform in height, and the ice has at one stage actually surmounted it, then several parallel overflows may be developed out of the gutters which are trenched in the outer slope by water

[1] Rep. Brit. Assoc. 1896 (Liverpool) p. 802.

flowing off the ice itself. The overflows, four in number, which cut through the Northern Cleveland watershed above the village of Egton are typical of this arrangement.

(2) Severed spurs.—I have applied this name to those cases where the drainage of minor valleys has been carried across spurs of a main watershed. Such cases arise where the ice-front, being opposed to a main watershed, has impounded the waters of valleys descending towards it at an elevation such that a direct overflow is not available. The waters of the lake then discharge, either across a depression of the spur, or by a channel cut on its outer face along the edge of the ice. The former case differs in no essentials from a direct overflow, but the latter constitutes my third type.

(3) Marginal overflows.—These are at first merely shelves cut in the hillside, and developed subsequently into actual gorges. Some marginal overflows cease to operate before reaching the 'gorge stage,' and in the Cleveland area every stage is represented.

In some instances a marginal overflow had its iceward side composed of moraine, and in other instances entirely of ice. The marginal overflows and severed spurs often are arranged in series, which may be of two kinds—the aligned sequence and the parallel sequence.

An aligned sequence is one in which several valleys may be obstructed, and drain from one to another by severed spurs, until free escape is offered either laterally or directly. These aligned series will all have their fall in the same direction, and the lake-levels will be successively lower along the series until the main escape is reached. When considering the evidence of any direct overflow, I have only in rare instances admitted the validity of the proof where no related severed spurs could be found to corroborate the available data.

In studying the severed spurs, with their variants, in an aligned sequence, no surprise need be felt if two spurs are severed, while an intervening one of equal prominence remains intact. The ice-margin has commonly been very sinuous, and even lobate, and a lakelet might stretch across two valleys or more. Very often it has happened that an aligned sequence has been modified by a differential retreat of the ice-margin, causing one lake to persist longer than another. Thus a retreat of the ice-front near the lower end of a series may throw some intermediate channel out of operation, while its neighbours, above and below, continue to fulfil their functions and to cut lower.

Upon a comparison of levels, we find that the intermediate channel is at a higher altitude than its neighbour up stream. The same statement may apply to a marginal overflow that has an ice-wall in the middle part of its course. A retreat of the ice up to this point may allow of a 'lateral escape' being formed, and the upper segment of the overflow may cut deeper than the lower. An example of this is afforded by the Murk-Mire-Moor channel.

A retreat from the upstream segment of a marginal overflow will produce a 'lateral intake.'

The other kind of serial development I have termed a parallel or successive sequence. These series, which frequently have also an alignment, consist of repeated trenchings of the same spur by parallel overflows. They are produced by an intermittent retreat of the ice-front, uncovering successively lower slopes of a hillside. It is satisfactory in these cases to find that the level at which each overflow commences to be cut is below the intake-level of its antecedent. This is beautifully illustrated by the interesting little pair of valleys on Moorsholm Rigg which I have termed 'the Double,' and even better by the splendid series cutting the hills above Hayburn Wike.

Sometimes a parallel sequence may be observed, in which the fall of the channels is in opposite directions in successive valleys of the sequence. This is found in cases where there are two main overflows at opposite ends of an aligned sequence, or where ice-streams from opposite quarters have successively invaded an area.

The clearest case of the latter kind known to me, I observed in the Cheviots between the valley of the Breamish and Roddam Dean [1]; but in Cleveland the former phenomenon is to be well seen near Stanghow, and in a most perplexing development between two main escapes north and south of Scarborough.

(4) In-and-out channels.—These are crescentic valleys excavated in the face of a hill by water flowing round a projecting lobe of ice. Two admirable examples are known to me in Cleveland, one detaching the hill known as Stony Ruck near Freeborough, and the other the Sunny Brake Valley near Glaisdale (see fig. 20, p. 530).

I may now consider some peculiarities of form displayed by these valleys.

The first feature that strikes the observer is their entire independence of the natural drainage. They cut across the natural watersheds, and frequently are deepest just where they pass through it. This feature it is which appears most decisively to point, not merely to obstructed drainage, but actually to the existence of bodies of standing water.

The fall of these overflow-valleys is usually very small near the head and steepens rapidly down stream, a feature which is rarely observed in normal valleys. The small fall in the upper parts of these channels usually results in the accumulation of peat (to the depth, in some instances, of more than 20 feet), and this produces often a drainage out at the top end which obscures the characteristics of the intake.

The transverse sections of the overflow-valleys are very characteristic: they invariably exhibit exceedingly steep sides, and,

[1] P. F. Kendall & H. B. Muff, Geol. Mag. 1901, p. 513.

where unmodified by subsequent stream-action, possess very broad flat floors. These features are exhibited in their highest perfection in those cases where the valleys have been excavated in very soft rocks, such as the shales of the Lower Estuarine Series: they indicate rapid cutting by a large stream.

The same deduction may be drawn from the character of the 'meanders.' In a large valley of normal drainage, the sinuosities of the valley bear little or no direct relation to the meanderings of the stream, and this independence is the more conspicuous the flatter the floor of the valley is. It is only the banks of the stream that show such a relation, the well-known one that the steep bank is on the outside of a bend, while a gently shelving bank is on the inside. The reason for this is obvious, and need not be enlarged upon. Now, in the valleys which I am describing, the glacial stream fitted the valley so closely that the valley-walls were also the banks and follow the rule just cited.

In each meander of one of these valleys the outer curve is steep, sometimes precipitous, while the inner curve has a more gentle slope. These features are nowhere more beautifully displayed than in the upper portion of Newton Dale above Raindale Mill. Here, for several miles, the railway from Pickering to Whitby runs through a superb cañon having a depth of 300 or 400 feet, and occupied through a part of the distance by a small stream, the Pickering Beck. The outsides of the meanders here are in many places so precipitous as to be unscalable.

It is a noteworthy circumstance, that at Raindale Mill a tributary stream of large size belonging to the normal drainage enters Newton Dale, and below this point the valley takes a nearly rectilinear course without meanders. This may imply that the valley above this confluence has been produced mainly by the lake-overflow, while below it a pre-existing valley of considerable size has simply been deepened and perhaps broadened, its main lines being preserved. The neighbouring normal drainage-valleys on each side of Newton Dale exhibit no such features as the upper part of that valley.

The head of an overflow-valley generally shows some very characteristic features, which may be well studied by the aid of contoured maps where the contour-lines are drawn every 25 feet.[1] As a rule, in ascending such a valley, the sky presently shows through the clear-cut notch of the intake, and on the map successive loops of the lower contours are replaced by lines of the higher elevations passing right through and round the hillsides. On the lakeward

[1] I would here remark that the extremely detailed work which I have been able to do in Yorkshire has been rendered possible only by the very perfect 6-inch contoured maps of the Ordnance Survey. In this favoured county the contours are drawn every 25 feet, whereas in such counties as Northumberland, Cheshire, Westmoreland, and Norfolk, they are drawn at each 100 feet. In comparatively flat Norfolk there are doubtless sheets without a single contour-line. The counties that I have mentioned can never be satisfactorily studied by glacialists, unless a new survey be made.

side the lower contours of a hillside pass unindented across below the intake (see Lady-Bridge Slack, Pl. XXII).

The outfall often displays analogous characteristics, and a valley will open out inconsequently upon a steep hillside. The level at which the debouchure takes place is approximately the level of a lake, but it is often rendered obscure by subsequent cutting on the part of a small stream; the Murk-Mire-Moor and Ringing Keld valleys are, however, practically intact. The intake frequently presents modifications of interest, which corroborate the views here set forth regarding their origin. The head of the valley often makes a sharp turn towards the quarter whence the main overflow took place. For example, the head of Ewe-Crag Slack looks directly westward towards the chain of lakes drained by it, although the main valley runs nearly due north and south. The same feature was observed by Mr. Muff and myself in an overflow at North Bierly, Bradford.

In other cases, a marginal shelf and scarp runs up to the intake, produced, evidently, by the ice being thrust forward against the lake-outflow, just in the same way that the Aletsch Glacier swells forward against the Eggischhorn (fig. 3).

Fig. 3.—*Map of the Märjelen See.*

[Scale: 1:50,000.]

This feature is shown in a very marked manner by the intake of the Moss-Swang Valley at Lords Seat.

At the outfall there is at times to be seen a mass of gravel constituting the delta. The materials usually consist of a preponderance of the materials eroded from the valley, where these are of a sufficiently durable character to form pebbles, together with erratics washed over from the ice-front. Sometimes these deltas are of very large size, and are generally proportioned to the magnitude and duration of the overflow. The largest that I have seen in the Cleveland area are those of Newton Dale, Ewe-Crag Beck, Tranmire (or Stonegate), and Forge Valley.

In connection with this I may mention a minor though interesting feature of outfalls, their bifurcation. Two quite distinct causes must be assigned. In an example in Cleveland at Smeathorne, a marginal overflow has bifurcated in consequence of a slight recession of the ice permitting the water which was flowing in contact with it along a hillslope to take a lower course. The other cause of dichotomy at the outfall I have observed only in the Cheviots. The case is that of a pair of lakes, with an intervening spur terminated near the ice-margin by a bold knob. The spur is cut behind the knob by a deep overflow-channel, at the outfall of which a great gravel-delta has been thrown down. The outlet was at first probably over the convex fan of deltaic material, but with a shrinkage of the ice and corresponding lowering of the lake-level, the flow took place along each side of the delta; then a further recession of the ice allowed the lower lake to drain off through a marginal channel, and this gave an advantage to the outfall nearest to the ice, which therefore became the sole outlet. These features are precisely repeated in two adjacent valleys, Monday Cleugh and the gorge behind Hambleton: the marginal outflows can be seen, and I therefore feel some confidence in the explanation.[1]

A remarkable and striking effect of fluctuations in the edge of the ice, both in advances and retreats, is the production of deserted oxbows. These features are peculiar to marginal overflows, never occurring in direct overflows. When the advance of a lobe of ice causes an obstruction of a marginal outflow at one point, then an 'in-and-out' crescentic valley is carved in the opposing hillside to connect the two portions of the valley. This new portion may be cut to such a depth as to become the permanent channel: the part obstructed by ice will therefore never come into use again, and on the withdrawal of the ice may appear as a high-level loop many feet (50 or more) above the functional channel. Such a case is to be seen at Brown Rigg, near Robin Hood's Bay. The more frequent case, however, is that in which the new channel has not been cut so deeply as the old one. In these instances, the withdrawal of the ice has reopened the main channel, and the new bow has been abandoned. The main valley continues to deepen so long as it is in use, and the abandoned bow will remain in singular isolation. Evan-Howe Slack, a quarter of a mile from Brown Rigg (see Pl. XXVI), and the channel which isolates Castle Rigg, in the Moss-Swang overflow near Goathland (see fig. 8, p. 510, & Pl. XXII) present examples of this type.

The last feature which it is necessary to mention, is that these deserted channels, as well as the other type of anomalous valleys (those which now carry one of the main streams of the district), never, or very seldom, receive any considerable tributaries; and when they do, there are usually manifest signs that the tributaries belong to a drainage which was on a much higher plane before the time when the anomalous valley was cut.

Newton Dale, which has served so often as an illustration, may

[1] Details of these will be found in a paper, by Mr. H. B. Muff and the author, read to the Edinburgh Geological Society on March 20th, 1902.

conveniently be taken as typical of this feature also. Above Raindale Mill several tributary streams come in, but they are all very short and of small volume, and it is clear that the main valley could not have been produced by confluence of such elements; moreover, they enter the main valley with a plunging slope, almost every one producing waterfalls, and sometimes sheer drops. They come out on the flat moor-tops 300 feet above the main valley, a few hundred yards above the confluence. It is right to point out that, for a considerable distance, the moor is a plateau corresponding with the top of a hard bed of rock (Kellaways), and therefore the small streams would find it difficult to cut through; but this condition is not general, while the peculiarity of the lateral valleys is.

An alternative possibility which I have had also to keep constantly in view is, that in limestone-rocks streamless valleys may occur which have been produced by normal drainage during the Glacial Period (when all rocks were frozen, and therefore impervious to water), whereas now no streams are possible in consequence of the porosity of the limestone. Such valleys I know well; they abound on the Chalk Wolds, but their characters are quite different from those of Glacial overflows: they do not cut watersheds.

V. Pre-Glacial Level of the Land.

The pre-Glacial level of Yorkshire appears to have been considerably above its present elevation, for borings and mine-workings have proved in many places Drift-filled hollows descending far below sea-level; yet in no case has anything like a sea-bottom or marine deposit been encountered, except in Holderness, to which reference will be made later.

Borings close to the coast prove nothing very definitely, as we do not know the exact form of the pre-Glacial coastline; so that the borings near the mouth of the Tees, stated by Mr. Barrow [1] to prove Drift down to 90 feet below sea-level, do not yield much enlightenment on this particular point; and the borehole at the Grand Hotel, Scarborough, which proved the presence of Boulder-Clay to a depth of 100 feet below sea-level,[2] may well have been *outside* the pre-Glacial shore-line. Right down the great valley from Newcastle to Doncaster, however, there is abundant evidence of a convincing kind. The great wash along the Leam depression described by Nicholas Wood & E. F. Boyd [3] is an old river-valley, Drift-filled at present, which at Gateshead is 140 feet below sea-level.

From the Tees southward, borings indicate a great depth of Drift, until a line connecting Northallerton and Bedale is reached. Here the Drift is shown by boreholes at Northallerton, Thornton-le-Moor, Leeming Lane, and other places to be very thin; and, as it

[1] Mem. Geol. Surv. 'North Cleveland' 1888, p. 68.
[2] Mem. Geol. Surv. 'Oolitic & Cret. Rocks South of Scarborough' 1880, p. 31.
[3] Trans. N. of Engl. Inst. Min. Eng. vol. xiii (1863–64) p. 69.

thickens again to the southward with a falling surface, it is clear that an old watershed extends across the valley.

In the neighbourhood of York, the Drift has in many places been proved to rest upon a rock-floor about 50 feet below sea-level: southward it descends lower still, namely, to 74 feet at Cawood, and in a boring at Barnby Dun, near Doncaster, I saw Drift-clay being brought up from a depth of about 170 feet below Ordnance-datum.[1]

In the Vale of Pickering, according to Mr. Fox-Strangways,[2] the superficial deposits reach a thickness of 107 feet, and

'if the superficial deposits were removed, the sea would again enter this valley to beyond Malton.' (*Loc. cit.* footnote.)

The foregoing facts, especially those regarding the country about York and the Vale of Pickering, show that in pre-Glacial times the land must have stood very much above its present level, the Barnby-Dun boring indicating a minimum of probably 170 feet; but there is a most perplexing complication introduced by the evidence obtainable in Holderness, to which I purpose reverting on some future occasion.

The researches of Mr. Lamplugh have shown that the ancient coastline south of Flamborough Head swept in behind (that is, west and south-west of) Bridlington, and he has admirably described the contents of an old sea-beach, clearly of pre-Glacial age, as it is covered by the oldest Glacial deposits of the district, which lies at the foot of a buried seaworn cliff at Sewerby. This cliff can be traced by borings and other excavations round to the Humber at Hessle; and the whole district of Holderness consists of Glacial deposits resting upon an old plain of marine denudation extending out from the foot of the cliff. The beach is practically at the level of the existing beach.[3] What relation in time this level of the land bore to the period of elevation, when the deep valleys were excavated, it is not easy to ascertain: but the Sewerby-beach stage seems to have been a long one, judging by the magnitude of the denuded floor under Holderness. The excavation of the broad Vale of York must also have been a very slow operation.

No marine or estuarine fossils have been discovered in the superficial deposits of either the Vale of York or that of Pickering, but near Speeton an estuarine deposit of pre-Glacial or early Glacial age occurs at an altitude of 90 feet above sea-level.[4] This, however, is outside the Vale of Pickering, or at least on the seaward face of the Chalk-escarpment which swings round out of the Vale. Moreover, if its present position is due to any general earth-movement, and

[1] I have prepared a map showing the depth of the rock-floor from Seaton Carew to Barnby Dun, which will be published in the Proceedings of the Yorks. Geological & Polytechnic Society.

[2] Mem. Geol Surv. 'Jurassic Rocks of Britain' vol. i (1892) p. 432.

[3] The maximum difference of level does not exceed 5 feet. See G. W. Lamplugh, etc. 'Report on an Ancient Sea-beach' Rep. Brit. Assoc. 1888 (Bath) p. 336.

[4] See G. W. Lamplugh, 'Drifts of Flamborough Head' Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 384.

not, as Mr. Lamplugh thinks, to a local deformation, it proves a lower land-level at that period, not a higher.

The blown-sand and landwash resting on the Sewerby beach do not necessarily imply even a temporary elevation, of however small an amount; for, as the obstruction upon the eastern coast of Britain of the great Scandinavian ice-sheet would be exercised progressively from north to south, and it is probable that the Straits of Dover had not been opened at the beginning of the Glacial Period, the narrowing strait to the northward would admit so little tidal water that the North Sea would become practically tideless, and the highest beaches (namely the 'storm-beach' and springtide beach) would be abandoned by the sea. I think it quite probable that the blown-sand and landwash of the Sewerby section represent this phase, which must have intervened between the abandonment of the beach and the onset of the ice that deposited the Basement Boulder-Clay. Briefly, the evidence of the Vale of Pickering and the Vale of York indicates a long period of pre-Glacial elevation; while the evidence of the Sewerby beach and cliff, with the wide plain of marine denudation which confronts them, shows very clearly that for a long period of time (pre-Glacial or early Glacial) the land-level was practically identical with that of to-day.

How these apparently conflicting results are to be reconciled I cannot undertake to suggest, beyond saying that the different levels were probably successive.

VI. Glacial Deposits and Glaciation of the Cleveland Area.

The Glacial deposits which fringe the Jurassic hill-country of Yorkshire, and penetrate at a few points into the interior of the system, present few features special to the region, save in the matter of distribution and the nature of the included erratics.

Most writers on the subject have recognized a threefold division of the Drift, namely:—

Upper Boulder-Clay;
Middle Sands and Gravels; and
Lower Boulder-Clay.

Few sections exist which show the three divisions superposed, and it appears to be mainly by its relation to a bed of sand or gravel—assumed to be the middle member of the series—that a mass of Boulder-Clay can be pronounced to belong to the Upper or Lower.

In the Geological Survey Memoir on the country round Northallerton, Mr. Fox-Strangways speaks of the 'reddish Upper Boulder-Clay,' and later of the 'Boulder-Clay,' maintaining throughout this region 'its usual character of a stiff clay having a dark colour when unweathered.' He further remarks that 'foreign rocks occur principally in the lower Boulder-Clay, the upper clay is almost stoneless.' It may be gathered from this, that there are two beds of Boulder-Clay—a lower, which is blue, and contains many boulders; and an upper Boulder-Clay, which is red, and almost destitute of included stones. This distinction has not been noted in the area to the south, but Mr. Barrow found that in the Northern Cleveland area the Upper Boulder-Clay was of the same character; while the lower bed differed from that described by Mr. Fox-Strangways only in being of a dark chocolate-colour, varying at Whitby to reddish purple. The same divisions, similarly characterized, are mentioned in the Geological Survey Memoirs on Eskdale & Rosedale, and on the country between Whitby and Scarborough, but in that on the country south of Scarborough no attempt at such a classification is made.

At Flamborough Head and in Holderness, however, the two Boulder-Clays appear with their normal characteristics. I may here remark that a relatively stoneless Upper Boulder-Clay has been recognized by Hull, Mackintosh, and others in Lancashire and Cheshire; but I am not convinced that the distinction is a constant and valid one. The Middle Sands and Gravels form a very unsatisfactory division; and while in some sections they appear to be entirely absent, in others there are several beds intercalated between successive sheets of Boulder-Clay (as, for example, in a boring at Stokesley).

Regarding the relative altitudes which these subdivisions are said to attain upon the hills, there appears to be complete accord among the officers of the Geological Survey. Both Mr. Fox-Strangways and Mr. Barrow remark that the Lower Boulder-Clay is found at much greater altitudes than the Upper Clay, and that the 'Middle Sands and Gravels range still higher.'

Apart from the general statement that foreign stones are more abundant in the Lower than in the Upper Clay, little has been recorded regarding any differences between the erratics contained in the Boulder-Clays. However, information of value has been supplied respecting the boulders contained in the Lower Clay at Whitby. They include Carboniferous Limestone, Magnesian Limestone, Yoredale cherts and sandstones and Shap Granite, along with patches of Lower Liassic shale. These records are of great importance, as they enable us to say that at the time when the oldest Drift-deposits of the district were being accumulated, a transport of erratics from the westward or north-westward had already set in. My own notes record the following stones from the 'Middle Sands and Gravels' in the same cliff:—

Jurassic and other sandstones, Magnesian Limestone, Carboniferous Limestone (not very abundant), basalt, greywacke sandstone and conglomerate ('sparagmite'?), jasper, alum-shale (a large block), *Gryphæa incurva*, and a ball of red Boulder-Clay.

This assemblage is very similar to that in the Lower Clay. Taking the whole of the erratics in the district without particularizing the beds in which they have been found, the following groups may be recognized:—

1. Sedimentary Rocks.

'Greywacke' sandstones and conglomerates; jasper-pebbles; Carboniferous basement-conglomerate (Roman - Fell type); Carboniferous limestones, cherts, grits, and sandstone; Brockram (Permian); red sandstone (perhaps Triassic); grains of red marl (perhaps Triassic); Liassic rocks and fossils representing every division; Jurassic sandstones and limestones; Chalk and flints (generally black, and not of the indigenous Yorkshire type).

2. Metamorphic Rocks.
   Gneisses and schists.
3. Igneous Rocks.
   Granites from the South-west of Scotland (Criffel, etc.); holocrystalline rocks (including Shap Granite), lavas, and ashes from the northern and eastern portions of the Lake District and the Vale of Eden; the Whin Sill, and Cleveland Dyke; porphyrites from the Cheviot Hills; elæolite-syenite, laurvigite, and rhomb-porphyry from the Christiania Fjord. Quartz-porphyries, granites, etc., the place of origin of which is at present doubtful.

The rocks may be grouped, according to the probable or ascertained place of origin, in the following manner:—

I. South-western Scotland.
   Criffel Granite.
II. The Lake District and the Vale of Eden.
   Shap Granite, lavas and ashes of the Borrowdale Series, Brockram, Carboniferous conglomerate, vein-quartz.
III. Teesdale or other valleys of the northern part of the Pennine Range.
   Carboniferous limestones, grits, sandstones, and cherts.
IV. South-eastern Scotland (Valley of the Tweed) and Cheviot Hills.
   'Greywacke' sandstones and conglomerates, jasper, porphyrites.
V. Eastern Durham.
   Magnesian Limestone (botryoidal type of Roker, near Sunderland).
VI. Christiania region.
   Rhomb-porphyries, laurvigite, elæolite-syenite, and perhaps some of the 'greywacke' sandstones and conglomerates ('sparagmite'), many metamorphic rocks.
VII. Gulf of Bothnia.
   Post-Archæan granite of Ångermanland, and probably some quartz-porphyries.
VIII. Denmark, or bed of the North Sea.
   Black flints.

These series may be arranged again in three sets, to indicate the possible routes by which they travelled. Series I, II, & III may well have travelled together in a movement from the Irish Sea by way of the Solway Firth, the Vale of Eden, Stainmoor Pass, and the Tees, probably with a loop-line *via* the Tyne. This may be termed the Western Group.

Series IV and V have probably travelled in company, as the coast of Durham lies immediately in the path from the Cheviots to the Cleveland area. It is possible that some of the Carboniferous rocks and the Whin Sill may have come by this route from Northumberland; but, except the Cheviot porphyrites, no distinctive Northumbrian rock such as the 'Pea-Post' (*Saccammina*-limestone) has yet been found in Yorkshire. It should, however, be pointed out that the Pea-Post is generally an extremely friable rock, unlikely to withstand much rough usage in transport. This may be termed the Northern Group.

Series VI, VII, & VIII, constitute a natural Eastern Group.

The Jurassic rocks and Cleveland Dyke are native to the Cleveland Hills. Mr. Barrow has noted several cases, in which large masses of Lias have been lifted and deposited at a higher level than the adjacent outcrops.

Reference has already been made to the relative distribution in altitude of the different members of the Drift Series. I may now briefly describe the distribution of the Drift as a whole.

The Drift-deposits, including in the term all deposits of Glacial age without reference to the mode of their formation, completely surround the Cleveland area, and extend through the two valleys, the Vale of Pickering and Eskdale, which run in a westerly to easterly direction across the Jurassic outcrop; but, except on the north, they extend only a short distance into the hill-country, and the great valleys which trench the Jurassic dome on the south side of the watershed, as well as the dome itself, are entirely Driftless.

Regarding the northern slopes of the Cleveland area, Mr. Barrow remarks, 'The Drift becomes very thin at 600 feet above sea-level, and disappears altogether above 850 feet.'[1] My own observations in the main confirm those of Mr. Barrow, but as, throughout this work, I have freely used a hand boring-tackle, I have in a few instances been able to rectify his lines in unimportant details of boundaries.

Commencing at the western end of the great Cleveland escarpment above Ingleby Arnecliff, the Drift is found to run up the slopes to an altitude of about 400 feet; and, though this appears to be the general level to which the continuous sheet of Drift attains along the steep face of the escarpment, in embayments, such as Scugdale, it extends to over 700 feet, and on a few spurs, as at Busby Wood, to over 800 feet, and a similar elevation is reached near the ascent to Chap Gate. Beyond this point the levels fluctuate considerably, and the maximum is attained on the Lockwood Hills, where a spread of gravel forms a capping at 867 feet. Farther eastward, the boundary varies slightly above and below 800 feet, until at Robin Hood's Butt the watershed falls at one col to the Drift-level, 760 feet. From Stonegate eastward, the Drift crosses the watershed in an almost continuous sheet as far as Whitby, interrupted however by Kempston Rigg, which forms a narrow Driftless strip at altitudes above 800 feet.

While the actual Drift-deposits are thus limited to levels not exceeding 867 feet, there is a sporadic scattering of small erratics reaching at three or four places upon the brow of the escarpment to higher levels: thus at Carlton Bank, pebbles of foreign rocks were found up to 1000 feet. Similar phenomena have been observed in other parts of the district: for example, scattered pebbles, mainly of white quartz, were noticed by the officers of the Geological Survey

[1] Mem. Geol. Surv. 'North Cleveland' 1888, p. ((.

on High Moor near Peak at 850 feet, and I have found in the same district a thin deposit of gravel at Green Dike at 825 feet, which yielded pebbles of granite, quartz-porphyry, porphyrite, and flint. I do not think that in all cases these scattered pebbles can be accepted as evidence of a wider extension of actual Drift-deposits. Still less do I consider that it would be safe to infer that they necessarily imply the invasion of the area by ice to so great an altitude.

Along the strip of country from Robin Hood's Bay to Seamer, the maximum altitude reached by the Drift falls from about 700 feet at Gate Hills, and 825 near Pye Rigg, to 600 feet on Scarborough Racecourse; but the general level between the two points declines fairly steadily from 700 down to about 400 feet. Some authors have experienced a difficulty in understanding how deposits laid down along the edge of a sheet of land-ice should show such variations as these, but it should be observed that higher grounds upon which such deposits could be laid do not exist continuously along a line connecting the two extreme points. At the southern end, it is noticeable that the Drift simply touches the front of the moor, and does not extend down its gentle westerly slope. Along this strip of seaboard, the Drift, except for a small patch in the bottom of the valley near Hackness, nowhere extends more than 4 miles from the coast, and the hill-country within is quite destitute of Drift.

Drift-deposits in the Vale of Pickering do not attain a greater altitude than about 350 feet. The patches of gravel and of Boulder-Clay at the western end of the Vale are worthy of a more extended study than I could devote to them; but Mr. Fox-Strangways records that the patch of Boulder-Clay near Thornton Dale contains local rocks exclusively, and I have recently examined two areas mapped as Boulder-Clay near Helmsley, at the Acres and at Sprotten respectively, and such scanty traces as I could find yielded local rocks solely.

The Drift-deposits along the escarpments overlooking the Vale of York, though outside the area dealt with in this communication, may nevertheless be mentioned, as they have an important bearing upon the mode of origin of the Glacial deposits and features herein to be described.

Mr. Fox-Strangways says,[1]

'Taken as a whole, the Glacial deposits never rise much above the 600-foot contour-line, and only attain this elevation along the northern escarpment of the Oolites; in the south they are not usually more than 400 feet above sea-level, except at Oulston, where the gravels rise to nearly the 500-foot contour.'

The Drift extends for a long distance to the southward, and, excluding some small patches marked as Boulder-Clay and gravel along the edge of the hills, it may be said to terminate in the two splendid moraines at York and Escrick respectively.[2] The summit-

[1] Mem. Geol. Surv. 'Northallerton & Thirsk' 1886, p. 53.

[2] Carvill Lewis, Rep. Brit. Assoc. 1887 (Manchester) p. 692, & 'Glac. Geol. of Gt. Britain & Ireland' 1894, p. 188; P. F. Kendall, Proc. Yorks. Geol. & Polyt. Soc. n. s. vol. xii (1893) p. 306.

altitude of the highest of these moraines at Bilbrough is rather over 150 feet above sea-level.

Glacial Striæ.

Down to the time when the geological maps and memoirs of the district were published, no Glacial striæ upon the bed-rock had been discovered; but Mr. Barrow, in his memoir on North Cleveland, stated that at Hob Hill, near Saltburn, when the Drift was cleared away, 'the Ironstone was found to be deeply grooved, the direction of these hollows running roughly north-west and south-east.'[1] The Drift here appears to have been recognized by him as Lower Boulder-Clay, an important fact. Mr. Barrow also mentioned that, 'as a rule, where the clay is thin it is so largely made up of the underlying rock, or the rocks a little to the west' (*op. cit.* p. 65) etc. Since that time, the geologists of the East Riding have taken up the study of the Glacial deposits with great earnestness, and the following observations of striated surfaces have been recorded:—

Filey, Carr Naze (south side). G. W. Lamplugh. N. 20° E.
Do. Do. (north side). J. W. Stather. N. 24° E.
Bayness (north of Robin Hood's Bay). H. B. Muff & T. Sheppard. N.
Sandsend, near Whitby. J. W. Stather. N. 35° W.
Roker, near Sunderland. P. F. Kendall. E.N.E.

Reference should also be made to the striations observed in the coast-region of Northumberland, as they bear directly upon many of the problems relating to the glaciation of Yorkshire.

The distribution of local materials in the Drift of the area under consideration is very significant, as Mr. Barrow has shown for the area north and west of Whitby. South of that town, I have observed the frequent occurrence along the coast of masses of Jurassic rock to the south of their native outcrop; but I have heard of only a single example that might be interpreted as indicating movement in the opposite direction, namely, Mr. J. W. Stather's record of blocks of Chalk at Scalby Mills, near Scarborough.[2]

Occurrence of Shells in the Drift.

Shells, mostly fragmentary, have been recorded from the Drift-deposits of various localities in the area under notice, except the western end of the Vale of Pickering. Mr. Fox-Strangways, speaking of the gravel which fringes the great escarpment to the east of Ingleby Arncliffe and runs up the dales opening off it, alludes to 'hinges of *Tellina balthica* being very plentiful in this gravel.'[3]

Mr. Barrow, in the North Cleveland Memoir, mentions the occurrence of the same shell at Rye Hill near Great Ayton (I also have found several fragmentary shells at this place); at Stanghow Moor, in sand resting on Lower Boulder-Clay (at an altitude of about 800 feet); and at Whitby, in Lower Boulder-Clay. In the Eskdale

[1] Mem. Geol. Surv. 'North Cleveland' 1888, p. 66.
[2] Rep. Brit. Assoc. 1898 (Bristol) p. 554.
[3] Mem. Geol. Surv. 'Country around Northallerton' 1886, p. 54.

& Rosedale Memoir the species is recorded in Eskdale at Egton, at Far Carr Wood, and at a pit near Egton Church with other shells, and again in the Lealholm moraine (see p. 506). In the Memoir on the country between Whitby and Scarborough, *Tellina balthica* is recorded as occurring in the Middle Sands at Robin Hood's Bay; and in the Memoir on the country to the south of Scarborough, it is stated that great numbers of shell-fragments occur in gravels on the north side of the Vale of Pickering, about Wykeham and Ayton.

VII. The Ice-Sheets.

It will greatly facilitate the line of argument which I propose to develop in the following sections, if I state at the outset the conclusions to which my studies have led me regarding the course and distribution of the ice-currents that operated about the margins and, to some extent, over the ridges of the Cleveland area. I may first remark, that I have been unable to detect any signs of the presence of the sea in the area at any time during the Glacial Period; and the occurrence of fragmentary and a few whole shells I ascribe to the invasion of the country by the edge of an ice-sheet, which advanced on to the land after traversing a sea-floor strewn with shells. I have elsewhere stated pretty fully the reasons which have weighed with me in arriving at this conclusion, and it is satisfactory to find that many of the *a priori* objections urged against the possibility of glacier-ice picking up, transporting, and redepositing marine shells derived from deposits over which it has passed, have been dissipated in a decisive way by the observations of Profs. Garwood & Gregory upon the Ivory-Gate Glacier.[1] The same observers also proved in a conclusive manner that shells and other materials picked up by a glacier could be transported to a higher level than the bed from which they were obtained.

The principal facts with which I started out were—firstly, the occurrence of three groups of erratics derived respectively from the west, the north, and the east; secondly, the distribution of the Drift as a continuous sheet on the west, north, and east of the Cleveland Hills, and not in the central part, except in the Esk Valley; and, thirdly, the striations and the nature of the deposits.

I will consider the western group first.

It has long been known, mainly thanks to the accurate researches of Mr. J. G. Goodchild, Mr. W. Gunn, and the late Prof. Carvill Lewis, that at one stage of the glaciation of England, so great a condition of congestion existed in the Irish-Sea basin, that a great volume of ice bore in upon the Solway, and being joined on the one hand by ice from the Southern Uplands of Scotland, and on the other by that from the Lake District, it filled the Vale of Eden to overflowing. One immense stream swept over the Tyne watershed and invaded Northumberland, while at the other end of the Crossfell

[1] Quart. Journ. Geol. Soc. vol. liv (1898) pp. 205, 206, 219, etc.

Range a great overflow took place by the Pass of Stainmoor, at altitudes ranging from 1435 feet (the lower pass) to 1800 near Roman Fell. This latter glacier entered Teesdale just below Middleton, where (as I am informed by Mr. Dwerryhouse) it was joined by a native glacier having its source in Upper Teesdale. It was charged with igneous rocks from the Lake District, most notable of which is the Shap Granite. This glacier made its way down into the low grounds, where it seems to have deployed considerably, and it reached the sea-coast, which was probably not very far distant from its present position. How far the glacier extended seaward has not been, and I think probably never will be, definitely ascertained; but a belt of very rough sea-bottom, known to fishermen as the 'Rough Ground,' strewn with large boulders, among which are many of Shap Granite, lies a few miles off the mouth of the Tees, and this was interpreted by Carvill Lewis as the moraine.

It is not to be supposed, however, that the boulders of Shap Granite were in all cases borne to their ultimate resting-place by the ice of the Teesdale Glacier—they are scattered right down the coast of Yorkshire, and even into Lincolnshire; and it seems to me most probable that those at least which are found to the southward of Robin Hood's Bay were carried by a later ice-movement. The advance of the Teesdale Glacier I believe to have effected the grooving of the rocks at Hob Hill described by Mr. Barrow (see p. 494), and the general west-to-east transport of local material associated with the Lower Boulder-Clay.

At some stage of the Glacial Period, the advance of the Scandinavian ice-sheet barred the access of the Teesdale Glacier to the coast-line—whether at an early or a late stage will be discussed subsequently; and the Teesdale Glacier was compelled to turn from its direct seaward path. Two courses lay before it—to turn northward into the Wear Valley, or southward into the Vale of York. The northerly route was preoccupied, however, by the native Weardale Glacier, which was perhaps already much encumbered by the pressure of the Tyne Glacier on the north, and consequently the route down the Vale of York was adopted. The watershed, which in pre-Glacial times separated the Tees drainage from the Ouse, was a very low one,[1] lying about on a line joining Bedale with Northallerton, where the Drift is now very thin, and over this the glacier passed. It received a great tributary from the Ure Valley, and possibly one from the Valley of the Swale, but I am rather disposed to agree with Carvill Lewis in thinking that Lower Swaledale was not occupied by a glacier. The western edge of the Teesdale Glacier, where it swept over into the Vale of York, surmounted hills 600 feet above sea-level, and may be presumed to have been of greater altitude. It stretched down to Escrick, where it left a splendid terminal moraine, and a second terminal moraine spans the Vale at the city of York itself.

[1] There was no doubt a very great sub-glacial denudation of the soft Triassic sandstone, but no attempt can be made to evaluate it. I think, however, that no material change was made by it in the position of this watershed.

The characteristic erratics of the western series occur throughout the Vale of York, and in particular the Shap Granite is found from side to side of the Vale, and even, on the western edge, to within 2 or 3 miles of the outermost lateral moraine, as at Lindrick Farm near Ripon.

The northern group of erratics was brought by an ice-movement, which may for present purposes be regarded as having originated in the Tweed Valley. The ice generated in the head of that valley appears to have flowed without hindrance as far as the neighbourhood of Coldstream, where, at one stage, instead of pursuing its direct course down to the sea at Berwick, it turned sharply round the projecting end of the Cheviots through an angle of about 140°, and took a course almost directly southward.[1]

What the constraining agent was, which bent a great glacier 20 miles wide through so rapid a turn, is not quite so clear as in the case of the Teesdale Glacier. When we observe, however, the way in which the whole of the Eastern Scottish glaciers suffer deflection, either northward or southward, as they approach the coast-line, it seems impossible to resist the conclusion pressed upon us with such skill and force by the late Dr. Croll and Prof. James Geikie, that it was the overmastering influence of a Scandinavian ice-sheet filling the North Sea, and bearing down upon the whole coast-line of Britain, from Norfolk to Caithness. The Tweeddale ice was undoubtedly driven to the southward over the seaward portion of Northumberland, and, to judge by the great profusion of the porphyrites among the Yorkshire erratics, and the large proportion which they bear to the other erratics in certain deposits and in particular districts, I think it highly probable that the ice which swept the belt of porphyrite-lavas fringing the Cheviots, did actually invade the Cleveland Hills and much of the coast-line farther south. The Cheviot porphyrites form a notable element in the Drift as far westward at least as Scarth Nick, near Ingleby Arnecliffe, and I am disposed to regard them as the natural associates of the fragmentary marine shells, with the distribution of which theirs very closely agrees.[2]

It appears to me not improbable that the Tweed-Cheviot ice passed off the land on to the bed of the North Sea somewhere between the mouth of the Coquet and that of the Tyne, and that it re-invaded the land, under pressure from the east, somewhere about Roker, or perhaps a little to the northward of that place. The striations at Roker clearly indicate a movement in from seaward, and at several places on that coast worn flints have been found in the Drift.[3] I have found them abundantly myself at West Hartlepool, and I think that they must have come from the sea-floor.

[1] P. F. Kendall & H. B. Muff, Geol. Mag. 1901, p. 513.

[2] For many important facts regarding the distribution of these rocks, see J. W. Stather, Geol. Mag. 1901, p. 17.

[3] R. Howse, Trans. N. of Engl. Inst. Min. Eng. vol. xiii (1863–64) p. 173.

The last of the great ice-flows to be considered is the Scandinavian ice-sheet. The evidences of the approach of this great ice-sheet to the coast of Yorkshire are both direct and indirect. Scandinavian rocks of unmistakable character are found in Glacial deposits both on the coast-line and far inland. Mr. J. W. Stather found in my presence a beautiful specimen of rhomb-porphyry, in a deposit of Boulder-Clay at an altitude of 810 feet above sea-level, on the hills above Lockwood: this is both the greatest altitude and the most westerly situation in which these rocks have been found in the district. The augite-syenite of Laurvig I have found on the shore between Saltburn and Redcar: this is the northernmost known occurrence of a Scandinavian rock in Britain.

Evidence is furnished by the consistent direction of the Glacial striæ along the Yorkshire coast of the operation of an ice-sheet invading the country from the north-east, and the distribution of the Drift strongly reinforces this evidence.

I must reserve for later discussion the question of the order in which these three ice-movements took place, but it will render my description of the special phenomena of the ice-margin more intelligible if I say at once that the general order appears to have been:—(1) the Teesdale Glacier's unobstructed access to the coast; (2) the arrival of the Scandinavian ice-sheet and diversion of the Teesdale Glacier into the Vale of York; and (3) the invasion of the Scottish ice.

VIII. The extra-Morainic Lakes.

I have found it convenient to deal with the mass of complicated and mutually related detail by the adoption of an arrangement of the facts partly geographical and partly chronological. I shall describe first Lake Pickering—the lowest lake of the sequence, and the one which for a long period received practically the whole drainage of the northern, central, southern, and eastern parts of the area under consideration, leaving, perhaps, the western margin to drain independently. I shall then deal with its great affluent Newton Dale, and so pass up into the Eskdale drainage. Here it will be necessary to recognize and describe two distinct periods or phases. These two phases will be dealt with separately, and between them it will be convenient to treat of the lakes of the outer face of the Northern Cleveland Hills. The next area to be considered will be Iburndale and the Sneaton-Stainsacre recess, two indentations of the southern side of Eskdale, east of Goathland; then the coastal strip from Whitby to Filey, in order from north to south in four sections—Robin Hood's Bay, Peak to Cloughton, Burniston to Scalby, Scalby to Filey. This arrangement will follow closely the actual course of the investigation, and, while the first portion, from the Vale of Pickering to the outer face of the Cleveland Hills, will ascend from lake to lake through a continuous system of drainage, the second portion, from Iburndale to Filey, will descend through another chain of lakes in the direction of a continuous drainage, finally reaching Lake Pickering again.

(1) The Vale of Pickering.

The geological and physical structure of this valley is simple. It is a long faulted synclinal trough of Kimeridge Clay, lying between the dip-slope of the Corallian Series on the north, and the Chalk-escarpment on the south. On the west, it is to a large extent shut in by a much-faulted tract of Jurassic rocks, from the Corallian down to the Lias; while on the east, along the strike of the Kimeridge Clay, it opens out into Filey Bay. This structure of the solid rocks would naturally give rise to an eastward-flowing river carrying the whole drainage of the basin; but this simple hydrographical arrangement no longer obtains. Drift-deposits of great thickness occupy the seaward end of the valley, and constitute the materials of the cliffs for a considerable distance to the south of Filey. They rise to a ridge which extends quite across the valley, and attains a minimum altitude of 130 feet.

At the western end of the valley there are two gaps in the Jurassic barrier—one broad and flat, *via* Coxwold and Gilling, having a summit-altitude of almost exactly 225 feet, at the village of Coxwold. This valley coincides with a couple of faults which bring down the soft Kimeridge Clay between harder rocks. The other gap is the narrow deep gorge of the River Derwent. This latter valley cuts through a watershed from 200 to 225 feet in height, and it bears all the characters of a lake-overflow of the first type—a direct overflow (see p. 481). The existing water-level in the gorge is well below 50 feet O.D. The floor of the Vale of Pickering is occupied by alluvium, consisting in part of fine laminated clay (Warp), and in part of sand with a little gravel. The Glacial deposits extend up the valley only a short distance from the seaward end, but a few small patches of gravel and small hill-cappings, mapped as Boulder-Clay, are near the western end.

The whole drainage of the country south of the Esk, except a strip a mile or two broad north of Scarborough, enters the Vale of Pickering, and instead of taking the simple and direct course to the sea at Filey, is all diverted, against the slope of the rocks and the grain of the country, and passes out into the Vale of York by the gorge at Kirkham Abbey.

The first suggestion that this anomaly was due to Glacial agency must, I believe, be accredited to Carvill Lewis, who made Lake Pickering one of the examples of extra-morainic lakes in his paper read at the Manchester meeting of the British Association in 1887. Mr. Fox-Strangways appears to have arrived independently at the same conclusion, and has supported it by new and valuable evidence in his paper on the 'Valleys of North-east Yorkshire,'[1] and in his

[1] Trans. Leicest. Lit. & Phil. Soc. vol. iii (1894) p. 333.

great Memoir on the Jurassic Rocks of Yorkshire. Mr. Fox-Strangways suggests that there was an original depression on the site of the present overflow, occupied by a small stream flowing towards Malton (Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. i, 1892, pp. 423–24):—

'Now, if we suppose the eastern end of the Vale of Pickering to be blocked by Boulder-Clay, the drainage must naturally find its way out at the lowest point; this appears to have been at the head of the little valley which we suppose to have occupied the position of the present course of the Derwent below Malton. By gradually lowering the higher part of this valley, it would in course of time change its slope to the opposite direction, and eventually drain the Vale of Pickering, which during this period must have been a lake. . . . .

'The edge of the escarpment, where it is cut by the present valley at Kirkham, is between 200 and 250 feet above sea-level; the level of the Boulder-Clay which now blocks the Vale of Pickering near Filey is 130 feet; so that it only requires the Glacial deposits along the seacoast to have been about 100 feet thicker, to have sent the water over the depression to the south of Malton.'

Mr. Fox-Strangways recognized that such a lake should have left traces of its strand-lines, and made the following observations on that point:—

'The most marked terrace at the present time is that on the north side of the valley at Hutton Bushel, the level of which is a little more than 200 feet above the sea, that is, exactly at the level that a beach would be formed when the exit from this lake was across the hills south of Malton. Below this there are two minor terraces, not so well marked, at about the 100- and 140-foot contour, which probably denote periods during which the denudation of the Malton gorge was for a time checked. Besides this there are no distinctly marked terraces, but there is a considerable amount of gravel here and there, all of which is below the 250-foot contour.'

While in thorough agreement with Mr. Fox-Strangways as to the main lines of his explanation, and very grateful for the valuable data which he has furnished, I am compelled to differ from him regarding three points—small points indeed, but, in view of my work in other areas, important.

The first relates to the nature of the barrier which held up the waters of Lake Pickering. Mr. Fox-Strangways considers that it was a barrier of Boulder-Clay, which has since been lowered by denudation to the extent of 100 feet. Such an amount of post-Glacial denudation, except in the erosion of a valley or gorge, is quite unparalleled. Everywhere we find moraines, drumlins, eskers, and kettle-holes preserving their sharpness of form in great perfection; and I find it much easier to believe that the ice which laid deposits upon the tops of the hills, at altitudes of 450 to 600 feet, both north and south of the Filey barrier, was the obstruction. I think that Mr. Fox-Strangways will himself accept this explanation, which indeed he offers for a similar case at Scalby, only a few miles to the northward.

Another point of difference is very similar. I have mentioned that there are two breaches in the hills which shut the Vale of Pickering to the westward—the one by which the Derwent makes its escape, and the Coxwold-Gilling depression. The difference between their respective summit-levels is very small, but in the event of a lake overflowing this way the advantage of even 5 feet would be decisive; it is, however, by no means certain that the Kirkham-Abbey route had the initial advantage. Mr. Fox-Strangways is of opinion that it had, and that the Coxwold-Valley erosion has no connection with the river-systems of the country, and is probably of later date than any of these river-gorges. I am unable to accept his explanation, which is, moreover, rendered unnecessary, in my judgment, by this consideration, that the Coxwold Valley itself was blocked by ice. The great glacier which descended the Vale of York obstructed the drainage of the western edge of the Cleveland area, and produced upon a small scale phenomena similar to those which are displayed in the east and north. It extended for more than 10 miles, perhaps much more, down the Vale of York below Coxwold, and its terminal moraine at High Catton attains an altitude of more than 100 feet. It therefore seems reasonable to suppose that at Coxwold the ice rose quite as high as the watershed. More than this, the officers of the Geological Survey have mapped Boulder-Clay at an altitude of 279 feet in the Coxwold-Gilling Valley, which was, I believe, invaded by a lobe of the glacier.

The third point of difference is as to the exact nature of the gravel-bench at Hutton Bushel. Mr. Fox-Strangways regards it as a lake-beach, but reasons fully stated later have led me to conclude that it partakes more of a deltaic nature, and that it came into contact with the static waters of Lake Pickering only at the western extremity.

Mr. Fox-Strangways has referred in his Memoir to a singular abandoned valley entering the Vale of Pickering in the south-west, near Settrington. He remarks that the cause of the alteration of the drainage is not very clear. I would, however, point out that this valley is excavated in the eminently porous and absorbent Corallian rocks, in which deserted valleys abound, as they do in the Chalk-area of the Wolds. Two general causes of these deserted valleys may be here noted:—(1) the dry valleys of the Chalk Wolds, and certainly many of those in the Corallian limestones, were excavated during the Glacial Period, when the rocks were in a frozen state, and therefore were impervious to water; and (2) many valleys in the Corallian limestones have been abandoned by streams which have found their way into subterranean courses, in the manner so common in areas of compact limestone. I have visited the spot, and have no suggestion to offer; but, so long as the phenomenon is unexplained, it remains a possible exception to generalizations respecting the intimacy of the association of deserted valleys with evidence of ice-action.

The evidence adduced by Mr. Fox-Strangways may, I think, be regarded as placing Lake Pickering among the well-established facts of Glacial geology; and we may proceed to consider one of the affluent streams, and see what conclusions may be drawn from its features. There are many large valleys opening into the Vale of

Pickering, some of which cut through the cover of the Oolites and produce singular inliers of Lias. These all lie in the western half of the area, and are probably due to the flatness of the top of the Cleveland anticline. Streams rising near the axis find difficulty in penetrating the harder beds of the Oolite, and so take an uncertain course over the high flat moorland. Hence some stream-heads, as Mr. Fox-Strangways has pointed out, have been captured by the Esk with its shorter course to the sea, and consequent steeper fall. When these moorland-streams pass away from the anticlinal axis, the dip of the rock increases, the fall steepens, and the increased cutting-power so obtained enables them to carve through the hard Lower Estuarine Sandstone and make a slash in the underlying Lias.

In the eastern region, the beds have not been thrust up so high, and the streams do not penetrate to the Lias. With the exception of the anomalous valleys near the coast, to which reference will be made in a later section of this paper (p. 535), these valleys are mainly cut in the Middle and Upper Oolites, and are of comparatively small dimensions. One, however, Newton Dale, has long been an object of interest to me and of wonderment: because of its immense depth, and the way in which it passes completely through the watershed. Reflecting upon these characters, with the light obtained by studies of Glacial overflows near Ripon and Knaresborough, I was brought to the conclusion that Newton Dale must be the overflow of a glacier-dammed lake in the Eskdale country. An inspection of a map showed that if the normal outlet of the Esk were closed, this would, by its altitude, be the outlet. This clue led to the unravelling of the whole chain.

(2) Newton Dale.

I have used this valley to illustrate so many features of overflow-valleys, that comparatively little remains to be said. From Pickering, where it debouches into the Vale of that name, it quickly assumes a gorge-like character, the very steep sides rising to 300 feet or more, according to the magnitude of the successive Oolitic escarpments which are cut through. Above Raindale, where the largest tributary valley enters, the Dale exhibits a series of bold windings, as already mentioned, which display the characters of the ordinary meanders of a stream, having steep outer curves and comparatively gentle inner curves.

The amount of drainage passing down Newton Dale is very small, especially above Raindale, and for $2\frac{1}{2}$ miles at the upper end there is no continuous stream, but a bog, with an occasional strip of running water. For half a mile at the actual summit there is a great peat-bog, and no stream whatever except artificial drains. This final half-mile is the most significant part of the valley, and must therefore receive a rather detailed description. The watershed is here cut completely through by Newton Dale as a broad, flat-floored trench, more than 50 feet deep, with steep sides. The peat is evidently of great depth. I spent some hours here, in

January 1900, boring the peat with a set of rods. I found that at the apparent sill or intake at Fen-Bog Houses, there was a depth of 16½ feet of peat below the level of the water in a drain, the water-level being about 4 to 6 feet below the bog-level. Another boring touched rock below 13 feet of peat; and a third reached gritty clay at between 13 and 14 feet. The actual altitude of the rock-floor in these cases was almost exactly 525 feet above sea-level. If the peat were removed, the channel through the watershed would appear as a clean cut, 75 feet deep. I was informed by a signalman on the railway that the peat was much deeper to the southward, and that piles were driven into it to a depth of 60 feet in the construction of the railway. This part of the valley, known as Fen Bogs, is a true lake-overflow, as pronounced as any of the 300 or more which I have seen.

On the northern side of the watershed the valley inosculates with that of Eller Beck, the normal valley of a stream which takes a rather aberrant course. It flows in from the eastward, receiving tributaries of about equal volume from the north and south; when it reaches the head of Newton Dale, a little over the actual sill of the intake, it turns northward and flows through a V-shaped valley to join the Murk Esk (see fig. 4, p. 504 and Pls. XX & XXI). Mr. Fox-Strangways, in the works quoted, suggests that Eller Beck originally flowed through Fen Bogs, and that it was captured by the headwaters of an active tributary of the Murk Esk, in the fashion since made familiar to English readers by Prof. W. M. Davis. Mr. Fox-Strangways regarded the great trough at Fen Bogs as a reach of the Eller-Beck valley, which had lapsed into disuse by the diversion of the stream.[1]

A comparison of the sections of the two valleys will show that this explanation is inapplicable, the Fen-Bogs channel being far too large to have been cut by such a stream as Eller Beck, and it belongs to a type wholly different from that which such a stream would produce. The water-level in Eller Beck, at its nearest approach to Fen Bogs, under conditions of heavy rainfall is only about 6 feet at most below the sill of the Fen Bogs-intake, but it flows over a bed of large boulders. It must have very narrowly escaped capture by Newton Dale.

At the outset of this enquiry, I recognized that, if Newton Dale were the overflow of a glacier-lake and subject to torrential rushes of water, then a vast quantity of detritus must have been carried into the Vale of Pickering to form a great gravelly and bouldery delta. Reference to the maps of Pickering showed that such a fan of gravel, the only one on the north side of the Vale, does exist

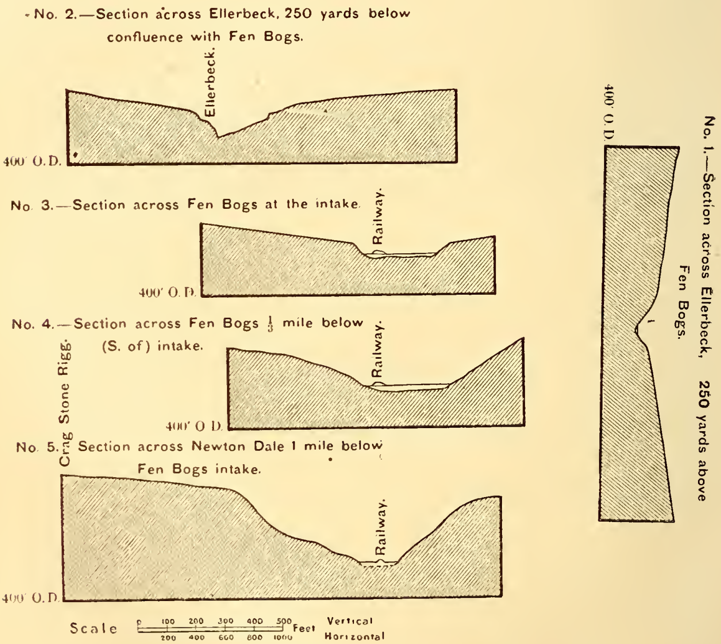
[1] Since this was written (in August 1900), Mr. F. R. Cowper Reed has published a full discussion of the evolution of the rivers of East Yorkshire. With most of his conclusions I am disposed to agree, indeed, geologists in Yorkshire have for some years employed like explanations; but, as to the history of the Fen-Bogs channel and a few other similar cases, I am compelled to dissent, as the sequel will show.

there; and an application to my friend Dr. Thornton Comber, of Pickering, elicited the following valuable notes:—

'The gravel-deposit is only marked as of a small area at Pickering. As far as I know, the breadth is accurately recorded, but the deposit really extends all the way to Risborough, and is found about 6 feet below the present surface whenever any digging has been performed. The stones are chiefly large, 1 to 2 feet in diameter, and rounded. They chiefly consist of hard moorland-grits. Occasionally I have found pieces of whinstone—a large boulder of this, weighing about a quarter of a ton, was found embedded some 6 or 7 feet deep in the clay, when the men were baring the surface of the limestone, in one of the quarries at New Bridge, at the mouth of Newton Dale.'

Here, then, appears to be a delta composed mainly of the harder rocks out of which Newton Dale was excavated, with some foreign rocks, notably a whinstone, which Dr. Comber identifies with the

Fig. 4.—*Comparative series of sections across the valley of Eller Beck and Newton Dale.*

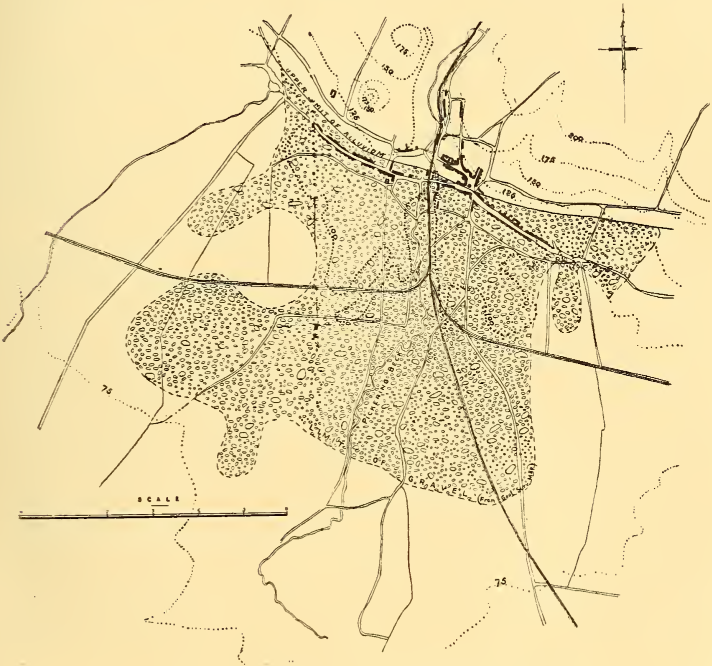


(In section No. 3 the peat is represented to scale.)

Cleveland Dyke that crosses the hills about 2 miles north of the intake at Fen Bogs. The coarseness of the material agrees well with the expectation founded on the steep fall of the valley.

The area of gravel mapped as surrounding the Pickering outfall is about 2 square miles, but Dr. Comber's data indicate that there is a much greater mass of gravel buried beneath a layer of Warp. The appended map (fig. 5) shows the surface of the ground at Pickering, which is seen to have the form of a digitated fan, precisely similar to an Alpine cône de déjection, but with a lower slope. It will be shown in the sequel (p. 531) that Newton Dale ceased to act as an overflow long before the close of the Glacial Period, and the layer of Warp which partly covers the delta is seen to have considerable significance.

Fig. 5.



CONTOUR MAP OF PICKERING DELTA.

[The gravel-covered area is copied from the 1-inch map of the Geological Survey.]

(3) The Eskdale System of Lakes.

The existence of an overflow at Newton Dale clearly implies a lake on the northern side of the watershed, and this could be produced only by an ice-dam blocking some part of Eskdale at an altitude exceeding 525 feet, the level of the overflow.

Direct confirmation of this implication was obtained from a first inspection of the maps. A series of 'severed spurs' forming an aligned sequence of overflows was found to extend from Eskdale across the spurs separating the Valley of the Esk from that of the

Murk Esk and Eller Beck. These channels all indicated a flow towards Fen Bogs. Details, with the field-observations, will be given later. The distribution of the Drift furnished equally clear evidence of the ice-invasion which would produce such a series of barriers.

Boulder-Clay and other Glacial accumulations extend completely across the Northern Cleveland watershed from Whitby westward to Stonegate; and they not only extend far up the Valley of the Esk itself to Lealholm, but also follow closely the boundary that might be assigned, solely on the evidence of the overflow-channels, to the ice in the valley of the Murk Esk. Indeed the precision with which, upon this evidence alone, I have been able to delimit the ice-margin convinces me that, in lake-overflows, we have a means of defining Glacial boundaries of the greatest value.

At the maximum extension of the ice, the Northern Cleveland watershed, as I have stated, was completely overridden as far west as the Stonegate Valley; but the lobate ice-margin appears never to have crossed Lealholm Rigg, or at least to have left no clear trace either as overflow, moraine, or any very definite Drift-deposit, though, in the village of Lealholm at 625 feet, clay with foreign stones is exposed, and scattered pebbles occur above the 700-foot contour.

An ice-lobe must have ascended Eskdale for a mile above the village of Lealholm, and laid down a moraine extending quite across the valley, obliterating the old course of the Esk.

This moraine has been cut through by the railway at its lowest point, and consists apparently of stony Boulder-Clay with fragmentary shells, but without admixture of sand or gravel. On the southern side of Eskdale, much Drift is observable up to altitudes of about 700 feet; but no recognizable moraine which could be referred to this stage is to be seen until Glaisdale is reached, where a great ridge of Drift extends across the valley with a minimum altitude of 450 feet, and a height above the valley which it obstructs of over 100 feet. In similar relation to the main valley is another morainic barrier across the Butler-Beck (Egton-Grange) valley.

The continuation of the line of maximum extension is much more definitely indicated from this moraine (which may not represent the extreme limit of the ice, and on the other hand may represent a later phase when the ice-front extended in a more westerly direction though not at so great an altitude) onward by a splendid series of overflow-channels. The first of these is a great trench deepening and falling towards the south, which cuts across the edge of Murk-Mire Moor. The sill of the intake is at an altitude of 714 or 715 feet (Ordnance Survey B.M.), and it extends for a distance of $1\frac{1}{2}$ miles as a deep groove of characteristic section, filled with moss and swamp so as to be impassable in the winter, when alone I have seen it.

After this stretch of complete trough, the channel is continued for another mile to Hazel Head by a marginal channel, which for the greater part of the distance is a mere shelf lacking an iceward retaining-wall, but in some parts that function is performed by some gravel-mounds. This shelf runs out, and disappears near the

Hollins just below the 675-foot contour; and as it fails to indent the 650-foot contour, it is clear to me that it reached the quiet waters of a lakelet at 670 feet or thereabouts.

Where this overflow terminates, a mass of gravel obstructs the valley of West Beck, which cuts over into the solid rock to avoid it, and so forms Nelly-Hay Force. This is probably both delta and moraine.

Between the West-Beck valley and the valley of Eller Beck, on this parallel, there stands forward a bold spur, Two-Howes Rigg, against which the ice must have abutted, ponding up the drainage of West Beck; for there is a beautiful marginal overflow, Moss Slack, cutting round the shoulder of the hill and just getting through the 675-foot contour. The precise correspondence of level between the Murk-Mire outfall and the Moss-Slack intake cannot be fortuitous.

The Moss-Slack overflow at its outfall-end cuts contours as low as the 625-foot contour, but below that an existing stream may be responsible. The way thence is open to Fen Bogs. (See Pl. XXII.)

The evidence of these overflows proves that at the maximum extension of the ice a lake was held up in Eskdale to an altitude of over 725 feet, lowering to 714 feet; and assuming that it extended no farther than the gap at West-Bank House (near Kildale), it would have been about 11 miles long and not less than 400 feet deep: it would have had ramifications up all the tributary valleys. I propose for it the name of Lake Eskdale.

Lake Eskdale drained by the Murk-Mire-Moor overflow into Lake Wheeldale, which stood at an altitude of 675 feet and was about 3 miles long. Its extreme depth was about 225 feet.

Lake Wheeldale drained over Moss Slack at 675 feet into a small lakelet in the Eller-Beck valley, the extreme altitude of which, determined by the top of the Fen-Bogs notch,[1] was about 650 feet. This lakelet, which I have always called the 'Vestibule,' but which it may be more convenient to particularize by a geographical name, Eller-Beck Lake, was probably 150 feet deep.

The period of occupation of the Hollins channel was very brief, and a slight retreat of the ice-front caused the production of the much more important channel consisting of two segments—Lady-Bridge Slack and Purse-Dyke Slack.

A further retreat of the Goathland lobe of the ice-sheet had for its first effect the withdrawal of the margin from Purse Moor, whereby a 'lateral escape' was opened in the Murk-Mire overflow so that the distal portion, Purse-Dyke Slack, was abandoned, and the outfall of the proximal half, Lady-Bridge Slack, was cut down below the 700-foot contour. I do not think that this affected the Moss-Slack

[1] In determining the site of an original watershed, it should always be borne in mind that an overflow cuts back as well as cuts down. I think that the original water-parting between Newton Dale and Eller Beck was at least as far back as Scar Nick, and Thack Sike was a tributary of Eller Beck.

Fig. 6.—*Intake of the Castle-Hill oxbow viewed from Moss Swany.*
(The sill is 50 feet above the floor of the main valley.)

Fig. 7.—*Randay-Mere valley viewed from the south.*

[The above figures are reproduced from photographs by Mr. Godfrey Bingley.]

overflow. The next shrinkage was a much more considerable one—the ice-margin withdrew to a position about a quarter of a mile from the Murk-Mire-Moor channel and parallel to it, and a new channel was commenced at the 675-foot contour. The channel ran round the edge of the moorland, and for a long distance was bounded on one side by ice. Traces of the scarp into the hillside are well seen above Struntry Carr, indenting the 650-foot contour.

Its continuity was interrupted across the middle of its course by the natural valley draining the moorlands, known as Oakly Beck, so that this, like the higher channel, was in two segments—one, the more northerly, Moss Swang, and the southerly, Randay-Mere valley.[1]

The next shrinkage took place when Lake Eskdale was lowered by erosion of the overflow at Moss Swang to about 625 feet. This opened a low gap in the side of the channel at Castle Hill, and led to the abandonment of the oxbow there. The main channel continued to be eroded, and the oxbow, a splendid example of an overflow, stands more than 50 feet above the main channel.[2] The view of this deserted channel from the main Moss-Swang valley is very striking. (See figs. 6 & 7, p. 508.)

The last stage of ice-retreat traceable in this region is represented by a deepening and deviation of the Moss-Swang channel, showing that the Randay-Mere segment was the first portion abandoned. This is clearly shown by the lower level of the Moss-Swang outlet, as compared with the Randay-Mere intake.

No overflows corresponding with these are to be found on the end of Two-Howes Rigg, and it is clear that the ice did not abut against that hillside at such an altitude as to maintain a barrier between Lake Wheeldale and Eller-Beck Lake. The two became continuous, and may now be called Goathland Lake. During the succession of events here described the Fen-Bogs outlet was being lowered, but at a diminished rate, due to the fact that the overflow had cut down to a bed of hard grit out of which the sill came to be formed.

There is a shallow groove running behind the church at Goathland, which may have been cut at the final stage of this lake. It is a few feet, probably not more than 5 or 6, below the level of the Fen-Bogs overflow; but there is another interest altogether attaching to it, in the form of a scarp in hard grit, the same which forms the sill at Fen Bogs, fronted and covered by bedded gravel

[1] The last-named valley contains the reservoir that supplies Whitby with water. In the course of some repairs executed upon the floor of the reservoir, a great thickness of superficial deposits was encountered. Mr. G. B. Williams makes the following remarks upon them :—' At the bottom of the reservoir there is a deposit of clay and silty sand, mixed with detritus from the surrounding rocks, and interstratified with layers of peat, the whole being 60 feet to 70 feet deep' (Proc. Inst. C. E. vol. cxxxvii, 1899, p. 357). The author gives no diagram of the section, and I suspect that some disintegrated rock *in situ* is included in his description.

[2] It is quite possible that the oxbow was produced by a slight re-advance of the ice blocking the lower end of Moss Swang. There are signs elsewhere of such an oscillation.

Fig. 8.—*Serial sections across the overflow-channels on Murk-Mire Moor.*

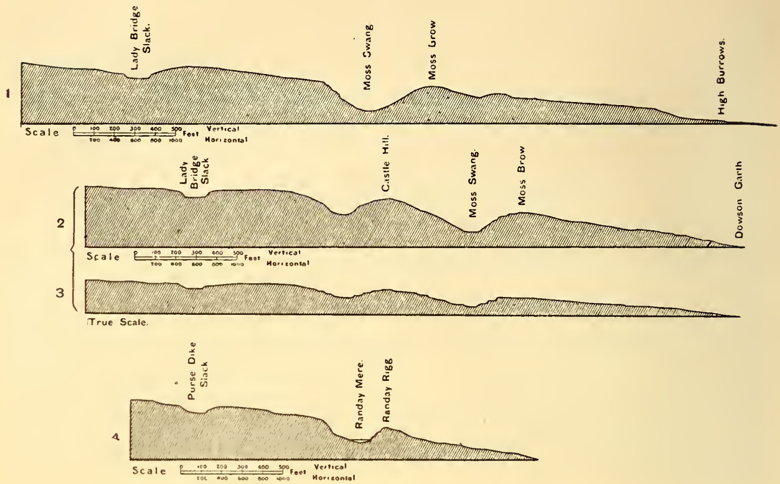
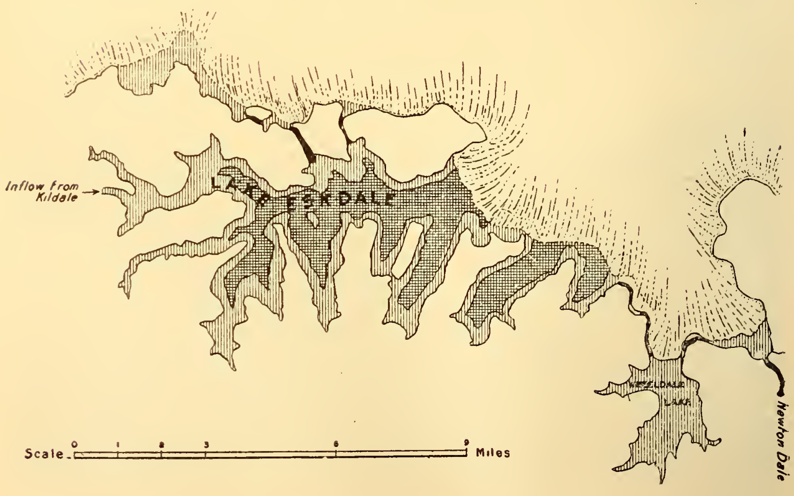


Fig. 9.—*Map of the Eskdale system of lakes, at the levels corresponding with the Lady-Bridge-Slack and Moss-Swang overflows.*



with a few foreign stones. The level at which this is seen is about 560 feet. This is about the level of the top of the Moor Grit at Fen Bogs.

At several points along the approach to Fen Bogs, a similar scarping is observable. For example, at Thorn-Hill House it can be seen extending across four fields; and farther on, at Moss Dyke, where the feature is very marked, there are clean sections visible, which show that although the scarp coincides in altitude with the outcrop of a hard rock, it is really due to an excavation in a facing of Drift-material, perhaps the delta of Moss Slack. At Thorn-Hill House the surface is Boulder-Clay with erratics, and at Moss Dyke the section is as shown in figs. 10 & 11.

Fig. 10.—*Section through the feature at Moss Dyke.*

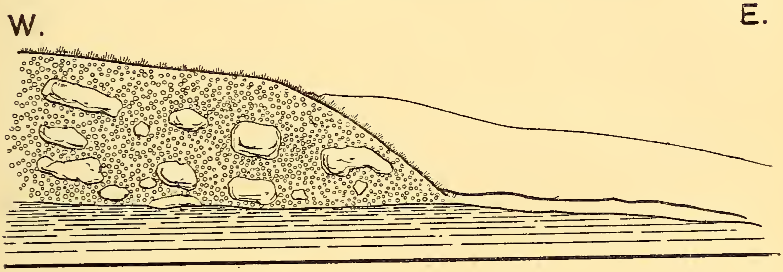
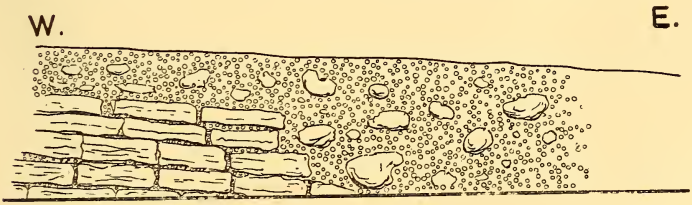


Fig. 11.—*Section 10 yards upstream from fig. 10, showing gravelly rainwash bedded against grit.*



A well-marked scarp is also visible about Hollin House, near the Randay-Mere outfall, for a distance of fully half a mile. It is at the same altitude as that mentioned above, namely, 550 to 560 feet.

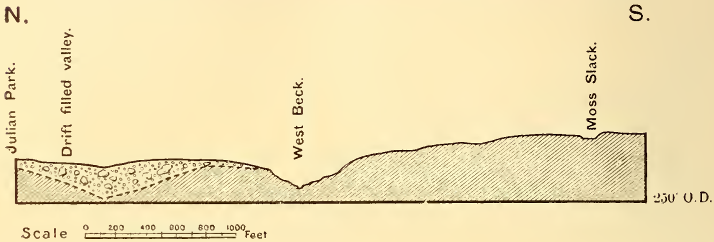
Two features must be mentioned in conclusion, the deltas. At the outlet of the Murk-Mire-Moor channel, from Hollin House to Hazel Head, there is a considerable accumulation of gravel which may represent the delta of that overflow, but the erosion of the gorge would not supply a very large amount of material.

The lower Moss-Swang and Randay-Mere overflow, however, is on a gigantic scale, much of it being at present 100 feet deep by

200 yards wide: we accordingly find at each outlet a vast accumulation of gravelly débris. That at the end of the Randay-Mere segment has, with the Boulder-Clay and other material thrown down directly by the ice, completely filled the old valley of West Beck, probably to a depth of 250 feet, and has compelled the stream to cut a new channel for itself at Scar Wood, in the form of a great rocky ravine nearly 200 feet deep.

About Julian Park, near the Randay-Mere outfall, great quantities of boulders are found in the fields. The separate outlet of the Moss-Swang valley at the lateral escape is also strewn with large boulders.

Fig. 12.—*Section from Julian Park to Two-Howes Rigg.*



We may now consider the conditions prevailing in Lake Eskdale during the formation of the Moss-Swang outflow. The intake itself presents some features of interest. Like the Fen-Bogs intake, the last stages of cutting were through, or into, a hard bed of grit, which forms a conspicuous platform in front of the actual sill. Along the hillside to the westward there is a very steep and strong scarp, probably due to the ice thrusting forward and confining the inflowing waters against the hillside.

Of beaches in Lake Eskdale I am unable to cite a clear example. At many places the hillsides are notched, but there is only one level at which the signs are at all widely prevalent: this is at about 560 or 575 feet. I have observed scarping at approximately this elevation at the following localities:—

Bramble Carr, near Danby Parsonage: about 560 feet.
Scale Foot, near Castleton: 560 feet.
Hornby House and Winsley Hill, Danby: above 575 feet.
Foul Green, Commondale, just above the old mine-shaft, two scarps at 575 and 600 feet.

At the same levels are two very pronounced terraces in the gravel-mass in Bellman Lane, Danby-Dale End, and along the hillside above Lealholm, especially near Hole-i'-th'-Ellers for a considerable distance, at about 575 feet. There are also remarkable benches of gravel at Stonegate at 560 and 575 feet respectively, to which more particular reference will be made later.

These scarps, although in some instances clearly connected with outcrops of hard rock, are in others, as for example at Scale House and at Danby-Dale End, cut in gravel; and I think that they may be regarded as marking the level of Lake Eskdale at the stages of cutting represented by the grit-outcrops at the Moss-Swang intake.

The remaining phenomena of Lake Eskdale can be understood only by reference to the conditions which prevailed in the country outside the watershed of Northern Cleveland.

(4) The Lakelets of Northern Cleveland.

The evidence already adduced has made it clear that a great press of ice bore upon the northern face of the Cleveland Hills. At the western end denudation has almost completely swept away one side of the Cleveland anticline, and left in its place a deep rectangular recess overlooked by a serrate escarpment, which exposes the sections of a number of beheaded valleys. Whether marine denudation has had any part in this, or whether it has been brought about solely by the action of rivers which have encroached by their headwaters and by the capture of tributaries, I am unable to say; but the cases of Lonsdale, the Leven, and Sleddale, to be presently mentioned, seem to indicate that subaërial denudation may have been the sole agent.

The distribution of erratics and other signs show that, at the maximum extension of the ice, an overflow of water may have taken place by every notch in the escarpment, though only of three places can this be positively asserted.

The Whorlton Recess.

At the western extremity of the escarpment there occurs the only example of a valley opening to the northward. This valley, Scugdale, is hemmed in by lofty ridges rising to upwards of 1000 feet except at one point, where a gap occurs in Stony Ridge on the west side of the valley. Here a narrow, sharply-cut notch breaks through the 1000-foot contour, and forms the intake of a deep channel, Holy-Well Gill, which has all the characteristics of a lake-overflow.

I have examined this valley on two occasions, and though I felt that there seemed to be an inherent improbability in the occurrence of an overflow at such an altitude—the highest that I have observed in the Cleveland area—at this particular place, yet the character of the valley compels me to include it. The Drift in Scugdale does not extend, or is not traceable, to so high an elevation. At Sparrow Hall there is gravel with erratics up to over 600 feet above sea-level, but along the hillside near the overflow, though traces of gravel are visible up to 925, I found no erratics above 875 feet. When this overflow was in operation, the valley must have been quite blocked with ice.

Simultaneously with the operation of this overflow, a small lakelet was formed in a minor recess above Scarth Wood, which cut a well-marked channel through the watershed into the valley leading down to Osmotherly; but its operation seems to have been of brief duration, and a slight recession of the ice-front opened a lower notch, the fault-valley of Scarth Nick, which now carried off the waters both of this lakelet and of Lake Scugdale.

Scarth Nick is a fine example of an overflow; the valley is 100 feet deep, with a breadth of only about 150 yards at the top of the cutting, narrowing to about 30 yards, or less, at the bottom. The floor is flat, and contains much peat. Near its confluence with Crabdale, a valley of normal shape, there is an immense accumulation of gravel standing as a mound in the middle of the valley. Lake Scugdale was, at its maximum, about 400 feet deep. When Scarth Nick was opened, the level fell nearly 200 feet, but the area of the lake was not greatly affected, for the hillslopes are steep, and the recession of the ice-front would compensate for the loss.

Carlton Bank.

This, the next opening to the east of Scugdale, is a valley of the southern slope which has been beheaded.

The intake-notch is very broad, and there is a broad flat sill at an altitude of about 930 feet. The watershed is almost on the extreme edge of the escarpment. I have found erratics right across the sill and on the hills a little above it, so that the ice here must have attained as great an altitude as in Scugdale; but though there was probably some wash of water over into the Rye drainage, there cannot have been much, as the escarpment is very straight along here, and there is no recess which could have held a lake.

The breach at Donna Cross has a double head a little over the 1000-foot contour. It shows no definite signs of overflow, and the same may be said of Carlton Bank; but the next opening, the last in the series, is of a different type altogether.

The Ingleby-Greenhow Corner.

The re-entrant angle of the Cleveland escarpment at the eastern end is breached by a splendid overflow-channel, which had been identified as such (before I saw it) by my friend, the Rev. J. H. Hawell, M.A., F.G.S., who has accompanied me over much of the Cleveland area. It is a deep, square-cut notch, carrying no stream at present. Probably it drained a considerable part of the ice-margin for a long period. It has no complications, and is a simple example of the 'direct overflow.'

Kildale.

This remarkable valley is as interesting to the geographer, and especially to the student of river-action, as to the glacialist.[1]

Its trough is a nearly direct prolongation of the axis of Eskdale, and whatever cause is responsible for the selection by the Esk of its valley must also have determined the formation of Kildale. The

[1] The following remarks were written in their present form in August 1900, before I had any knowledge of Mr. F. R. Cowper Reed's work in the district.

River Leven, which flows down Kildale, takes its rise in the moorland to the south, and makes two turns nearly at right angles, so that its upper course is actually parallel to Kildale, but in the opposite direction. Here is very clearly a case of river-capture; and this conclusion is greatly strengthened by the fact that a tributary, in Lonsdale, similarly flows eastward and turns abruptly into the westerly drainage of Kildale. I think that these cases of capture belong to a pre-Glacial time. Lonsdale certainly was incorporated with the western drainage before the Glacial Period, but the head-waters of the Leven are not so clear a case. It is possible that both the Leven and its neighbour Sleddale Beck were captured by the western drainage before the Glacial Period, and that Sleddale Beck returned to its original direction.

Kildale is obstructed at its western outlet by a moraine, which has compelled the Leven to make a new cut, the fine gorge at the Bleach Mill. The moraine is 100 feet above the floor of the valley, and the lowest part is at the northern end where the gorge is cut. The upper part of the valley is largely occupied by Drift-deposits, consisting mainly of sand and gravel, which cover the central part of the valley, and Boulder-Clay is mapped along the margins.

Lonsdale, a valley long attached to the western system of drainage, opens into it on the northern side. Its high watershed is notched slightly at the top, at Gribdalegate, by what I take to be a small Glacial-lake overflow. The head of Kildale contracts in a very marked fashion before reaching the point of entry of the Leven, which is a very small and insignificant stream; then it expands to the watershed at West Bank. The watershed is broad and flat, and is occupied by an extensive bed of peat. Sleddale Beck comes in as soon as the watershed is passed, and is a large and swift stream, many times the volume of the Leven. It flows at first through a deep bed of alluvium, and then enters a more gorge-like region with steep rocky sides composed of the hard grit, instead of the Lias which formed the upper part of its course. It was early impressed upon me that some extensive overflow must have taken place across this pass during the Glacial Period, and I have taken some pains to form an idea of the exact order of events. The altitude of the Bilsdale overflow, which at the maximum extension of the ice is the only one by which an escape could be found to the westward for water in Eskdale and Kildale, is so much above the highest level of the Eskdale Lake (725 feet), that an inflow must have taken place from Kildale during that stage; and I can discover no evidence of reversal of this flow, though it might have occurred as a temporary episode, and left no sign. There is, however, such an uninterrupted series of overflows into the Goathland area from the highest (725 feet) down to the lowest phase of Moss Swang (560), which is below the level of the West-House watershed, that I do not think a reversal of flow at all probable. This being so, there must have been a flow of water through the West-Bank pass into Eskdale. At the higher levels of Lake Eskdale (725 to 715 feet) there would have been a depth of about 150 feet of water over the pass; but as the Moss-Swang overflow was deepened, the Kildale pass became awash, and at the lowest level the overflowing stream would actively cut its way across. The evidence of this stage is very clear. Any overflow through the pass in either direction would, of course, be checked by the tranquil waters of a lake, and such coarse detritus as it carried would be cast down in the form of a delta. Now, at Commondale, where the narrow valley of Sleddale Beck expands, there is a great mass of gravel extending up the southern slopes to about the 600-foot contour, and forming a very well-defined plateau at 550 to 575 feet O.D. It has a very steep face looking eastward, due perhaps to the winding of the beck against it. The gravel consists mainly of Jurassic sandstone, but there are also many foreign stones, the most significant of which is a small boulder of Shap Granite. I infer that this material constitutes the delta of an overflow down Sleddale Beck, which was arrested by standing water at levels from 600 feet down to about 560 feet.

The gravel extends down Eskdale for about 2 miles, as an infilling of the floor in which the river has cut a new valley. At Holme Bank it forms a barrier across the valley, and the river has cut through the live rock on the north side. Here the top of the gravel-mass is flattened off at an altitude of between 525 and 550 feet, which I think represents a stage of Lake Eskdale when the withdrawal of the ice-barrier at Moss Swang opened a free way to the Fen-Bog overflow, the level of which is about 525 feet, a sufficiently close correspondence to be worthy of observation.

This second plateau is very distinctly lower than the one at Commondale, and I regard it as evidence of a partial redistribution of the materials of the upper delta when the lowering of the lake caused an extension of the stream across its delta. A third stage is represented by a gravel-flat extending to the eastward of the Howe at Danby, at an altitude just above 500 feet. This, however, belongs to a phase of the later history of Lake Eskdale which cannot be described at this stage.

I may now say a few words about the post-Glacial history of the West-Bank drainage.

Whether Sleddale Beck was ever captured by the Leven drainage or not I am unable with any confidence to affirm; but if, as I have surmised, it had been, then the great flow of water which took place eastward to Lake Eskdale must have had the effect of cutting back the watershed and recapturing it. This shifting of the watershed would gradually begin to operate upon the channel between Sleddale and the Leven across West Bank. If the erosion were arrested at this stage, we should find that the Leven would remain a constituent of the western drainage; but if, on the other hand, the erosion proceeded farther, we might have the Leven in its turn recaptured. This view I held at one time, but subsequent investigations have somewhat weakened my confidence, and I am content to state the facts and the alternatives, and draw no deductions.

I have ascertained by levelling, that the watershed on the peat-bog at West Bank is 584 feet 6 inches above O.D. I made an almost complete traverse of the valley here, by a series of seven boreholes, extending from the edge of the valley on the south to the railway which is close to the north side of the valley. The first boring gave:—

	Feet.	
Peat	11½	
Clay, soft clay or peat. Hard blue sand in lower part.	6½	
	18	or 566½ feet O.D.

2nd. 15 yards to N. Surface 585½ feet.

Peat	15	
Clay, gritty clay	7½	
	22½	or 563 feet O.D.

3rd. 13 yards to N. Surface 585½ feet.

Peat	16½
Gritty clay	0½
	17

4th. 20 yards N. Surface 585½ feet.

Peat	17

5th. 20 yards north.

Peat	16
Gritty clay.	
	16

6th. 20 yards north.

Peat	13
Impenetrable obstacle of wood.	
	13

7th. At the railway.

Peat	16
Buttery blue clay with particles of grit-stone	1
	17

These borings, which were made by me, with the kind assistance of Mr. Robert B. Turton (of Kildale), show that, even if, as seems probable, the boreholes, with the exception of Nos. 4 & 6, actually reached the Lias, the rock-floor of the valley here is below the level of the Leven, and it is very hard to understand why that stream does not flow eastward to the Esk.[1] Four possible explanations suggest themselves:—

1. That the Leven has been diverted by human agency.
2. That it has been obstructed by peat growing over a flat too broad to permit of free drainage.
3. That it threw down a delta where it reached the flat, and that it subsequently flowed round the margin of that delta.
4. That its old channel, now built up by peaty accumulation, is actually deeper than the rock-barrier at West House.

The first of these has little to commend it, though the Leven is now controlled by an artificial embankment. Between the other explanations, in the absence of the necessary data, I do not attempt to judge.

[1] [Other borings, made in January 1902, show that sandstone-rock comes to within 5 feet of the surface along the road between the watershed on Peat Carr and the River Leven; but borings beside the Leven were carried to a depth of 11 feet 8 inches in gritty clay.]

Fig. 13.—*View looking up Ewe-Crag Slack. (The white objects are boulders of grit.)*

Fig. 14.—*View looking down Ewe-Crag Slack. (The bluff on the right is the feature shown on the left of fig. 13.)*

[The above figures are reproduced from photographs by Mr. Godfrey Bingley.]

Kildale to Girrick Moor.

To return now to the consideration of the outer face of the Cleveland Hills. The country between Kildale and Roseberry Topping is of complicated form, and though I think it probable that lakelets with their overflows may have existed, I have seen in the course of a rather imperfect examination no clear traces. At Pinchinthorpe a small overflow is, I think, traceable out of the head of High Bonsdale, but I attach no importance to it.

Passing eastward, two comparatively low gaps are met with, in the great escarpment to the east of Hutton, formed by the two heads of Sleddale. The higher of these, Highcliff Gate, is below 950 feet O.D., but there is nothing in the arrangement of the contours to suggest an overflow, and I have not examined it. The other, known as Bold Venture, is a flat about a quarter of a mile wide, immediately below the 800-foot contour. Though its aspect on a contoured map is unpromising, I examined it, and was rewarded by some interesting observations.

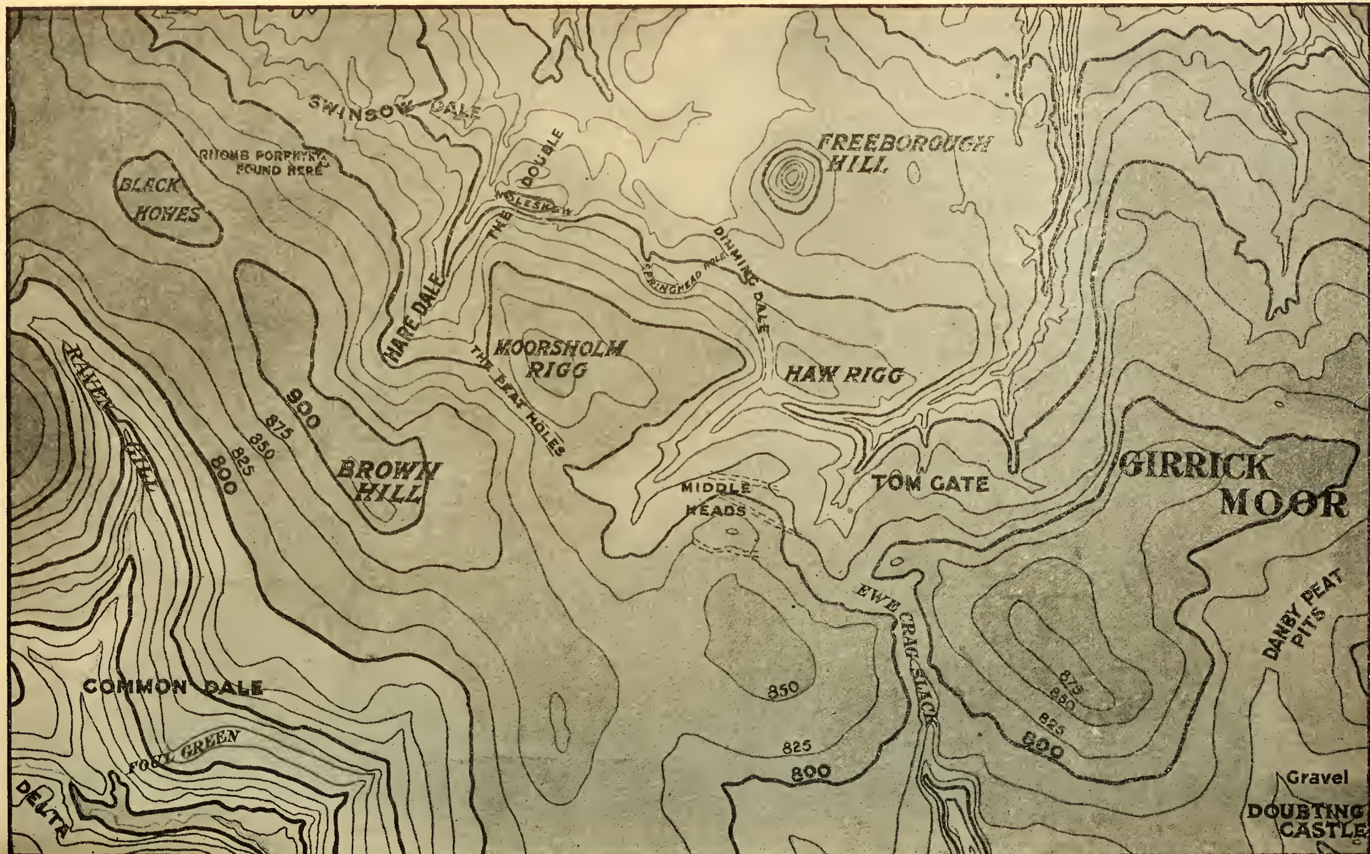
On the eastern side of the gap (at 800 to 825 feet) are abundant erratics, among which I observed Cheviot porphyrites; and on the western slopes I also found many pebbles, including porphyrite and ash. The broad gap itself is encumbered with gravelly material of considerable thickness, cut into a close-set series of mounds with their long axes running down the valley. To the south of this Drift-barrier is a great tract of peat. Some overflow must have gone across here, both from the actual drainage of the ice, and also from a temporary lake in its advance and retreat, but no definite channel can be traced.

From Bold Venture in an easterly direction the watershed, save for Highcliff Gate, is high and unbroken for a distance of about 6 miles measured in a straight line. Then ensues a region of great interest, where the watershed is traversed by a succession of direct overflows, three in number, diminishing in altitude from west to east.

The first of these is Ewe-Crag Slack, a great winding valley which for the first half-mile has a very slight inclination; then it rapidly steepens after cutting through a thick bed of hard grit, and enters the valley of Black Beck[1] a normal moorland stream-course. The intake of Ewe-Crag Slack is turned sharply to the westward, and opens out in a great swampy area. The first half-mile of the slack is occupied by a deep accumulation of peat. In order to ascertain the exact form of this part of the valley, I made a series of fifteen transverse sets of borings or probings (54 in number) into the floor, and found that, agreeably to expectation, the greatest depth of peat was at the point where the peat-moss sloped up stream as well as down. Here a depth of $21\frac{1}{2}$ feet was attained, and the boring ceased in tough deposits, not rock (see Pl. XXIII & figs. 13, 14, p. 518).

[1] So named on my maps. It should be Haw-Rigg Slack, as on the Ordnance-Survey maps.

Fig. 15.—*Relief-map of the country between Commondale and Doubting Castle.* (*Scale: 2 inches = 1 mile.*)



The overflow first came into operation at an elevation of a little over 800 feet, and it cut down to below 775 feet, probably about 750 across the watershed. There is no stream at present flowing in the upper half-mile, but where the slope steepens a small stream emerges from the peat-moss and trickles down through the dried peat of the steeper region, sometimes in an open channel. Often for considerable distances, however, it is arched over by peat, and down to the confluence with Black Beck it can be bestridden at any place. The usual features observable in the meanders of overflow-channels are seen in this gorge, and there are lofty crags along the west side for a considerable distance. Near the confluence with Black Beck, at 625 feet O.D., is a great mass of gravel which has yielded many erratics, including Cheviot porphyrites, and one example of the Norwegian rhomb-porphyry.

This gravel-mass then spreads out and forms two distinct terraces (see p. 512), at 600 feet and 575 feet O.D. respectively. These represent the two halts in the lowering of Lake Eskdale.

So great an overflow as this, might be expected to bear some relationship to a correspondingly extensive lake-area on the northward, and this expectation is fully realized by an examination of the outer slopes of the hills. Not only is the intake connected with a large recess in the hills, but a suite of 'severed spurs' show that upon it converged the drainage of a considerable chain of lesser lakelets. The evidence of the distribution of Drift-deposits is consistent with that of the overflows. Mr. Barrow[1] remarks

'There can be no doubt that this high ground [above Guisborough, on Moorsholme High Moor, and on Danby Low Moor] at present more than 850 feet above sea-level, has not been glaciated, as not a single foreign pebble can be found . . . . Briefly, the Drift becomes very thin at 600 feet above sea-level, and disappears altogether above 850 feet.'

On the Lockwood Hills, up to 867 feet, I found a great spread of gravel forming a fringe to a lower area of Boulder-Clay; and at the entrance to Ewe-Crag Slack, Drift-sands and gravels reach the watershed. These gravels yield fragmentary marine shells and many foreign stones, especially Cheviot porphyrites, and out of a small patch of Boulder-Clay on West Rigg at 810 feet, Mr. J. W. Stather obtained the specimen of rhomb-porphyry already mentioned (p. 498). Scattered erratics may often be found on the moors above the limit of the continuous Drift-sheet, but except on the Lockwood Hills I found none above, or even up to 850 feet O.D.

The overflows aligned to the Ewe-Crag-Slack overflow are few in number, but of great interest.

On the Lockwood Hills (Stanghow Moor) there is a shallow and rather obscure channel falling eastward into Seavy Sike. It barely indents the 850-foot contour. This carried, for a very brief period, the overflow from a lake at the head of the Boosbeck Valley, into a lesser lake, with which it later became confluent, held up by a lobe of ice that stood against the spur called Moorsholm Rigg (see fig. 15, p. 520). The Moorsholm lakelet was of long duration, for its over-

[1] Mem. Geol. Surv. 'North Cleveland' 1888, p. 66.

flow behind the spur is of considerable magnitude. This channel probably commenced to be eroded at a little above 825 feet, and continued to cut down almost to the 800-foot contour, though the valley now called the Peat Holes is so deeply filled with peat as to conceal the 800-foot contour where it passes. A small projection of the hillside known as Middle Heads, near the Ewe-Crag-Slack intake, is trenched by a small parallel series of marginal channels. The upper one is a little above the 825-foot contour, the next between 800 and 825 feet, and the lowest, perhaps the best marked, runs a little above the 775-foot contour. These belong to the aligned sequence falling to Ewe-Crag Slack; and it is interesting to observe that the single large channel at the Peat Holes is the equivalent in time of these three small overflows. The lowest overflow is at a higher altitude than Ewe-Crag Slack. A period of somewhat rapid retreat of the ice-margin seems to have ensued, and this area was, by means of a series of marginal channels, placed in communication with a great direct overflow at Stonegate, 4 miles to the eastward. Before considering this, I will briefly mention a temporary direct overflow that possesses some features of especial interest.

On the Eskdale side of the watershed near Doubting Castle, just 1 mile east of Ewe Crag, a small patch of gravel occurs exactly on the 725-foot contour. This gravel is well-bedded, and contains foreign stones, such as porphyrite, granite, flint, and basalt. Its position and contents alike render it probable that it has washed over the watershed, and it is seen that it lies in a small valley which rises to a depression in the watershed on Girrick Moor, only 760 feet above sea-level. The actual passage through is a broad swampy tract marked at Danby Peat-Pits. I have probed the peat at many places up through the depression, and found about 8 feet of peat resting on gravel. On the outer face of the hills, a thin covering of Drift extends quite to the watershed. The explanation of these phenomena appears to be that, at the maximum extension of the ice, one lobe of its very much indented front reached for a short time far enough to impound water in a small recess of the hills. The overflow passed over into Eskdale, and the gravel which it carried was arrested at the level of Lake Eskdale (725 feet), the exact height at which the Murk-Mire-Moor overflow commenced its action. This would indicate that the maximum extension of the ice at Girrick synchronized with its farthest advance into the Murk-Esk Valley: such coincidences are, I conceive, neither necessary, nor usual (see fig. 15, p. 520).

The Stonegate Direct Overflow and its Related Phenomena.

I now come to one of the most complicated and difficult problems that has yet engaged my attention. I have already stated that the Cleveland watershed was overridden by ice from the seaward end as far as Stonegate, and the overriding mass not only pushed for $1\frac{1}{2}$ miles up the Esk Valley and formed a moraine above Lealholm Bridge, but it also extended across the valley and up beyond Goathland. Round the margin of this invading sheet, a deep overflow-channel was soon initiated, running down the Stonegate Valley. This channel, upon the retreat of the ice from the Moorsholm watershed, took the whole drainage from the Lockwood Hills, and probably the Boosbeck Valley, eastward.

The Drift-maps of the Geological Survey show an extension of the gravels on Black-Dyke Moor, for which there is no corresponding overflow. This was laid down at the maximum extension of the ice, and no definite channel would be produced, as Lake Eskdale would be at its highest level (725 feet). The gravel is mapped at an altitude exceeding 725 feet, but below 750.

The first clear indication of a channel to carry drainage from the westward is Hardale Slack, an immense trench cut in the plateau of Roxby Old Moor and running quite through it. This is a typical example of a severed spur. Its upper end cuts through the 700-foot contour, and there is a long stretch of peat-swamp which conceals a deeper channel. (See map, Pl. XXIV.)

A beautiful example of a deserted oxbow is found on the south side of the channel, immediately west of Black-Dyke Slack. It isolates a small conical hill, and was no doubt produced by a temporary forward movement of the ice-front, which compelled the water flowing past it to cut a small marginal 'in-and-out' channel round its edge.

A second, and much greater intake, Tranmire Slack, comes directly through the plateau from the north-west; and a third, Moses Slack, of lesser size, from the north. These two latter originated as mere gutters to carry water flowing directly off the ice itself. Their arrangement and disposition is what I have generally found in cases where the ice came quite on to, or overrode, the watershed.

We may now consider the series of channels carrying the water through to Tranmire Slack, first describing those of the Moorsholm area. Hardale Slack seems to have been a channel formed during or near the maximum extension of the ice, for the marginal drainage of the country from Danby Peat-Holes eastward. There is a fine gravelly moraine, which extends from Great Dinnond through Little Dinnond, Middle Rigg, and Good-Goose Thorn. Flow seems to have taken place along the outside of this moraine, and there is a more or less defined channel all through. It is best seen at Good-Goose Thorn, where its position is marked upon the 6-inch maps by two ponds. At the upper end it lies between 725 and 750 feet, but to the eastward the 725-foot contour is cut completely through.

A slight retreat of the ice-front opened another series of channels in this region. Three small marginal channels cut across a spur of the hill marked 'Water Dittins (B.S.)', above the 700-foot contour, and open into a valley of the same name. The line of flow

Fig. 16.—*Map of the country round Stanghow.*

is continued by a valley round an isolated patch of ground at Easington High Moor, whence it passes into Hardale Head by a fine valley at the Nan Stone, each of these cutting the 700-foot contour.

The westernmost channel of which I can be certain is a small one which crosses Smeathorns Road, and cuts sharply the 750-foot contour; it falls eastward into Swinsow Dale, and has already been mentioned as affording an example of 'down-stream dichotomy:' as the ice withdrew to the northward, a new outfall was produced on the northern side of the earlier outfall. Examples such as these are very impressive, for they enable the observer to picture vividly to himself the exact margin of the ice.

Of about the same age is a remarkable little 'in-and-out' channel called Spring-Head Hole, at the edge of Moorsholm Rigg. A lobe of the ice-sheet appears to have stood against the smooth hillside here, and caused the impounded waters of Hare Dale to the westward (as well as all flowing from the Lockwood area) to sweep round the edge of the ice, and excavate a loop in the face of the hill, leaving a central block intact. The cutting of this loop commenced above the 725-foot contour, and continued down nearly to the 700. It is possible that this may belong to the final stages of the Hardale-Slack (Roxby Peat-Holes) overflow.

Near Spring-Head Hole is a singular valley cutting round Haw Rigg, which must, I think, have been shaped by alternate flow to eastward and to westward. The westerly escape was the last, and took place subsequently to the formation of the Spring-Head overflow.

An exceedingly clear and well marked pair of marginal overflows, which I have called the Double (see Pl. XXV), marks a further slight shrinkage of the ice-margin from Moorsholm Rigg. The upper one, marked on the maps by the appropriate name of Hole Skew, is a sharply hooked channel opening out of Hare Dale by a square-cut intake 50 feet above the floor of the valley; it falls rapidly towards its eastern end, and cuts through the 700-foot contour, but not down to the 675. Its twin companion, distant from it about 75 yards, just cuts the 675-foot contour except at the intake where there is a considerable accumulation of peat. It is interesting to observe that the top of the lower valley is immediately below the intake-level of the upper one.

I have not been able to study with sufficient care the country to the north of Roxby High Moor and Wapley, so I cannot say which of the overflows in that area continues the alignment indicated by the contoured maps of the overflows at Moorsholm. The head of Tranmire Slack ends in a great expanse of swampy ground, Tranmire itself, which forms the common head of Birch Hill Beck, flowing northward, and a minute stream that flows down the Slack and joins Stonegate Beck; the two streams actually anastomose at their common head.

The swamp scarcely rises above the 625-foot contour, and I believe that the actual rock or Drift-floor is well below that elevation. If this be so, it will explain the occurrence of a well-defined overflow-channel at Stanghow, 6 miles away, which cuts the 625-foot contour throughout its course. It occurs in a morainic country, and at one point east of the village it appears to have been choked by a subsequent deposition of gravel. This is the lowest channel possessing an easterly drainage that I have been able to trace in the area north of the Cleveland Hills; and I would particularly emphasize the critical relation of its altitude to that of the Tranmire overflow, which is the lowest breach in the main watershed. Within 200 yards of the intake of this Stanghow channel, and a few feet lower,

Fig. 17.—*Map of the Boosbeck valley, showing the deviation of the stream at Slapewath.*

we find the head of another valley running through Bushy-Dale Wood with a steep fall to the westward. It cuts deeply into the 600-foot contour (see fig. 16, p. 524). It seems quite clear that in the same way that the direct overflow at Ewe-Crag Slack ceased its operation because of the opening of the much lower Tranmire series of direct overflows, so Tranmire in its turn was abandoned in favour of some overflow to the westward. The steep fall of the Bushy-Dale overflow shows that the main overflow to which it was related was at a low level, and I feel assured that it was into the Vale of York. Other westward-flowing channels exist on the lower slope of the Cleveland Hills, and the constant westerly aberration of the courses of the existing streams proves to my mind conclusively that in the closing stages of the retreat of the ice in Cleveland, the only escape for the water was into the Vale of York. (Some further deductions I shall draw in my conclusions.) A very notable instance of this aberration is the anomalous behaviour of Boosbeck, which, instead of pursuing its course straight down the great open valley to which it clearly belongs, swerves westward through the gorge at Slapewath to join Eller Beck (see fig. 17, p. 526).[1]

The conditions of drainage set up in Stonegate Beck during the maintenance of this overflow are very complex, and it is necessary now to return to the Valley of the Esk to obtain a new set of data.

(5) The Low-Level Phases of Lake Eskdale.

I suspended my description of the Glacial history of Eskdale at the stage at which, by the shrinkage of the ice-lobe which invaded the valley of the Murk Esk, Lake Eskdale became confluent with the Goathland Lake (p. 509). The overflow would now be by way of Fen Bogs, and the lake-level would gradually fall by the cutting of the sill down to its actual level, about 525 feet, or perhaps a little lower. The discovery of the subsequent events proved a great surprise to me. There are along the south side of Eskdale several rock-gorges excavated by lake-overflows, some of which are still occupied by the River Esk,[2] made in such relation to the moraines or to the open valley as to show that the ice-lobe overriding the northern hills must have persisted here after, not merely the mouth of the Esk, but practically the whole coast-line of Yorkshire down as far as Scarborough, was free of ice.

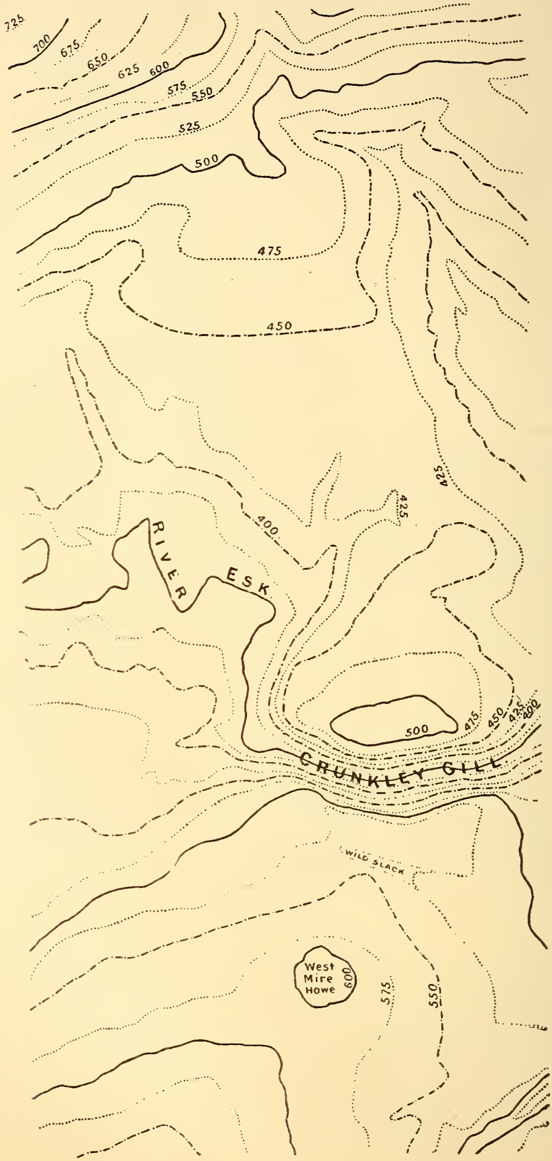
Now, just as it will, I think, be conceded that a lake-overflow is *ipso facto* proof of a clear fall at or below the level of the outlet, similarly a deviation-channel to avoid a moraine-barrier must have

[1] Since these lines were written I have, with the help of my lamented friend the late Mr. J. A. Ridgway (of Beverley), put down a series of boreholes over this area. Within the great Tranmire Slack we made a series of four borings from south-west to north-east, beside the peat-holes near Roxby-Moor House. The first two indicated rock at 11 feet below the surface; the next passed through about 8 feet of peat, and penetrated 4 feet into gravel; and the fourth, beside the stream (on the outer curve of the valley), passed through 10 feet of peat, and stopped in gravel at 18 feet beneath the surface. As the ground-level is about 630 feet, the rock-floor must lie at an elevation below 612 feet.

Another set of three borings was put down on the flat watershed, which is at about 635 feet O.D. Two of these were beside the stagnant drain which connects the northern and southern streams: they were both stopped by something hard, after passing through 5 feet of peat and 4 feet of clay. The third boring, 25 yards to the east of these, gave peat, sand, and gritty clay, and the boring was abandoned in the last material at 17 feet from the surface and about 618 O.D. These observations, so far as they go, are in complete corroboration of the conclusions drawn from the two overflows at Stanghow: namely, that overflow by way of Tranmire was possible at 625 feet, but not at 600 feet.

[2] This fact is referred to by Mr. Barrow in Mem. Geol. Surv. 'North Cleveland' 1888, p. 70.

Fig. 18.—*Contoured map of the Lealholm moraine and the gorge of the Esk at Crunkley Gill.*



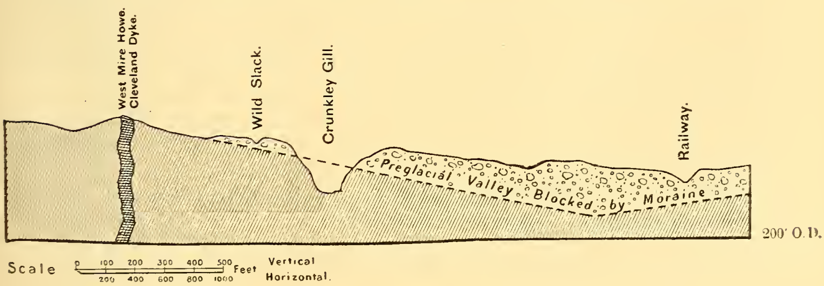
Scale. 0 200 400 600 800 1000 Feet

been cut below the level of the lowest part of the moraine, while the ice still stood against it. I have mentioned that a moraine, the highest in Eskdale, extends across the valley near Lealholm. The lowest point in this moraine is at most 433 feet above Ordnance-datum; yet there is a pair of channels, giving twofold proof that water was flowing from a diminished Lake Eskdale round the end of the moraine at altitudes exceeding 500 feet.

The highest channel is a small, but very definite overflow, known as Wild Slack, which cuts the southern limb of the moraine immediately south of Crunkley Gill; it is not more than 20 feet deep, but is very well defined. It notches slightly the 525-foot contour, although from the gentleness of its slope I am convinced that the fall was very small beyond this: indeed the Slack dies out at the 500-foot contour. It is just possible that the lake into which this drained overflowed by Fen Bogs, although the facts next to be mentioned render it very improbable.

A small shrinkage of the ice opened a slightly lower gap in the moraine on the site of Crunkley Gill, where a spur of rock was covered by about 50 feet of Drift. A new notch was started here, and the level of Lake Eskdale was lowered from about 500 feet, the original level, down to 450 feet, when the outlet began to cut into live rock. By this time it had probably passed the critical level of the moraine, and any further withdrawal of the ice could not affect the position of the overflow. Subsequently, perhaps in post-Glacial times, the final drainage of Lake Eskdale was achieved, and the great gorge of Crunkley Gill, 125 feet deep, completed.

Fig. 19.—*Section across Crunkley Gill and the Lealholm moraine.*

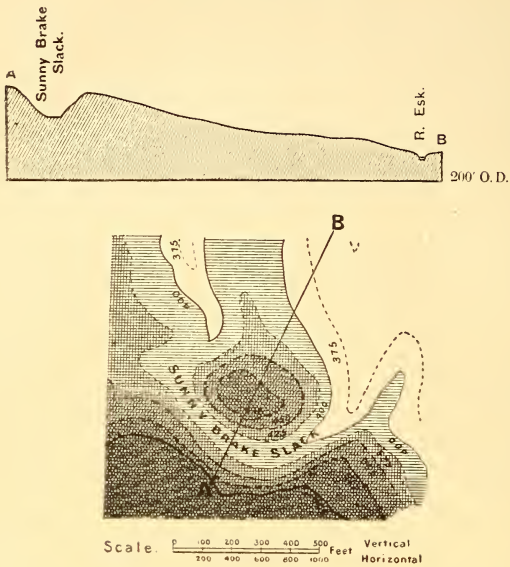


It may be objected that a simpler explanation would be to suppose post-Glacial denudation to have removed 100 feet of Boulder-Clay from the central part of the moraine. It appears to me exceedingly improbable, however, that such excessive denudation has taken place, judging by the remarkable perfection in which many small features of the Glacial deposits have survived. Moreover, the small overflow at Wild Slack demonstrates the existence of a constraining mass of ice. Whatever defect or uncertainty may be found here, is entirely absent from the next case to be described.

About a mile below Crunkley Gill, the steep hillside on the south of Eskdale is excavated by a very perfect example of an 'in-and-out' channel. Sunny - Brake Slack, the channel in question, is about 75 feet deep, with sharply cut sides and a broad peaty floor falling to the eastward. The excavation was commenced above the 475-foot contour, and it cuts through the 425 nearly to the 400 - foot contour.

The main Esk Valley here descends to 275 feet, and at the 475-foot contour it is three-quarters of a mile wide, so that it will hardly be believed that the post-Glacial denudation could have achieved all this; but besides this, it is not the habit of rivers to forsake a rock-gorge on account of the difficulty of cutting in it.

Fig. 20.—*Map and section of Sunny-Brake Slack 'in-and-out.'*



The levels show, I think, that the ice-barriers stood simultaneously here and at the gap in the Lealholm moraine, for the cutting commenced at Sunny Brake at a level above that at which the Lealholm gap would have been open. Between Crunkley Gill and Sunny Brake a narrow marginal lake probably extended, much of it more river than lake; and at several places scarping is observable, especially in the fields south of Low-Wood Lane, where there is a very pronounced feature between the 450- and 475-foot contours.

A third significant gorge occurs at Glaisdale, less than half a mile below Sunny Brake. Here the Esk has cut a deep gorge into the rock to evade a morainic obstruction, although the moraine is of less height (325 feet O.D.) than the top of the gorge, which is distant only 300 yards. (See map, Pl. XXIV.)

Other rock-gorges, always, as Mr. Barrow has remarked, on the south side of the valley, may be seen at East Arncliffe and Bank Wood, but their testimony is not decisive. They may be due merely to the impartial cutting of the river into a Drift-filled valley, although that leaves unexplained the coincidence of its invariable preference for the south bank.

The three examples, Crunkley Gill, Sunny-Brake Slack, and Glaisdale, show, I believe, that an ice-obstruction extended across Eskdale at the same time that a free fall for water could be obtained at the levels which I have indicated, namely:—for Crunkley Gill, 500 down to 450 feet; Sunny Brake, 475 down to below 400 feet; and Glaisdale, about 350 down to 325 feet.

Where, now, was the actual escape to the southward?

One of the peculiarities of the Fen-Bog overflow which, at the outset of this enquiry, convinced me of the significance of its features, is that it is the lowest outlet from Eskdale, saving only Whitby Harbour. The 500-foot contour is intact right along the southern watershed until Bay Ness is reached, half a mile from the coast at North Cheek, Robin Hood's Bay. The 400-foot contour extends to about the same distance from the cliff-edge at Hawsker: and the 300-foot contour is unbroken up to within 100 yards of the cliff at Whitby High Light, $1\frac{1}{2}$ miles from the town. There is, moreover, no sign of an overflow-channel at any level from Bay Ness to Whitby Harbour; at the latter place, however, there is a great rock-gorge 100 feet deep running along a line of fault.

It is quite possible that the form of the ice-front was such that a broad way existed, a narrow marginal lake, across the space between Whitby Harbour and the High Light, but I have seen nothing to suggest it; and I think it more probable, taking into consideration facts presently to be adduced regarding the next stage of retreat, that the gorge at Whitby Harbour was the actual outlet. This, of course, need not imply that the coast at Whitby was free from the edge of the ice, for the cutting of the gorge may have been merely commenced at this stage, and marine erosion on this coast has no doubt removed a broad strip, perhaps a mile or two in breadth, since the Glacial Period. But there must have been a free fall to the southward, and this can have been obtained only by low-level channels in a coast-tract since carried away, or by actual open water.

The stages of retreat in Eskdale here described are indicated imperfectly by a series of moraines. I have not succeeded in tracing any between the Lealholm moraine at Crunkley Gill and the series of successive ridges that descend from the northern moors across Eskdale at Glaisdale. These last differ in composition considerably from that at Lealholm, consisting mainly of sand and gravel, while the Lealholm moraine is almost entirely composed of Boulder-Clay. The difference is probably due to the latter having been accumulated wholly under water.

I have already indicated that there are some signs that, at the period represented by the Wild-Slack and Crunkley-Gill overflows, a large volume of water was entering Lake Eskdale by way of Kildale and West Bank. For, just as a higher level of the lake is attested by the deltaic spread of gravel at Commondale, so a fragment of a lower delta is found at Hell Hole or Holme Bank, near Castleton. It has been much cut into by the Esk and its tributaries, but at its termination at Hell Hole it extends quite across the valley, except for a narrow gorge-like gap cut by the river through hard rock. There is not much to distinguish this diversion from that produced by a moraine, except the form of the gravel-mass. The surface-level of the delta is about 525 or 550 feet.

It is quite possible that an ice-dam obstructed portions of the lower valley of the Esk long after the stage represented by the Glaisdale moraine; but no definite evidence would remain, as the morainic barriers have not, like the Lealholm and Glaisdale moraines, any gap below the top level of the gorges cut by the Esk in evading them. The Stonegate valley presents some features of exceptional interest, which belong apparently to a transitional stage between the high-level and the beginning of the low-level phases of Lake Eskdale. The head of this valley at Tranmire has already been referred to, but not its intermediate course nor its outfall.

At the lower end of the Tranmire Slack, from its confluence with Hardale Slack the valley is excavated through a flattened floor of gravel, which forms a very notable terrace, especially on the eastern side of the valley—or rather a pair of terraces one above the other. Their structure is admirably displayed in the cuttings of a railway, partly made and then abandoned. The lower terrace about the village of Stonegate is a shelf of hard sandstone in which the stream has cut a splendid gorge, but just above where the road to Whitby crosses the stream, the old railway-cuttings begin, and they show about 30 feet of very coarse gravelly clay, containing so many fragments of Upper Liassic shale as in parts to make up a large proportion of the mass. Blocks of Jurassic sandstone, rounded, subangular, and angular, are abundant; some attain a length of 3 or 4 feet. Among the stones are many foreign to the district, of which a list has been published in the Report of the Erratic Blocks Committee.[1] The most noteworthy fact is the comparative rarity of Carboniferous rocks, and the abundance of Magnesian Limestone with botryoidal and other concretionary structures. These gravels continue up the valley above Low Whin. A second terrace at about 575 feet shows a marked rise as it runs up the valley.

The explanation of these features which seems to me at present most satisfactory, is that they were produced as a kind of marginal delta between the hillside on the west and the ice-margin on the east of the valley. The phase seems to coincide with the stage when the Lealholm moraine was being formed. The ice-margin then swept round the angle of Lealholm Moor, and past Hole'-i'-th'-Ellers to the terminal moraine. The gravelly material, very imperfectly washed, was laid down alongside the ice in the Stonegate valley, while the flowing water cut a marginal shelf in the face of the hills overlooking Eskdale.

[1] Rep. Brit. Assoc. 1899 (Dover) p. 400 & 1900 (Bradford) p. 345.

Lower down the Stonegate Valley, some features are seen which are connected with the stage of retrocession marked by the lower phase of Lake Eskdale. At Stonegate-Gill Wood, just south of the hamlet of Stonegate, there is a mass of Drift, mainly gravel, but apparently more clayey in its lower part, which has evidently blocked up the original valley and caused a deviation to the western side, where a fine gorge nearly 200 feet in depth has been cut, the lower 100 to 125 feet in solid rock. The fact that this deflection is to the westward, while the southern tributaries of the Esk are thrown to the eastward, is interesting, as it indicates very plainly the position of the ice.

The last chapter in the Glacial history of Eskdale and Northern Cleveland which I have deciphered is very clearly recorded by a series of overflow-channels cutting through the northern watershed above Egton Bridge. The northern face of the hills here forms a great amphitheatre about Ugthorpe and Hutton Mulgrave, and is prolonged in the great spur extending due northward parallel with the Stonegate-Tranmire channel for about 3 miles. On the eastward, another spur runs in a northerly direction. The main watershed rises into a fairly sharp crest, culminating at 850 feet above Ordnance-datum in Kempston Rigg. The central portion of the amphitheatre is broader and lower, and for a space of about a mile is only about 700 feet above O.D. (See map, Pl. XXIV.)

The retreat of the ice from Eskdale carried the melting front, step by step, backward up the northern slopes of the Esk Valley, until it fell entirely behind the crest. It withdrew similarly from the Stonegate Valley in an easterly direction, and halted on the watershed, where a series of gravelly mounds are seen with strongly-channelled fronts overlooking the valley. In the retreat, many trenches were cut by streams flowing from the melting ice: some of these, as the ice-front drew back behind the watershed, cut steadily backward through the crest, and produced a set of overflow-channels for the discharge of a series of small lakelets formed along the margin of the ice. One or two failed to cut through the watershed, and therefore their share in the system of extraglacial drainage was simply to carry off water flowing down the front of the ice. An example of the latter type slightly notches the watershed on Egton Low Moor immediately above the 700-foot contour.

Three true lake-overflows cut the watershed more deeply. These are, in order from east to west:—(1) Middle-Carr Slack, which makes a slight trough through the watershed near Lady-Cross Gate, but deepens to a pronounced feature in its lower course. (2) Stonedale Slack, a very fine ravine which now cuts the crest in a very marked fashion. A curious cross-channel connects these two valleys near their head. The two channels probably were of brief occupation, and their strong development in their lower parts, as compared with the heads, is consistent with the view here adopted, that they were primarily channels carrying the direct drainage of the glacier. (3) The third overflow is of a very different type—it is a great gorge 30 to 40 feet deep, which forms a very conspicuous breach in the line of watershed at Barton 'Howl.'[1] The overflowing stream commenced to cut at about 680 feet, and ceased at about 665. These, then, may be regarded as the approximate water-levels of a small lakelet on the iceward side of the watershed. This lakelet had a maximum area not exceeding 3 or 4 square miles.

At the easternmost extremity of the Hutton-Mulgrave amphitheatre, just above the village of Aislaby, two small valleys cut through a spur at about 630 and 580 feet respectively. The former of these, Galley-Hill Slack, has much the appearance of a lake-overflow, but so large a volume of water at present descends from springs and surface-drainage, as to suggest the possibility that the valley may be the product of normal drainage. The latter valley displays features so lacking in distinction that, without the corroboration of other members of a related series, I should not venture to include it in my enumeration of Glacial overflows.

The last evidence of constrained drainage in Eskdale that demands notice, is the actual outlet of the River Esk at Whitby. The river here flows through a rock-gorge about 100 feet deep, and so narrow as to forbid the supposition that this was its ancient course. Landslips frequently take place, and it is evident that the channel is very modern. Mr. Barrow has called attention to this case in his fine Memoir on Northern Cleveland, and has drawn the same conclusion. He says[2]:—

> 'The River Esk at Ruswarp is approximately in the centre of its old course and shows no rock. But further north it begins to flow between steep rock-banks, which, near Whitby, are nearly vertical. Its pre-Glacial course was to the west of the town and into the sea, where the cliffs are entirely composed of Glacial deposits. A deep well sunk in this old line of flow went down a great depth without meeting with any rock, but the exact details we were unable to obtain.'

Whether this deviation was due merely to the fact that the old valley was packed with Boulder-Clay and other Glacial materials so as to be completely obliterated, or whether the post-Glacial Esk was, like so many other streams in the district, constrained to take a course along the outer edge of the ice, I am unable to say. Many facts could be cited in favour of either view.

The drainage of that part of the south side of the Esk Valley which lies east of the Murk-Esk Valley must now be considered.

It has already been explained that a lobe of the great ice-sheet at the maximum extension overflowed the northern watershed, and welled up the Murk-Esk Valley as far as the moorland south of Goathland. I have remarked that the evidence that Kempston Rigg was ever completely overridden seems inconclusive, and the phenomena seen on the southern side of Eskdale may perhaps find an easier explanation upon such an assumption, though it does not appear to me to be probable.

[1] An eccentric spelling of the word 'Hole.'
[2] Mem. Geol. Surv. 'North Cleveland' 1888, p. 69.

(6) Iburndale.

This valley is deep and rather narrow, forming a V both in plan and section. It opens northward into Eskdale at Sleights, and is separated from the Murk-Esk Valley on the west by Sleights Moor, a broad tract of Lower Estuarine grit, which forms a steep escarpment on the west, north, and east. This constitutes a watershed nowhere falling below 800 feet. On the east, Iburndale is enclosed by the high moorlands (of the same grit) of Ugglebarnby and Sneaton, which attain an elevation of 700 feet quite near to Eskdale; and this altitude, or a still greater one, is maintained nearly to the head of the valley.

Drift-deposits of great thickness occur in the floor of the valley, and to a considerable height up its sides. My observations inclined me at one time to the belief that no portion of the valley south of New May Beck had been invaded by ice, but that opinion has given way before an accumulation of facts, which I think cannot be satisfactorily explained without such an extension.

The position of this valley, opening due northward towards the invading ice, was selected by me at the outset of this enquiry for the *experimentum crucis*. If the obstruction of an ice-barrier produced a lake at Goathland, then Iburndale should similarly show signs of a lake and overflow.

The preliminary examination of contoured maps, which has always constituted the first reconnaissance in this survey, proved the presence of a very suggestive gap in the eastern wall of the valley near its head. The field-observations demonstrated in the clearest manner its character as that of a lake-overflow. (See map, Pl. XXVI.)

The intake is an abrupt notch on the lakeward side. It cuts the 675-foot contour, but the 625-foot contour is not at all indented, and the 650 is but little affected, while a deep, thickly peat-filled valley, Biller-Howe Dale, of characteristic section, extends eastward into the Jugger-Howe-Beck drainage, which constitutes the true source of the River Derwent. Other characteristics of this valley will be mentioned later.

Sneaton Moor is a long, gently curved crescent of high ground presenting a concavity to the northward. At the maximum extension of the ice, this watershed was completely overriden, and the ice extended forward to the Iburndale overflow. In the stage of retreat, the watershed was trenched by two well-marked lake-overflows, both now streamless where they cross the watershed, and containing a considerable depth of peat. A bench-mark at the intake of one, Nigh-Middle Slack, indicates a level of 676·9 feet, while the other is considerably above 675 feet, though below 700. The watershed here is of exceedingly soft muddy shales of the Lower Estuarine Series, with a few scattered Drift-pebbles; and I infer that no considerable body of water can have drained across, or the channels would have been cut more deeply in such easily-eroded materials.

From Sneaton Low Moor the watershed runs in a general easterly direction, and remains intact and unbroken quite to the coast: therefore the retreat of the ice must have been in such wise that no lakes were formed, for neither direct overflows, nor any sign of marginal overflows can be found.

There are many ways by which this fact may be explained. The retreat may have been so rapid that, though evanescent lakes were produced, the overflows were not cut deep enough to be recognizable: several shallow grooves can, it is true, be seen to cross the watershed, as on the Whitby road. Or, again, the shrinkage of the ice may have been progressive from east to west, so that no lakes could form. Or, as a third explanation, it is possible that marine denudation has removed a coastal region which was channelled by overflows.

A combination of the first and second of these suggestions seems to me to explain the phenomena most fully. The third hypothesis appears to be excluded by the form of the ground at Bay Ness, where the watershed reaches the coast. There are, however, as will be shown later, clear cases in which seaward tracts carrying overflows have been wholly or partly swept away.

(7) The Eastern Coastal Tract.

The line of watershed extending from the head of Iburndale round Sneaton Low Moor marks the beginning of a drainage-system displaying many remarkable anomalies, some of which have been ably described and elucidated by Mr. Fox-Strangways. A narrow coast-strip of country, extending from Robin Hood's Bay on the north to Hunmanby on the south, and varying in breadth from 100 yards up to a maximum of about 3 miles, drains in a general way down the normal slope of the land into the sea. But, behind this, at a short distance, seldom more than 3, and never more than 6 miles, there runs a great gorge or connected series of gorges (like the intercepting drains of the engineer) which receives all the drainage of the hinterland and carries it away to the southward, and finally westward, through the Vale of Pickering, into the Ouse and Humber drainage. Thus it is that streams, rising within 2 miles of the sea at Robin Hood's Bay or Peak, pass into a system which enters the sea at Spurn.

In the initiation of this drainage, the effects of an ice-sheet which shut the seaward ends of the valleys is clearly traceable, just as was the case in Northern Cleveland, but with this difference, that in the northern area the lake-overflows were rarely cut to so great a depth as permanently to deflect the larger drainage-channels. On the eastern coast, the ice-invasion was not so extensive, and the overflows were all of the marginal type. Some of the cutting was over high and prominent watersheds, but more often existing drainage-lines were followed and deepened. Moreover, the effects were cumulative, as one aligned sequence remained in occupation for a long period, and an increasing volume of water was brought to bear upon just those regions where the greatest barriers were encountered, namely at Hackness and Suffield Moors. It will be further shown that at these two places the physical features of the country were such as to secure a stable position of the overflows during considerable oscillations of the ice-front, so that persistent cutting on one line of overflow would take place, instead of the excavation of a parallel series of successive channels such as occurred in many areas.

I shall deal with this region in four sections, corresponding with four natural divisions of the country:—(*a*) Robin Hood's Bay; (*b*) Peak to Cloughton, and Hellwath to Harwood Dale and Burniston; (*c*) Burniston to Scalby; and (*d*) Scalby to Filey.

(*a*) Robin Hood's Bay.

Physically, Robin Hood's Bay is the half of a dome-like inlier of Lias produced by a cross-fold at the seaward end of the Cleveland anticline.

The various divisions of the Lias, down to the *planorbis*-zone, are exposed round the shores of the bay; above these come the Lower Oolites, consisting mainly of the Lower Estuarine Series, a succession of sandstone, shales, and coals presenting a surprising resemblance to the Coal-Measures.

The bay is surrounded by a much deeper amphitheatre of high ground composed of the Lower Estuarine Grits, which form a bold, and in places precipitous, escarpment recessed by several alcoves, where streams come, or came down into the bay from the surrounding moorlands. The interior bay is packed with Boulder-Clay to so great an extent, that very few rock-exposures are to be found even in the deeply-cut ravines, and at least at one place, at the mouth of Stoup Beck, the Drift-deposits extend below the beach-level.

An outer fringe of Drift near Kirk-Moor Gate and Latter-Gate Hills consists of sand and gravel heaped up in large mounds.

The pre-Glacial watershed has, in part, been already defined, being on the north-west and north that of Iburndale and Sneaton Low Moor. To the south and south-east, it extended from Peak through Stony-Marl Howes, and thence in a wide sweep, round by Burn Howe and Blea-Hill Rigg, to John-Cross Rigg above Iburndale. The drainage of the whole of this area probably converged on Robin Hood's Bay, as that of the northern segment still does, and the gradients down to the edge of the grit-escarpment were in the main so low as to produce rather the appearance of a plateau than of a ridge. (See map, Pl. XXVI.)

At the period of maximum extension, the margin of the ice-sheet appears to have extended from the head of Iburndale along a west-to-east line to the great bend of Biller-Howe Dale, and thence to have run in a southerly direction past the side of Biller-Howe farmhouse, and on to the junction of a little nameless beck, south of 'the Island,' with Jugger-Howe Beck. The margin is well defined along the whole line by the extension of the Drift and pebbles, and by the occurrence of the marginal channel which carried the drainage from Lake Iburndale and the ice-free country within the watershed.

The upper part of this channel has already been referred to, in discussing the overflow of Iburndale. This valley, Biller-Howe Dale, opens upon the skyline at its head in the manner so characteristic of these lake-overflows. On its northern side, in the upper and streamless part, is an abandoned high-level oxbow separated from the main channel by a small hill of the solid rock of the country (see fig. 21). I interpret this to mean that the oxbow was a portion

Fig. 21.—*View looking up Biller-Howe Dale. (The conical hill near the intake is isolated by the deserted oxbow.)*

[From a photograph by Mr. Godfrey Bingley.]

of the first-formed channel, which was overridden by the ice in a temporary advance during which the present channel was cut to such a depth, that, on the recession of the ice-front, any resumption of the first line of flow was impossible. Such cases are not uncommon in the Cleveland area, and especially in the portion yet to be described.

From the point where Biller-Howe Dale makes a right-angled bend to the southward, a series of three high-level channels can be traced running parallel with the great gorge which at present carries the scanty drainage of this area. These three are really not so much an aligned sequence as one channel, the course of which has been intersected by two modern streams. The first segment runs behind Biller-Howe farmhouse, and it is a streamless gully of about 20 feet in visible depth, but is known to contain at least 15 feet of peat near the house. Its intake is seen as a notch in the skyline 100 feet above the floor of Biller-Howe Dale. The second segment is a moss-swamp forming a deep trench across Biller-Howe-Turf Rigg. The third, rather less sharply-cut, segment continues in accurate alignment across the spur called 'the Island,' and its lower course has been adopted by a modern stream, forming a rocky gorge 100 feet deep at its confluence with Jugger-Howe Beck.

Beyond this point, a breach was made in the watershed on Jugger-Howe Moor: this separated the Robin-Hood's Bay drainage from that of the Hellwath Burn, which now flows into the Derwent drainage, but formerly entered the sea near Burniston. The margin of the ice-sheet appears to have stood for a very short time at its farthest point of advance, then to have retreated rather rapidly for a time to a position about which it lingered for a very long period, long enough for many large and deep channels to be cut which are, I think, unsurpassed in the whole Cleveland area.

The first effect of the retreat appears to have been to produce a great sinuation of the ice-margin which withdrew from Biller-Howe Dale, and uncovered a large part of Sneaton Moor. A large channel, Grey-Heugh Slack, was now developed running along the western margin of the ice-lobe from Fylingdales Moor to Biller-Howe-Dale Slack. This channel would carry off the water flowing from the ice-front, as well as that coming from the ice-free ground on Sneaton Moor. As the shrinkage of the ice progressed, a series of small shallow trenches were worn through the gravelly eastern banks of Grey-Heugh Slack by water from the ice-front. The best preserved of these is a small slack draining to the westward from Foulsike Farm.

The next phase of retreat initiated a line of drainage, second in importance in the Cleveland area only to the great Newtondale gorge: this is the valley, bearing different names in its parts, which I may call the Jugger-Howe Valley. The margin of the ice had withdrawn northward so as to lie upon, or entirely behind, the Sneaton-Moor watershed. The shrinkage to the eastward brought the edge of the ice along the line of the present Jugger-Howe Valley, which at that time, however, had no existence. A recess in the hills at the northern end produced by the valley of Kirk-Moor Beck now became a small lake receiving the water draining from Sneaton Moor by the two channels mentioned, and also from its own section of the ice-front. A marginal channel was then initiated, which wound along the edge of the ice to join the Biller-Howe-Dale overflow from Lake Iburndale. This new channel, which I may call the Foulsike overflow, continued to operate for a long time, and its broad and steep-sided gorge, though containing a great thickness of peat, still shows a depth exceeding 75 feet. It opens out abruptly at its intake into the very dissimilar valley of Kirk-Moor Beck. No stream, but only swamp, occupies the upper part of the gorge.

Simultaneously, perhaps, with the formation of this valley, or possibly of an earlier date, coinciding more with the cutting of Grey-Heugh Slack, a magnificent channel was being excavated along the southern edge of the great amphitheatre near Stony-Marl Howes.

I have been unable to satisfy myself that all the high ground bounding Robin Hood's Bay on the south, which culminates in Stoup Brow (871 feet O.D.), was overriden by the North Sea ice-sheet; but, if so, the phase was a very brief one, and the ice-front broke up into a sinuate outline. The lobe, which was thrust into the upper bay formed by the escarpment of Estuarine Sandstone, would have a strong southerly component of its motion, if one may judge by the general phenomena of a boulder-transport in the coastal tract of Yorkshire; and this conclusion is strengthened greatly by the direction of the few glacial striations observed upon the rock-surfaces. One striated surface has been observed in Robin Hood's Bay by my friends Messrs. H. B. Muff & T. Sheppard,[1] and I had the pleasure of seeing it under Mr. Muff's guidance. It occurs on the top of a hard bed of Estuarine Sandstone at Bay Ness, and the striæ have a direction towards the south. The effect of a thrust in a southerly direction would be to cause the ice-lobe to stand well away from the escarpment at its north-westerly angle, while it would press much more closely against the very precipitous slopes on the south and south-east; so that while in the north-west there would be a considerable lake to discharge by the Foulsike overflow, there would be only space for a series of small narrow lakelets along the southern edge. These lakelets appear to have drained for a long period by means of a marginal channel trenching the face of the escarpment, and attaining at last a depth of about 70 or 75 feet. This channel, about a mile in length, is now occupied in its lower half by a small rivulet, Burn-Howe Beck, but near the intake at Cook House it is streamless.

Two related channels trench the western end of Stony-Marl Howe, and converge before opening into the head of Burn-Howe Valley, near the confluence with which the small stream that they at present conduct doubles back and flows into the Robin-Hood's Bay drainage, while the old course is still traceable as a dry valley.

I am convinced that the Burn-Howe channel continued to operate for a long period, yet not for the whole time during which ice-dammed lakes persisted in the district, as its thalweg falls steadily from the intake at Cook House to within about 600 yards of Jugger-Howe Beck, in which distance it has declined from about 610 or 615 feet O.D. to 525 feet. Beyond that point, however, the slope is much steeper into Jugger-Howe Beck, namely, about 100 feet in 600 yards. The steeper slope represents the more active cutting by Jugger-Howe Beck since the abandonment of the Burn-Howe channel by the Glacial waters.

The recessed character of the grit-escarpment brought about, as

[1] Glac. Mag. vol. iv (1896) p. 52.

the ice-edge retreated, the formation of two other marginal lakes similar to that in the valley of Kirk-Moor Beck, and each of these had its own separate overflow-channel cutting through the narrow watershed between the Robin-Hood's Bay drainage-slope and the great intercepting-drain of Jugger-Howe Beck. These overflows doubtless originated in the channels produced by streams running directly off the ice-front itself as it slowly retreated.

Some channels such as I describe were thrown out of action, as soon as the ice shrank well away from the watershed, and lateral communications were opened up. One good example of these temporary overflows is seen running from the cross roads near Evan-Howe farmhouse towards Evan-Howe Slack.

We now have the recess of Robin Hood's Bay occupied by three lakes—Kirk-Moor Lake on the north, Evan-Howe Lake in the centre, and Blacksmith-Hill Lake on the south.

The overflow of the first of these by Foulsike I have already described. The second, Evan-Howe Lake, was drained by a gigantic trench, Evan-Howe Slack, a valley about half a mile long, 100 yards wide across the floor, and nearly 100 feet deep. There is at present no stream in the upper two-thirds of its length, and only a diminutive rivulet in the lower part; its broad intake is probably at about 535 or 540 feet above sea-level.

During the shrinkage of the ice-lobe, the spur separating this lake from Kirk-Moor Lake to the northward was gradually uncovered, and, as the outlet of Evan-Howe Lake was lower than that of its neighbour, channels were cut across the lower parts of the spur whereby Kirk-Moor Lake was drained into Evan-Howe Lake. Therefore the Foulsike overflow now became functionless. Two of these lesser channels are traceable at Moor-Close Plantation and Chapel Garth respectively. The former has its intake somewhat above 550 feet O.D., and the latter is a little lower. I am unable to explain why the levels should be arranged as they are. If the Chapel-Garth overflow, which is the farthest from the ice-front, were a deep and strong cut, I should be inclined to suggest that it had been re-deepened in consequence of the closure of its rival by a forward oscillation of the ice, but in fact it is a very shallow and ill-defined valley.

The southern lakelet drained by the Blacksmith-Hill overflow, which is a gorge almost exactly comparable in its dimensions with Evan-Howe Slack. It is about 1000 yards long, and 50 to over 100 feet deep; a small stream occupies about two-thirds of its length. The intake is about 510 feet above O.D.; but, as in all other large channels, there is a good deal of peat in the floor. The lake was probably from its inception fed by the drainage previously flowing down Burn-Howe Dale, which channel was consequently abandoned. This is indicated clearly by the levels—the intake of Burn-Howe Dale is above the 600-foot contour, but the watershed upholding the Blacksmith lakelet for more than half a mile lies below that level. The retreat of the ice-front threw the central and southern lakes into confluence; and as the Blacksmith-Hill outlet was well below the intake of Evan-Howe Slack, it took the whole drainage. When this happened, the ice still stood for a short time against Swallow Head, the spur which bounded Kirk-Moor Lake, for the overflow across the spur at Moor-Close Plantation cuts at its lower end below the Evan-Howe-Slack intake.

A final and, I think, rapid recession of the ice opened some way for the waters round the seaward end of Peak, and perhaps by channels cut in lower grounds of which marine denudation has left no relic; or it may be that some traces exist in the curious undercliffs which have long been among the problems of the geology of the Yorkshire coast.[1]

I think it probable that during nearly the whole period of prevalence of the lakes which I have just described, water was flowing out of Iburndale by way of Biller-Howe Dale. No lower escape for the drainage of that valley or of the outer face of the Sneaton Moors existed, or could have existed without leaving unmistakable traces.

I must mention two remarkable examples of deserted oxbows occurring in the system of valleys here described. They possess a more than common interest, as they are of opposite types, and prove with unusual clearness the nature of the agency which constrained the drainage in these channels and the radical change which was effected.

A small deserted oxbow in Biller-Howe Dale has already been mentioned. In that case, the old channel was on the 'iceward' side of the more modern one, and I attributed its closure to a slight advance of the ice. An exactly similar, but far finer example is found running behind Brown Rigg—a bold and steep-sided hill dissected out of a high patch of moorland on the east side of the Jugger-Howe Valley. The old channel is very sharply cut; it has a maximum depth of about 60 or 70 feet, and a length of nearly half a mile. At both ends, it opens out on the very precipitous wall of the Jugger-Howe Valley, at an altitude of about 60 or 70 feet above the floor of the valley. (See fig. 22, p. 543.)

The explanation which occurred to me during my examination of the ground, was that this was a portion of the main marginal channel which was produced at an early stage of the ice-invasion, when the maximum extension was almost attained; and that a subsequent forward movement brought the ice-edge across one or both ends of this loop, and caused a new and deeper channel to be cut outside. In this particular case, interesting confirmation of my hypothesis was found in the discovery of a patch of stony clay with erratics on the northern end of Brown Rigg. Also, on a sort of terrace or bench on the face of the Jugger-Howe Valley, a little to the north of the intake of the oxbow, a quantity of gravel was found that extended up the slope to the watershed, which is rather low there.

[1] The undercliff at Peak is largely, I am sure, of origin similar to the Cretaceous undercliffs of the South of England. It is due, that is, to landslipping, as I have observed considerable landslips actually in motion.

The other example of a deserted oxbow is on the western side of Evan-Howe Slack. It is, like the last, of crescentic form, but the crescent is turned in the opposite direction. It is about a quarter of a mile long, some 40 feet deep, and opens on the wall of the main valley at an altitude of about 50 feet. I consider that in this case the main Evan-Howe channel was first formed, and that it was closed by a slight forward movement of the ice, probably the same as that which closed the Brown-Rigg channel. On the retreat of the ice the old channel was still the deeper, and flow along it was resumed.

Fig. 22.—*Brown Rigg viewed from the west side of Jugger-Howe Beck. (The deserted oxbow is shown on the left of the ridge. Jugger-Howe Beck in the foreground.)*

[From a photograph by Mr. Godfrey Bingley.]

Before taking final leave of this section of country, I may just say that the discovery of this complex reticulation of channels cut by the overflowing waters of Glacial lakes, out of a gently-sloping plateau of at present heatherclad moors, impressed me more than any other illustration of the effects of the Ice-Age that I have seen. The necessity for some explanation dependent upon the admission of a great ice-sheet in the North Sea has never appeared to me more imperative; and I earnestly hope that the few distinguished British geologists who still find themselves more impressed by the difficulties—great and real difficulties—in the way of the acceptance of such an ice-sheet as a postulate in post-Pliocene geology, than with the facts which have led so many to accept it as, with all its consequences, the only possible solution of the problem, will find an opportunity of examining this remarkable region. An easy way to see three of the great valleys, namely, Burn-Howe Dale, Blacksmith-Hill channel, and Evan-Howe Dale, is to take the coach from Scarborough to Whitby. Not only does the main road between the two towns cross these three valleys at their best parts, but it also traverses many fine overflow-channels in the country farther south.

(*b*) Peak to Cloughton, and Hellwath to Harwood Dale and Burniston.

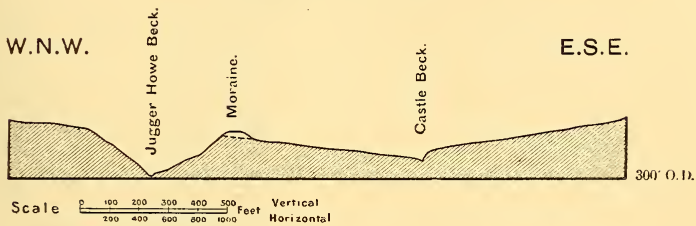
The very complicated area now to be described extends from Jugger-Howe Beck to the country between the parallel of Peak on the north and the line of the Lindhead (Burniston) Beck on the south. The western and southern boundaries coincide closely with two great pre-Glacial valleys. The area thus enclosed is traversed by two streams flowing along ancient lines of drainage—Hayburn Beck and the nameless stream in Staintondale, which become confluent close to the sea at Hayburn Wyke: their respective valleys were the sites of glacier-lakes. (See map, Pl. XXVII.)

The area is extensively Drift-covered, especially near the coast and near the western boundary. Not even the highest prominences on the northern watershed appear to have entirely escaped glaciation. I have found, as before stated (p. 493), Drift-gravel with various erratics, including flint and Cheviot porphyrites, on the moorland near Green Dyke at about 825 feet above sea-level, and over Stony-Marl Howe. But Pye Rigg, only a mile farther south, appears to be Driftless, though my examination was restricted to the eastern and northern slopes and the summit, and I did not realize at the time that any special significance could attach to the observation.

It seems certain that, for a short time at the period of maximum extension, the ice reached the edge of what is now Jugger-Howe Beck. Whether the ice-margin was entire from Burn Howe to the confluence with Hellwath Burn, or whether it swept in two lobes round Pye Rigg and Stony-Marl Howe, leaving an unglaciated area behind (that is, west of) the high ground, I am unable to say; but the evidence is quite decisive that this condition quickly supervened. I shall assume that the latter was the case, as for the purpose of the present discussion all the special phenomena belong to the stage of retreat. Before the Robin-Hood's Bay watershed was breached by the overflow of Jugger-Howe Beck, a wide valley of normal type descended from Stony-Marl Moor along the Hellwath valley nearly to the site of its present junction with Jugger-Howe Beck; thence, however, its course was continued down the Castle-Beck valley.

When the ice advanced over the country, it thrust across this valley so as to impound the water, which in consequence took an extramorainic course along the opposite side of the valley, until it cleared the obstruction, at the same time that the overflow from the Iburndale–Robin Hood's Bay area was sweeping down the same line. In this way the Jugger-Howe valley was produced. A well-marked range of gravelly moraine now extends along the verge of Jugger-Howe Beck, which here runs in a narrow gorge from 100 to 130 feet deep, contrasting very strikingly with the broad open

Fig. 23.—*Section across Jugger-Howe Beck and Castle Beck, showing the moraine.*



valley of Castle Beck which runs beside it (see fig. 23). The watershed separating the head of Castle Beck from Hellwath Beck is not more than 50 yards from the bottom of the deep ravine in which the latter stream flows. At the assumed stage of maximum extension, a small lakelet was held up by ice on the north side of Stony-Marl Howe, and a fine streamless valley with a double intake now comes down to join Hellwath Beck. The altitude of the intakes is about 750 feet. A marginal channel, already noticed in the section on Robin Hood's Bay, also passed down the northern face of the same hill, and carried its drainage into Burn-Howe Dale. The southern ice-lobe appears to have withdrawn somewhat rapidly, its margin retreating simultaneously to the south and the east until it fell behind the north-and-south line of water-parting through Pye Rigg and Hallow Rigg. So soon as this stage was reached, marginal lakes began to be formed. One of these was drained southward by means of a marginal channel, Pye-Rigg Slack, which was joined later by a small overflow behind Moorland House, Rudda Howe. Perhaps to this stage should be referred a small overflow towards Castle Beck which passes through a spur near Thorn Howe. A fine gravel-mound marks its outlet on the southern bank: it cuts the 525-foot contour. A slight shrinkage of the ice enabled the water here to escape in a south-easterly direction down the valley, at present carrying very little drainage, which extends into the Broadlands valley, cutting through a bold belt of moraine in its course. From this point, the retreat of the ice seems to have been very gradual, with long and frequent halts and even some re-advances, repeating in a striking way the fluctuations recorded by the Robin-Hood's Bay series of overflows. The retreat produced two definite lakes—one at the head of Bloody Beck, the principal affluent of the

Staintondale stream, the other at the headwaters of Hayburn Beck. As I shall have many occasions to refer to these, I may designate the former Lake Staintondale, and the latter Lake Hayburn. The Pye-Rigg-Slack and Rudda-Howe overflows were the first effects of the northern lakelet, which formed an aligned sequence with Lake Hayburn and drained into it. The retreat of the ice-margin opened an outlet for Lake Staintondale by a broad col at Rudda Road, where a well-marked overflow, now a swampy gully, exists. It is barely indicated by the 575-foot contour, and its intake may be at about 580 feet. Corresponding with this is an outlet to Lake Hayburn, Cowgate Slack, which commenced to trench the long spur of Hardhurst Moor at about 625 feet. I think that but little cutting took place before a temporary retreat of the ice-front freed a lower col, and the gorge called Hardhurst Slack was cut by the overflowing waters. This channel began operations at or a little below 625, and although it failed to lower its intake to 600 feet (namely 607), it is nevertheless a fine example of a glacier-lake overflow, in its lower part 40 feet deep, with very steep sides and almost dry.

A slight re-advance of the ice closed the intake of this channel, and brought Cowgate Slack again into operation. This continued now to perform the functions of an overflow for a great length of time, and the channel was cut to a depth of more than 50 feet, deepening where it crossed the old watershed to more than 75 feet.[1]

The view into the intake of this valley (which is at 580 feet) from the Scarborough-and-Whitby Road near the Falcon Inn is highly impressive. A very diminutive stream now trickles at the bottom, not of sufficient volume to keep the channel clear of vegetation. During the period covered by the formation of Cowgate-Slack Lake, Lake Staintondale cut through a second col in the spur between the two lakes, and an overflow-channel was produced nearly on the line of Tofta Road. It was commenced at an altitude well over 625 feet, but ceased operations at over 600 feet. The unbroken line formed by the 600-foot contour at the Hayburn-Lake side shows that this overflow cannot have operated for long after the resumption of the Cowgate escape, and I therefore conclude that there was a retreat of the ice-front by which the two lakes became confluent.

A further retreat of the ice-front to the eastward began to free the long spur bounding Lake Hayburn on the south, when a point was at length uncovered which was lower than the intake of Cowgate Slack: at that precise level a new channel began to be formed close against the edge of the ice — this is the Ringing-Keld overflow. At first it competed with Cowgate Slack on something like equal terms, but the narrowness of the spur to be cut through, and the further recession of the ice, gave a decisive

[1] I think that it may be possible for some future investigator to correlate the oscillations here recorded with those in the Robin-Hood's Bay area, and even perhaps with that which produced the oxbow at Moss Swang, and the one in Hardale Slack.

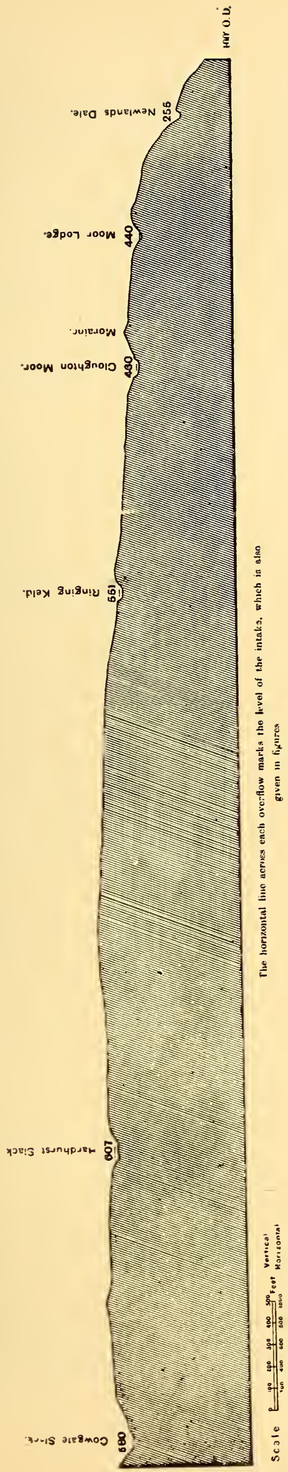


Fig. 24.—*Section along the watershed, from Cowgate Slack to Hayburn-Wyke Station (Newlands Dale).*

advantage to the new outlet, which developed into a large and deep valley, now very swampy in its upper parts, but drier lower down where the steep fall enables a small stream about a foot wide to form. This valley is just a mile long, and falls in that distance 100 feet. It terminates abruptly at 400 feet in a fine terrace, which evidently represents the level of another lake to be presently mentioned. The intake of Ringing-Keld Slack was cut down to about 551 feet.

The further course of the ice-margin is well shown by Oxdale Slack, a magnificent gorge nearly a mile long, and not less than 75 feet deep at the intake, which gashes completely through a bold spur composed of hard and massive grit forming the last limb of the Lake-Hayburn watershed. There is scarcely any more instructive and convincing example to be found in the district than this wild rocky gorge sweeping completely through from side to side of the hill. The cutting was commenced at a little over 450 feet, and it ceases at a little above 375. The form of the contours at the intake shows that a small lake probably received the water from Ringing-Keld Slack and transmitted it to Oxdale Slack.

Another overflow, rather doubtful, and difficult to observe on account of a thick growth of young pine-trees, crosses Cloughton Moor at a slightly lower elevation. But the next marked halt of the ice-margin was at Cloughton-Moor Cottage, where a new overflow was formed which commenced to operate at about 500 feet O.D., and continued to carry the drainage until, by the cutting down of the intake, the lake-level had fallen to about 460 feet. The valley thus formed is nearly $1\frac{1}{4}$ miles long, with a lengthy stretch of morass in its upper part, a virtually streamless middle portion, and a small rivulet in the lower half. The intake-end of this valley is particularly interesting, as it enables the precise relation to the ice-margin to be defined. At Cloughton-Moor Cottage, within 100 yards of the intake, a transverse section of the valley would show a narrow ridge-like retaining-wall on the iceward side composed of gravel, which extends for a quarter of a mile; and on the opposite side a quarry shows live rock with a cover of only 2 to 4 feet of superficial deposits. These observations are in harmony with the conclusions which might be drawn from the existence of this valley on the brink of a steeply-sloping hillside—they show that the ice must have stood steadily against the gravelly ridge, which I should therefore regard as a moraine, until the overflow-channel was well established. The precise position of the ice-margin at this stage can also be fixed at another point. The hillside bounding Staintondale on the west is steep and straight for a distance of about a mile; and in the neighbourhood of Staintondale village there are numerous scarped shelves at altitudes of about 500 feet down to 475 feet. This feature is specially well-marked through three fields just below the Shepherds' Arms Inn.

These scarps, like those observed in parts of Eskdale and in the Murk Esk, seem to have been produced by water flowing between the ice-front and the hill. I conclude that Upper Staintondale at this stage formed again an independent lakelet.

The next recession of the ice from Cloughton Moor through a distance of about a quarter of a mile cleared a shoulder of the hill about 450 or 460 feet above sea-level. This was a little lower than the intake of the Cloughton-Moor-Cottage overflow, and the lake-waters flowed round the margin of the ice, and commenced the formation of a new channel which passes through the grounds of Moor Lodge, the house itself being in the valley. The continuation of this valley is by a remarkable and intricate set of reticulations, brought about in part by the fact that the retaining-wall of the valley was at one place the glacier itself, and in part also by slight oscillations of the ice-margin, which closed and opened channels in a rather capricious fashion.

The Moor-Lodge valley is in reality merely a gully 300 yards long cutting off a corner of the hill. When it was lowered to about 440 feet, the water, after passing into an ice-bound channel for 200 or 300 yards, cut a notch behind Craven Hill producing a valley of very characteristic form about half a mile long and 25 feet deep at the upper end. A fluctuation of the ice, however, opened a way in front (that is, east) of Craven Hill, and a shallow valley was excavated there which was joined along a tributary cut, by a flow directly from the ice-front.

The southern spur, trenched through by Oxdale Slack, was now nearly freed from ice, but both it and an intervening spur were still obstructed by the ice; and in the northern one near Cloughton-

Newlands a gorge called Stonedale was cut, much smaller than Oxdale Slack, but of the same general type: the cutting was commenced at about 360 feet and continued down to about 315 feet. This carried the drainage at all stages of the cutting of the Moor-Cottage and Craven-Hill overflows. In the earlier stages of the Stonedale overflow, an overflow was cut through the southern spur at Goosedale, but it was small and shallow. At a later stage than that represented by Goosedale Slack, a retreat of the ice permitted escape by way of Cloughton, at first through Stonedale, Holm Hill, and Moor Lane, and later by Little-Moor Slack. A further retreat of the ice freed the eastern edge of Little Moor, and a sharp valley was cut parallel to the hillside, isolating a long hill known as Cober. This hill is morainic at its northern end, while the southern end I found (from a temporary excavation at the residence of the late Sir Frank Lockwood) to be composed of solid rock. This 'Cober' valley has a free opening to the eastward at the upper (northern) end, while it also continues for a little distance to the north-west, where it makes a blind termination at some moraine-like hills. The valley previously referred to, as running from Holm Hill to Moor Lane, has a somewhat similar arrangement at its upper end, where it is closed by the sudden ascent of the valley-head.

The next retreat of the ice produced results of a less equivocal nature—an easterly recession took place which freed a long straight hillside for a distance of about $1\frac{1}{4}$ miles. A new cut was commenced at about 325 feet and was steadily cut down to 255 feet, forming the splendid streamless ravine, Newlands Dale, through which the Scarborough & Whitby Railway now runs. The intake near Hayburn-Wyke Station and Hotel is at about the 250-foot contour. The iceward boundary of the intake is very like that of the Cloughton-Cottage overflow, and perhaps, like it, is composed of Drift.

I may now briefly refer to the strip of country between Staintondale and the sea.

A line of morainic gravel-hills forms a strong ridge about Prospect House and Whin Hill, and the western face of this ridge is deeply guttered, as though by water flowing off the ice—a feature that is also well shown farther north at Danes Dale.

At Heathard Point, at Rigg Hall, and to the east of East-Side Farm, are three Glacial stream-channels, but they have all been beheaded by the erosion of the coast; and I am unable to say whether they drained lakelets, or merely, like those just named, flowed directly off the ice. Their magnitude renders the latter supposition improbable.

There remains now in this section of country the great valley of the West and East Syme, extending from Harwood Dale to Burniston. This valley, which is bounded along the south side by the great Corallian escarpment of Hackness and Silpho Moors, is now occupied by two diminutive streams which flow westward and eastward respectively from a low, scarcely perceptible watershed at

275 feet across the middle of the valley. It is quite obvious that the valley was not cut by such runlets as now trickle through it, and we must seek an explanation in the diversion of the drainage by ice-obstruction, in the same way that similar phenomena elsewhere have been explained. Mr. Fox-Strangways has apparently not included this in his explanation of the vicissitudes of the Derwent, but it seems to me clear that whatever cause operated to produce Forge Valley, was equally in operation here to give rise to the Hackness gorge.

The valley of the two Symes extends, as before remarked, to Harwood Dale, and it cannot be doubted, I think, that in pre-Glacial times whatever stream flowed in that valley must have come through to Burniston, and so to the sea. But the pre-Glacial drainage of Harwood Dale would have been less than that which now flows down the valley by all the captured waters from the Robin Hood's Bay area, and so I think would not have produced unaided so large a valley as that of the Symes. If, however, we suppose that the Derwent also flowed in this direction, the difficulty is removed. The Derwent flows in a course nearly parallel to Harwood Dale, to within a little over a mile of the West Syme, then turns eastward as though to make for the sea; then, after following this direction for about 200 yards, it turns again southward, and enters the great Hackness gorge, more than 300 feet deep. At the southerly turn it receives the stream from Harwood Dale that has flowed along the foot of the Corallian escarpment in a cross-channel, which is not only a direct continuation of the valley of the Symes, but resembles it closely in configuration.

I therefore regard the Derwent as the stream primarily responsible for the cutting of the valley of the Symes, while the origin of the Hackness gorge I consider to have been somewhat as follows:—Before the Glacial Period, it was merely one of the many deeply-cut valleys which trench the Silpho and Hackness Moors, but this was one of the lowest. When the valley of the Symes was obstructed by the ice-invasion, the waters of the Derwent were impounded, together with those of the Harwood-Dale stream, and formed a lake which overflowed the rock-barrier about 550 feet above O.D., at the head of the Hackness gorge. With the augmented volume of water poured over, the barrier was cut down to such a level, before the withdrawal of the ice, as to prevent any resumption of the drainage along the old line through the valley of the Symes, which was left by the ice much obstructed with an infilling of Glacial deposits.

There are two features of the Symes Valley which are peculiar and rather perplexing. On the north side of the valley, nearly as far as the transverse watershed, is a great accumulation of gravel in steep-sided hills, elongated in the direction of the valley. The most remarkable of these extend for, say, half a mile about the Thirley-Beck Farm. To the south-east of the farm they are hog-backed hills of gravel some 30 feet high, with sides steeper than I have ever observed in any other British Drift-mounds. To the north-west they are much broader, and enclose a deep longitudinal hollow in the form of a series of connected basins. The hollows open to the westward, and are closed at the eastern end, so that the enclosing hill has the form of a deep loop. The surfaces of these hollows are strewn with very large boulders of Jurassic sandstone, weighing perhaps from 2 to 10 cwt. each. The whole surface of the hills was no doubt at one time covered with such blocks, for all the drystone walls are composed of them. A section cut through the deposits by Thirley Beck showed a packed mass of large and small boulders. The source of these materials is not far to seek—the excavation of Oxdale Slack would provide enough for a hundred such hills, but their transport and accumulation I find it difficult to explain.

The second singular feature displayed in the valley is a remarkable and gigantic 'in-and-out' on the north side of it at the watershed. A valley loops back into the hillside for a distance of a quarter of a mile, then returns to the main valley, so that it winds in and out again behind a central ridge of solid rock more than 50 feet high. The explanation which would ordinarily be given, is that it was a detour effected by a stream to evade the ice-margin, and this I believe it to be. At the same time it is difficult to explain both its situation and the fact that such fall as the valley displays is to the eastward, not to the westward as might have been expected. Upon the latter point, however, it may be noted that two small streams which enter the bend of the loop have been conveyed in an artificial channel across and for some distance down the very level floor to the east. The western limb of the loop is very boggy, and there may be a mass of peat there which perhaps conceals a westerly slope of the floor.

(*c*) Burniston to Scalby.

This tract of country presents few features of which the interpretation is clear. On the west, the heights of the Suffield-Moor escarpment constitute a possible landward barrier against which glacier-lakes might have been upheld, but the distance is very small, only about $1\frac{1}{2}$ miles. Moreover, above the 400-foot contour, the escarpment is very steep and unindented: no recesses occur in which lakes could be maintained. At and below the 400-foot contour, the country is much more diversified; but a difficulty is encountered which has not previously been experienced—two direct overflows occur, one at each end of the area, and a slight differential recession of the ice-front might open the one or the other.

At the northern angle of the escarpment, a long spur of Drift-deposits continues northward for half a mile, and I regard this as a moraine marking a halt in the recession of the ice. Behind the moraine, a shallow overflow falls to the northward. It shows a later phase in which the channel exhibits what I have termed 'downstream dichotomy': the ice-front receded a little, and allowed the overflow-waters to escape down the eastern and inner side of the moraine.

Much moraine-gravel extends from here to Hollin Rigg, but no decisive evidence of lake-overflows is visible. At the southern angle of the escarpment at Scalby Nab a gravel-covered spur exists, of much smaller dimensions than the northern one, but, like it, scored on its outer (western) face by a small gully with a fall to the southward.

(*d*) Scalby to Filey.

The last tract of country to come within the scope of this paper is that which completes the system of extra-morainic drainage of the Cleveland District on its seaward side. It extends from Scalby to Filey along the coast, and inland from Mowthorpe at the top of Forge Valley to Wykeham in the Vale of Pickering. The physical features of the region are simple—there is a coastal tract of Middle Jurassic rocks backed by a bold escarpment of Corallian rocks, which sweeps round from Mowthorpe by way of Scarborough to Gristhorpe, where it reaches the coast and forms the fine range of cliffs terminating in the natural breakwater of Filey Brigg.

The Corallian rocks dip in towards the Vale of Pickering, but the strike, which is nearly due east and west in the Forge Valley, swings round to a west-north-westerly and east-south-easterly direction near Filey, while in a westerly direction it changes in the opposite sense; the dip-slope is consequently arcuate. Many deep valleys exist in the Corallian rocks which are almost or quite destitute of streams at the present time. Such valleys may have been produced like those in the Carboniferous Limestone, by streams which have subsequently taken to underground channels; or again they may, like the great valleys in the Chalk Wolds, have been excavated by running water during the Glacial Period, when the rocks were all rendered impervious by their frozen condition. It has been necessary to discriminate carefully between these valleys and the abandoned lake-overflows. The Drift-deposits attain a great thickness in the area (in one case noted by Mr. Fox-Strangways, probably as much as 200 feet) in the deeper pre-Glacial hollows. I have found it desirable in this investigation to examine very carefully the extension of the Glacial deposits at high levels on the Corallian rocks: it seems clear that they extend completely over the range from Scarborough to Filey. The great elevated block to the westward of Scarborough—Seamer and Irton Moors—opposed, however, so great an obstacle to the ice, that although the escarpment was overtopped even at its highest part, and gravelly moraine was laid down near the brink to form the irregular range of hills culminating in Seamer Beacon 600 feet above sea-level, yet the western slope was never invaded.

The edge of the ice here can be made out with great precision. Hagworm Hill is a mound of sand and gravel with erratic pebbles, and similar hills range southward to Riggs Head, but I searched in vain the cultivated land immediately to the westward for a foreign pebble—the soil appeared to be entirely the product of underlying rocks.

The pre-Glacial drainage-lines of this region differed in one very material respect from those now followed—the great wide valley of the Sea Cut which passes between the Corallian blocks of Suffield and Seamer Moors was occupied by a large stream, consisting of the confluent waters of the Black Beck, Sow Beck, Kirk Beck, and the stream which flowed down the Hackness Valley before the overflow of the Derwent. It is not improbable that the Sea-Cut valley remained open after the closure of the corresponding valley to the north, that of the two Symes. In that case the drainage of the whole country from Iburndale southward would, after passing into a lake at Harwood Dale, overflow down the Hackness gorge and come through the Sea Cut, but not even then would it obtain direct access to the sea.

An advance of the ice-front to the Row-Brow escarpment near Seamer Beacon would impound the drainage of the Sea-Cut valley, producing a lake, which may (for convenience) be referred to as the Hackness Lake. When the waters rose to about 400 or 425 feet O.D., the lowest gap in the Corallian escarpment, which was at Spikers Hill, would be surmounted, and a large volume of water would flow down the dip-slope of the Corallian rocks towards West Ayton, in the Vale of Pickering. I do not think that any considerable valley existed previously on this line, the contour of the country seeming opposed to such a view.

The line of drainage thus initiated was rapidly deepened and a veritable cañon, Forge Valley, produced, which in the sharpness of its lines surpasses even the Hackness gorge. Some features of the emergence of the Glacial torrent into the Vale of Pickering will be described a little later (p. 557).

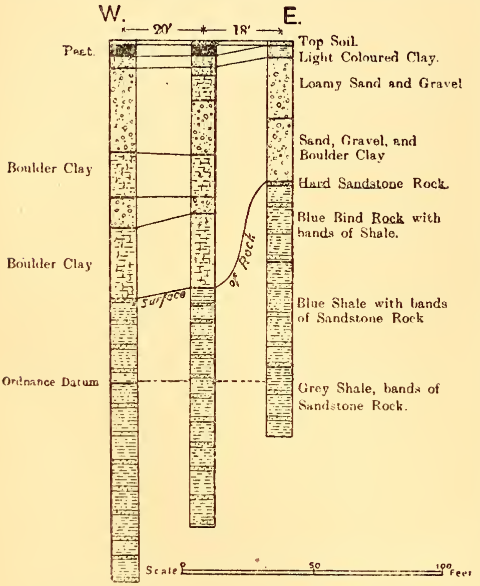
An ice-lobe appears to have penetrated far up the Sea-Cut valley, and I am disposed to regard the great mounds of gravel at Thorn Park, close to the Derwent, as of direct Glacial origin; but I do not think that the ice advanced much beyond this point, for there is a second low gap in the Corallian watershed less than three-quarters of a mile beyond the entrance to Forge Valley, and had the invading lobe reached this point, Kimlin Slack would have usurped the functions of Forge Valley. The cutting of the last-named valley must have proceeded, *during* the maintenance of the ice-barrier, to a depth not far short of 135 feet O.D., as the present watershed of the Drift-obstructed valley of the Sea Cut only reaches that altitude, and a great artificial drain has been cut through from the Derwent to Scalby Beck, by which a considerable volume of water is discharged at normal seasons, and still more when the Derwent is in flood. Unless Forge Valley had been cut as deep as this, the Derwent would have reverted to the old channel.

We may now consider the Glacial drainage of the Scarborough embayment.

The Oolitic escarpment is much indented between the north-eastern angle of Seamer Moor and Wheatcroft, a hamlet about 1 mile east of Scarborough. Many deep valleys existed hereabouts in pre-Glacial times, and through one of these a great overflow was cut which must have played an important part in the stages of advance and retreat of the ice-front, when small lakelets were held up in numerous re-entrant angles of the hills. This valley is that through which the railway passes from Seamer to Scarborough.

The way in which it expands towards Scarborough shows that it is not, like Forge Valley, entirely the result of Glacial stream-erosion, but that a pre-Glacial valley existed with a northerly outlet. At present it is quite streamless, and an artificial pool, the Mere, occupies a position near the watershed which is roughly 135 feet above sea-level, but there is a good deal of peaty material in the floor, and the actual rock-floor is probably considerably lower.[1]

Fig. 25.—*Borings at Scarborough Gasworks.*



Now, with an outlet at each end, namely, by Forge Valley and by the Seamer valley, the drainage of the recess at Scarborough must necessarily have been very liable to reversal, according as some slight fluctuation of the ice-margin freed the one or the other outlet. This fact was strongly borne in upon me in working over the ground. Lake-overflows are numerous, but no clear system can be recognized; for, not only may two overflows in the same spur drain in opposite directions, but even one and the same channel bears evidence of flow at one time to the northward to the Forge overflow, and at another southward to Seamer. I will speak of some of these in detail.

The outstanding shoulder of Cornbrash beyond the north-eastern corner of Row Brow, near the village of Throxenby, is deeply trenched by a fine overflow in which Throxenby Mere has been

[1] Since this was written I have been furnished, by the courtesy of Mr. Crawford, manager to the successors of the late Mr. G. Smalley, well-sinker, of Hull, with details of three boreholes put down at the Scarborough Gasworks, which are situated about 1500 yards north of the watershed, and stand at a surface-altitude of about 115 or 120 feet O.D. Fig. 25 shows the details of these borings, which furnish complete corroboration of my surmise, and further reveal a very remarkable cliff-like sub-Glacial declivity.

formed by an artificial dam at the eastern end. The western intake however is closed by so slight an elevation, that I think a flow has taken place in both directions, the last being that to the eastward. The cutting of the valley was probably commenced at about 275 feet, and ceased at about 235 feet. Hackness Lake, therefore, stood between those levels for a short time.

An earlier stage is represented by a very small notch 100 yards to the northward, which shows a slight fall in both directions from a central watershed about 385 feet above O.D. This overflow is cut through gravel. The flow seems to have occurred in both directions, the eastern being the last. There is a bench like a beach at the 300-foot contour on the south side of the hill.

To the westward a well-marked marginal channel, with a fall towards Forge Valley, occurs in a gravelly tract above Ox-Pasture Hall. The intake is a little below 225 feet O.D., and it is traceable to a point about a quarter of a mile to the westward, where it cuts the 175-foot contour.

Turning back towards Scarborough again, we find a channel cutting the 300-foot contour behind (west of) Hatterbord Hill. This hill is a portion of a fine moraine, which projects forward from the escarpment at the farmhouse called Row Brow. The channel drained northward towards Forge Valley, and it was modified considerably by subsequent morainic accumulation. On the eastern side of the same hill a long shallow channel exists, which is in my judgment clearly an overflow. It cuts the 225-foot contour, and falls to the south towards the Seamer escape: it is quite streamless. Lady Edith's Drive is another related drainage-valley having an easterly fall. Taken in conjunction with the last, it seems to indicate a recession of the ice-front to the eastward and northward.

Four remarkable valleys cut through the ridge of Kellaways Rock to the eastward. At Northstead the northernmost cuts the ridge with a fall to the westward down almost to the 225-foot contour. The intake has a southerly curvature, probably indicating that the water was flowing from that direction, and this is confirmed by the fact that the hill falls away to the northward. The ice must, as in the former cases, have stood to the northward.

The next, Peasholm Valley, is now occupied by a stream flowing eastward, and, *ipso facto*, I should have concluded that the Glacial drainage of which it is certainly a relic had the same direction. Nevertheless, I am inclined to the opinion that a reversal of the drainage has taken place since Glacial times, mainly perhaps by the action of springs.

The Scalby-Road valley, which cuts well through the 200-foot contour, was formed by a stream flowing westward; the last, the Stepney-Road valley, which also falls westward, cuts through the 225-foot contour.

The group of four I should regard as a connected or parallel sequence; but it is necessary to assume, what is by no means improbable, that there were fluctuations of the ice-front. These fluctuations may not only have closed with an ice-barrier a channel after it was cut, just as happened to Hardhurst Slack, but may also, as we have seen, have caused an actual reversal of flow.

I think it not improbable that the series was partly cut in order from south to north, the Northstead Valley being the last; but that a re-advance of the ice and second recession completed the cutting of all except the Northstead one, which, owing to its greater elevation, could not have been eroded while lower channels stood open farther south.

In the angle of the Scarborough recess, two overflows of brief occupation may perhaps exist in the cols at Cross Lanes at 307 feet above sea-level, and beside the ancient camp near the Racecourse.[1] In the latter case, two valleys inosculate on a col at 464 feet O.D., but the abandoned head of the southern valley is traceable in the high ground to the eastward. Both these overflows, if overflows they be, drained into the Seamer Valley.

The last Glacial drainage-channel cutting through the Oolitic escarpment from the Scarborough recess, is the fine valley called Deepdale. This valley has many of the characteristics of the Seamer valley, from which it is separated by the bold ridge of Weaponness, culminating in Oliver's Mount, about 500 feet above sea-level.

The present watershed across Deepdale is situated well to the northward of the Corallian escarpment, and from this point a small stream flows in each direction. The watershed, which is in a country heavily covered with Drift, is a little above the 250-foot contour. There is a boulder of Shap Granite within 20 yards to the eastward.

This valley seems to have carried off the drainage of a small lakelet about Wheatcroft, but though the valley is of considerable size, the amount of cutting was probably not very great. I do not think that the beheading of the stream by marine erosion would account for its present form and condition. I should consider its sharp outline and precipitous sides to indicate the passage of a large volume of water through it at some date too recent for the comparatively slow erosion of the coast to explain it.

From this point onward to Filey Brigg no definite overflows are traceable, marine denudation having probably carried away a considerable tract of land higher than that which remains.

(8) The Vale of Pickering: Eastern End.

It now remains to consider certain phenomena displayed by the country within the Vale of Pickering, that is, behind the Corallian outcrop.

The closure of the Vale by a species of morainic barrier running through Hunmanby was long ago recognized by Carvill Lewis, Mr. Fox-Strangways, and others; but it has seemed to me very

[1] A re-examination of the ground has rendered me more sceptical as to these gullies.

important to ascertain how far the ice extended westward, and upon this point there was a lack of data. My friend, Mr. J. W. Stather, F.G.S., has kindly placed his extensive knowledge of the district at my disposal, and aided me greatly in attempting to solve the problem.

I have described the occurrence of a range of gravel-mounds on Seamer Moor, which I take to mark the extreme limit of the ice at that level; beyond this, which I consider to be the moraine, Mr. Stather and I found the country absolutely free of Drift. Not so much as a foreign pebble could be discovered at a distance of 200 yards beyond it, even upon lower ground. Outside the moraine the steep slopes of the moorland towards the south are deeply trenched by dry gullies, which appear to have been produced by water flowing from the ice-front. This remark applies especially to the groove running down to Betton Farm.

At Seamer an immense spread of gravel is to be seen near the railway-station, and this may perhaps be connected with the two great gorges, Deepdale and the one admitting the railway to Scarborough. Between the latter valley and the entrance to Forge Valley, the lower slopes of the moors present some noteworthy features. Several valleys occur which run for some distance from east to west, then swing southward: one of them, Waydale[1] for example, cuts across a spur, or rather through two—one a projection of the moors bounding the Scarborough-Seamer valley, and the other a swell of the hill near Waydale House. A very common feature of these channels is that they frequently have a blind head, or there is some transverse mound interrupting the continuity of the thalweg. The features are repeated in certain channels to the west of Forge Valley, which will be mentioned later.

Much gravel occurs in the strip of country displaying these features; but it is intermittent, until a point is reached immediately north of East Ayton and close to the beginning of Seave-Gate Gill. Thence onward to Gallows Hill, between Wykeham and Brompton, the great gravel-bench extends which Mr. Fox-Strangways supposed to be the beach of Lake Pickering. This mass presents an abrupt scarp over 50 feet high overlooking the Vale of Pickering. The brow of the scarp is, at the eastern end, above the 200-foot contour, but it declines westward. The breadth of the terrace varies from less than a quarter up to over half a mile; and its upper edge, where it rests upon the slopes of the hills, falls from very nearly 250 feet (probably about 245) on the south of Forge Valley, to a little over 200 feet near Wykeham. (See map, fig. 26, p. 558.)

The surface-features of this gravel-bench are very noteworthy. Deep valleys come down the dip-slope of the Corallian rocks, of which some (for example, Yedmandale) are destitute of streams; while others, like Beedale and Sawdondale, carry little becks, and one (Forge Valley) is occupied by a small river, the Derwent.

[1] The local name for this valley is 'Marra Mat,' and the stranger will fail to find it as Waydale.

Fig. 26.—*Relief-map of the country from Wykeham to Seamer, showing the approximate form of the gravel-bench and the deviation-channels.* (*Scale*: $1\frac{1}{4}$ *inches* = 1 *mile.*)

Each of these valleys, when it reaches the gravel-bench, undergoes a sharp westerly deflection; moreover, across the flat top of the gravel-bench, a series of deep channels has been left, forming an almost complete series of links connecting each stream or valley with its neighbour on the west. These channels are generally at a level of 30 or 40 feet above the streams that they appear to have served, and only in two cases, Beedale Beck and Sawdon Beck, are they at present occupied by streams. One very fine example, forming Rushton-Cottage Pasture, the deepest of the whole series, is interrupted by a ridge of gravel which shuts in a deep hollow in a part of the channel.

At the western end, by Wykeham and Rushton, the gravel-terrace is extremely uneven, and it comes to an abrupt and singular termination in a great horn running for nearly a mile out into the valley, from the dead-flat floor of which it rises as a bold and picturesque ridge bearing the ancient Wykeham Abbey. This portion of the gravel-mass presents contours quite unlike the scarp of the terrace at West Ayton or Hutton Bushel. A small outlier of gravel lies to the west of the Wykeham ridge, and rests upon a prominence of rock forming Gallows Hill. Beyond this, both terrace and gravel abruptly cease.

Some features of the composition and condition of the gravel may be mentioned. Many sections exist, from which its constituents can be ascertained: I paid particular attention to two gravel-pits at Yedmandale and Hutton Bushel. At the former the beds were of sands and gravels, the pebbles consisting mainly of Jurassic sandstones and limestones, with many Cheviot andesites, some greywackes (probably from the Valley of the Tweed), some jasper, and a few granite-pebbles. I also found fragments of marine shells, among which I identified *Tellina balthica* and *Cyprina islandica*. At Hutton Bushel, in a gravel-pit on the 200-foot contour, rather coarse, horizontally-bedded gravels were exposed, often of the type (so common in Glacial accumulations) which I have termed dry gravels, that is stones packed with open interspaces not occupied by sand or other infilling. The stones were mainly local (Corallian), but there were fragments of Kimeridge Clay, many pebbles of Cheviot porphyrite, and some Magnesian Limestone of the Roker (Sunderland) type, gneiss, and granite. I was informed by the Rev. W. C. Hey that shell-fragments are common in these gravels, and that a great many were obtained in a temporary pit opened immediately east of Forge Valley near East Ayton.

We have here, I think, a body of facts which show conclusively that the Hutton-Bushel terrace is not a simple lake-beach. The pronounced fall of its surface from east to west might, of course, be explained upon the supposition of a differential movement or tilt of the region; but, even if there were no other difficulties remaining, I should hesitate to have recourse to so bold an expedient, except in presence of proof of such a movement of an overwhelming character. There are other, and in my opinion even more weighty, objections, still remaining. I ought, however, to remark that there are several facts which might be interpreted as evidence of an uplift of the Yorkshire coast since Glacial times, and one which might be regarded as evidence of a differential movement. Dr. W. Y. Veitch[1] has described a raised beach at Cat Nab, near Saltburn, and his observations are confirmed by Mr. Barrow.[2] The beach is clearly post-Glacial, and is about 30 feet above sea-level. Mr. Lamplugh has described a band of shell-silt in the Speeton cliffs containing estuarine molluscs, as, for example, *Cardium edule* and *Scrobicularia piperata*, with the paired valves in apposition and the siphonal ends upward. They occur at an altitude of about 80 feet above sea-level.

Lastly, I may mention that, whereas at Barnby Dun borings indicate the rock-floor to be at least 170 feet below Ordnance-datum, yet none of the borings made in the bed of the Humber or in Holderness struck a hollow of sufficient depth to afford an outlet to such a valley. A boring on Reeds Island made by Mr. Villiers (of Beverley) in 1888, found rock at a depth of 95 feet from the surface, or about 85 feet below Ordnance-datum. If the evidence regarding the Humber were complete enough to justify the assertion that no such hollow or channel existed, then it might be allowable, or even necessary, to attribute the discrepancy between the levels of the Barnby-Dun Valley and its seaward outlet to a differential movement and uplift along the coastline.

I mention these facts so as to assure critics of my views that the alternatives have been considered.

The persistent westerly 'aberration' of the debouchure of the valleys points to the operation of some constraining agent which is no longer present; and when the deserted high-level channels which linked these valleys together are reviewed, and found to indicate a similar persistent tendency, the constraining agent seems to be clearly indicated—ice in the form of a glacier-lobe would produce this effect. Upon this hypothesis, the edge of the great ice-sheet (which I have traced by its morainic deposits on Seamer Moor) passed farther inland, where it encountered the feeble opposition of the range of heights to the south of Scarborough, and so was enabled to thrust its way up the Vale of Pickering to, and a little beyond, Wykeham. The phase of maximum extension is, on this view, indicated approximately by the gravel-patch on Gallows Hill. After a very brief sojourn at this extreme extension, a protracted halt took place about Wykeham, and I regard the great gravel-mass there as the terminal moraine of this ice-lobe. Under the conditions now set up, we may suppose the Forge-Valley overflow to have come into operation, and a vast quantity of water from the extensive area of land and ice to have come down the incipient valley.

This stream would bring over a few erratics, along with immense quantities of gravel and stones obtained from the denudation of the gorge; and these materials, mingled with lateral moraine, would be

[1] Proc. Yorks. Geol. & Polyt. Soc. n. s. vol. viii (1883) p. 221.
[2] Mem. Geol. Surv. 'North Cleveland' 1888, p. 71.

washed into the space between the margin of the ice-lobe and the hills to form a species of deformed delta, just such as I have observed beside the Findelen Glacier. The stream on encountering the ice would turn away westward towards the only point of escape, Lake Pickering. The lake-level was at this early stage probably about 200 or 225, or possibly 250, feet above sea-level, and the extra-morainic stream would spread its gravels so as to produce a uniform gradient from the floor of the rock-gorge down to the level of the lake; hence the glacier would be margined by a bench of gravel the surface of which fell from east to west.

Each valley descending the ice-free slopes west of Forge Valley would behave in the same way as the main stream, and would, like it, turn along the gravel-bench towards the escape into Lake Pickering. Flood-action would periodically operate to level-off the larger inequalities of surface of the gravel.

In the recession of the ice-lobe, successive avenues of escape in front of the ice would be found by the stream, and thus every step of the retreat would leave a segment of the main channel high and dry upon the top of the gravel-terrace. Irregularities in the gravel-accumulations in time of flood may account for the curious transverse interruptions in the slope of a channel. The most remarkable case of the kind is that of a dry valley extending in a devious course from the inner edge of the terrace at Beedale for nearly a mile, until at Rushton-Cottage Pasture it forms a very deep groove like a railway-cutting, and enters the valley of Sawdon Beck. It is quite clear from its position that this channel at one time carried Beedale Beck round the end of the moraine; and I suggest that the closed hollow in its course, which is surrounded by the 175-feet contour, was produced in the subsidence of a flood which preceded or accompanied a retreat of the ice-front, allowing the present outlet of Beedale by Dingdale to open out. I am bound to say, however, that a simpler explanation might be found in irregular solution of the underlying rock.

When the ice-lobe retreated entirely to the eastward of Forge Valley, the Derwent would debouch directly into Lake Pickering. During some part of this retreat, it seems to me certain that a lateral dwindling of the ice-lobe would permit the river to flow between the elevated terrace of gravel and the ice. The result would be some scarping of the gravel-bank, and a partial re-distribution of its materials. Mr. Fox-Strangways has remarked that besides the main terrace, 'there are two minor terraces, not so well marked, at about the 100 and 140-foot contours.'[1] I have not observed these as very definite features, but the explanation which I offer would account for them.

In the recession from Forge Valley, the phenomena of the ice-margin would repeat upon a small scale those already described, and the Marra-Mat (Waydale) and other valleys would be produced. When the edge of the ice had retreated to the spur forming the

[1] 'Valleys of N.E. Yorks' Trans. Leicest. Lit. & Phil. Soc. n.s. vol. iii (1894) p. 339.

western wall of the Seamer-Scarborough valley, a small lake discharged by Waydale Lane, and cut the notch which severs the end of the spur. The peculiar 'dry' condition of the gravel at Hutton Bushel, and the common occurrence of fragmentary marine shells, would be readily explained by the hypothesis here proposed; but it would be exceedingly difficult to explain their occurrence in a lake-beach, whether the lake were closed by ice or by moraine.

It is a singular circumstance that no trace whatever can be found either of beach or of moraine along the foot of the Chalk-escarpment which forms the southern margin of Lake Pickering; but the explanation which seems to me most probable is that there was a deficiency of materials, both for the beach and for the moraine. The supply of moraine may well have been small, as compared with that upon the north side, for the glacier-lobe would have a southwesterly impulse which would bring upon the north side an ice-margin that had rasped a large tract of hilly country, while on the south side comparatively clean ice would come in.

Another important difference between the two sides of the valley is, that on the north side occurs the long dip-slope of the Corallian rocks, which would be drained by many streams carrying gravels. Moreover, on the same side the enormous gorge of Forge Valley yielded its waste to provide deltaic materials. On the south side, the short escarpment-slope of the Chalk would contribute very short torrential streams carrying but little detritus, and no overflow appears to have taken place from other lakes.

IX. Sequence of the Ice-Movements.

In the section dealing with the Drift-deposits (§ VI, p. 489), I reviewed the evidence which has led me to the conclusion that there were three main ice-movements affecting the Cleveland area—a northern, from Scotland and Northumberland, not previously recognized; a western, proximately from the Stainmoor Pass and the Valley of the Tees; and an eastern, from the North Sea, and more remotely from the area lying to the northward of the Skager-Rack and the Baltic.

It now devolves upon me to endeavour to show the way in which their very complex interactions produced the phenomena that I have described.

The fact that rock-grooves running from north-west to south-east across Hob Hill were disclosed by clearing away the Lower Boulder-Clay—the oldest Glacial deposit of the district—may, I think, be taken to imply that in the country north of the Cleveland Hills the western ice was the first upon the ground. This inference is greatly strengthened by Mr. Barrow's observation that the Lower Boulder-Clay consists mainly of materials from the actually underlying rock or the rocks cropping out *immediately to the westward*[1]; and when it is remembered that one of the rocks borne by this stream, the Shap Granite, is not only dispersed along the whole coastline of Yorkshire, but even far down into Lincolnshire, and

[1] Mem. Geol. Surv. 'North Cleveland' 1888, p. 66.

that at two places, Whitby and Robin Hood's Bay, it has been found *in situ* in Lower Boulder-Clay, no further argument seems to be needed to prove that the earliest stage of glaciation was effected by the Shap-Granite-bearing Teesdale stream. This conclusion is a reversion to an early opinion of mine, which was (I am bound to say) scarcely warranted by the information that I then possessed.

The many and far-reaching assumptions which such a conclusion as this implies, are not realized until we have considered what must have been the condition of the Irish-Sea drainage-basin at the time when a regurgitation of the ice flowing down the Vale of Eden was produced, and the lofty ridges near the headwaters of the Tees were overridden by the reversed flow. The Irish Sea was the common receptacle for ice, not only from the mountains of Wales, the Lake District, the South-west of Scotland and of Ireland, but the extreme state of congestion to which the Stainmoor overflow was due may be said to have resulted from a great influx of ice from the Clyde. Clear testimony to the fact of this influx is furnished by three lines of evidence. The striæ upon rock-surfaces in Ayrshire and on the Mull of Galloway show a gradual sweep-round of the ice, so that both the Mull of Galloway itself and the low grounds south and east of Loch Ryan were overridden. Fragmentary shells are found in the Drift about Loch Ryan, which is what might be expected if the ice out of the Clyde had moved over the land; and, finally, the copious dispersal of the very characteristic Clyde rock, the eurite of Ailsa Craig, over the Irish Sea, and especially in the Isle of Man and the North-east of Ireland, proves that the movement was upon a large scale.

Tracing our chain of causation backward link by link, we may, I think, enquire what caused the Clyde ice to attain such proportions; and we find here a clue in the signs which exist down the whole of the eastern coast-line of the British Isles, from the Orkneys to Norfolk, of the pressure of a great ice-sheet, the radiant point of which was somewhere in the neighbourhood of the head of the Baltic. The evidences of this pressure are too well known to need any description here, but among its effects were not only a deflection of our eastward-flowing ice into a northerly or southerly coastwise-flow, but a general shifting of the Scottish line of ice-shedding towards the eastward, so that erratics from the Eastern Highlands were carried over the watershed and out to the west coast.

This effect was felt at the mouth of the Firth of Forth, and though I cannot ascertain that any erratics have crossed the watershed into the Clyde, yet I do not think it can be doubted that, but for the obstruction of the ice-sheet in the North Sea, a much larger proportion of the Highland ice descending into the great Lowland Valley of Scotland would have gone into the North Sea.

If this be granted, then it follows that the Scandinavian ice-sheet was the direct cause of the excess of ice in the Clyde, which by overflowing into the Irish Sea caused the reversal of the ice-flow in the Vale of Eden, and the consequential descent of the Teesdale Glacier to the sea at Teesmouth. It may be objected that the mouth of the Tees would itself have been closed by the ice-sheet in the North Sea; but I think that the impact of the Scandinavian ice would have proceeded from north to south, and the Firth of Forth (being 100 miles to the northward of the Tees) would have experienced its effects long before they reached the coast of Yorkshire.

The Teesdale Glacier must have continued to discharge into the North Sea for a long period of time, for erratics of Shap Granite are very numerous in the Drift of Yorkshire. Messrs. Muff & Sheppard enumerated 89 of large size, all exposed at the same time, on the foreshore of Robin Hood's Bay, in a distance of about 3 miles. How far to seaward the glacier made its way I am unable to determine, though the 'Rough Ground,' regarded by Carvill Lewis as its moraine, lies some miles from the coast (see p. 496). I am equally unable to decide how far down the coast it made its way when the ice-sheet deflected its flow to the southward, and to what altitude it attained along the northern front of the Cleveland Hills. The dispersal of its characteristic erratics in horizontal and vertical extensions is of no assistance in determining this point, as the dispersal may have been accomplished—and I believe it was—largely by the redistributing action of the later ice-streams.

It might be thought that the high altitude attained by the Lower Boulder-Clay mentioned in an earlier section would have been decisive, as that division of the Drift contains Shap Granite, but I have long felt that the classification of the Glacial deposits was in a very unsatisfactory condition. I am far from being convinced that the 'Lower Boulder-Clay' of the high grounds is the same as that of low levels, for I find a most marked difference between the assemblage of erratics in the whole of the Drift observed by me at high altitudes, and that recorded as characterizing Lower Boulder-Clay at Whitby and Robin Hood's Bay. Whereas at those two localities the recorded erratics belong almost exclusively to the western or Teesdale type, I have found a very remarkable deficiency of Carboniferous rocks at high elevations; while rocks of the northern group (see p. 491), such as Cheviot porphyrites, greywackes, sandstones, and the Roker Magnesian Limestone, are extremely common both in the Boulder-Clay and the Gravel. Scandinavian rocks are also occasionally to be found. My impression is that the differences between the 'Upper Boulder-Clay' and the 'Lower Boulder-Clay' are indicative more of local conditions than of age.

I have not succeeded in establishing any correlation of the lake-phenomena with the period of prevalence of the Teesdale Glacier, nor can I expect to do so, for the evidences of lakes formed during the advance of the ice must in almost all cases be obliterated.

The second phase of the glaciation of Cleveland was the complete diversion of the Tees ice into the Vale of York. This was brought about by the growth of the Scandinavian ice-sheet, and the gradual and progressive obstruction of the British coasts from the Forth downward. Whether the Scandinavian ice ever directly impinged upon this part of the coastline of Yorkshire or not, I will not venture to say; but if it did, its sojourn must have been brief, and the resolution of the conflicting pressures and movements in the area to the northward soon brought in the third element, the Scottish-Northumbrian ice, as a buffer.

The immense abundance of erratics of Cheviot volcanic rocks has only within the last three or four years been fully recognized by geologists in Yorkshire; and I cannot think that their occurrence can be ascribed to anything short of actual contact with the Yorkshire uplands of ice which came by a fairly direct route from the Cheviot Hills, and probably out of Tweeddale. These rocks can be found at all altitudes, and while they are very common on the coastline, they attain to a far greater prominence in the deposits at high levels. These facts have been impressed most strongly upon me during my work in Cleveland, and my friend Mr. J. W. Stather, F.G.S., has found the same conditions to prevail in Holderness and on the Chalk Wolds. The uppermost fringe of the Drift contains a quite exceptional proportion of Cheviot rocks. I have previously pointed out that, in the high-level deposits, Magnesian Limestone of the type found on the coast of Durham is also exceptionally abundant, while Carboniferous rocks are proportionately rare. These facts are consistent with the view that the Cheviot ice passed over the comparatively small outcrop of Carboniferous rocks of Northumberland and out to sea; then, describing a great curve, re-invaded the land somewhere between the Tyne and the Tees, bringing in stones, such as flints, from the bed of the North Sea, and marine shells in a more or less smashed condition, from the same source. Some of the boulders of basalt and dolerite found in Yorkshire may, not improbably, have been derived from Northumberland. The movement of the northern ice-stream down the coast appears to have been very extensive and protracted, and it may have extended even to Lincolnshire, where the characteristic erratics are found as far south as Horncastle.

Inland, the extension of the Cheviot ice was, in my opinion, coincident with the limit of a maximum glaciation from the Wykeham moraine right round to Scarth Nick; but if it reached to the very edge of the Vale of York, I can see no reason why it should not have even contributed its quota to the great glacier that descended to York. This, however, is a topic which cannot be conveniently discussed in the present communication, but must be reserved for another paper in which I propose to deal specially with the Vale of York.

The direction of movement seems to have been straight upon the northern face of the Cleveland Hills, with a westerly component at the western end, while at the seaward end an easterly direction was imparted by the form of the ground, and especially by the North-Sea depression. I am unable to indicate the position of the point where the westerly passed into the more easterly movement—doubtless it would fluctuate incessantly throughout the whole period of ice-occupation, as one or another of the component elements of the ice-sheet waxed or waned.

The striations on the coastal tract may probably be referred to this period; and, as Mr. Stather points out in his description of the Sands-End striæ, they form a consistent series indicating a practically continuous route. The striæ at Roker may mark the emergence of the ice from the sea-bed.

The recession of the Cheviot ice took place in a very singular fashion. It appears to have withdrawn from the coastline in regular order from south to north, as the Scandinavian and British ice-sheets shrank back towards their sources; and thus one after another the British river-mouths were freed from obstruction and resumed their normal drainage. But in this shrinkage one most noteworthy irregularity is very clearly indicated. After the almost complete disengagement of the ice from the mouth of the Esk near Whitby, a great lobe still traversed the northern watershed and reached the moraine near Lealholm. It must have crossed the hills with a somewhat westerly tendency, in order to have reached so far up the Valley of the Esk. To this stage we may conceivably refer the abandonment of the Tranmire overflow, the reversal of drainage across the spur at Stanghow, and the diversion of Boosbeck through the gorge at Slapewath. This last diversion is interesting, as it throws an important light upon the condition of the country to the westward. The ice-front must have stood across the Boosbeck Valley until the Slapewath gorge was lowered below the level of the Drift-barrier across Boosbeck, that is to say, below 425 feet O.D. From this clue it is possible to define some of the further course of the stream; and consequently of the ice-front.

It will be remembered that the overflow-channel into Eskdale by way of Kildale is at an altitude of 580 feet; therefore it is quite certain that there must have been a line of drainage open into the Vale of York. I infer from this that the Teesdale Glacier had already withdrawn behind the Magnesian-Limestone escarpment of the Tees Valley.

The last trace of the Cheviot ice-stream to be found in Yorkshire is perhaps the line of the Drift-hills which fringe the southern bank of the Tees. I do not press this explanation, as I can still perceive difficulties in the way of its acceptance; at the same time, I can see no other way of explaining the presence of this ridge of Drift and the behaviour of the little River Wiske, which flows northward from the Cleveland escarpment to within $1\frac{1}{2}$ miles of the Tees, then turns southward and joins the Swale.

X. The Sea-Outlet of the Lakes.

One problem remains to be considered, the question of the route by which the waters of Lake Pickering ultimately reached the sea.

There is twofold proof that, while yet the ice-sheet was standing against the coast of Yorkshire as far as Flamborough Head, the outlet of Lake Pickering had been cut down to 130 feet O.D. The moraine across the seaward end has an altitude at its lowest point of only

130 feet; and unless the outlet had been lowered to some such altitude, the Drift-barrier would have been surmounted by the waters of the lake, and a new channel would have been rapidly cut, leaving the actual Kirkham-Abbey gorge as one more example of an abandoned channel. Testimony to the same effect is borne by Forge Valley, which has very narrowly escaped the resumption of its functions by the New Cut. The latter piece of evidence indeed proves that the level of Lake Pickering must have fallen well below this, for the fall of Forge Valley is considerable, and if the head of the valley was at 135 feet the outlet into Lake Pickering must have been much lower.

Lake Pickering in its turn fell into Lake Humber, an extra-morainic lake held up in the great central valley of Yorkshire by an ice-dam at each of its exits. The late Prof. Carvill Lewis, to whom the idea of a glacier-dammed lake in this region is due, represented its extension in a very diagrammatic fashion in his maps, and showed no ice-barrier at the Wash, or even in such a position as to close the mouth of the Humber, but in the accompanying letterpress he says explicitly, 'The mouth of the Wash would be similarly obstructed by the North-Sea Glacier.'[1] With this conclusion I entirely concur. Not only is such a lake necessitated by all the evidence regarding the extension of the ice, but the floor-deposits are present over an enormous area. The fine laminated mud, of identical character and appearance with that of the Cleveland lakes, is widely distributed down the Vale of York, and far southward both in the Triassic valley and in the valley made by the outcrop of the Middle and Upper Oolitic clays in Lincolnshire; but, so far as I am aware, there are no signs of beaches or deltas.

Some other examples of floor-deposits of great interest will demand full consideration on another occasion, and for the present I must restrict myself to the question of overflows. Carvill Lewis boldly carried his rivers across whatever watersheds lay below the supposititious level of his lakes, and showed these streams as broad sounds 10 or 15 miles in breadth. My experience has convinced me that waters of such volume, with such a fall as the positions imply, would cut deep trenches of moderate breadth quite different from those which he imagined. Moreover, a lake would only under the rarest circumstances have two outlets operating simultaneously, and these never at different elevations. Now, Carvill Lewis's Lake Humber is depicted with four overflows at widely different levels. I mention these matters in order to make clear the way for a more satisfactory discussion of the problem, and not merely for the purpose of controverting the views expressed by Carvill Lewis, to whom I owe so much inspiration and encouragement in Glacial geology.

In seeking an outlet for the waters of Lake Humber, I looked—as 'direct overflows' across the Pennine range were forbidden alike by the altitude of the passes and the ice-bound condition of

[1] 'Glacial Geology of Gt. Britain & Ireland' 1894, p. 56.

the western slopes—for traces of 'severed spurs' near Derby, by which overflows might have evaded the end of an ice-lobe that deposited any of the sheets of Boulder-Clay described by Mr. Deeley,[1] but without result. Similarly, I failed to find any sign of an overflow from any part of the Trent Valley into the Severn drainage, though there are boulders of Red Chalk, a distinctive East-Coast rock, in the Drift of the Severn Basin. I can, moreover, find no definite traces of lakes in Yorkshire which could have drained at such a high altitude into the affluents of the Severn—all the lake-phenomena of Lake Humber lie below 200 feet O.D., and perhaps much below.

Of low-level outlets two or three exist. The valleys of the Lea and the Churwell would, I think, repay examination, as one or the other, or even both, may have acted as lake-overflows; but these could not have carried off the waters of Lake Humber when, as in its last stages, its level was little above 100 feet O.D. At this altitude, when the Wash was closed, there would be but one channel by which drainage could escape, namely, by the singular valley which cuts completely across Norfolk, and in the central marshy portion of which, near Diss, the westward-flowing Little Ouse and the eastward-flowing Waveney have their common source. The Straits of Dover were, I think, not improbably brought into existence by the discharge of the overflow-waters of our British extra-morainic lakes, and a corresponding but much vaster series lying outside the great ice-sheet across the continent of Europe, as was long ago suggested by Belt.[2]

In conclusion, I gladly add a few words of grateful acknowledgment of the help and encouragement given on many occasions by Mr. H. B. Muff, B.A., F.G.S., the Rev. J. H. Hawell, M.A., F.G.S., and Mr. J. W. Stather, F.G.S., who have been my companions in many journeys, in fair weather and in foul, over the Cleveland Hills; as well as to Mr. Godfrey Bingley, Mr. Geoffrey Hastings, Mr. Arthur Stather, and Dr. John Kirk for the beautiful photographs from which many of the illustrations accompanying this paper are selected.

EXPLANATION OF PLATES XX–XXVIII.

Plate XX.

Fig. 1. View of Eller Beck and Fen Bogs from the north-west, showing the 'intake' of the Newton Dale overflow-channel and the contrast between the contours of the Eller-Beck and Newton-Dale valleys. The watershed is at the sharp bend of the railway.

2. View looking up Eller Beck from the 'intake' of Newton Dale.

Plate XXI.

Newton Dale at Fen Bogs, viewed from Eller Beck. The stream in the foreground makes a sharp turn to the northward and leaves the great trench untenanted.

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[1] Quart. Journ. Geol. Soc. vol. xlii (1886) p. 437.
[2] Quart. Journ. Sci. vol. xiv (1877) pp. 67–90.

Fig. 1.—*View of Eller Beck and Fen Bogs from the north-west.*

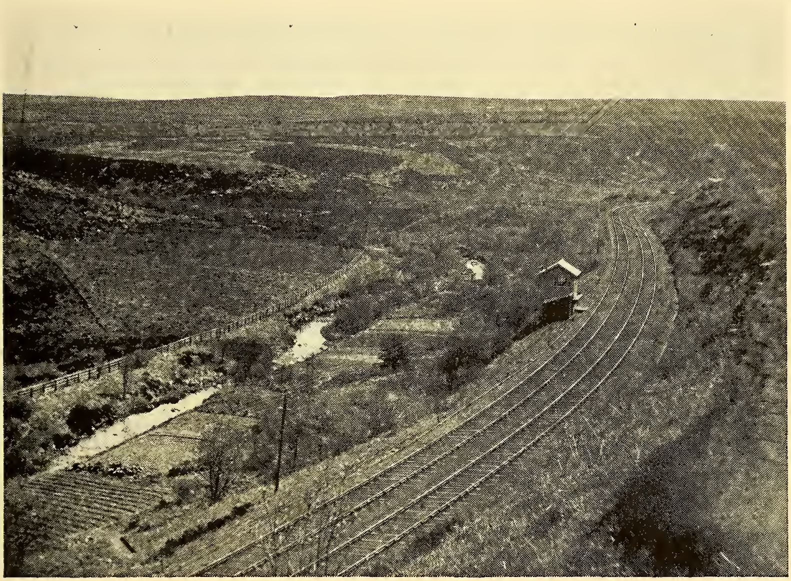
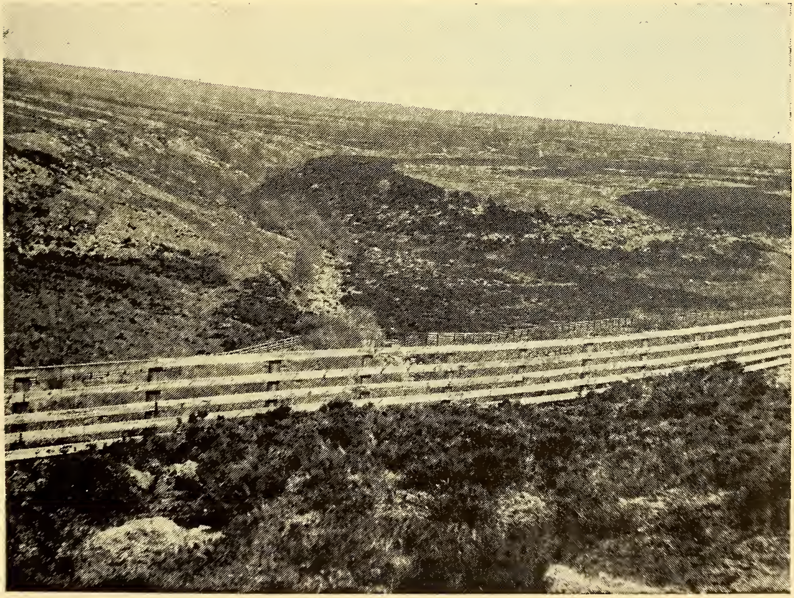


Fig. 2.—*View looking up Eller Beck from the intake of Newton Dale.*

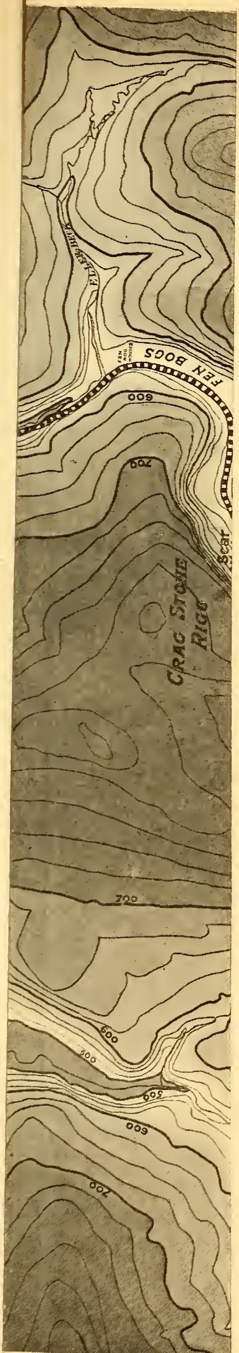


[Both the above figures are reproduced from photographs by Dr. John L. Kirk.]

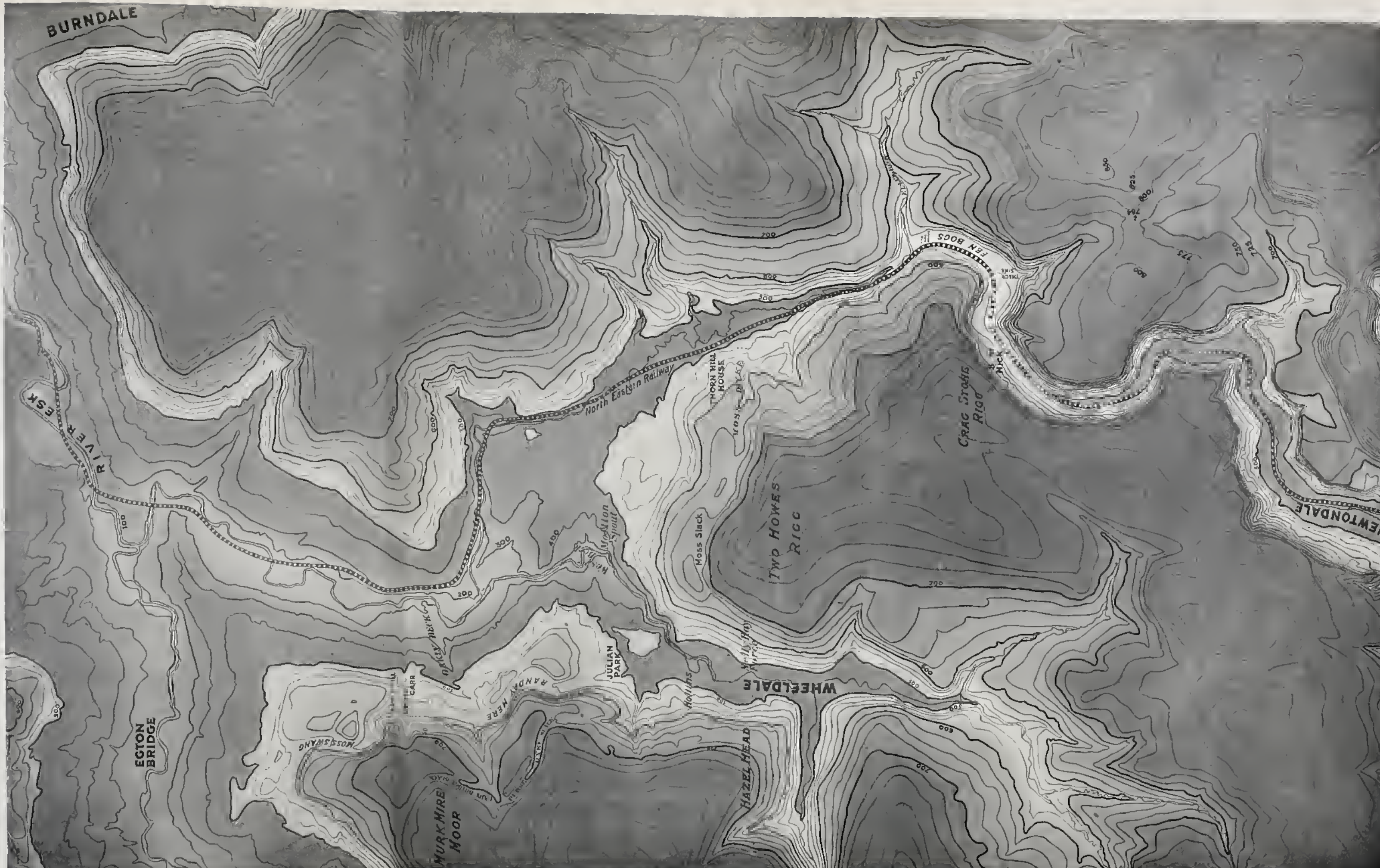
NEWTON DALE AT FEN BOGS, VIEWED FROM ELLER BECK.

The stream in the foreground makes a sharp turn to the northward and leaves the great trench untenanted.

[From a photograph by Dr. John L. Kirk.]


FEN BOGS
600
700
Scar
CRAG STONE
RIGG
700
600
500
600
700

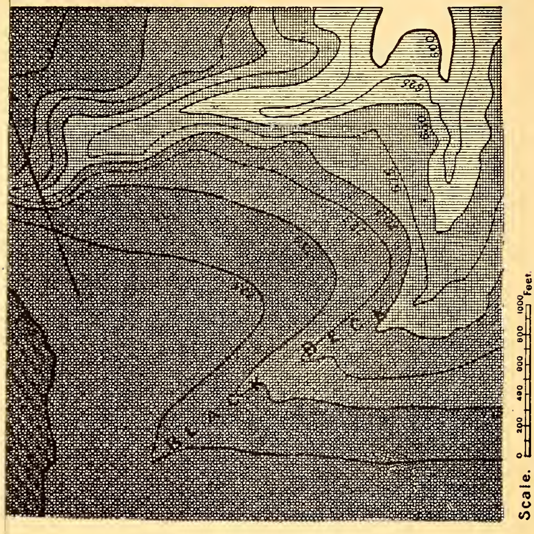
NORTH



SOUTH.

Relief-map of the country between Fen Bogs and Egton Bridge.

[The scale is a little less than 2 inches to a mile, and the distance from north to south is exactly 6 miles.]



of the borings in the flat floor

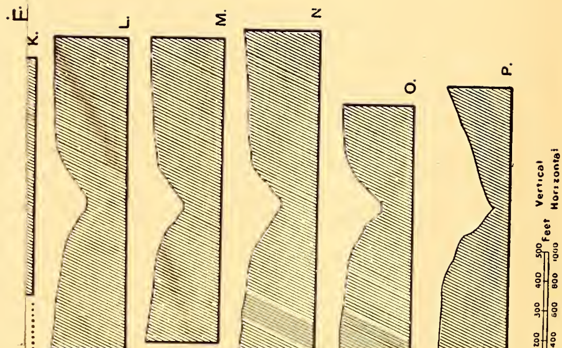


Fig. 1.—*Series of sections across Ewe-Crag Slack, with details of the borings in the flat floor of the valley.*

W. E.

All these passed through peat and were stopped by tough materials.
A.—16′ 6″ : 19′ 6″ : 21′ 6″ : 15′ 6″

To rock-floor.
B.—10′ 6″ : 17′ 0″ : 15′ 0″

To rock-floor.
C.—15′ 0″ : 16′ 6″ : 15′ 0″

To rock-floor, after passing through peat resting upon clay.
D.—9′ 0″ : 10′ 0″ : 12′ 6″ : 12′ 0″

E.—14′ 0″ : 10′ 0″ : 9′ 0″

F.—11′ 0″ : 9′ 6″ to some obstruction : 11′ 6″ finished in clay : 11′ 0″ stopped by a stone

G.—14′ 0″ to clay : 9′ 0″ to ? tree : 14′ 0″ / 6″ clay : / 14′ 6″ : 13′ 0″ / 6″ in clay. / 13′ 6″

H.—12′ 6″ to rock : 12′ 3″ / 6″ in clay : / 12′ 9″ : 12′ 6″ to rock : 5′ 6″ to rock

I.—8′ 6″ to clay : 9′ 0″ to clay : 8′ 9″ / 9″ in clay : / 9′ 6″ : 9′ 0″ to clay : 5′ 6″ to rock : 5′ 6″ to rock

J.—4′ 6″ to ? wood : 7′ 0″ to rock : 4′ 6″ to clay-band or wood : / 3′ 9″ to rock : / 8′ 3″ : 8′ 0″ to clay : 9′ 0″ to clay : 4′ 6″ to clay

K.—5′ 0″ : 6′ 0″ : 6′ 0″ (To rock.) : 4′ 0″ to clay

To rock.
L.—5′ 0″ : 7′ 0″

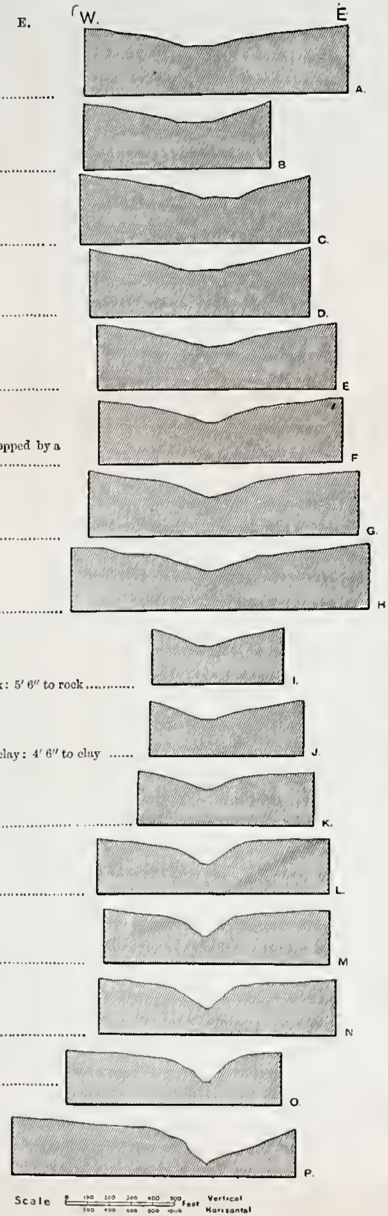
M.—5′ 6″ to clay : 6′ 0″ to rock : 7′ 0″ to clay with stones

To rock.
N.—5′ 6″ : 5′ 6″

Peat 8′ 6″.
O.—Silt

P.—No borings

[Thicknesses in feet and inches.]



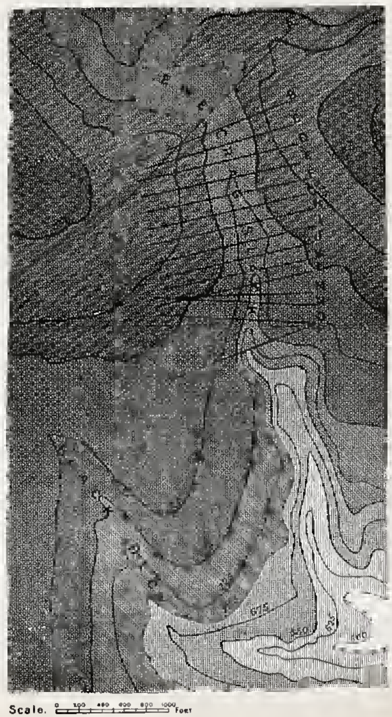
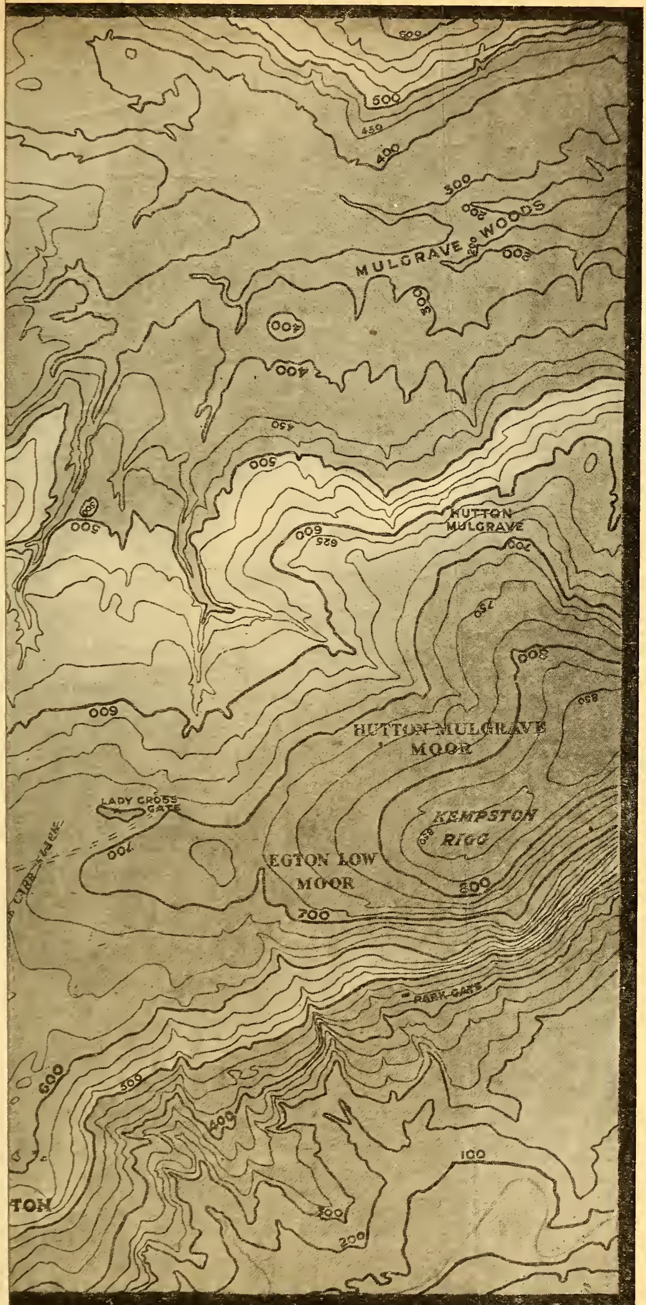


Fig. 2.—*Relief-map of Ewe-Crag Slack, indicating the positions of the transverse sections and the lines of borings shown in fig. 1.*



AND KEMPSTON RIGG.

Relief-map of the Northern Cleveland Watershed, between Danby Beacon and Kempston Rigg.

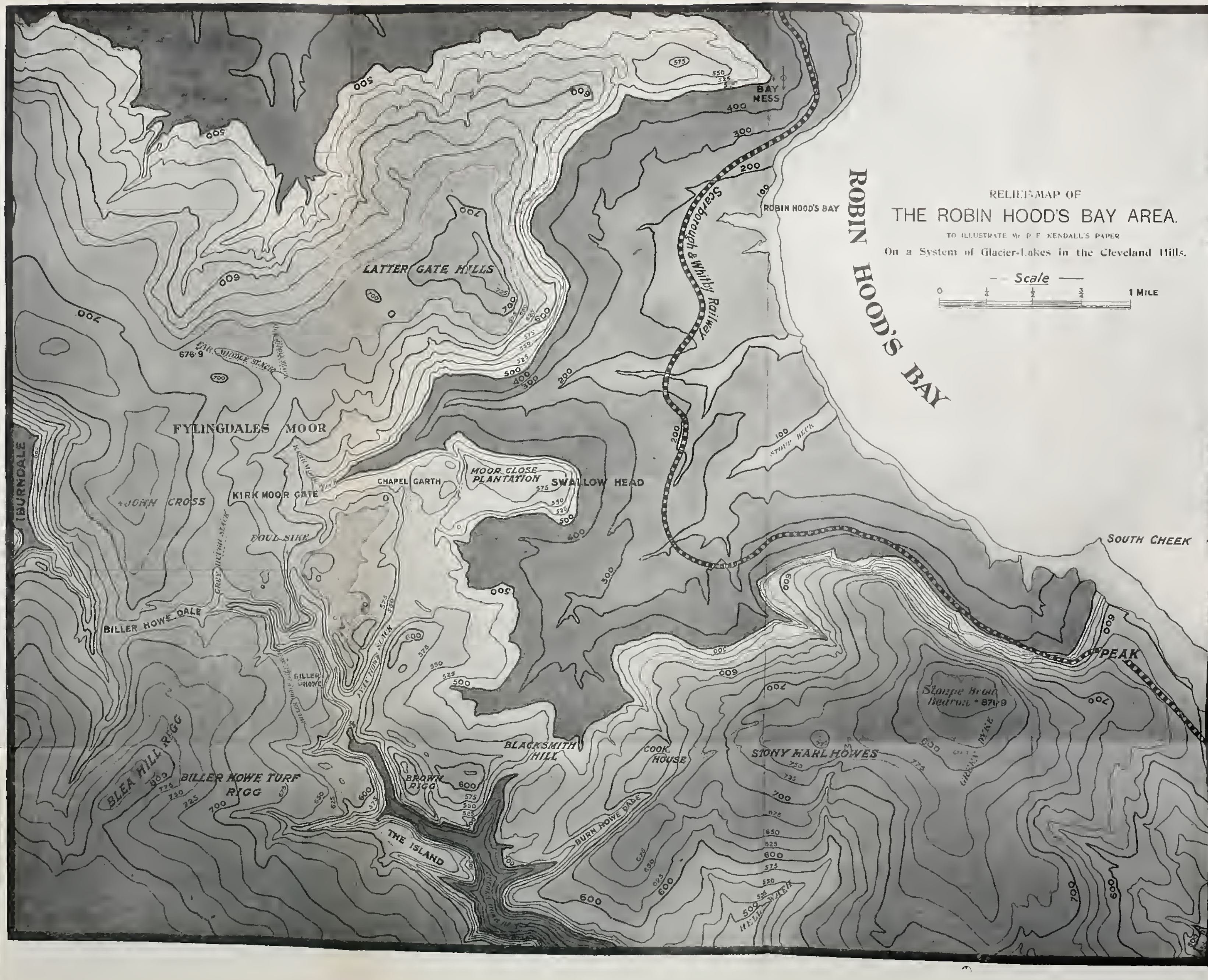
(Scale: slightly less than 2 inches = 1 mile.)

Fig. 1.—*View of the 'Double,' Hare Dale.*

[The conical hill in the distance is Freeborough.]

Fig. 2.—*View looking up Hole Skew, Hare Dale.*

[Both the above figures are reproduced from photographs by Mr. Arthur Stather.]


RELIEF-MAP OF
THE ROBIN HOOD'S BAY AREA.
On a System of Glacier-Lakes in the Cleveland Hills.
Scale
0
1 MILE
ROBIN HOOD'S BAY
BAY NESS
ROBIN HOOD'S BAY
Scarborough & Whitby Railway
LATTER GATE HILLS
FAR MIDDLE SLACK
FYLINGDALES MOOR
IBURNDALE
JOHN CROSS
KIRK MOOR GATE
CHAPEL GARTH
MOOR CLOSE PLANTATION
SWALLOW HEAD
STOUP BECK
SOUTH CHEEK
FOUL SIKE
BILLER HOWE DALE
BILLER HOWE
PEAK
STONY MARL HOWES
COOK HOUSE
BLACKSMITH HILL
BROWN RIGG
BLEA HILL RIGG
BILLER HOWE TURF RIGG
THE ISLAND
BURN HOWE DALE
HELL WATH

S

maximum extension.]

Contoured map of the country between Hellwath and Cloughton.

[The shaded band on the west from Hellwath Slack to West Syme indicates the approximate margin of the ice at, or near, its maximum extension.]

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GENERAL MAP OF THE GLACIERS AND GLACIER-LAKES OF THE CLEVELAND AREA, AT THE PERIOD OF MAXIMUM EXTENSION OF THE ICE.

The area covered by ice is left un-shaded: the lakes are indicated by marginal shading; and the area occupied neither by ice nor by lakes is cross-hatched, to show the relief of the land. The edge of the ice is indicated by a heavy black line. Brcken lines are used upon the south and west, as the marginal phenomena have not yet been studied.

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PLATE XXII.

Relief-map of the country between Fen Bogs and Egton Bridge, on the scale of about 2 inches to the mile.

PLATE XXIII.

Fig. 1. Series of sections across Ewe-Crag Slack, with details of the borings in the flat floor of the valley.

2. Relief-map of Ewe-Crag Slack, indicating the positions of the transverse sections and the lines of borings shown in fig. 1.

PLATE XXIV.

Relief-map of the Northern Cleveland Watershed between Danby Beacon and Kempston Rigg, on the scale of about 2 inches to the mile. The south-eastern edge of the map overlaps Pl. XXII, and the western edge joins fig. 15 (p. 520).

PLATE XXV.

Fig. 1. View of the 'Double,' Hare Dale.

2. View looking up Hole Skew, Hare Dale. The flat floor of the valley is perfectly dry.

PLATE XXVI.

Relief-map of the Robin Hood's-Bay area, on the scale of about 2 inches to the mile.

PLATE XXVII.

Contoured map of the country between Hellwath and Cloughton, on the scale of about 2 inches to the mile. The shaded band on the west, from Hellwath Slack to West Syme, indicates the approximate margin of the ice at, or near, its maximum extension.

PLATE XXVIII.

General map of the glaciers and glacier-lakes of the Cleveland area, at the period of maximum extension of the ice, on the scale of 2 miles to the inch. The area covered by ice is left unshaded; the lakes are indicated by marginal shading; and the area occupied neither by ice nor by lakes is crossed-hatched, to show the relief of the land. The edge of the ice is indicated by a heavy black line. Broken lines are used upon the south and west, as the marginal phenomena have not yet been studied. Contours, as throughout, in feet.

DISCUSSION.

Mr. BAUERMAN said that he desired to thank the Author for bringing before them a close and detailed study of the superficial geology of a district which was comparatively little known. He also commented upon the skilful way in which the cartographical evidence had been arranged.

Mr. CLEMENT REID said that, speaking from his remembrance of the Cleveland district, he was quite prepared to accept the Author's main conclusions. When surveying part of the Esk Valley he was much puzzled to account for the laminated clays referred to by the

Author. The clays were obviously of lacustrine origin, but were entirely unfossiliferous, and no corresponding shore-lines could be discovered. Unfortunately, the necessity for detailed mapping had led to the area being so divided that no one officer of the Geological Survey had had an opportunity of examining both the lacustrine deposits and the deserted outlet of this lake. He heartily congratulated the Author on a most valuable piece of work.

Mr. J. E. Clark remarked that the fact that many perplexing points were made clear by this suggestive paper, made him very ready to fall in with the views contained in it. As to raised beaches, did they occur to any extent in now existing glacier-lakes? Their rapid fluctuation in level made it seem *prima facie* unlikely. The fact that the ice-fringe fell just short of the northern end of Forge Valley was botanically interesting, as that was, possibly, the only habitat of the May lily in England, an abundant species in Scandinavia.

Mr. Harmer offered his warmest congratulations to the Author. The paper that he had just read was of great importance, and would be of service not only to glacialists working in the hills, but to those of the lower districts also. The way in which the surface of East Anglia had acquired its present form, for example, had always been difficult to explain. The whole region is intersected by valleys, great and small, out of all proportion, both in number and size, to its extent, or to the streams which run, or ever could have run, in them. On such questions the Author's paper threw much light; and it would mark, he believed, a new departure in the study of Glacial geology.

Mr. A. E. Salter said that he was glad to find that glacial geologists were making more use of contoured maps. He regarded the area under consideration as of the same type as that lying between the Chalk and Oolitic escarpments of Central England, and thought that many of the interesting and complicated phenomena described by the Author could be better explained by regarding the area as being made up of 'cuestas' of Cretaceous and Oolitic strata, separated by lower ground. By the cutting-back of the two escarpments, the subsequent stream-valleys would be truncated, and a system of obsequent valleys formed, which would give rise to the gravel and other so-called 'Glacial' deposits referred to.

Mr. Barrow congratulated the Author on this paper. Having surveyed the area about Robin Hood's Bay many years ago, he recognized at once that the Author's ideas furnished a perfect key to the mode of formation of the narrow dry valleys that constitute so striking a feature of the watershed west of that area.

The Rev. John Hawell said that he had accompanied the Author in very many of his excursions in the Cleveland district; he had wandered with him through his 'dry valleys,' and assisted him in his boring operations. However convincing the Author's excellent presentation of his conclusions and the evidence on which they were based had been, the evidence in the field was still more strikingly so. He had, himself, resided in the district for the last 22 years, and during nearly the whole of that time had paid special attention to its Glacial geology; but very many of the problems which presented themselves were insoluble, until the Author came down and threw a flood of light upon them. He regarded the reading of this paper as marking an extremely important advance in our knowledge of Glacial geology.

The AUTHOR thanked the speakers for the terms in which they had spoken of his communication; he was particularly glad to have the general approval of Mr. Reid and Mr. Barrow for the views contained in it. With the latter he most fully agreed, as he had himself worked upon the Glacial phenomena of the district for many years without obtaining any enlightenment, before he discovered the clue to their interpretation.

In reply to Mr. Salter, he said that he had exercised the utmost caution in dealing with dry ravines in limestone-rocks, and admitted their glacial origin only in the most patent cases: very few were mentioned in the paper. He dissented entirely from the view that the gorges which he had described were due, as suggested, to protracted denudation of limestone-rocks: they bore every indication of extremely rapid denudation.

He wished strongly to emphasize his indebtedness to the admirable Drift-mapping of the Geological Survey, which had been confirmed by his own investigations in a remarkable way.

30. *The* Glaciation *of* Teesdale, Weardale, *and the* Tyne Valley, *and their* Tributary Valleys. By Arthur Richard Dwerryhouse, Esq., B.Sc., F.G.S., Assistant-Lecturer in Geology at the Yorkshire College, Leeds. (Read January 8th, 1902.)

[Plates XXIX & XXX—Maps.]

Contents.

I. Introduction.

My attention was first called to this District by reading the admirable paper by Mr. J. G. Goodchild on the distribution of the boulders of Shap Granite over the moors in the neighbourhood of the Vale of Eden.[1] In this paper, Mr. Goodchild describes the track taken by the ice which carried the boulders of Shap Granite across the Valley of the Eden, and traces these boulders past Brough-under-Stainmoor to the summit of the Pennine Escarpment, at the head of Lunedale, Balderdale, and Deepdale. Here Mr. Goodchild leaves us, but the rocks have been traced by Prof. Lebour and other observers, down the lower part of Teesdale and out into the North Sea, and also down the Central Valley of Yorkshire as far as the city of York.

In the present communication it is my intention to deal with the distribution of the ice in Upper Teesdale, Weardale, and the Valley of the Tyne, and their tributary valleys, and to discuss certain features produced during the retreat of the ice.

[1] 'Glacial Phenomena of the Eden Valley & the Western Part of the Yorkshire-Dale District' Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 55.

II. Teesdale.

(1) Topography and Structure.

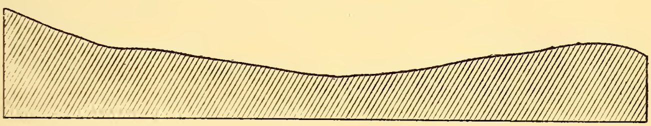
In order that the details which follow may be better understood, I purpose first to describe briefly the form and the solid geology of the district.

The Tees rises on the eastern side of Cross Fell, and receives several tributaries from the surrounding hills. The upper part of the valley has a low gradient, especially in the region immediately above the waterfall of Cauldron Snout. The upper end is enclosed by a semicircle of hills, which are mostly over 2000 feet in height, some of them being over 2500 feet. These hills, commencing at the southern end, are Meldon (2403 feet), Knock Fell (2604 feet), Cross Fell (2930 feet), Rake End (2283 feet), and Calvert End (2196 feet).

About 2 miles from its source the Tees receives several tributaries from the semicircle of hills already mentioned; but the first important stream which falls in, is on the right bank and is known as Troutbeck.

About a mile farther down Crookburn Beck comes in on the opposite bank, and the Tees enters on a stretch of level country through which it winds in a long expanse of still deep water known as The Weel. Fig. 1 is a section of this part of the Dale. At the bottom of The Weel the river plunges over a cliff of basalt, forming the picturesque waterfall of Cauldron Snout.

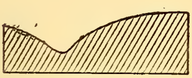
Fig. 1.—*Section across the Weel.*



[Vertical scale = twice the horizontal.]

Immediately below Cauldron Snout, the Tees receives one of its most important tributaries, Maize Beck. This rises on the very summit of the Pennine Escarpment, in Great Rundale Tarn, on Dufton Fell; it flows down the dip-slope, and receives several smaller streams from the east, and at a lower level from both banks.

Fig. 2.—*Section across Cronkley Gorge.*



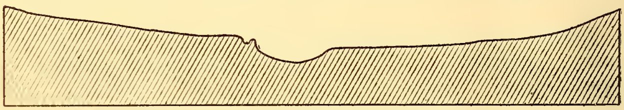
[Vertical scale = twice the horizontal.]

After receiving Maize Beck the Tees runs through a narrow gorge between almost vertical cliffs of basalt (fig. 2), and emerges opposite Widdybank Farm. So soon as it reaches the open ground, the river is largely augmented by the waters of Harwood Beck, with its tributary Langdon Beck. Harwood Beck rises very near to Crookburn Beck in the peat-bogs of Yad Moss, but flows on the opposite side of Herdship Fell. Langdon Beck, the only important tributary of Harwood Beck, rises on the high ground between Teesdale and Weardale, in the neighbourhood of Ireshope Moor.

Below the junction of Harwood Beck the Tees is again confined by the basalt-rocks of the Whin Sill (which has been let down by a fault), and emerges to plunge over the edge of that Sill at High Force (1).[1]

Below this point Teesdale is much more open, but the river has a very steep fall. The western side of this section of the Dale is bounded by the precipitous escarpment of the Whin Sill, and the eastern side is also steep (fig. 3).

Fig. 3.—*Section through Newbiggin (Teesdale).*



[Vertical scale = twice the horizontal.]

Several small streams join the Tees on both banks between High Force and Middleton-in-Teesdale, and about a mile below that town the River Lune comes in. At Middleton-in-Teesdale itself, Hudeshope Beck joins the Tees. It rises on Outberry Plain (2144 feet) and flows in a deep valley nearly parallel to Teesdale. Farther east, and rising near the same point is Great Eggleshope Beck, running in a deep V-shaped valley.

This beck, by its junction with Little Eggleshope Beck, forms a stream known as East Skears, which flows into the Tees near the village of Eggleston. This is the last important tributary on the left bank of the Tees, until Barnard Castle is reached.

The greater part of the surface of Upper Teesdale is formed of the limestones, shales, and sandstones of the Carboniferous Series, with their accompanying sheets of basalt. The basaltic rocks form most of the salient features in the scenery of the Dale, especially in that portion which lies between Cauldron Snout and High Force.

At the foot of Cronkley Scar (3), according to the Geological Survey, there occurs a patch of Skiddaw Slates and Borrowdale volcanic rocks, brought in by the disturbance known as the Burtree-Ford Dyke. Doubts are sometimes expressed as to the existence of the Borrowdale Rocks in this part of the Dale, and some observers are of opinion that the so-called 'Skiddaw Slates' are Carboniferous shales which have been altered by contact with some mica-trap dykes which penetrate them. I was unable to see any Borrowdale Rocks *in situ*, as the part of the Dale where they are mapped is very much obscured by Glacial Drift and by talus from

[1] This and subsequent numerals in parentheses refer to the map, Pl. XXX.

the basalt-cliffs. Judging, however, by the distribution and large size of the boulders of andesite, etc. which occur in the neighbourhood, I see every reason for accepting the Survey reading.

As the number of easily identifiable rocks in the Dale is small, it becomes necessary to trust largely to the nature and distribution of the Drift, and to physical features, in order to determine the direction of flow of the ice. There is a large number of metalliferous veins in the Carboniferous rocks, but as none of them possess any very distinctive characters they are not of much use in this investigation.

(2) The Glacial Deposits.

There are four distinct types of Drift in the area :—

(*a*) A sandy reddish or brownish clay, with a large number of well-scratched stones.
(*b*) A black loamy or peaty clay.
(*c*) A coarse gravelly deposit, with many waterworn and a few scratched stones.
(*d*) A stiff blue Boulder-Clay.

(*a*) The red clay with scratched stones is by far the most widely distributed of these four varieties. It usually occurs in more or less elongated ridges, somewhat after the form of drumlins. It is for the most part confined to the main valleys, and is the direct product of ice-action on the rocks of the upper part of the Dale.

(*b*) The black loamy clay contains very few scratched stones, and is found only in some of the small tributary valleys, at considerable altitudes above the floor of the main valley.

This type of deposit is characteristic of such parts of the district as can be shown, from other considerations, to have been occupied by ice-dammed lakes during some part at least of the Glacial Period.

(*c*) The coarse gravelly material with waterworn stones occurs in long esker-like ridges, which run parallel to the trend of the main valleys. It is particularly plentiful in the country formerly occupied by the Stainmoor Glacier, and can be well seen in parts of Lunedale.

(*d*) The dark-blue Boulder-Clay takes the place of the red deposit in Upper Teesdale, where the Drift was mostly derived from Carboniferous rocks.

The Drift of Teesdale and its main tributary dales (as, for example, Harwood Beck) is arranged for the most part in ridges which are approximately parallel to the sides of the valleys. Those ridges which occur in the bottoms of the valleys are rounded and are of sub-glacial origin—they are, in fact, drumlins.

The ridges lying nearer to the sides of the valleys are more irregular in form, and follow closely the curves of the sides of the valley. These appear to be the lateral moraines of the glaciers, formed at a time towards the close of the glaciation when the quantity of ice had considerably diminished. They do not form the limit of the Drift, but are seen to be followed by a more evenly distributed sheet of Drift which extends considerably higher on the hillsides, and was evidently produced at the period of maximum glaciation.

The following is a description of these ridges, both as regards their distribution and probable origin, commencing at the source of the Tees.

As already stated, the Tees rises in the neighbourhood of Cross Fell, and receives several tributaries from the semicircle of hills forming part of the Cross Fell Group. The headwaters of the Tees, together with these upper tributaries, occupy a basin-shaped hollow, the bottom of which is covered with mounds of Drift containing only such rocks as occur *in situ* in this part of the Dale, namely:—Carboniferous Limestone and shales, sandstones and grits from the Limestone Series, and from the Millstone Grit, which forms the summits of several of the higher hills.

I have not been able to find any basalt in the Drift of this part of the Dale, above the point where Troutbeck enters the Tees; but $1\frac{1}{2}$ miles below that junction basalt occurs *in situ* in the bed of the river, and from this point onward it is a characteristic of the Drift.

The sheet of Drift-material, which has been already mentioned as extending beyond the lateral moraines of the lower part of the valley, can also be seen in this upper portion, and at the head of the river it extends up to a height of 2000 feet above sea-level.

From Troutbeck to Cauldron Snout there is not very much Drift exposed, the ground being thickly covered with peat. Here and there, however, mounds of Drift appear through the peaty covering, and Drift can also be seen in the beds of the tributary streams, again underlying the peat. The Drift is of the same general type as that higher up the stream, except that it contains a large quantity of basalt.

On the western side of Herdship Fell the Drift extends up to the 1900-foot contour-line, and completely covers the col at Cow Green (4), between Herdship Fell and Widdybank Fell (5), being thus continuous with the Drift of Harwood Beck.

There is little Drift on the east side of the river at Cauldron Snout, the rocks being very precipitous; but on the western bank there are several large mounds. Immediately below Cauldron Snout the Tees receives Maize Beck, and then enters the gorge between Widdybank Fell and Cronkley Scar. Here the Drift becomes decidedly more morainic in character, consisting largely of angular and subangular blocks of basalt and limestone. It is sometimes difficult to distinguish between the true Glacial deposits and the post-Glacial talus, in this part of the valley.

On the summits of both Widdybank Fell and Cronkley Scar can be seen a number of boulders of basalt, resting on the surface of a saccharoidal limestone which is both higher in the series than the

Whin Sill and is at a higher elevation. The summit of Cronkley Scar is strongly *moutonnée*; but I was unable to find any actual striæ, as the rocks have long been exposed to the action of the weather.

In the bottom of the gorge several well-developed lateral moraines occur; and as these reach the open valley below, they sweep round the foot of Cronkley Scar and spread out over Cronkley Pastures, between the Scar and the river. Near this point is a small lake, Tarn Dub, which is held up by one of these moraine-ridges, and there are also several small peat-bogs entangled among them.

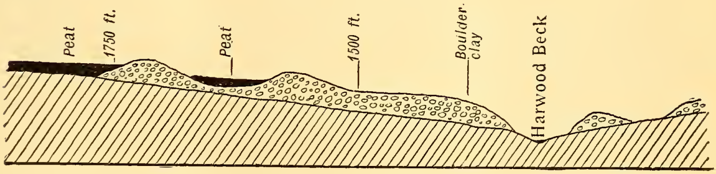
Before proceeding to describe the deposits in the lower parts of the valley, it will be convenient to discuss those of Harwood Beck and its tributary Langdon Beck, together with those at the junction of Harwood Beck with the Tees.

On Yad Moss, near the source of Harwood Beck (1990 feet), there is a thin covering of Drift with a considerable thickness of peat on the top. Above Greencombe Sike the Drift becomes thicker, and much more moundy in appearance. At a point near the junction of Greencombe Sike with Harwood Beck is a large mound of bluish Boulder-Clay, which has been cut into by the river, so as to expose a clear section; it contains boulders of Carboniferous Limestone and sandstone, also pieces of shale and grit, but no basalt-boulders.

Comber Hill (8) consists of similar material, basalt being again absent. The country lying between Comber Hill and St. Jude's Church is covered by similar Drift, lying rather more evenly over the land than is the case nearer the head of the valley. At St. Jude's Church are several well-formed Drift-hills of typical contour.

Fig. 4 is a section across the valley, as seen in the beds of

Fig. 4.—*Section across the valley of Harwood Beck (Upper Teesdale).*



Sevendarg Sike and another small stream not named on the Ordnance Survey-maps. This is the only case in Upper Teesdale where the Drift is terminated by a moraine usually it thins out gradually against the slopes of the hills. This moraine is at a height of 1750 feet, and holds up a peat-bog of considerable dimensions against the hillside.

Lower down Sevendarg Sike other ridges are to be seen running parallel to that last described; and at a height of 1500 feet another peat-bog is seen resting between two ridges of Drift.

Rowantree Rigg is a hill consisting, so far as can be seen, of a gravelly clay with boulders.

The farms of Gill Town, Unthank, and Pegborn Lodge are situated on a plateau of Drift, which terminates on Harwood Beck in a line of cliffs. From sections in these cliffs, the plateau is seen to consist chiefly of a hard blue Boulder-Clay, which becomes more sandy in its upper part. The Drift-plateau is continued upward on the sides of the valley by mounds of Drift of a more morainic character. A clear section of this is to be seen in Easter Sike, opposite Bink House (10), at a height of 1500 feet; it consists of blue Boulder-Clay, with many stones both large and small. The boulders consist principally of sandstone, limestone, and shale, and are for the most part angular, but some of them are subangular and striated. Basalt appears still to be absent. Upwards of 20 feet of Drift is exposed in this section, but the bottom is not seen. There is no lateral moraine at this point.

Easter Sike rises in a peat-bog known as Sour Mere, which is confined between the edge of the Drift and the side of Touting Hill, at a height of about 1700 feet. The peat has grown to such an extent that it overlaps the clay in some parts.

At Coarse-Foot Hill (11) a dyke of basalt cuts across Harwood Beck, and below this point basalt forms a conspicuous constituent of the Drift.

At or about Pegborn Lodge (12) is the point where the Drift of Harwood Beck unites with that of Cow Green. Coarse-Foot Hill, Seavy Hill, and several others close by consist of blue Boulder-Clay, with boulders of limestone, shale, and basalt, many of them being striated.

The valley of Langdon Beck is covered with Drift similar in character to that of the main valley, but containing only Carboniferous rocks such as may be found *in situ* in the valley itself.

The surface of the Drift is deeply channelled by streams, but the mounds are not so well marked as in the larger valleys. The lower end of the valley is closed, or nearly so, by a ridge of Drift, a lateral moraine of the Harwood-Beck Glacier, and the stream has had to cut its way through the solid Carboniferous rocks at Valence Lodge.

The Parsonage (13) at Langdon Beck stands on a hill of Drift, consisting, so far as can be seen, of a gravelly clay.

Cocklake Rigg and Widdybank Pastures (14) are occupied by long and somewhat curved ridges of gravelly Drift, sometimes accompanied by stiff Boulder-Clay. On Cocklake Rigg the ridges run in an approximately east-and-west direction, but as they are traced into the lower ground of Widdybank Pastures, they gradually curve round towards the south, until at Loom Sike they are running from north-west to south-east.

At Whey-Sike House this set of mounds is joined by another set running almost due east and west, being a continuation of the series at Widdybank Farm. From this point onward there were no more tributary glaciers until the junction with the western or Irish-Sea ice, below the town of Middleton-in-Teesdale.

How Hill (16) is a mound of stiff bluish Boulder-Clay, capped by more gravelly material. It has been cut into by the river, and shows a section 75 feet in height, containing the following boulders:—basalt, limestone, shale, brown sandstone, red sandstone, and andesite of the Borrowdale Series. The first boulders of Borrowdale Rocks occur in the bed of the Tees immediately below the point where these rocks are marked on the Geological Survey map; that is to say, opposite Widdybank Farm, a most careful search above that point having failed to reveal a single pebble.

Dine-Holm Scar (17) and Yeart Hill, which consist of basalt, have practically no Drift upon them, but there are a few boulders which have been carried from points higher up the valley.

Round High Force (1) there is very little Drift, but on the east side of the Dale, behind the High-Force Hotel, a series of long mounds run parallel to the main road. One of these mounds skirts the road from the Hotel to Ettersgill Bridge (13). Below this point Teesdale is a valley within a valley, as the contour-section in fig. 3 (p. 574) will make clear. The inner valley contains a number of long ridges of somewhat gravelly Drift, ranged with their long axes approximately parallel to the river, and all showing the characteristic outlines of the drumlin. There are many large boulders in and near the river, but these are without exception such as could be derived from rocks which occur in the upper part of the Dale.

On the top of the basalt-cliffs on the right bank of the river there is very little Drift; but on the slopes of Green Fell above these cliffs, it is again met with in considerable quantity. As in the upper part of the Dale, the sheet of Drift thins out gradually against the side of the fell.

At Green-Fell End the Drift extends up to the 1750-foot contour-line, but above Crossthwaite Common it terminates at about 1500 feet. In the stream immediately south of the house at East Crossthwaite (20) are several good sections of the Drift, which consists of a dirty yellow gravel with many boulders, principally of basalt, some of them being beautifully striated. At a height of 775 feet there are boulders of Carboniferous Limestone, sandstone, and shale, also some masses of a stiff blue clay which appear to have been transported bodily. There are no stones foreign to the Dale. Farther up the same stream, at a height of 825 feet, in the cutting of the quarry-railway (not shown in the Ordnance-Survey maps), is some gravel of a similar nature with similar boulders, including a very well striated boulder of basalt. The surface of the hill in this part is covered with mounds of Drift, which all trend parallel to the valley, and appear to form a lateral moraine, though they do not limit the Drift.

On the Durham side of the river the country is thickly covered with Boulder-Clay.

In Hudeshope Beck, at the back of Middleton, the stream is cutting deeply into soft black Carboniferous shales, which are capped by a great thickness of Boulder-Clay on the right bank of the stream. This thick sheet of Drift extends over the side of the hill at

Tinklers Allotment (21), 1250 to 1500 feet; but on Hardberry Hill (22), at a height of 1742 feet, there is very little, if any, Drift. On the east side of the stream, at the limestone-quarry, there is about 20 feet of Drift above the limestone. The boulders in Hudeshope Beck include limestones, shales, and sandstones from the Carboniferous Series, basalt, Millstone Grit, and green andesites of the Borrowdale Series.

The andesites appear to be entirely confined to the eastern side of the Dale, where they are fairly plentiful.

The valley of Great Eggleshope Beck is in its upper part (above the lead-works) apparently free from Drift. But at the junction of the stream with Little Eggleshope Beck there is an enormous accumulation of bluish Boulder-Clay containing many boulders, both large and small, of the following rocks:—andesite (Borrowdale Series), Carboniferous Limestone, Millstone Grit, Carboniferous sandstone, and basalt (Whin Sill). Many of these boulders are striated. This sheet of Drift extends up both becks. In the case of Great Eggleshope Beck there is no great thickness, and it disappears entirely before reaching the lead-works.

In the valley of Little Eggleshope Beck there is more Drift, and it extends up to a point $1\frac{1}{4}$ miles above the junction of the streams. In the upper part of this valley, in the neighbourhood of the California Lead-Mine, the Drift is represented only by a few scattered pebbles of Whin Sill (which does not occur *in situ* in the valley).

The thick mass of Drift extends from the junction of the streams continuously across Cowlake (23), 1114 feet, and ends in the cliff overhanging the Tees, in the neighbourhood of Stotley Hall. In a southerly direction it extends to, and is continuous with, similar Drift in the valley of Blackton Beck. The surface of the Drift is undulating, its elevation varying from 1100 to 1250 feet above O.D.

In Blackton Beck the Drift runs up to Blackton Head, and is connected by scattered boulders with that of Spurlswood Beck and Rowley Beck, both in the Wear drainage-basin.

There are patches of Boulder-Clay containing Teesdale rocks on various parts of Woodland Fell (24) and Langleydale Common (25).

It is now necessary to consider the Drift of that part of the area which was invaded by the ice from Edenside. Here we at once meet with a type of material which is entirely different from that of any other part of the district.

So far, the Drift described has been principally derived from Carboniferous rocks; but in Lunedale and Balderdale the deposits are distinctly red, owing to material derived from the Trias and Permian of the Vale of Eden. As Mr. Goodchild has shown, the Drift bearing Shap Granite and Triassic material can be traced to the summit of the upper Pass of Stainmoor, and this Drift is found over the whole of the country between Lunedale on the north and the Greta on the south.

At the head of Lunedale there is very little Drift, the slope of the ground being very steep; but, so soon as the county-boundary is crossed, enormous ridges of red and somewhat gravelly clay are seen. These ridges run parallel to the valley, are much longer in proportion to their breadth than those of Teesdale, and are much more esker-like. Pasture Rigg (26) and Gross Hill are two of these ridges, and there are many others like them all the way down the valley; in fact, the valley-floor is covered with them.

In the bed of the stream at Grains-o'-th'-Beck Bridge (28) a number of boulders of 'Brockram' occur, also many fragments of bright-red sandstone of Permian or Triassic origin. These are at a height of 1173 feet above Ordnance-datum, and are therefore considerably above the highest outcrop of the parent-rocks.

At Lunehead Moss (29) the Drift is distributed in a much more uniform manner, conspicuous ridges being absent, such relief as does occur being attributable to post-Glacial erosion, which on these steep slopes has been severe. The deposits are bluish-black in colour, and contain some carbonaceous matter. Similar deposits occur in Arngill Beck, Hargill Beck, and Wemmergill Beck. In these deposits striated boulders are much less common than in those of the main valley.

At Rigg House, about half-a-mile west of Wemmergill, long mounds of gravelly Drift with rocks from Edenside occur; while on the hillside above this is a sheet of similar material, which gradually thins out against the slope of Cocklake Side (30).

Smithy Holm (31) consists of a plateau of red Boulder-Clay, packed with Triassic material, and containing many scratched stones. It ends against the River Lune in a steep scarp, where a good section is to be seen, and thins out against the 'solid rocks' of the hill.

Bink-House Bank is a similar mound, and consists of similar material.

Near Grassholm Bridge (32), slightly up-stream and on the right bank of the Lune, is a high cliff of Boulder-Clay, the edge of a Drift-plateau partly cut away by the river. The clay is tough and red, and contains a large quantity of Permo-Triassic material, together with boulders of local rocks, many of which are striated.

The lower part of Lunedale is covered by long parallel ridges of Drift. These ridges run approximately east and west in Lunedale; but, as they approach Teesdale, they curve round and run in a south-easterly direction, becoming continuous with the Drift of that valley.

(3) Glacial Striæ, etc.

Nearly all the striæ in this district are on the basalt of the Whin Sill. Considering the severity of the glaciation, and the abundance of hard rocks which are present in the Dale, the number of instances of striated surfaces is extremely small. This is, in all probability, to be accounted for by the very exposed nature of the country.

Although striated surfaces are few, the rocks have nevertheless retained a characteristically glaciated outline in many parts of the district, *roches moutonnées* being abundant.

The following is a list of the striated surfaces which I have observed in the district, with the mean direction of the striations :—

1. Surface of basalt, at the junction of Green Burn with the Tees (1663 feet). S. 55° to 87° E. (33).
2. Surface of basalt, in Bothermeer Sike (1625 feet). S. 75° to 88° E. (34).
3. Surface of Carboniferous Limestone, in Sand Sike (1500 feet). E. 18° N. (35).
4. Surface of basalt, at Crag Nook (1500 feet). S. 30° E. (36).
5. Surface of basalt, in Harwood Beck, opposite Peghorn Lodge (1300 feet). S. 67° E.
6. Surface of basalt, in the bed of the Tees, opposite Cronkley Green (1200 feet). S. 60° E.
7. Several surfaces of basalt, at Dufton Moss, Forest (1200 feet). S. 65° E., S. 80° E., S. 63° E., S. 68° E. (37).
8. Two surfaces of basalt, at Holwick Head (1100 feet). S. 57° E., and S. 68° E. (38).
9. Surface of basalt, at Rotton Rigg (1150 feet). S. 63° E. (39).
10. Surface of Millstone Grit, half-a-mile north of Hollingside Wood. E. 3° to 5° S. (40).
11. Surface of Coal-Measure sandstone, a quarter of a mile north-west of Hawksley-Hill House. N. 60° E. (41).
12. Surface of Coal-Measure sandstone, on Roger Moor (1000 feet). N. 75° E. (42).
13. Surface of Coal-Measure sandstone, at Stainton. N. 75° to 80° E. (43).

The foregoing directions have been corrected for magnetic declination.

(4) Boundaries of the Ice at the Period of Maximum Glaciation.

The glacier which filled the upper part of Teesdale during the Glacial Period took its rise in the semicircle of hills at the head of the Dale, at an elevation of about 2000 feet above the present level of the sea. The ice flowing from this reservoir of *névé* soon divided into three branches. The main branch flowed down Teesdale. The next in magnitude found its way across a part of Yad Moss and down the Harwood Valley, eventually joining the ice which flowed down Teesdale proper near the point where the Tees now receives the waters of Harwood Beck. The third branch flowed down the Valley of the South Tyne towards Alston, the further course of this branch being described in § IV, p. 601.

That ice flowed down the upper part of the Valley of the Tees is proved by the occurrence of glacial striæ at the junction of Green Burn with the Tees. These striæ will be seen, on reference to Pl. XXX, to point down and slightly towards the left bank of the river. The next set of striæ which occur in this part of the valley are in the bed of Bothermeer Sike, and point almost directly across the course of the river, towards its left bank.

When the glacier reached the narrow part of the valley below Cauldron Snout, the gorge being too small to take the whole flow, the ice became ponded-up to such an extent that it overflowed the col at Cow Green (4), and so joined the ice of Harwood Beck, and eventually that which went by the more circuitous route of the present Valley of the Tees. The direction taken by this stream is marked by the striæ at Bothermeer Sike, already mentioned, and by those at Sand Sike and Crag Nook, also by the direction of the axes of the Drift-hills on Widdybank Pastures (14), p. 578.

The Harwood-Beck ice flowed down the valley to its junction with Langdon Beck, where it became confluent with the ice from Cow Green. (See striæ at Peghorn Lodge, p. 582.)

That a large portion of the ice came through the gorge below Cronkley Scar is shown by the fact that large numbers of boulders of the Borrowdale volcanic rocks (which occur *in situ* in the gorge) are to be found widely distributed in the Glacial Drift lower down the river; while they are entirely absent from similar deposits in that part of the valley which is above the point where they occur *in situ*.

Although the main flow of the ice was probably through these two paths (namely, Cronkley Gorge and Cow Green), nevertheless some appears to have passed not only over Widdybank Fell, but also over the summit of Cronkley Scar and Thistle Green (1793 feet). That these fells were overridden at the period of maximum glaciation is shown by the occurrence of boulders of basalt, which have been carried up on to the surface of an overlying bed of limestone, as already mentioned (p. 576).

So far as I have been able to ascertain, there does not appear to have been any glacier in the valley of Maize Beck, as the Drift which occurs there is of an entirely different type from that of the main valley, the materials being of extremely local origin. One notes also a general absence of scratched stones and striated surfaces, although the conditions there are quite as favourable for their preservation as in any other part of the valley-system.

The Drift is of a type similar to that which occurs in some of the smaller tributary valleys which can be shown to have been occupied by lakes during the period under consideration, and to these I shall refer later (p. 585).

After the reunion of the three streams of ice at Cronkley Green, the whole glacier swept down the Valley of the Tees, filling not only the narrow valley below the basalt-cliffs, but also a great part of the wide outer valley. A short distance below Middleton-in-Teesdale (the exact line cannot be determined, owing to minor oscillations which have occurred), the Teesdale ice became confluent with that which flowed from Edenside.

The ice from Edenside, by way of Lunedale and Balderdale, owing to its steeper fall, thrust the ice of Teesdale over on to the Durham side of the valley. Thus the Triassic material and the Shap Granite are confined to the right bank of the River Tees for some distance from the line of union of the Edenside and Teesdale Glaciers, while the rocks from Teesdale proper are to be found plentifully on the slopes of the left bank. At the same time, the high ground between Lunedale and Balderdale was entirely buried beneath the great sheet of ice pressing over from Edenside, though a large part of Mickle Fell (44) and Green Fell were free from ice. The effect of this pressure is well seen in the case of the valleys of Great and Little Eggleshope Becks. Here the ice was forced for some distance up-stream and stood against the shoulder of Middle End (45), which separates the two valleys at a height of 1250 feet, in such a manner as to block the mouths of both of them.

In the case of the Blackton-Beck Valley, the Teesdale ice was forced over the watershed into the Wear-Valley drainage, and to the south of Langleydale Common (25) the country was completely overridden, as shown by the striæ at Holiingside Wood, Hawksley Hill, and Roger Moor, and by the occurrence of a large boulder of Shap Granite near the village of Lynsack (p. 592).

The following are some of the levels of the ice in different parts of the valley-system at the period of maximum glaciation:—

At the head of Teesdale the ice appears to have stood at about 2000 feet above sea-level; while on Herdship Fell, between Teesdale and Harwood Beck, which was a nunatak, it stood a little lower.

At Green-Fell End the ice stood at the 1750-foot contour-line, and at Harter Fell (46), where it became confluent with the Lunedale ice, its level was about 1500 feet.

This gives a total fall of 500 feet in a distance of about 15 miles, or a surface-gradient of 33 feet per mile.

At the head of Lunedale the ice stood at a level of 2000 feet, and fell to 1500 feet at Harter Fell, where it joined the Teesdale Glacier, giving a fall of 500 feet in 9 miles, or 55 feet per mile.

The foregoing heights are obtained from that of the upper limit of the Drift, and therefore refer to the edges of the glaciers. The central parts of the glaciers would doubtless be somewhat higher—how much higher it is impossible to ascertain.

(5) Glacial Lakes and Drainage-Channels.

It will have been seen from the foregoing observations that, even at the period of maximum glaciation, the highest parts of the district were not covered with ice.

These more elevated parts of the country appear to have been comparatively free from snow, at all events in the summer-time, inasmuch as traces of the existence of lakes and of copious streams of water are to be found in several parts of the area. The largest of these lakes occupied the valley of Maize Beck, and appears to have had its overflow at the head of Hilton Gill (47), or at High-Cup Nick (48), or at both these places, the watersheds being at about the same level.

As has been already stated (p. 583), the Drift of this part of the area is of a type different from that occurring in the main valley, scratched stones being very uncommon and striated surfaces absent.

The valleys now occupied by Hudeshope Beck and Great Eggleshope Beck were also the sites of lakes at this period, the former having its overflow into the latter between Carrs Hill and Monk's Moor.

In the case of Little Eggleshope Beck, the ice standing against Middle End, as already described, caused the ponding-up of the drainage of that valley; and it would also appear that a large volume was discharged into this lake from the ice-front, as there is a deep and wide gorge (now practically streamless) connecting this valley with Eden Beck (49), a tributary of the River Wear.

The best-marked series of glacier-dammed lakes in the area is that which occurs in the Mickle-Fell and Green-Fell range (Pl. XXIX). The uppermost lake of this series occupied the area now known as Philip-Reed Moss; it received the drainage from all the southern side of Mickle Fell, and probably also waters from the eastern edge of the Eden Glacier. Its waters found an outlet over the col between Closehouse Hush and West Hush, at an elevation of about 1700 feet (51). The waters of this lake flowed into a second lake which occupied the valley of Arngill Beck; this, in its turn, overflowed by way of the col at East Hush into the valley of Hargill Beck.

This valley was also occupied by a lake, and overflowed by way of the col between Cock Lake and Bink Moss into Wemmergill Beck. At the period of maximum glaciation this lake not only received the whole of the drainage from its own side of the Mickle-Fell watershed, but also the overflow from a lake which occupied the broad upland valley known as Howden Moss and Bleabeck Grains (53). The overflow of this Bleabeck Lake was through the channel of Dry Gill (54), between Hagworm Hill and Bink Moss, the level of the lake being about 1750 feet. There was still one more in this chain of lakes, and this occupied the valley of Wemmergill Beck. Its overflow at its maximum was at an elevation of 1600 feet, between How Top and Scarsett Rigg, by way of Merry Gill (55).

About a mile below the foot of Merry Gill the ice appears to have stood at a level of 1500 feet, that is to say 100 feet lower than the outlet of Lake Wemmergill, and therefore the water probably flowed on to the ice, or may have found its way under or through the glacier, as do some of the streams on the Malaspina Glacier in Alaska.

(6) Phenomena during the Period of Retreat.

Having seen what was the probable state of affairs at the time of maximum glaciation, we may now consider what took place during the period in which the ice dwindled. Of course, we can learn nothing directly of the sequence of events during the period of advance, as the traces of this advance were necessarily obliterated during the period of greatest extension. By a careful study of the phenomena of retreat we can, however, learn something of that

Fig. 5.—*View of The Castles, at High Holwick (Teesdale).*

which took place during the phase of advance, as the ice must have stood successively at the same levels during both advance and retreat. In the whole of Upper Teesdale I have not observed any well-marked terminal moraine, unless the mound of clay and gravel at the junction of the Tees and Harwood Beck can be considered to be of that nature.

The absence of terminal moraines produced during the phase of retreat seems to point to a very rapid removal of the ice after it had once ceased to be confluent with that of Edenside. The ice of Lunedale shrank somewhat, and then stood at a constant level for a considerable period; after which it seems to have disappeared rapidly from the valley, probably because the ice from Edenside was no longer able to surmount the high watershed above Brough-under-Stainmoor, and the supply of the ice was thus cut off. The level at which the ice stood at this stable period is indicated by the level of the lower outlet of Lake Wemmergill.

At the time of maximum glaciation this lake stood at a level of 1600 feet, and overflowed by way of Merry Gill. At a later epoch the ice had retreated sufficiently to allow the waters of the lake to escape, by way of the hollow between Merrygill-Head Moss and Sleight Edge (56), and the large size and great depth (about 75 feet) of this channel bear witness to the long time during which the ice stood at this level.

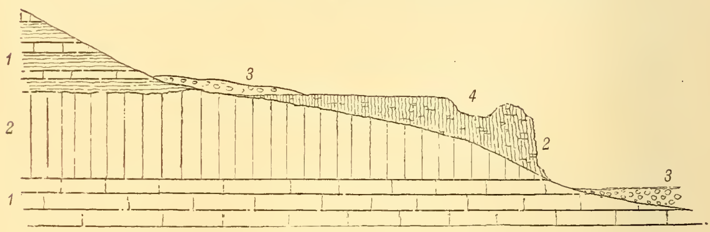
The valley is now quite streamless; and although the floor consists of limestone, the fact of its dryness cannot be attributed to the absorption of a former surface-stream by the rock, as there is no catchment at the head of the channel capable of yielding a stream competent to produce so large a valley. The waters of the lake overflowing by this channel at a height of 1475 feet, produced a large gravel-fan above the farm of Low Wythes (57). This halt of the ice during its retreat is not confined to Lunedale, but is just as well marked in Teesdale itself.

The best evidence in Teesdale is to be seen on the basalt-escarpment which runs along the Yorkshire side of the valley opposite Middleton-in-Teesdale, and extends to High Force. During the stable period the ice appears to have filled the inner valley, but to have been unable to surmount the basalt-cliffs. The result of this was that a system of streams was produced, flowing parallel to the side of the glacier, along the summit of the cliffs.

These streams have left records of their presence in a series of gorges and channels which run parallel to the line of cliffs, in some cases only a few yards from their edge. The summit of this line of cliffs at its northern end is at a level of 1175 feet, while opposite Middleton it stands at about 1000 feet. A series of gorges cut back into this cliff-line, approximately at right angles to its face. These gorges have very steep sides, and the streams which occupy them have very steep gradients; they have been started by the ordinary drainage of the wide outer valley, the floor of which is formed in this region by the upper surface of the basalt-sill. Connecting these normal valleys with each other is a series of channels, now quite dry, and running parallel to the edge of the cliff. The most marked is that of the group of rocks known as The Castles, at High Holwick (fig. 5, p. 586). In this case the water from the edge of the ice has cut a channel, about 100 feet deep and possessing an average width of 50 yards at the top, thus severing The Castles from the main mass of the escarpment.

The large size of this channel, as compared with some of the other gorges in similar situations farther down the valley, is to be accounted for by the fact that this upper channel must, at that stage, have taken the whole drainage of the country around Howden Moss and Bleabeck Grains, in addition to the water from the side of the ice in the neighbourhood of Cronkley Scar. The spur above Gill Brae is severed by a channel known as the Hind Gate, which is now dry, and evidently belongs to the same drainage-system. The upper end of the Hind Gate opens into the Gill Gate, a normal drainage-channel, at a height of 30 feet above the bottom of the latter, and ends downward in a gulley of the basalt-cliff at a height of 1150 feet above sea-level.

Fig. 6.—*Section near West Crossthwaite (Teesdale).*



1 = Carboniferous Limestone. 3 = Boulder-Clay.
2 = Whin Sill. 4 = Dry valley.

Another excellent example of a channel of this description is that on the edge of the cliffs immediately above the sheepfold at West Crossthwaite. It is a channel cutting off a spur, and commences at its upper end in the side of a normal gulley, which is at this point 40 feet deeper than the dry valley (fig. 6). The bottom of the channel is full of peat, and there is now no stream, nor is there, under existing conditions, any possible catchment for such a stream. This channel is continued on the opposite side of the gulley, but it is not so well marked there.

Thus, during the period of retreat, there was an interval of considerable duration, during which the level of the ice remained constant both in Teesdale and in Lunedale. The cause of this stable interval during the final retreat of the ice I am unable even to guess at, at the present time; but Mr. P. F. Kendall informs me that he has met, in the Cleveland district, with evidence pointing in the same direction. After this period of constant level the ice seems to have dwindled very rapidly, as there are no terminal moraines to be seen, with the doubtful exception of the mound at the junction of Harwood Beck with the Tees.

A further piece of evidence in favour of rapid retreat after this period is to be found in the absence of any Glacial drainage-channels below the level of the ice at its stable period.

III. Weardale.

(1) Topography and Structure.

The Wear has its origin in the elevated land (2300 feet) lying to the east of the main Cross-Fell range, and separated therefrom by the valley of the South Tyne. At its upper end the Wear Valley is divided into three branches, the northernmost of which is that of the Kilhope Burn; the other two being occupied respectively by Welhope Burn and Burnhope Burn, the Wear itself being formed by the union of these three streams. Several lateral valleys come in on both banks, as will be seen on reference to Pl. XXX.

The country consists for the most part of the limestones and shales of the Carboniferous System, the higher hills being capped by Millstone Grit. There is a small intrusion of basalt near Cowshill (58), and a larger outcrop of the Whin Sill near Stanhope. The lower part of the valley, in the neighbourhood of Bishop Auckland, is in the Coal-Measures. A basalt-dyke crosses Weardale at Witton-le-Wear.

(2) The Glacial Deposits.

Above Cowshill the Wear Valley contains a considerable amount of Drift. In the upper portion of the valley gravelly materials predominate, and there are not very many scratched boulders; but a little way above Cowshill the Drift is a true Boulder-Clay of a bluish colour, and contains abundantly planed and striated boulders of Carboniferous Limestone, also masses of shale.

At the basalt-quarry at Cowshill is a thick deposit of blue Boulder-Clay with striated stones, all such as could have been derived from the upper part of Weardale. Below Cowshill, basalt appears in the Drift, but is by no means plentiful, owing doubtless to the limited area of the outcrop of that rock.

The left bank of the Wear is covered with similar Drift down to Wear-Head Station. The central lobe of the valley, that of Wellhope Burn, contains sandy and gravelly Drift derived from the Carboniferous rocks at its head. The third or southern lobe is that of Burnhope Burn, which is formed by two streams arising on Burnhope Moor (59), and is occupied by mounds of gravelly Drift and Boulder-Clay of local origin, scratched stones being common in the lower portion but rarer in the higher parts.

Ireshope Burn rises on the col at the head of Langdon Beck, a tributary of the Tees (p. 574). At the summit of the col

(1800 feet) there is a deposit of peat, resting upon gravel formed of local material and for the most part angular. This gravelly deposit is continuous with true Glacial material on both sides of the col.

Ireshope Burn is formed by the union of two principal tributaries. The eastern stream cuts through thin Drift, containing angular and subangular stones; but in the western tributary, which is the larger, occur esker-like mounds of gravel of a more rounded type. Below the junction of the two streams the stones become striated, and the amount of striation increases at still lower levels.

There is a railway-cutting 30 feet deep, three quarters of a mile west of Westgate Station (60). This is in stiff Boulder-Clay containing many striated stones. A thickness of 10 feet of the same material is to be seen close to Westgate Station. About a quarter of a mile below Westgate, the river cuts through similar material resting upon limestone, the surface of which is planed.

Similar deposits are exposed in the cutting 1 mile above Eastgate Station (61), the boulders being very large and well-striated. In a quarry on the north side of the railway, half a mile above Stanhope, there is an exposure of 20 feet of blue Boulder-Clay resting on the 'solid rock.'

In the large quarry at Jack's Crag (62), about 1 mile south-east of Stanhope, is a very fine striated surface. The surface originally exposed measured 100 yards by 50, and was moutonnée and striated throughout. There is still a large portion exposed, and the striæ pass under the Boulder-Clay, the surface being therefore of unknown extent. This is the finest example of a striated surface that I have seen in the North of England. The direction of the striæ is south 50° east, or approximately that of the main valley. The Boulder-Clay in this section varies from 15 to 20 feet in thickness, and contains boulders of Carboniferous Limestone, sandstone, Millstone Grit, and less commonly basalt. Many of the boulders, especially those consisting of Carboniferous Limestone, are striated.

The 'Great Limestone' is quarried at Ashes Quarry, Stanhope (63), and is covered by stiff bluish Boulder-Clay containing limestone- and sandstone-boulders, to a depth varying between 20 and 40 feet. When exposed to the air this clay weathers to a reddish-brown. A year or two ago there were fine examples of striæ to be seen in this quarry; but the portion of the quarry where they occur is not now being worked. Mr. W. M. Egglestone, of Stanhope, Secretary of the Weardale Naturalists' Field-Club, informed me that the direction of the striæ was north-north-west to south-south-east. That is the direction of the valley of Stanhope Burn, at the mouth of which the quarry is situated.

In the portion of Weardale that extends between Stanhope and Frosterley there are patches of Drift on both sides of the river; but at many places the limestone-series appears at the surface. Thus, in the long quarry on the side of the main road between Stanhope and Frosterley, there is very little if any Drift, and the uppermost beds of the limestone are not striated, though in places they show a little crumpling. This may, however, be due to 'creep.' At Broadwood Quarry, near Frosterley (64), on the right bank of the Wear, 40 feet of Boulder-Clay rests on the limestone. The boulders in this deposit consist of Carboniferous Limestone and sandstone, both of which occur *in situ* in the Dale. The surface of the limestone is striated, the direction being S. 80° E. (true). Mr. Barker, the manager of the quarry, informed me that when first cleared the striated surface was several acres in extent.

Between Frosterley and Wolsingham the Drift is of the same general type as that occurring higher up the Dale, but sections are not so plentiful. Opposite Harperley Station the river has cut through Boulder-Clay to a depth of 20 feet; the boulders are all such as occur *in situ* in Weardale. Below Harperley are wide 'garths,' which occur alternately on the right and left banks of the river. These 'garths' are flanked by wooded slopes of Boulder-Clay, often of considerable height.

There are no good sections of the Drift to be seen, until a point about a mile above the bridge at Witton-le-Wear is reached. Here the river has exposed a section of Boulder-Clay and gravel 60 feet thick, and is still running in Drift: this is on the left bank. The railway also cuts through the mass of Drift, but the sides of the cutting are sloped and grassed over. On the hillside above this point is a large quarry in Carboniferous sandstone and shale, and also a heading driven into the Whin Dyke which crosses the valley at this point. In neither of these sections is any Glacial material to be seen.

At Garth Ford (66), above the bridge at Witton-le-Wear, and on the right bank of the river, is a cliff of Drift consisting of 40 feet of blue Boulder-Clay, with a capping of gravel 20 feet thick. The gravels are much waterworn, the stones in the Boulder-Clay being subangular and sometimes striated. They consist of Carboniferous Limestone and Gannister, many being of very large size. I found one piece of andesite from the Borrowdale Series *in situ* in this clay.

In the bed of the Wear at Witton Bridge are boulders of basalt, Coal-Measure sandstone, Gannister, Millstone Grit, Carboniferous Limestone, and brown shale with encrinite-stems. I also found one piece of a close-grained green andesite, belonging to the Borrowdale Volcanic Series.

The following tributary valleys contain Drift consisting entirely of local material, namely:—

Right Bank: Grain Beck, Swinhope Burn, Westernhope Burn, and Bollihope Burn.

Left Bank: Middlehope Burn, Rookhope Burn, Stanhope Burn, and Wascrow Beck.

In the valley of Bedburn Beck the Drift is much more gravelly than in any of the preceding, and furthermore it is of a red colour and contains material derived from the Teesdale area. Thus, by the footbridge below Mayland Cottage (67) there is a boulder of andesite-breccia (Borrowdale Series); and close to Mayland Cottage, one consisting of pink rhyolite, which is striated.

On the road between 'Robins Castle' and Mayland Cottage are many boulders of basalt, which are also plentiful in the village of Woodlands (68).

In the village of Lynsack (950 feet) is a boulder of andesite; while on the main road 300 yards south-east of that village, and at a height of 900 feet, is a boulder of Shap Granite measuring $2 \times 2 \times 1\frac{1}{2}$ feet.

The country between Bishop Auckland and West Auckland (69) is covered with Drift; but there are few sections to show its nature. There is a large boulder of basalt in the village of West Auckland, at the corner of the road leading to Etherley. Near the bridge carrying the Etherley road over the River Gaunless is a section 30 feet deep through a mound of gravelly clay, which contains boulders of basalt, Coal-Measure sandstone, and Carboniferous Limestone. Above Spring-Bank railway-crossing the Gaunless cuts through similar Drift to a depth of 40 feet, and is still running in Drift: but nearer Etherley (70) the Drift ceases at a height of 550 feet, although there are still a few scattered boulders.

In the village of Etherley, Drift is absent, as is also the case at the cross-roads north of the village. A quarry in Coal-Measure sandstone north of the crest of the hill, and on the road between Etherley and Witton-le-Wear, shows the rock passing up into a normal subsoil, there being no Glacial Drift. Descending towards Witton-le-Wear, the Drift again appears at a height of about 400 feet above the sea.

The country to the north of Wear-Valley Junction (71) is covered by a reddish sandy Boulder-Clay, of a character quite different from that of Weardale. In a quarry near High-Nook Station (72), lying between the road and the railway, 6 feet of red Boulder-Clay rests upon Coal-Measure sandstone. The clay contains Eskdale Granite (Cumberland), Silurian grit (South of Scotland), and various Carboniferous sandstones, including Gannister and Millstone Grit. Near this quarry are several heaps of small boulders lying at the roadside, which I was informed had been picked off the neighbouring fields. They consist for the most part of Millstone Grit and Coal-Measure sandstone, but also include Silurian grit and an andesitic ash similar to those of the Borrowdale Series.

At the bridge over Abbey Burn, north of 'The Hermitage' (73), there is a section 30 feet deep, in yellowish-brown Boulder-Clay, containing the granites of Eskdale (Cumberland) and Criffel, together with a large quantity of local material. The Drift in Wascrow Beck is principally of a brown colour, and contains local material only.

(3) Glacial Striæ, etc.

The striæ in Weardale occur on the beds of limestone, and are especially plentiful in the neighbourhood of Stanhope. In all cases they are approximately parallel to the valleys in which they occur. Among others, I noted the following :—

1. Surface of the Great Limestone, at Ashe's Quarry, Stanhope (900 feet). N.N.W. to S.S.E. (63).
2. Surface of limestone, in quarry at Jack's Crag, near Stanhope (950 feet). S. 50° E. (62).
3. Surface of limestone, Broadwood Quarry, near Frosterley (550 feet). S. 80° E. (64).

[Since writing the above I have received a copy of the Transactions of the Weardale Naturalists' Field-Club, which contains an account of a striated surface at Sandy Carr, 1 mile north of Wolsingham.[1] The surface consists of a Gannister, being situated near the base of the Millstone Grit, at an altitude of 900 feet above sea-level. The direction of the striæ is given as east-north-easterly.]

(4) Boundaries of the Ice at the Period of Maximum Glaciation.

The valleys of the Wear and of its tributaries appear to have been occupied by ice of local origin, with the exception of Bedburn Beck, which at the period of maximum glaciation was occupied by a lobe of ice connected with the Teesdale Glacier.

At the head of Weardale and in the upper portions of Wellhope and Burnhope Burns the ice stood at a level of 2000 feet.

At the head of Ireshope Burn (1800 feet) the ice of Weardale seems to have been confluent with that of Langdon Beck (Teesdale), but there is no evidence that there was any flow of ice from Weardale into Teesdale or *vice versa*, the ice being apparently shed off the col in both directions.

In Swinehope Burn and Westernhope Beck, and on Snowhope Moor (74), the ice reached the 1750-foot contour-line ; and in the lower portion of the Dale, near Witton-le-Wear, the whole country appears to have been overridden.

Below Witton-le-Wear the ice of Weardale was confluent with that of Teesdale, as is shown by the boulders of Lake-District rocks ; and also with that from the Tyne Valley, as evidenced by the boulders of Scottish granite and Silurian grit in the Drift north of Tow Law. This Drift is practically continuous with that of the Derwent Valley, which I shall show in § IV to be connected with that of the Tyne Valley.

[1] 'Glacier Footprints in the Wear Valley' by W. M. Egglestone, Trans. Weardale Nat. Field-Club, vol. i (1900) pp. 78–86.

(5) Glacial Lakes and Drainage-Channels.

The valleys tributary to Weardale having been, without exception, occupied by ice, no glacial lakes were produced, and, as a result, there is a complete absence of the dry valleys so common in Teesdale. The only case in which the drainage was abnormal was at the head of Bedburn Beck, where the tributary known as Fuden Beck received the waters from the lake in the valley now occupied by Little Eggleshope Beck, on the Teesdale side of the watershed (see p. 574).

IV. The Valley of the Tyne.

(1) Topography and Structure.

The South Tyne rises on the eastern slope of the Cross-Fell range, in the neighbourhood of Yad Moss. This is practically in the drainage of the Tees, the watershed being flat and composed of Drift and peat, and the South Tyne being actually connected with the Tees by channels of sluggish water in wet seasons.

The South Tyne flows northward down Alstondale, receiving important tributaries on both banks from the northern portion of the Cross-Fell range on the west and from Alston Common (75) on the east. It continues to flow northward, until it reaches the line of faulting which cuts off the northern end of the chain, and then turns abruptly eastward, in which direction it continues to flow to its junction with the North Tyne, $2\frac{1}{2}$ miles north-west of Hexham.

Near the bend a small tributary, Tipalt Burn, comes in on the left bank. This rises about 6 miles to the north-west of Haltwhistle, and for the first part of its course flows in a south-westerly direction towards Gilsland; it then turns down the broad valley which carries the Newcastle & Carlisle Railway, and flows south-eastward to join the South Tyne about $1\frac{1}{2}$ miles above Haltwhistle.

Between Haltwhistle and Hexham the River Allen, formed by the junction of the East Allen and West Allen, joins the Tyne on the right bank.

The North Tyne rises in the Cheviot Hills near Deadwater, and flows in a general south-easterly direction to its junction with the South Tyne near Hexham. The main river, formed by the junction of the North Tyne and South Tyne, then flows in a general easterly direction to the sea at Tynemouth. About 3 miles below Hexham the Devil's Water comes in on the right bank, and the River Derwent joins the main stream on the same bank 3 miles above Newcastle.

The drainage-system of the Tyne is entirely excavated in the rocks of the Carboniferous System, which are penetrated in places by the Great Whin Sill. The watershed between the basins of the North and the South Tyne corresponds approximately with the line of the Roman Wall, and is formed by the outcrop of the Great Whin Sill. The North Tyne cuts through this outcrop in the neighbourhood of Barrasford.

The Great Whin Sill also crops out at the head of Alstondale, and at numerous points on the northern and eastern slopes of the Cross-Fell range. The Carboniferous Limestone and Yoredale Series cover most of the ground, but there are important outcrops of Millstone Grit capping the hills between Alstondale and West Allendale and Devil's Water, and between the latter stream and the River Derwent. Several small faulted outliers of Coal-Measures occur in the valley of the South Tyne, between Haltwhistle and Hexham; while for the last 20 miles of its course, the River Tyne flows over the rocks of the Northumberland coalfield.

(2) The Glacial Deposits.

The valley of the South Tyne above the town of Alston contains considerable quantities of bluish Boulder-Clay, with scratched boulders consisting of the Carboniferous rocks of the Dale, together with a few boulders of Whin Sill. The Drift is of a similar nature in the tributary valleys, and also in the lower part of the main valley from Alston down to Lambley.

The valley of the Nent, an important tributary which joins the South Tyne on its right bank at Alston, contains Boulder-Clay with local boulders, many of which are striated.

Below Lambley the Drift assumes a reddish colour, and becomes more gravelly in texture. It is also much more widely distributed, being continuous with that of the Vale of Eden. In the neighbourhood of Harperstown I found several pebbles of the granite of Eskdale in Cumberland; also several boulders of Borrowdale andesite, together with large quantities of Carboniferous Limestone and shale and Whin-Sill dolerite. Between Featherstone Castle and Bellister Castle the Drift contains the full suite of rocks characteristic of the Drift beyond the Pennine watershed round Carlisle and Brampton, together with Whin Sill. On the hill behind Bellister Castle (600 feet) the Drift contains a similar assortment of rocks. Seeing that this Drift is similar to that of the Brampton district in the Valley of the Irthing (of which I had made a hasty examination), I determined to visit that locality again, in order to investigate the matter more fully.

The country between How Mill and Brampton Junction is covered with Glacial gravels arranged in mounds. Near Brampton Junction (400 feet) the gravel is reddish in colour, and contains pebbles of Borrowdale volcanics and large quantities of Triassic or Permian sandstone. Between Brampton Junction and Talkin' Tarn is a large hollow lying between the gravel-hills, and containing a considerable quantity of peat, 4 feet of this deposit being exposed in a cutting. This points to the presence of beds of clay below the gravel. Talkin' Tarn lies in a similar hollow, and apparently has a gravelly bottom. The overflow of the tarn is by a small stream at the southern end at a height of 400 feet.

North of Brampton Junction are numerous Drift-mounds, which have their longer axes approximately parallel and running south 30° east.

The country to the north-west of Brampton is flat, the hills of Drift only occurring near the Pennine Chain. I found large boulders of the following rocks between the Station and the town at Brampton, namely:—Dalbeattie Granite, Borrowdale volcanics (several varieties), Penrith Sandstone, Coal-Measure sandstone, andesitic breccia of the Yewdale type, and Silurian grit.

There is a cutting near 'Westwood' Brampton, which exhibits the following section:—Red sandy material, current-bedded towards the south, and also much contorted and in places faulted. The sand is extremely fine, and contains some coherent beds a quarter of an inch thick. Below the sand is a red gravel, with pebbles of Borrowdale volcanics and fragments of shells. The shell-fragments are so small and friable, that I found it impossible to determine the genera. This portion of Brampton is called Sands.

In the town of Brampton itself are many large boulders of andesite used as corner-stones.

In Gelt Woods, near Brampton, are quarries in Triassic sandstone. Immediately above this sandstone is a bed of fine red sand, between 2 and 3 feet thick, and evidently derived from the underlying rock. Above this is a bed of red gravel containing pebbles of Borrowdale volcanics, Triassic sandstone, Buttermere granophyre, and Criffel Granite.

I was unable to find any basalt of the Great Whin Sill in the Drift of the Brampton district.

Following up the Valley of the Irthing, I noticed that the Drift became more clayey on the flanks of the valley, retaining, however, its gravelly character in the valley-bottom. At Upper Denton, near Gilsland, there is a moraine lying across the river-valley and considerably deflecting the stream. This moraine has its concave side up-stream, and points to a late movement of ice down the Irthing Valley. There are enormous masses of reddish gravelly clay in the neighbourhood of Gilsland. They are disposed in morainic hills, many of which are cut through by the river.

In and about the village of Gilsland, and between the village and the Hydropathic establishment, are many large boulders of Criffel, Dalbeattie, and Eskdale Granite, Whin-Sill dolerite, Borrowdale andesite and andesitic breccia, and Carboniferous sandstone and Limestone; Silurian grits, though less common, are well represented.

Similar Drift, containing the same assemblage of rocks, occurs in large quantities in the valley of Tipalt Burn, which connects the Valley of the Irthing with that of the Tyne; and between the point where this burn joins the Tyne and the town of Haltwhistle a fine section of Drift is exposed on the left bank of the Tyne. The upper portion of the section consists of gravel, which is comparatively fine above, but near its base consists of boulders up to 3 feet in length. This gravel rests unconformably upon a mass of contorted red Boulder-Clay, which contains tongues and shreds of fine sand and gravel. I collected the following rocks from this section, the gravel and Boulder-Clay being similar as regards their contents, with the exception that local rocks predominate to a greater extent in the gravel; many of the boulders, both local and foreign, were well striated:—Carboniferous Limestone and sandstone, Millstone Grit, Borrowdale volcanics (several well-marked types, including the Yewdale breccia and the hypersthene-dolerite of Eycott Hill), New Red Sandstone, Dalbeattie Granite, Criffel Granite, Eskdale Granite, and Buttermere granophyre.

Between Haltwhistle and Bardon Mill there is much gravelly Boulder-Clay of a prevalent red tint, with patches of gravel here and there. The same characters obtain in the portion of the main valley from Bardon Mill by Haydon Bridge and Fourstones, to the junction of the North and South Tyne at Warden.

North of the main valley similar Drift covers a great part of the country up to the outcrop of the Great Whin Sill; and to the north of this line the contents of the Drift gradually change, until the valley of the South Tyne is reached. The Borrowdale volcanics and the other Lake-District rocks are the first to disappear, and to the north of Houxby Burn they are entirely absent; but boulders of Silurian grit, Dalbeattie Granite, and New Red Sandstone are present in large numbers in the bed of that burn, close to its junction with the North Tyne.

North of Bellingham the valley of the North Tyne contains large quantities of bluish Boulder-Clay, less gravelly than that of the South Tyne and containing boulders derived from the local Carboniferous rocks, with a few consisting of Silurian grit.

The country between Bellingham and the Cheviots is covered with similar material, with a few local patches of gravel, except a few of the most prominent ridges, which are swept clear of Drift and exhibit glacial striations. Whin-Sill dolerite, though absent from the Drift of the upper part of the valley, becomes a conspicuous element immediately to the south of the outcrop of that rock at Barrasford.

I observed several small boulders of Borrowdale andesite in a little stream near Walwick Grange (79) on the right bank of the North Tyne, about a mile south of the Roman Wall, but none to the north of that place. From Walwick Grange southward, Lake-District rocks become increasingly numerous, until the South Tyne is reached.

The Drift of the left bank of the North Tyne appears to be entirely free from Lake-District rocks as far south as the village of Acomb (80).

Returning now to the right bank of the South Tyne, we shall note that the Valleys of the East and West Allen and of Devil's Water are encumbered with Drift of a character distinct from any of that described as occurring in the main valley. In each of these valleys are enormous masses of stratified gravels, sands, and clays, disposed in plateaux which are deeply trenched by the streams.

The section at Wooley Park, half-a-mile south of Allendale Town, is typical of the class of Drift occurring in these valleys. It consists of stratified sands, gravels, and buttery clays. The materials are for the most part derived from the Carboniferous rocks, but include pebbles of Lake-District and Scottish rocks. The pebbles are water-worn, and exhibit no signs of glaciation.

Near Sinderhope Post-office (81), 3 miles south of Allendale Town, the Drift rises to a height of 1000 feet. It is roughly stratified, reddish-brown, and contains Carboniferous sandstone and shale, with a few pebbles of andesite and Silurian grit.

Three quarters of a mile east of High Studdon (82), at the upper end of a large valley which cuts through the watershed into the Valley of Devil's Water, there is a patch of buttery blue stratified clay containing fragments of Millstone Grit and Coal-Measure sandstone. This is at a height of 1100 feet. Another class of deposit is found in parts of these valleys, namely, a well-washed gravel consisting of pebbles similar to those found in the stratified Drift. These gravels are arranged in fans or deltas at the lower end of several of the larger valleys described in sub-section 5, p. 602.

In the Valley of the Derwent there is no Drift above Blanchland; but about a mile to the eastward much gravelly material is found, containing Lake-District and Scottish rocks with an abundance of local material.

Thus, in the valley of Acton Burn a large deposit of gravel and Boulder-Clay occurs, both above and below the point where the road crosses the burn. Millstone Grit, Coal-Measure sandstone, Borrowdale volcanics, Carboniferous Limestone, dolerite (Whin Sill), and Silurian grit are plentiful in this deposit. A few of the pebbles of Silurian grit are striated. The deposit forms a thick mantle over the country for a considerable distance.

The Drift of the main valley of the Tyne below the junction of the two branches is more gravelly than is the case higher up. The following sections at Hexham will serve to illustrate its nature:—In the gravel-pit at Bridge End, Hexham (left bank), is a section of coarse gravel 10 feet deep, base not exposed, containing boulders of Carboniferous sandstone, Carboniferous Limestone, Millstone Grit, New Red Sandstone; Borrowdale volcanics (several types); granites of Criffel, Dalbeattie, and Eskdale (Cumberland); Silurian grit (two varieties); Buttermere granophyre; Whin-Sill dolerite, and Brockram.

The sand-and-gravel pit at the northern end of the Seal at Hexham is excavated in a mound of Drift. The section is between 40 and 50 feet deep, and consists at the top of coarse gravel, which is succeeded by beds of contorted gravel finer in texture, and this rests unconformably upon horizontally-bedded sands with current-bedding, and a few thin beds of buttery red clay. Below the gravel, and exposed in a small cutting giving entrance to the pit, is a bed of sandy Boulder-Clay, which is the lowest bed exposed. The gravel contains Carboniferous sandstone, Millstone Grit, and Borrowdale volcanics.

South-east of Hexham, the country between the Tyne and the Derwent is thickly covered with Boulder-Clay, up to a height of about 850 feet, except at the mouths of several of the abnormal valleys to be mentioned later (p. 602), where there are large spreads of gravel. This Drift contains all the erratics that have been recorded as being found in the valley of the South Tyne, between Haltwhistle and Hexham.

Notable spreads of gravel occur round Riding Mill (north of Dipton Burn), between Stocksfield Station (N. & C.R.) and Hindley near Ebchester (Derwent Valley), the mouth of a valley cutting through the watershed to the west, and at Edmondbyers and Muggleswick, higher up the Derwent.

(3) Glacial Striæ, etc.

The Glacial striæ in this area are apparently confined to the valley of the North Tyne, where there is a series of outcrops of hard limestone and basalt lying athwart the direction of the ice-flow. The following are those which I observed; they are nearly all marked on the 1-inch maps of the Geological Survey :—

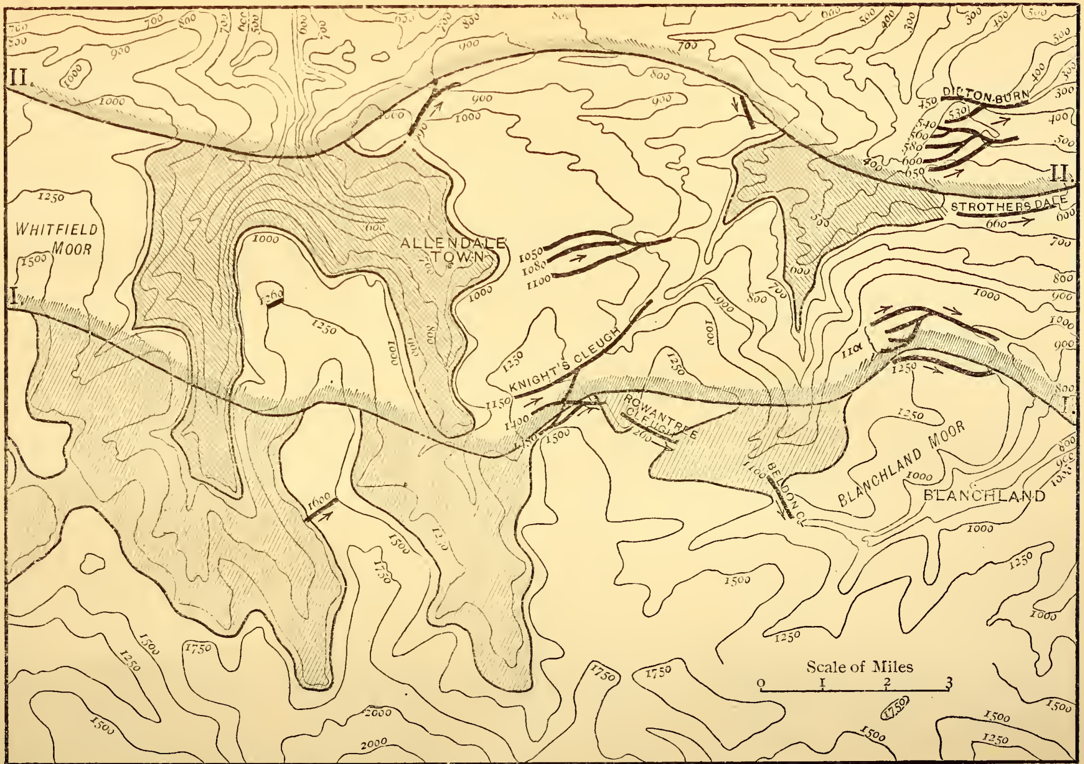
Right Bank of the North Tyne.

1. Surface of limestone, Birks Moor, on the right bank of the North Tyne, S. 52° E. (650 feet). (83.)
2. Surface of limestone, at Whitchester, 4 miles west of Bellingham, S. 54° E. (500 feet). (84.)
3. Surface of sandstone, at Old Man's Shield, $3\frac{1}{2}$ miles west of Bellingham, S. 71° E. (500 feet). (85.)
4. Surface of sandstone, at Mortley, 2 miles west of Wark, S. 53° E. (600 feet). (86.)

Left Bank of the North Tyne.

5. Surface of sandstone, three quarters of a mile north of Field Head, 3 miles north-west of Bellingham, S. 54° E. (850 feet). (87.)
6. Surface of sandstone, at Close Hill near last, S. 51° E. (650 feet). (88.)
7. Surface of sandstone, at Charlton near last, S. 65° E. (500 feet). (89.)
8. Surface of sandstone, between Charlton and Long Haugh Shield, S. 72° E. (550 feet). (90.)
9. Surface of sandstone, a quarter of a mile west of last, S. 80° E. (850 feet).
10. Surface of sandstone, on Callahues Crag, $2\frac{1}{2}$ miles north of Bellingham, S. 67° E. (1100 feet). (91.)
11. Surface of sandstone, at Hightown, 1 mile north of Bellingham, S. 67° E. (800 feet). (92.)
12. Surface of coarse grit, on Aid Moss near Redesdale, 5 miles west of Bellingham, N. 82° E. (1000 feet). (93.)
13. Another surface, a quarter of a mile south-east of last, N. 78° E. (1050 feet).
14. Surface of sandstone, 1 mile north of Birtley, S. 69° E. (750 feet).
15. Surface of sandstone, near Folly-Moss Reservoir, 3 miles west of Birtley, S. 80° E. (700 feet). (95.)

Fig. 7.—*Glacial lakes of Allendale and Devil's Water.*



Edge of the Ice **I.** Maximum Glaciation. **II.** A Period during Retreat.
Heavy black lines, with arrows, represent overflow-channels.

Group of striated surfaces along the line of the Whin-Sill escarpment, north of Chollerton.

16. Surface of dolerite, near Colwell, S. 80° E. (550 feet).
17. Surface of sandstone, near Swineburn Castle, S. 26° E. (450 feet).
18. Surface of sandstone, on Barrasford Common, S. 50° E. (400 feet).
19. Surface of limestone, half a mile east of Gunnerton, S. 20° E. (500 feet).

Group of striated surfaces on the line of the escarpment of the Great and Little Limestone, line of the Roman Wall, east of the North Tyne (96).

20. Surface of sandstone, near Wall, S. 14° E. (500 feet).
21. Surface of basalt-dyke, at Crag House, S. 25° E. (600 feet).
22. Surface of sandstone, near Fallowfield, S. 30° E. (650 feet).
23. Another surface of sandstone, S. 58° E. (650 feet).
24. Surface of sandstone, 1 mile north-east of Acomb, S. 52° E. (700 feet).

(4) Boundaries of the Ice at the Period of Maximum Glaciation.

I have mentioned (p. 582) that the ice formed on the eastern slopes of Cross Fell sent an arm down the valley of the South Tyne towards Alston. This forms the commencement of the glacier-system of the South Tyne, and at the period of maximum glaciation it filled the valley up to a height of 1800 feet above sea-level.

In the neighbourhood of Lambley, the glacier of Alstondale became confluent with a lobe of ice which came from the Irish-Sea Basin over the northern end of the Pennine Chain and through the valley of the Irthing, and extended in a northerly direction up to the Scottish Border. This great stream of ice then moved eastward down the valley of the South Tyne, and across the wild stretch of undulating moorland to the north of the Roman Wall, until it reached the valley of the North Tyne, deflecting to the eastward the glacier which came down that stream, as is shown by the direction of the striæ on the left bank of the river and in the neighbourhood of Redesdale. The effects of this thrust have been traced up to the south-eastern slopes of the porphyrite-hills of the Cheviots.[1]

The northern boundary of this great glacier cannot be traced, as it seems to have been confluent with ice flowing in a general south-easterly direction round the flanks of the Cheviot massif. From the general absence of boulders of Lake-District rocks east of the North Tyne, I should infer that the ice which passed eastward over Redesdale was that proper to the North Tyne, the boundary of the western ice lying approximately on an east-and-west line drawn through Chollerton.

The southern limit, on the contrary, can be traced with great accuracy by the series of lakes and overflow-channels which were produced along that line. The boundary, at the maximum extension of the ice, passed across the northern end of Whitfield Moor (97),

[1] P. F. Kendall & H. B. Muff, Geol. Mag. 1901, p. 513; Rep. Brit. Assoc. 1901 (Glasgow) p. ≈46.

across West Allendale, across the spur between the West and East Allen, at a height of 1600 feet, across East Allendale above Allendale Town, across Harwood Side (98) at 1450 feet, over Lilswood Moor (99) at 1400 feet, across the Valley of Devil's Water over Blanchland Moor (100) at 1300 feet, and so into the Valley of the Derwent. Continuing the line farther south-eastward, we find it skirting the Millstone-Grit fells by Edmondbyers Common and Muggleswick Park (about 1200 feet), and finally passing over Whitehall Moss (101) into the Valley of the Wear, at 1100 feet above sea-level.

(5) Glacial Lakes and Drainage-Channels.

The ice of Alstondale produced several small lakes in the tributary valleys by closing their lower ends. The highest of these was in the valley of Garrygill Burn (102), on the right bank. The water of Garrygill Lake stood at the level of 1800 feet, and was drained by a channel (now dry) over Black Moor into the Valley of the Nent.

Below Alston, on the same bank, were two lakes in the valleys of Ayle Burn (103) and Barhaugh Burn (104) respectively. Barhaugh Lake stood at a level of 1575 feet, and overflowed by a channel over Willyshaw Rigg into Ayle Lake (1500 feet), which in its turn drained over the col at the head of Ayle Burn into West Allendale. This must have taken place *after the period of maximum glaciation*, when the waters of the lake in West Allendale, which will subsequently be shown to have stood at 1600 feet at that period, had subsided somewhat.

The most important system of lakes and channels, however, is that produced along the southern border of the South-Tyne Glacier at the period of maximum glaciation, and by means of it I have been able to trace the level of the margin of the ice at that period (fig. 7, p. 600).

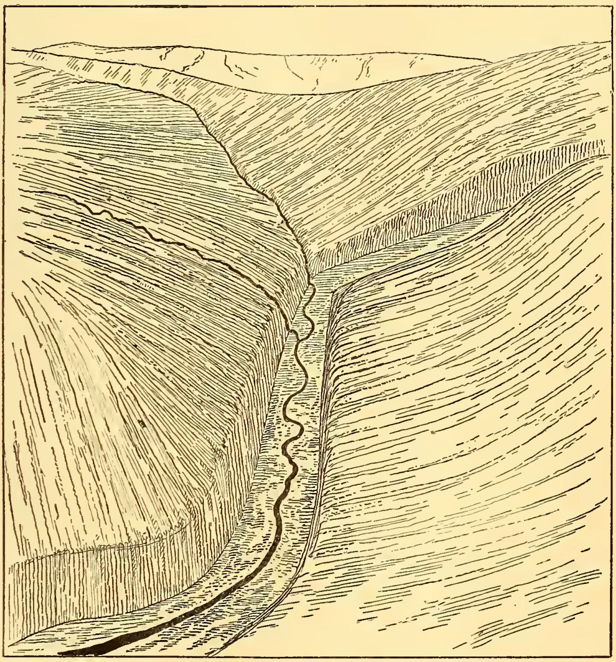
The uppermost of this series was at the head of West Allendale. The water stood at a level of 1600 feet, and drained by a channel at that level over Kevelin Moor (106) into a similar lake occupying the valley of the East Allen.

The lake in East Allendale stood at a level of 1450 feet, and overflowed by a channel at that elevation over the ridge to the east into a small lake occupying the upper part of the valley of Linn Burn, a tributary of Devil's Water. This was continuous with a larger lake occupying the upper part of the Devil's-Water valley, and its overflow cut the deep notch known as *Rowantree Cleugh* (the highest point of which is at 1260 feet) at a somewhat later period, when the water of the latter lake had fallen in level owing to the cutting-down of its overflow, Beldon Cleugh.

The lake in the Devil's-Water valley stood at a level of 1250 feet at first, but fell during the period of maximum glaciation to about 1100 feet, by the cutting-down of its overflow-channel over Bulbeck Common by way of Beldon Cleugh. This channel is 150 feet deep, it has a flat bottom 100 yards in width, and is now quite dry. The watershed, which is at the northern end of the valley, is now at 1100 feet. The stream which occupied this huge channel flowed into the valley of Beldon Burn, a tributary of the Derwent.

Above its junction with the overflow the valley of Beldon Burn is a normal V-shaped river-valley, but immediately below the junction it widens out into a broad gorge with almost vertical sides, and a flat bottom on which the existing stream swings to and fro in a series of windings. All the small tributary streams which enter the burn below the junction of the overflow-valley, do so by a series of waterfalls, showing that this part of the valley was excavated by the overflow of the Allen and Devil's Water lakes, the present stream being an obvious misfit. (See fig. 8.)

Fig. 8.—*Diagrammatic view of the Beldon-Burn valley.*

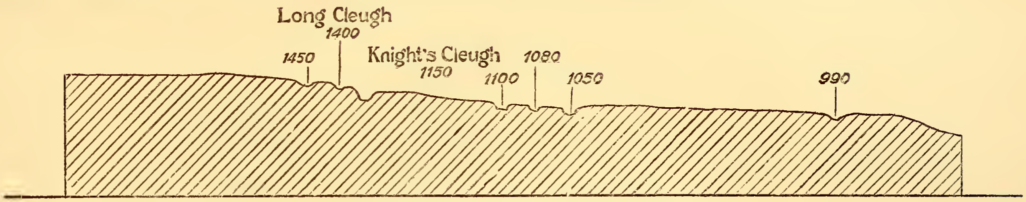


The water was again impounded by the margin of the ice crossing the Derwent Valley below Blanchland, forming a lake in that valley. Thence it overflowed by a channel over Edmondbyers Common (1100 feet) into Burnhope Burn, the valley of which formed another of this chain of lakes. This, in its turn, drained over the Fell above Muggleswick Park at Lamb Shields (1100 feet), forming yet another lake which occupied the upper portions of the

Fig. 9 *a.—Section parallel to the southern edge of the South-Tyne Glacier.*

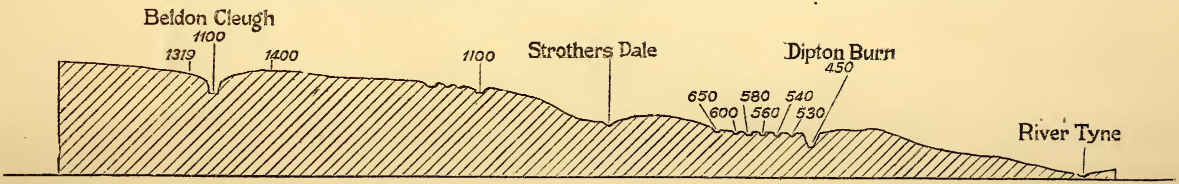
[Horizontal scale : 8 miles=1 inch. Vertical scales are 4 times the horizontal.]

Fig. 9 *b.—Section along the watershed between the East Allen and Devil's Water.*



[Horizontal scale : 4 miles=1 inch.]

Fig. 9 *c.—Section along the watershed south and east of the Devil's-Water valley.*



[Horizontal scale: 4 miles=1 inch.]

valleys of Hisehope Burn and Horsleyhope Burn. The waters of Horsleyhope Lake stood at 1020 feet, and drained over the Derwent-Wear watershed at Lindisfarne, 1½ miles east of Waskerley, and so into the drainage-basin of the River Wear.

There are large fans of gravel, in some cases forming well-marked deltas, at the lower ends of all the overflow-valleys above mentioned.

The relation of this series of lakes to each other will be readily seen by reference to fig. 9 *a*, p. 604, which is a section across the country approximately parallel to the margin of the glacier. As the South-Tyne Glacier dwindled, and the edge of the ice retreated northward, lower and lower outlets were successively opened for the waters of these lakes. The level of the water consequently fell step by step, until the normal channels of the rivers were once more exposed and the lakes completely drained (fig. 7, p. 600). Thus on the spur between West Allendale and East Allendale there is a dry gorge at 1260 feet. On the ice retreating from the 1250-foot line of this spur, the lakes of East and West Allen would become continuous.

In the case of the ridge between East Allendale and Devil's Water there is a large series of such channels, as follows (fig. 9 *b*):—at maximum glaciation, 1450 feet, then 1400, then Knight's Cleugh 1150 feet; then 2 miles farther north a series of 1100 feet, 1080 feet, 1050 feet; and finally one at 990 feet, 1 mile north of Catton.

There is a still larger series on the high ground forming the watershed to the east of Devil's Water, at the following elevations: 1200 feet, 1100 feet (several), 660 feet, (Strothersdale) 650 feet, 600 feet, 580 feet, 560 feet, 540 feet, 530 feet; and finally an enormous gorge now almost dry, known as Dipton Burn, at 450 feet. (See fig. 9 *c*, p. 604.)

These valleys are for the most part small, and would not appear to have carried the drainage of the lakes for any lengthened period. There are, however, some notable exceptions, as, for instance, Knight's Cleugh, East Allendale to Devil's Water, Strothersdale, and Dipton Burn.

Farther eastward the country is intersected by numerous valleys of a type similar to those already described, but here the problem is complicated no doubt by the action of a glacier moving southward from the Cheviots after the period of maximum glaciation, and by the presence of the Scandinavian ice-sheet on the coast. I therefore prefer to leave this portion of the district for the present, and to collect further details before venturing upon any explanation of its abnormal valleys.

Before leaving the subject, however, mention must be made of a very large valley which cuts through the Derwent-Wear watershed, half-a-mile south of Consett Station. This is at a height of about 700 feet, and connects the valley of the Derwent with that of the Browney, a tributary of the Wear.

(6) Phenomena during the Period of Retreat.

As the ice dwindled in the valley of the South Tyne, a marked effect was produced upon the series of lakes along its southern margin. This I have already described under the heading of Glacial Lakes (p. 602). At the same time, the diminished supply of ice from the Solway area allowed the North-Tyne Glacier to resume its normal south-easterly course.

V. General Conclusions.

(i) Upper Teesdale was heavily glaciated by ice formed in the upper parts of the Dale, and on the eastern slope of the Cross-Fell range.

(ii) This part of the Dale was never invaded by ice from the Irish-Sea area.

(iii) At no time during the Glacial Period was this district completely buried by ice, but the higher peaks stood out as 'nunatakkr' from the surrounding glaciers.

(iv) At the period of maximum glaciation a number of lakes were formed, owing to the obstruction of the drainage of lateral tributary-valleys by the ice of the main glaciers.

(v) Lunedale was occupied by ice which came over from the drainage-basin of the Irish Sea. In the neighbourhood of Middleton-in-Teesdale this stream of ice became confluent with the Teesdale Glacier, and then the joint stream flowed on towards Barnard Castle.

(vi) The ice of Teesdale was deflected by the thrust of the Stainmoor Glacier and caused to flow over into the valley of the Wear, where it became confluent with the Weardale Glacier in the neighbourhood of Wear-Valley Junction.

(vii) During the period of retreat of the ice there was a long interval, in the course of which it remained at a constant level, producing well-marked drainage-channels.

(viii) After this interval of constant level the ice was removed from the country with great rapidity.

(ix) A tongue of ice flowed from Upper Teesdale, by way of Yad Moss, into the valley of the South Tyne.

(x) Weardale and its tributary valleys above Witton-le-Wear were heavily glaciated by ice formed within the drainage-basin of the Wear, but this part of the Dale was never invaded by ice from outside.

(xi) The ice which passed over from the head of Teesdale into the Valley of the South Tyne, there formed a glacier which stood at a level of about 1800 feet to the south of the village of Alston, and was joined at that place by a glacier which flowed westward down the Valley of the Nent.

(xii) A large glacier flowed across the northern end of the Pennine Chain in an easterly direction, becoming confluent with that of Alstondale in the neighbourhood of Lambley. This glacier was continuous in a northerly direction with the ice of the Southern Uplands of Scotland and the North-Tyne Glacier, and when at its maximum deflected the latter glacier to the north-eastward, causing a movement in that direction along the southern flanks of the Cheviot Range. It would not appear, however, that the Solway ice ever crossed the North Tyne above the Roman Wall.

(xiii) At the commencement and also at the end of the glaciation the Valley of the North Tyne was occupied by a glacier flowing in a general south-easterly direction, but, as already stated, this was deflected to the north-east by the eastward-flowing stream from the Solway district at the period of maximum glaciation.

(xiv) The southern margin of the South-Tyne Glacier passed across the heads of West and East Allendales, and Devil's Water, and over Blanchland Common into the valley of the Derwent, thence by way of Edmondbyers, Muggleswick, and Horsleyhope into the Valley of the Browney, a tributary of the Wear, where it joined the northern boundary of the Weardale Glacier.

(xv) A series of ice-dammed lakes, with a corresponding series of overflow-channels, many of which are now streamless, was produced along this margin.

The western face of the Pennine Chain still remains to be worked out, and much more field-work will be necessary before the complicated Glacial phenomena of the Northumberland and Durham Coalfield and the Carboniferous uplands between this and the Cheviots can be fully elucidated.

In conclusion I should like to thank Mr. Percy F. Kendall for the information which he kindly gave me with regard to the Glacial lakes of Cleveland, and the principles which he had drawn from his recent work in that area, for without this information I should have been unable to work out many of the complicated phenomena of the district described in this paper.

EXPLANATION OF PLATES XXIX & XXX.

Plate XXIX.

Map of the glaciers and glacier-dammed lakes in the Teesdale, Weardale, and Tynedale areas, on the scale of about 5 miles to the inch.

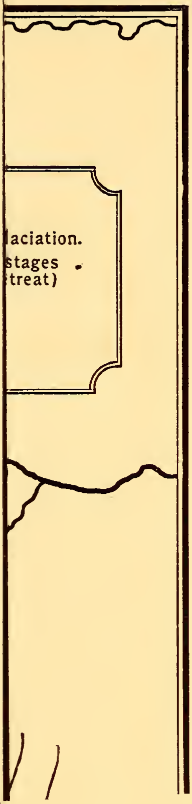
Plate XXX.

Map illustrating the glaciation of Teesdale, Weardale, and the Tyne Basin, on the scale of about 6 miles to the inch.

Discussion.

Mr. P. F. Kendall offered his warm congratulations to the Author upon a very valuable piece of work, in a district presenting unusual difficulties. The high, bleak, inhospitable moorlands were exceedingly hard of access, and superadded to these natural obstacles was the imperfection of the Ordnance map, as the 6-inch sheets were contoured only at 100-foot intervals, and even this failed above an elevation of 1000 feet. The Author had to discover all the overflow-channels of his district by laborious expeditions along every watershed, whereas in the case of the Cleveland area, he (the speaker) had been able to trace almost every dry valley by the beautiful contoured maps which they possessed in Yorkshire, before studying them in the field. He had some years ago worked over much of the region described, but had been unable to obtain any clear or connected ideas of the relation of the Glacial phenomena. Now, the Author's researches had, he thought, quite satisfactorily explained them.

The Author, in his reply, thanked Mr. Kendall for the information which he had kindly supplied regarding his work in the Cleveland Hills while that work was still in progress, without which the Author would have been unable to solve many of the problems in the area described.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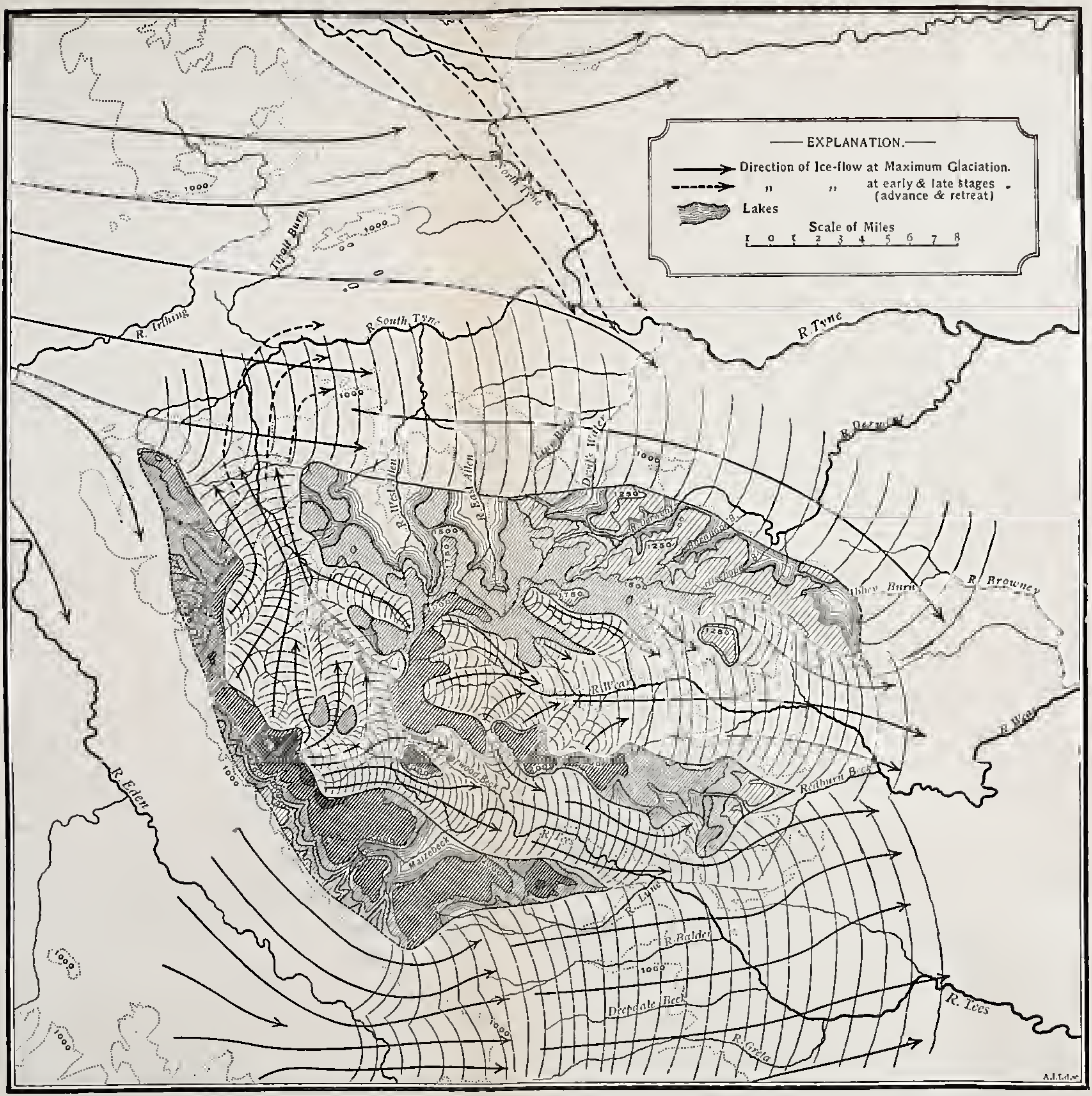
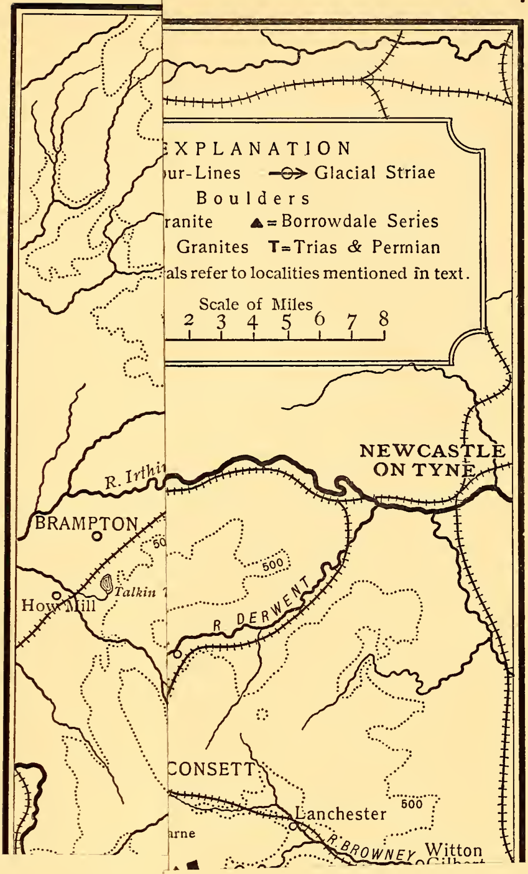


MAP OF THE GLACIERS AND GLACIER-DAMMED LAKES IN THE TEESDALE, WEARDALE, AND TYNEDALE AREAS.

[The shaded areas, darkening in proportion to height, represent the 'nunatakkr' which then projected above the ice.]


EXPLANATION
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Glacial Striae
Boulders
ranite
▲= Borrowdale Series
Granites
T=Trias & Permian
als refer to localities mentioned in text.
Scale of Miles
2 3 4 5 6 7 8
NEWCASTLE
ON TYNE
R. Irthi
BRAMPTON
500
Talkin
How Mill
R DERWENT
CONSETT
Lanchester
500
rne
R. BROWNEY
Witton

MAP ILLUSTRATING THE GLACIATION OF TEESDALE, WEARDALE, AND THE TYNE BASIN.

31. OVERTHRUSTS *and other* DISTURBANCES *in the* BRAYSDOWN COLLIERY; *and the* BEARING *of these* PHENOMENA *upon the* EFFECTS *of* OVERTHRUST-FAULTS *in the* SOMERSET COALFIELD *in general.* By FREDERICK ANTHONY STEART, Esq. (Communicated by H. B. WOODWARD, Esq., F.R.S., F.G.S. Read May 14th, 1902.)

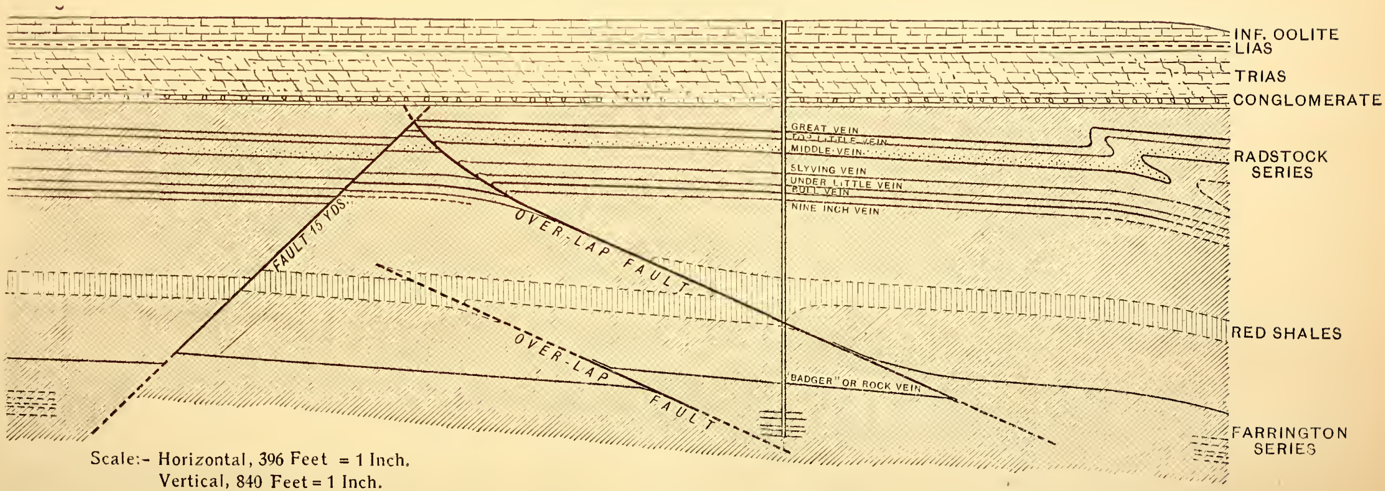
THE Somerset Coalfield is a remarkable one in many respects. Unlike most of the larger coalfields of this country, by far the greater part is concealed by Secondary rocks, consisting of Oolites, Lias, and Trias, which lie almost horizontally upon the disturbed Coal-Measures beneath. Faults in these newer rocks are comparatively few and small. The Coal-Measures, however, present a marked contrast in this respect—for this coalfield is in part the most disturbed and contorted of those known and worked in the United Kingdom. Its area covers about 240 square miles, and it is presumably an isolated basin, bounded on all sides by anticlines of older rocks. On the north, in the Coal-Measures at Kingswood, near Bristol, there is an anticline and overlap-fault, which separates the Somerset Coalfield on the south from the Bristol or Gloucestershire Coalfield on the north, on the borders of which the margin of older rocks is clearly defined. On the south and south-west the great Mendip anticline separates it possibly from a similar coalfield, concealed beneath the thicker Secondary rocks on the farther side of the Mendip Hills; and on the east, the anticline which passes from the far north near Cromhall, in Gloucestershire, through or near Yate, probably continues slightly to the west of Bath and thence to Frome on the south.

The object of this paper is an attempt to describe the overfaults and related phenomena in a single colliery, namely that of Braysdown, near Radstock, and to show how the conclusions that may be drawn from them account for some of the remarkable disturbances which have been locally met with elsewhere.

In the first instance, it may be useful to recall attention to some of the more important phenomena of this nature that have already been observed in other parts of the Somerset Coalfield.

The faults in the Somerset Coal-Measures range from a few inches up to 200 yards in downthrow. In some of the collieries they are so close together, that it is rare to see a face of coal 200 yards in extent without a fault or some other disturbance. There are ordinary faults, step-faults, trough-faults, and—in many collieries—overlap-faults. Moreover, the strata in places are inclined at all angles. As pointed out long ago by Buckland & Conybeare, in the neighbourhood of the Nettlebridge Valley, to the north of the Mendips, the mass of the Lower Coal-Measures is entirely inverted; for, instead of rising to the south in conformity with the Mendips, the beds dip southward and rise towards the north.

Fig. 1.—*Overthrusts at Braysdown Colliery (Somerset).*



The strata moreover are disturbed and contorted to such an extent, that some of the coal-seams are so folded that a vertical shaft may pass through the same seam two or three times in succession.[1] Thus at different collieries, what should be the roof of the seam has now become the floor.

In the Radstock Series of the Upper Coal-Measures, distant nearly 4 miles from the Mendips, there occurs a huge overlap-fault, which has not yet been proved in the Middle or Farrington seams, as they have not been worked to the same extent. The effect of this fault, as proved in the Upper seams, has been to thrust them bodily forward one over the other in a remarkable manner, and for a great distance. The first seam, or Great Vein, overlaps 140 yards. The amount of overlap increases in each successive seam, in descending order, until, when the sixth, or Bull Vein, is reached about 80 yards below, it amounts to 360 yards.[2] The vertical displacement or uplift also increases in each seam in descending order, being to the north and amounting to about 70 yards in the case of the Bull Vein. The strike of this overthrust seems to coincide with the long axis of the inversion on the north side of the Mendips. This being the case, these two disturbances would appear to be in some way connected, and to owe their origin to the same lateral pressure. But, whatever the origin of this pressure (as to which question there are different opinions[3]), it is probable that the cause of the formation of the Radstock overlap-fault also gave rise to a series of other smaller and parallel overthrusts on the north side of it.

Two of these minor overthrusts have been met with at Braysdown Colliery, situated about 1½ miles north-east of Radstock (see fig. 1, p. 610). These have been proved to run parallel one with the other and with the larger Radstock overthrust to the south, that is, nearly due east and west. The notable fact about these smaller overthrusts is that they exhibit the same features as the Radstock one, only on a smaller scale. In the case of the overthrust on the north side of Braysdown Colliery, the amount of overlap increases from about 10 or 12 yards on the first, or Great Vein, to about 80 yards on the sixth, or Bull Vein; the vertical upthrow also increases in each seam in descending order, from 12 yards in the Great Vein to about 30 yards in the Bull Vein.

The overthrust on the south side of the pit is somewhat similar to that on the north side, but the vertical lifts and overthrusts are greater. A peculiar feature here, however, which has been proved by actual working in some cases, is, that although the strata seem to have been subjected to a severer lateral pressure than in the case of the fault on the north side of the pit, the coal-seams have not

[1] Trans. Geol. Soc. ser. 2, vol. i (1824) pp. 255–56.

[2] G. C. Greenwell & J. McMurtrie, 'The Radstock Portion of the Somersetshire Coalfield' 1864, p. 17.

[3] See J. McMurtrie, *op. cit.* and Proc. Bath Nat. Hist. Club, vol. iii (1877) p. 287; H. B. Woodward, Mem. Geol. Surv. 'Geol. East Somerset & Bristol Coalfields' 1876, pp. 190, etc., and Proc. Geol. Assoc. vol. xi (1890) p. 485; W. A. E. Ussher, Proc. Somerset Arch. Soc. vol. xxxvi (1890) p. 88.

been entirely shorn off: as, for example, in the case of the Middle Vein (see fig. 1, p. 610). When the workings reached the commencement of the overthrust, it was found that the coal-seam dipped slightly towards it; and after continuing for some distance to dip in this manner, it began to thicken from an average of 2 feet to 6 or 8 feet. It then began to rise rapidly, until it became perpendicular and finally inverted, so that the floor of the seam now formed the roof, and the hard sandstone-roof formed the floor. This was found to continue, until the seam and associated strata gradually again became vertical, and ultimately regained their former state with the soft black shale under foot and the hard sandstone overhead. The workings have not been sufficiently extensive to give the dimensions of these overthrusts in each seam, but they are greater than those of the overthrust on the north side. The continuity of the coal-seams throughout the overfold has been practically proved in the cases of the Great Vein, Top Little Vein, and Middle Vein. As the overthrusts, however, appear to increase uninterruptedly in magnitude below this point, it is very probable that these more deeply-seated seams have been entirely shorn off, and are not continuous.

It is a matter of interest whether, in the case of the great overthrust at Radstock, the amount of overlap still continues to increase in the same manner below the Bull Vein, as above that seam. If this should be so, the amount of overthrust in the coal-seams of the Farrington Series, some 200 yards below, would be very great. If, however, the Radstock overthrust is a magnified reproduction of the smaller Braysdown thrusts to the north of it, then it seems probable that this will not be the case, for the following reason.

The overthrust on the north side of Braysdown Colliery has been proved in the Farrington Series, where, however, it occurs on the south side of the pit. This overthrust, as before mentioned, has been traced in all the Upper or Radstock seams. It was met with in the shaft, where it probably accounted for the unusual thickness of Red Shales; and on the south side of the shaft, in the working of the first seam of the Farrington Series, the dimensions of this overthrust (or the linear extent of the displacement) have been found to be practically the same [1] as that on the Bull Vein or last seam of the Radstock Series, and therefore the fault (or vertical distance by which the same coal-bed has been separated) may not be larger, nor the overthrust (or extent to which the ends overlap) be any greater below this point.

If we accept the theory that these Braysdown faults owe their origin to the same cause as the Radstock overlap-fault, it is reasonable to suppose that when the Radstock Fault is proved in the Farrington Series, it will be found to have the same dimensions approximately as in the bottom seam, or Bull Vein, of the Upper Series. If this be so, proof will be afforded that these faults did not take place until after the last-named seam had been deposited.

[1] In some cases slightly less.

Mr. McMurtrie has taken the view that the increase in overlap and uplift of the Radstock Fault in the seams of coal, from the Great Vein down to the Bull Vein, is due to the commencement of this fault before the deposition of the Upper seams, and to a continuance of this movement during their deposition[1]: and in a recent paper he says:—

'A natural inference would be that the lateral movement (whatever its cause) had commenced before the deposition of the Upper Veins, and that it must have been continued afterwards—either as a gradual movement, or in successive periods, which would fully account for the more limited overlap in the upper strata.'

The facts observed at Braysdown Colliery show that this could not have been the case; for, had this been so, there should be a marked difference in vertical thickness between the corresponding strata lying between the same seams on the north and on the south side of the faults. At Braysdown Colliery there is practically the same thickness of strata between corresponding seams on both sides of the fault. And, so far as I have heard, this is the case with other overlap-faults of the Somerset Coalfield; except, perhaps, where the seams lie in close proximity and are much contorted.

It appears to me, therefore, that we must come to the conclusion that these overthrusts in the Somerset Coalfield did not take place until after all the seams of coal in the Radstock Series had been deposited; but, from some cause or other, the rate of overthrust was continuously lessening above the Bull Vein, as we find that the amount of overlap diminishes in each seam above this one.

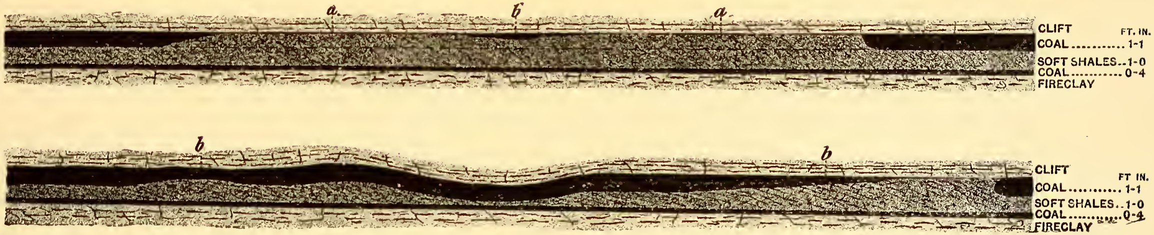
Dead Ground.

In the Radstock Series, areas are frequently met with, in some of the seams, where the coal is entirely replaced by soft black shales. Such areas are known locally as 'dead ground.' So far as I am aware, no attempt has been made to account for these areas of 'dead ground' in this coalfield, the prevailing idea being that they are 'wash-outs,' that is to say, that the coal has been washed away by currents of water previous to the deposition of the roof above it. From observation in the mine I am led to believe that the areas of dead ground are not wash-outs, but that they have been produced by the differential movement of the strata, which also originated the overthrusts before mentioned.

If they were wash-outs, we might expect the space washed out to be occupied by the same strata as those which form the roof; but in almost every instance the place of the removed coal is occupied by the same material as that which constitutes the floor, namely, soft black shales. The points of contact also of the coal and dead ground do not suggest wash-outs (see fig. 2, p. 614). The areas are usually irregular in shape, but when surveyed are generally quite

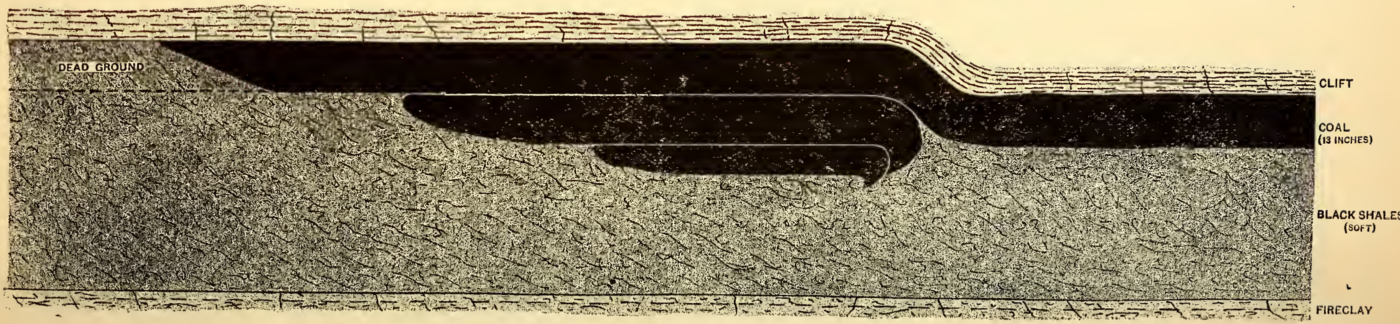
[1] See Greenwell & McMurtrie's 'Radstock Portion of the Somersetshire Coalfield' 1864, p. 18; also J. McMurtrie, 'Geological Features of the Somerset & Bristol Coalfields' Trans. Inst. Min. Eng. vol. xx (1901) p. 331.

Fig. 2.—*Section showing dead ground, thin coal, and undulations in the Top Little Vein.*



[The thin bed of coal, lying on a hard floor, nearly always remains intact; while the Top Coal, lying on soft shales, is subject to removal.] *a* = Dead ground; *b* = Thin coal.

Fig. 3.—*Section of thick coal and dead ground in the Under Little Vein of Braysdown Colliery, taken from the coal-face.*



[Scales: Horizontal, 1 inch = 132 feet; Vertical, 1 inch = 4 feet.]

Note.—The rounded and turned-down ends are of common occurrence, and are always smooth and highly polished.

unlike the course of a stream. Many of these areas contain isolated patches of coal in them.

Dead ground occurs more frequently in the vicinity of faults (although it is sometimes met with at long distances from them); moreover, it often takes a course more or less parallel to faults, and especially overthrust-faults.

Sometimes, in close proximity to dead ground the coal-seam presents an abnormal thickness, consisting of layer on layer of coal piled one above the other (see fig. 3, p. 614). Such areas of thick coal are sometimes extensive, and it is not uncommon in some collieries for a seam 2 feet thick suddenly to attain 5 or 6 feet in thickness. For instance, at Braysdown Colliery the Great Vein (which is the thickest seam in the Radstock Series, having an average thickness of 28 inches) has been observed suddenly to reach a thickness of 6, 10, and 15 feet, continuing so occasionally for a considerable distance and then quite suddenly reverting to its original thickness, or more often disappearing entirely, dead ground taking its place. It is a general rule that thick coal is nearly always preceded or followed, sooner or later, by either unusually thin coal or dead ground.

An instructive and remarkable fact which has been observed at Braysdown Colliery is, that in the Radstock Series the dead ground occurs only, in the majority of instances, in those seams of coal which lie on a floor of soft black shale, known locally as 'blacks'; whereas where the floor and roof are formed of hard rock no dead rock is met with. This is especially noticeable in regard to the Bull Vein, which lies almost immediately upon a hard fireclay floor; there little dead ground is found. In the place of dead ground, however, large areas of very thin coal are common in faulted districts in the Somerset Coalfield.

The case of the Top Little Vein is still more interesting, for this seam consists (see fig. 2, p. 614) of a bed of coal 13 inches thick, lying on a bed of soft black shale about 1 foot thick, with a thin band of coal beneath about 4 inches thick, which in its turn lies immediately on a hard fireclay floor. This seam, therefore, really consists of two beds of coal, the one above lying on soft shale, the one below on hard fireclay; and it is a remarkable fact that large areas of dead ground are constantly displacing the 'top' coal-bed; but throughout these entire areas the 'bottom' coal-bed lying on the hard floor nearly always remains intact.

Where 'thin coal,' 'bad ground,' or 'dead ground' has been met with in one seam in this district, the same state of affairs may be expected as a rule in the next seam, vertically above or below, in the same place or its neighbourhood. There are exceptions to this, but it has been proved over and over again to be the general rule. We may take one example. Recently the Great Vein proved to be very thin and irregular, with frequent intervals of dead ground in a certain locality for a long distance. Subsequently the Middle Vein, some 27 yards below, was opened out under the same places where the Great Vein proved so badly, and almost exactly the same circumstances were met with throughout the entire area: that is, the same irregular and thin coal and the same intervals of dead ground vertically below the corresponding accidents in the seam above. If these abnormal areas were deposited as we find them, it is surely remarkable for these irregular deposits to occur in almost the same corresponding place in different seams of coal.

The flat roofs of the coal-seams within the areas of dead ground are invariably striated, the striæ as a rule running north and south. The termination of coal against dead ground is always smooth and polished, and often rounded. The same fact is noticed in the case of the termination of thick coal.

On the Slyving Vein, which has about 1 inch of inferior cannel on the top of the seam, it has often been observed, where thick coal has occurred, that the cannel is found on the top of each layer of coal. If the thick coal had been deposited as such, it is curious that a layer of cannel should occur on the top of each piece of coal.

Dead ground is very rarely met with in the seams of the Farrington Series.

My view is that all these effects have been caused by the gradually increasing amount of movement of the strata from the top seam (or Great Vein) to the bottom seam (or Bull Vein), after all had been deposited. Evidence has already been given of the increasing amount of overthrust of each seam of the series in the overthrust-faults which have been noticed. I consider that the effect in the strata in descending order was to cause friction between the beds, which must have moved differentially. This friction must have become more effective along the lines of the coal-seams and underlying soft shales, these being weak points; and here the effect has been to scrape the coal away from the under side of the seam as a rule, causing areas of 'thin coal,' or sometimes entirely removing the coal, leaving only the soft shales, when it is known as 'dead ground.' In other localities the same action has packed one and the same coal in several layers one under the other, and has caused the polished and rounded ends of the same as shown. This differential action would account for similar circumstances vertically under each seam, and would account for the striæ on the roofs of the seams which are always so abundant in these areas. It would account for the coal-seams nearly always thinning-out from the under side upward, for although the roof and floor have both moved in the same direction, still the floor has moved farther or at a greater rate than the roof, and has therefore rubbed against the under side of the coal, which (as a result) has thinned out, or been entirely removed.

Study of the overthrust-faults may also explain the reason why the coal-seams of the Farrington Series remain so much more uniform in thickness than those of the Radstock Series, and their comparative freedom from dead ground. For we have noticed that the variation in amount of overthrust in the faults appears to cease below the Bull Vein: the first seam of the Farrington Series having the same amount of overthrust as the last in the Radstock Series. Therefore, as there has been comparatively little variation in the relative amount of movement in this series, there has consequently been little friction between the beds, and as a result little dead ground, and little thinning of the seams; while, in contrast with this, the Lower Coal-Measures of the Nettlebridge Valley, which have been considerably crumpled and distorted, contain much dead ground.

Discussion.

The President expressed his appreciation of the careful observation of facts and cautious inference from them, evinced by the Author of this paper, which afforded fresh evidence in support of the opinion that it is in the study of minor and local phenomena that we may eventually find the clues to the interpretation of the grander deformations which affect vast tracts of country. He had himself often urged that in all likelihood the majority of the underground abnormalities in British coal-seams generally, such as the so-called 'wash-outs,' 'horsebacks,' etc., the local thickenings and thinnings, and the occasional temporary disappearance of coal-seams, might be due merely to subsequent deformation; but few mining men were as yet willing to concede this. It was to be hoped that the publication of the Author's results would prompt others who had met with corresponding phenomena in coal-workings to bring forward similar papers, and place the facts on record for the benefit both of geology and of economics.

Prof. Boyd Dawkins welcomed the paper, and fully accepted the conclusion that the phenomena described are the result of overthrust-faulting in this district, which is traversed by the Axis of Artois of Godwin-Austen. Along a line reaching from the South of Ireland on the west, to the Boulonnais and beyond on the east, similar overthrusting is conspicuous. In the Boulonnais it is illustrated by the fact that in one section the Devonian rocks have been thrust over the Coal-Measures, in which three seams of coal have been won, by shafts through the above rocks. In the whole of this region the absence of seams of coal from their natural position was mainly, if not entirely, due to overthrust. In other regions, however, as in the Forest of Dean and the South Yorkshire Coalfield, the absence of coal-seams was due to the cause usually assigned—the action of water traversing the Carboniferous morasses (now coal-seams), and depositing sand and mud, now sandstone and shale, in these old channels.

Prof. Groom said that facts gleaned from the adjacent area of the Forest of Dean seemed to lend support to the Author's contention that the so-called 'wash-outs' in Somerset were due to dislocations. Mapping on the eastern side of the Dean-Forest Coalfield showed that a pair of trough-faults had let down a portion of the coalfield, and had given rise to appearances which had been interpreted as due to an unconformity in the Coal-Measures. One of these faults was parallel to the south-western margin of the basin, and to the 'Horse,' and if continued would pass close to the latter. The 'Horse' was perhaps the best-known example of its kind in the British Isles. Its existence had been attributed to contemporaneous fluviatile denudation, but Mr. Arnold Thomas, F.G.S., had informed the speaker that the side of that portion with which he was familiar, so far from presenting the appearance of a river-bank, showed a clean-cut slickensided surface: he had, moreover, proved the existence of coal—presumably the seam that was being worked at the time—beneath the level of the workings, and thought that the 'Horse' was probably due to a pair of trough-faults.

Sir Archibald Geikie remarked that the progress of investigation in recent years had shown that overthrusts are of much more frequent occurrence than had previously been surmised. They occur even in districts which would not have been thought to have undergone any marked amount of disturbance. He had lately found them by no means infrequent in the various subdivisions of the Carboniferous System in Fife. And they have been shown not to be confined to our older formations, but to be well marked even among the Cretaceous formations of the South of England. He thought it quite possible that some structures, which had been otherwise interpreted, before the prevalence of overthrusts had been realized, might be explained by faulting of this kind; though there could be no doubt as to the existence of many proofs of contemporaneous erosion, to which such an explanation would not apply. It was by such detailed observations and measurements as had been furnished by the Author of the paper that these disputed questions could best be settled.

Mr. Strahan thought that the Society was indebted to the Author for the care with which he had made observations under the difficulties inseparable from mining work. He agreed in the main with the Author's conclusions. No one probably would deny the existence of true 'wash-outs' in the Coal-Measures. All the phenomena of contemporaneous erosion had been observed in more than one district. He (the speaker) had himself seen repeatedly in a neighbouring district evidence of movement along bedding-planes, or along planes diverging but slightly from the bedding. Shale-partings between coals had been sharply puckered, or bands of coal rendered schistose, while the beds above and below remained unaffected. Open quarries showed overthrusts in coal-seams ranging from a few inches to upwards of 20 yards, and the doubling or even trebling of the seams. In other places the coal had been squeezed out for several yards, leaving an area of dead ground, such as that described by the Author. He suggested that the tendency of the overthrust to decrease towards the surface might be due to its splitting into subsidiary planes of overthrusting along the coals of the Radstock Series.

The AUTHOR said, in reply, that the rapid decrease in amount of overthrust and vertical uplift from the bottom coal-seam to the top one in the Radstock Series, as exhibited by the large overthrust at Radstock and the smaller ones at Braysdown, was a difficult problem, and he did not suggest that the ideas brought forward in his paper would meet all the difficulties of the case. Similarly with regard to the question of 'dead ground,' he did not suggest that this phenomenon was in *every* case due to earth-movements, and that there were no true 'wash-outs,' especially in other districts. But, in this particular locality, the evidence of the polished and often rounded termination of coal against 'dead ground,' the striæ on the roofs within the affected areas, the differential movement of the strata as shown by the overthrusts, together with the other evidence which had been brought forward, pointed to the conclusion that in the great majority of cases the 'dead ground,' 'thick coal,' and 'thin coal' were due to these differential earth-movements.

He thanked the Fellows very much for the kind way in which they had received his paper; and he desired to thank Mr. H. B. Woodward for reading it, and for the kindly interest which he had shown in it throughout.

32. *The* MINERALOGICAL CONSTITUTION *of the* FINER MATERIAL *of the* BUNTER PEBBLE-BED *in the* WEST OF ENGLAND. By HERBERT HENRY THOMAS, Esq., B.A., F.G.S. (Read April 30th, 1902.)

[PLATES XXXI & XXXII.]

CONTENTS.

I. INTRODUCTION.

MUCH work has already been done on the pebbles and larger fragments of rock of the Budleigh-Salterton Pebble-Bed, but little or none on the finer material forming the matrix of this most interesting deposit. It occurred to me that a microscopic investigation of this finer material might bring out a few points of geological as well as mineralogical interest. Therefore it has been my endeavour to make as complete a mineralogical analysis of the sands as possible.

Specimens were collected at intervals along the strike of the Pebble-Bed, from Budleigh Salterton on the southern coast of Devon to Fitzhead, north of Milverton, in Somerset; other sands, for comparison, were taken from the Red Rocks above and below.

After treatment with acids, so as to remove the coating of iron-oxides from the grains, the sands were separated by means of heavy liquids into three parts:—

(*a*) Heavy residue, with a specific gravity greater than 2·80.
(*b*) The bulk of the quartz; and
(*c*) The lightest part, with most of the alkali-felspar.

II. PETROGRAPHY OF THE SANDS: DESCRIPTION AND DISTRIBUTION OF THE MINERAL SPECIES.

At the southern end of the outcrop of the Pebble-Bed, the matrix consists of incoherent material, each sand-grain being covered with a coating of red iron-oxide. On tracing the deposit northward, however, to the borders of Somerset, the bed loses much of its red colour, and in this area, owing to the presence of many masses of Culm-Measure limestone in the vicinity, the grains are cemented in a calcareous matrix, the deposit ultimately taking on the form of the Dolomitic Conglomerate.

The sands contain, on the whole, a very small percentage of mineral-grains the specific gravity of which is greater than 2·80; while the ratio of material over 2·58 to that under 2·58 is about 70 or 80 per cent. to 30 or 20 per cent. In some cases the heavier material rises to as much as 88 per cent. (at Milverton).

The following is the percentage of material of specific gravity greater than 2·58, at various localities along the outcrop of the Pebble-Bed, taken from south to north :—

	Per cent.
Budleigh Salterton	75
Fair Mile, near Tallaton	73
Uffculm	71
Burlescombe	·78
Milverton	88
Fitzhead	83

It is interesting to note that the percentage of heavy material and the percentage of light material are almost constant throughout the thickness of the bed at Budleigh Salterton, being 75 and 25 respectively. This, unfortunately, was the only locality where there was a section from which I could be sure of collecting a series of samples at regular intervals, from the top to the bottom of the deposit. Rounding of the grains has taken place, but the degree of rounding is by no means constant, even in the same sample. However, taking into consideration any one mineral, we notice that the rounding becomes more complete as we travel from south to north.

The chief mineral species that occur in the sands forming the matrix of the Pebble-Bed, arranged according to their crystal-systems, are :—

Cubic.
- Fluorspar.
- Garnet.
- Magnetite.

Rhombohedral.
- Apatite.
- Ilmenite.
- Tourmaline.
- Quartz.

Monoclinic.
- Biotite.
- Muscovite.
- Orthoclase.
- Sphene (titanite).

Tetragonal.
- Anatase.
- Cassiterite.
- Rutile.
- Zircon.

Orthorhombic.
- Brookite.
- Sillimanite.
- Staurolite.

Triclinic.
- Cyanite (disthene).
- Microcline.

Under the head of amorphous minerals and compound grains may be mentioned :—

Felsite, quartzite, and chert.
Shimmer-aggregates, pinite, and mica-schist.
Leucoxene, and other decomposition-products.

The following comprises a description of the species and grains mentioned above, giving in some instances the chief characters by which the minerals were identified.

Fluorspar.—This mineral occurs in colourless isotropic grains, usually angular, with the octahedral cleavage {111} well shown. They reach a size of 0·40 millimetre in greatest length. The index of refraction is low, and this character is useful for purposes of identification.

Fluorspar has been found in the sands from Berry Head[1] to the west of Torbay, from Budleigh Salterton, and Woodbury Castle; but it has not been noticed in the Pebble-Bed north of the last-named locality, nor does it seem to occur in the so-called 'Permian Breccias,' or in the beds above the Pebble-Bed.

Garnet.—The garnets of these sands occur in irregular but somewhat rounded isotropic grains, usually not more than 0·25 millimetre across, but sometimes reaching as much as 0·30 millimetre.

They are of a pale pink colour, and if in large crystals would undoubtedly have been of a very deep red. Crystal-outline is generally wanting.

In the Pebble-Bed they are confined to the North of Devon and Somerset, occurring only along the line from Uffculm northward to Fitzhead. They have not been found to the south, but are common, in fact abundant, in all the red beds above the Pebble-Bed.

Anatase[2] (Pl. XXXII, figs. 1–5).—This mineral occurs in minute, but usually perfect, colourless, transparent tetragonal crystals (rarely exceeding 0·10 millimetre in greatest width). The habit is in most cases tabular, the base being large and the pyramids narrow.

An optically negative axis emerges normally to the basal plane (001). Many of the larger grains are turbid and of a yellow-brown colour: this turbidity seems to be due to a superficial decomposition, possibly resulting in the formation of rutile.

One example only of an octahedral crystal[3] has been noted, and that from the sand of Fitzhead. The basal plane on this crystal was very small.

This mineral is not very plentiful in the Pebble-Bed, but is fairly constant in its occurrence. It is more plentiful in the sands of the Upper Bunter, where it occurs with the same tabular habit.

Rutile[4] (Pl. XXXI, figs. 10–13).—This mineral is very prevalent throughout the whole of the Pebble-Bed, and is no less common in the beds above and below. Simple crystals are seen to consist of the simple tetragonal prism {110} capped by a pyramid {111}. The commonest occurrence, however, is in the form of rounded prisms with indistinct terminations, and grains.

The colour is from yellow to amber-red or brown.

The mineral is often twinned, these twins being mostly poly-

[1] This sand exists as an outlying patch in a fissure in Devonian rocks; from analogy in composition to the finer material of the Pebble-Bed, I should suspect it to be made up of resorted material derived from that deposit.

[2] W. F. Hume, 'Chem. & Micro-mineralog. Researches on the Upper Cretaceous of S. England' 1893, p. 97; J. J. H. Teall, 'Brit. Petrogr.' 1888, pl. xliv, fig. 6.

[3] H. L. Bowman, Mineral. Mag. vol. xii (1900) p. 362.

[4] J. J. H. Teall, 'Brit. Petrogr.' 1888, pl. xliv, fig. 4.

synthetic (figs. 11 & 12), or more rarely geniculate (fig. 13). The long axes of the individuals make an angle of about 65° one with the other. Inclusions are not common.

Although this mineral, as has been stated, is common all through the Red Rocks, it is more plentiful to the north of Uffculm.

Cassiterite is difficult to distinguish from rutile, but it occurs in small quantity in the heavy residues from some of these sands. There seem to be two modes of occurrence: (i) in pale-yellow, well-shaped crystals, and (ii) in more or less rounded brownish grains.

The crystals are generally short tetragonal prisms, with an ordinary pyramid. A basal plane is usually present. The grains and crystals differ considerably from the rutile in the same sample. The prism seems to be less elongate, the colour is paler, twinning is less frequent, and the lustre is submetallic.

The crystals have been compared with stream-tin from Devon, in order to establish their identity.

This mineral so far has only been obtained from the sands north of Uffculm, and does not appear to be present in the sands south of that locality.

Zircon[1] (Pl. XXXI, figs. 1–9).—Zircon is one of the most abundant minerals in the heavy residues of these sands, and occurs generally in colourless, highly refracting prisms, in all essentials identical with those so commonly met with. The crystals seldom attain a length of more than 0·25 millimetre.

An interesting form has been discovered by my friend, Mr. J. B. Scrivenor, in the heavy residue from Fitzhead. It consists of a 'capped' crystal (Pl. XXXI, fig. 3)[2], the two individuals being connected by their basal planes and in perfect optic continuity. This is the only example of the kind that has been met with.

The basal plane (001) is a rare face on microscopic zircons, but it has been noticed to be fairly common on the crystals from Burlescombe, Milverton, and Fitzhead. Although this mineral is usually colourless, a pink variety occurring in stumpy prisms, capped seemingly by a simple pyramid, has been noted from Newton Poppleford in Devon (fig. 9). Colourless, and pale-brown stumpy crystals also occur. These last-mentioned varieties have all the optical properties of zircon, and evidently belong to that group: if, however, they are not true zircons, they must belong to an allied species, possibly xenotime.[3]

Many crystals of zircon show a beautiful zonal structure, which is very characteristic.

Inclusions in this mineral are common, and are seen to consist of colourless needles, probably apatite, and of a dark-brown, highly pleochroic mineral, crystallizing in stumpy prisms, with

[1] J. J. H. Teall, 'Brit. Petrogr.' 1888, pl. xliv, fig. 1.
[2] A. B. Dick, 'Nature' vol. xxxvi (1887) p. 91.
[3] O. A. Derby, Mineral. Mag. vol. xi (1897) p. 308.

straight extinction. These seem to be rhombohedral, but as yet I have come to no definite conclusion regarding the mineral species to which they belong. Negative crystals are common, as also are gas- and fluid-cavities. The inclusions and cavities usually occur along definite lines, which are either parallel to the prism, to the pyramid, or to both.

With regard to the distribution of this mineral, it is abundant everywhere; but the zircons with the basal plane well-developed are more common in the sands north of Uffculm, than from localities farther south.

Ilmenite.—This mineral was probably abundant, for leucoxene is a prevalent constituent, and may replace original black grains, of which only a few are left.

It is opaque, or only slightly transparent, but of a whitish-yellow or greenish-brown colour by incident light. It has a granular structure, and the grains are usually round.

Micaceous ilmenite[1] occurs in minute flat plates of a bright reddish-brown colour, enclosing rutile-needles arranged symmetrically at angles of 60° one with the other, taking on the form of sagenite.

Here it might be well to mention another ore of iron which also occurs in some cases, and that is a deep red mineral in thin flakes, made up of minute spheres with a radiate structure: Each sphere gives a perfect black cross between crossed nicols. It is probably a form of hæmatite.

Tourmaline[2] (Pl. XXXI, figs. 14–17).—This mineral is abundant in all the residues, and occurs in various forms. The most plentiful are stumpy crystals, consisting of a prism terminated by the simple rhombohedra μ {100} and μ {$\bar{1}$00}. In these the pleochroism is intense but variable, even in one and the same crystal, the dominant colour being brown. The true form of these crystals is somewhat obscured by the rounding which the majority have undergone; indeed, some are almost spherical.

At the southern end of the Pebble-Bed outcrop they reach 0·25 millimetre in diameter, but are smaller in the north. Another variety occurs, of a rich blue colour, in radial aggregates of acicular crystals (Pl. XXXII, fig. 8). Inclusions usually consist of minute opaque grains, without crystal-outline.

It is worth noting that the blue tourmaline, which is so common in the so-called 'Permian Breccias,' and also occurs in moderate amount in the sands both above and below the Pebble-Bed, is extremely rare in the Pebble-Bed itself. Only a grain or two has been met with in samples from the southern portion of the outcrop. It is, however, more plentiful in the Pebble-Bed sands north of Uffculm.

[1] H. Rosenbusch [transl. Iddings], 'Microscop. Physiogr. of Rock-making Minerals' 4th ed. (1898) p. 166.

[2] J. J. H. Teall, 'Brit. Petrogr.' 1888, pl. xliv, fig. 3.

Quartz.—The grains of this mineral vary considerably, both in size and in their degree of rounding. The more angular, however, seldom exceed 0·6 millimetre, and the perfectly rounded ones are seldom more than 0·5 millimetre in diameter.

Secondary growths of silica on the grains have not been met with, but Dr. Irving[1] records it as of common occurrence in the sands above the Pebble-Bed.

Fluid-cavities are common, occurring both in lines and irregularly distributed through the grain. Inclusions are numerous, and consist of tourmaline, usually blue, and often arranged in radiating masses simulating luxullianite; rutile and apatite, in fine needles; and what I take to be sillimanite,[2] in colourless fibrous crystals.

Much of the quartz gives undulose extinction.

Brookite (Pl. XXXII, fig. 6).[3]—This mineral is rare in the Pebble-Bed of this district, and has been found only as far north as Newton Poppleford. It is associated with anatase. In the Upper Bunter[4] Sands of Ladram Bay, west of Sidmouth, it is seemingly more common.

It occurs in small, tabular, rhombic crystals (0·15 millimetre), flattened parallel to the face (100). This face is characteristically striated, parallel to the vertical axis. A positive bisectrix emerges at right angles to the tabular face. The index of refraction is high, and the double refraction strong. The crystals have a pale yellow colour with feeble pleochroism. The lustre by incident light may be said to be submetallic.

Staurolite[5] (Pl. XXXII, fig. 7).—This mineral is of a yellow to amber-red colour when the grains attain much thickness. It occurs in angular and rough grains up to 0·5 millimetre in greatest diameter, bounded presumably by the cleavage (010) and that parallel to the prisms (110). A conchoidal fracture also occurs. The index of refraction is high, and the pleochroism distinct, ranging from pale to deep yellow or brown. The double refraction is strong, and the interference-tints brilliant. Some grains show a biaxial figure with a positive bisectrix, and an angle between the optic axes varying between 80° and 90°. The plane of the optic axes lies in the plane bisecting the acute angle formed by the intersection of the prismatic cleavages.

The grains are mostly very fresh, there being hardly a trace of decomposition. Occasionally, however, grains may be seen passing into a micaceous decomposition-product.

[1] Rev. A. Irving, Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 71.

[2] H. Rosenbusch [transl. Iddings], 'Microscop. Physiogr. of Rock-making Minerals' 4th ed. (1898) pl. xvi, fig. 3.

[3] W. F. Hume, 'Chem. & Micro-mineral. Researches on the Upper Cretaceous of S. England' 1893, p. 97.

[4] E. Hull, Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 65.

[5] H. Rosenbusch, *op. supra cit.* p. 201.

In some cases inclusions are numerous, consisting mostly of quartz, and of opaque black particles of doubtful nature; other fragments of staurolite occur which are quite free from inclusions of any kind.

This is one of the most abundant of the heavy minerals in the Pebble-Bed, forming fully 20 per cent. of the heavy residue in the Budleigh-Salterton area; but it gradually decreases in quantity northward, till at Fitzhead in Somerset the percentage is relatively small. The greatest percentage was noted from the sand of Berry Head (footnote, p. 622). This mineral is mainly confined to the Pebble-Bed, although a few grains do occur both above and below that horizon.[1]

The Micas.

White mica is fairly abundant, and occurs in colourless flakes, usually about 0·45 to 0·50 millimetre across. A negative bisectrix emerges normally, but the angle between the optic axes is variable. Much of the mica gives undulose extinction. Inclusions are common, and consist of zircon in well-shaped crystals, needles and knee-shaped twins of rutile, and fine, colourless, curved and branched needles of obscure nature (Newton Poppleford).

Blue and brown pleochroic needles of tourmaline are also common, which lie in intersecting rows and radiating groups. Pleochroic halos may be noticed rarely round the more minute inclusions.

Brown mica is not very abundant, but its presence has been proved in many of the sands by the flakes of gelatinous silica, left after treatment with acids. Where the mineral has escaped decomposition, it is of a pale-brown colour with intense pleochroic halos round inclusions.

The micas, so far as one can judge, seem less abundant in the Pebble-Bed than in the beds above and below it.

Felspars.—The majority of the felspar is of the ordinary potash variety orthoclase; some microcline, however, occurs, easily recognized by its characteristic cross-hatching. Decomposition has in many cases gone on to such an extent that the grains have lost most of their original characters. Even the freshest grain is usually much clouded by decomposition-products. The orthoclase sometimes shows the characteristic Carlsbad twinning, but no undoubted plagioclase has been met with.

Felspar is fairly abundant in the Pebble-Bed sands, reaching, as far as one can estimate it, about 6 per cent. of the total mass.

Sphene occurs in rounded, irregular, feebly transparent, brown grains, reaching 0·20 millimetre in diameter, which are traversed by rough cracks. The pleochroism is poor. This mineral is not very common, but is fairly constant in its distribution; it occurs also in the Upper Bunter and Keuper Marls.

Grains have been noticed, enclosed in a highly refracting crypto-crystalline mass which exhibits a rudely radiate structure. This enclosing material is probably a decomposition-product.

[1] It may be recollected that staurolite has been found in the dune-sands of Holland.

Cyanite.[1]—This mineral occurs as the unaltered colourless cores of some of the shimmer-aggregates (see below) which are so common. The cleavage is distinct, the refractive index high, and some grains show in convergent light a negative bisectrix perpendicular to the good cleavage (100).

Compound Grains.

As might be expected in a deposit of this nature, compound grains are very prevalent. They consist of the following:—

Quartzite, which occurs in more or less rounded grains; it is of a fine texture, and may be referred to the quartzite that forms the mass of pebbles of which the bed is chiefly composed.

Chert in rounded grains.

Felsites in cryptocrystalline masses, sometimes showing micropegmatitic structure.

Mica-schist in rounded or oval grains, consisting largely of white mica with a parallel arrangement. In some cases a well-marked knotted structure is noticeable. Included minerals are common, and consist of rutile and tourmaline in fine needles, grains of staurolite, as well as many other minerals which, owing to their minute size, are difficult to identify.

Shimmer-Aggregates.[2]—These aggregates, which consist of a felted cryptocrystalline mass of a white micaceous mineral, with no parallel structure to speak of, are one of the commonest constituents of these sands. They are crowded with inclusions of great variety. These aggregates are evidently decomposition-products from aluminous silicates, probably from cyanite, andalusite, and possibly others.

Cyanite has been recognized as an unaltered core in some cases, while altered andalusite from the Skiddaw Slates presents an exactly similar structure.

Among the inclusions the following may be observed:—zircon in its usual form, tourmaline and rutile in fine needles, crystals and grains of magnetite, and grains of staurolite and sphene. Thin hexagonal and rounded grains of a reddish-brown mineral also occur, and in some instances are very plentiful: it is probably a garnet, possibly melanite.

These shimmer-aggregates are slightly more abundant in the south.

Pinite.[3]—Cryptocrystalline aggregates of a green micaceous mineral, usually not more than 0·30 millimetre across, have been noted; but they are rare.

They include grains of an opaque mineral, probably some ore of iron, and from their general characters would seem to be a decomposition-product of some mineral, probably cordierite. No unaltered cordierite has been met with.

[1] J. J. H. Teall, 'Brit. Petrogr.' 1888, pl. xliv, fig. 2.
[2] G. Barrow, Quart. Journ. Geol. Soc. vol. xlix (1893) p. 349 & pl. xvi, fig. 5.
[3] H. A. Miers, Mineral. Mag. vol. xi (1897) p. 283, and A. Lacroix, 'Minéralogie de la France' vol. i (1893–95) pp. 517–18.

III. Possible Directions of the Sediment-bearing Currents, and Sources of the Mineral-Grains.

There are many peculiarities in the distribution of the foregoing minerals, which point more or less distinctly to the direction in which the material was carried. From these we may, I think, deduce the existence of a southerly main current, over the whole line from the southern coast of Devon to Fitzhead in Somerset, a distance of about 30 miles; and at the same time it will be seen that this main current was joined to the north of Uffculm by a minor current, probably from the west.

The evidence for the foregoing statement is as follows:—Taking into consideration the percentage of material with a specific gravity greater than 2·58 (see p. 621), we see that from 75 per cent. at Budleigh-Salterton it falls gradually northward until at Uffculm (20 miles to the north) the percentage is 71. It now begins to rise, and continues to do so until it reaches as much as 88 per cent. in the neighbourhood of Milverton in Somerset, north of which the percentage again falls. The gradual diminution of the percentage of heavier material as we pass from south to north, would in itself suggest a transport of material in that direction; while the rise in the neighbourhood of Burlescombe would point to a fresh influx of material. This view is strengthened by the distribution of the individual minerals. For instance, staurolite, which is so plentiful in the extreme south, diminishes considerably in quantity in the more northerly part of the outcrop of the Pebble-Bed, and a gradual diminution in the size of the rounded tourmaline-grains has been noted in the same direction. Fluorspar does not extend northward farther than about 4 or 5 miles from the coast. Associated with the rise in percentage of the heavy material at Burlescombe and the other localities near, an assemblage of minerals occurs which differs markedly from that of the normal, more southerly type.

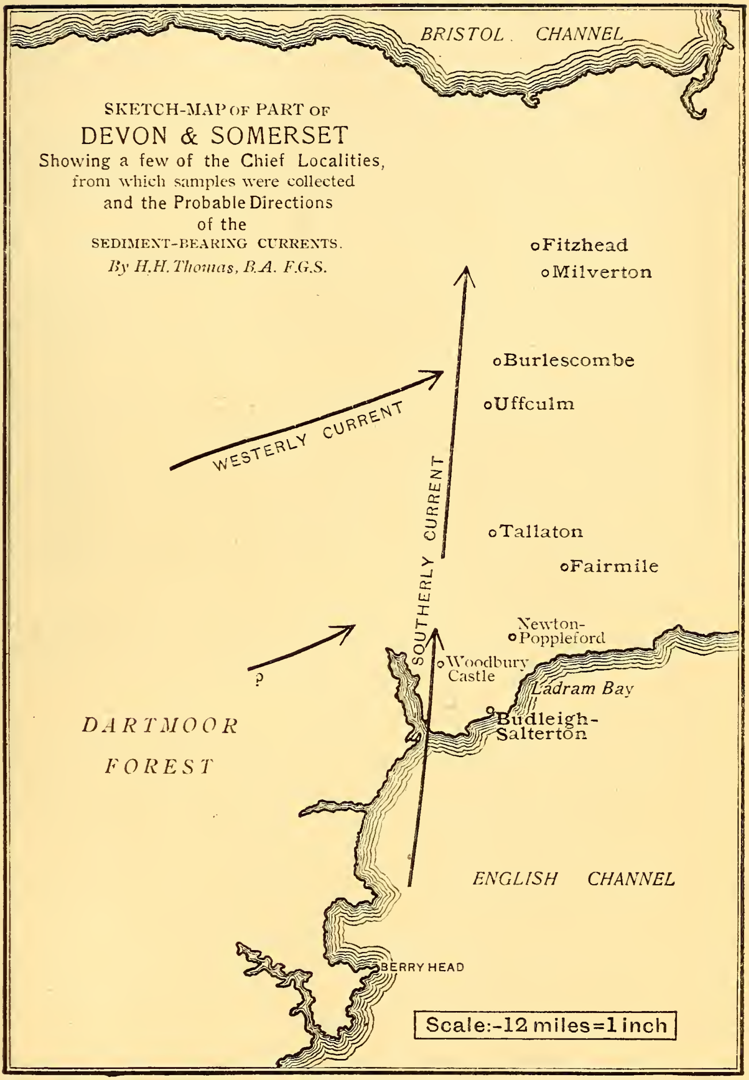
Several minerals, such as garnet and cassiterite, make their appearance for the first time, and the blue variety of tourmaline becomes more common. It thus seems probable that the main current was from the south, which is in accordance with the conclusion arrived at by Mr. Ussher[1] from a study of the distribution of the pebbles.

The confluent westerly current is simply one of many minor currents such as are met with in any drainage-system.

When we consider what are the minerals which have been recorded, we can hardly refrain from concluding that an area differing widely from any in the South or West of England must have been undergoing denudation to supply them. The occurrence of minerals such as staurolite, cyanite, sillimanite, microcline, and probably cordierite, and the prevalence of 'shimmer-aggregates,' suggest some great metamorphic area as the source of much of the material. So far as is known at present, staurolite does not occur in the metamorphic rocks round the Devon-Cornwall[2] granite-masses.

[1] Mem. Geol. Surv. 'Exeter' 1902 (in the press). See also W. A. E. Ussher, Quart. Journ. Geol. Soc. vol. xxxiv (1878) pp. 246–47.

[2] K. Busz, Neues Jahrb. Beilage-Band xiii (1899) p. 90.


BRISTOL CHANNEL
SKETCH-MAP OF PART OF
DEVON & SOMERSET
Showing a few of the Chief Localities,
from which samples were collected
and the Probable Directions
of the
SEDIMENT-BEARING CURRENTS.
By H.H. Thomas, B.A. F.G.S.
Fitzhead
Milverton
Burlescombe
Uffculm
WESTERLY CURRENT
SOUTHERLY CURRENT
Tallaton
Fairmile
Newton-
Poppleford
Woodbury
Castle
Ladram Bay
Budleigh-
Salterton
?
DARTMOOR
FOREST
ENGLISH CHANNEL
BERRY HEAD
Scale:-12 miles=1 inch

An examination of the Pliocene sands from St. Erth and St. Agnes, in Cornwall, which contain local minerals[1] such as andalusite, cyanite, cassiterite, and brown and blue tourmaline, shows that staurolite is extremely rare or absent; and in view of the essentially local origin of these sands, it should be present if derived from a local source. It seems, therefore, that we must look to some other area to supply us with staurolite. Evidence already given points to a southerly source, and the question arises what land-area existed at the time capable of supplying it.

In Triassic times, the Armorican massif is generally believed to have been high land. That it formerly extended much farther north-westward is also probable. Indeed, most geologists hold the view that the present Armorican peninsula was connected with the South-west of England.[2] In the schists and gneisses of Britanny[3] and of the North-west of France generally, rock-masses occur in which staurolite is fairly abundant. This area therefore, or its northerly extension in Triassic times, seems to be the probable source of the staurolite, and many of the other heavy minerals associated with it.

It seems likely that the brown tourmaline is partly of local origin, and partly derived from a more distant area. This would account for the different degree of rounding noted in grains of identical size. The idea of a distant origin is possibly strengthened by the fact that Mr. E. B. Wethered[4] seems to have obtained detrital tourmaline from rocks of Middle Devonian age, which were deposited prior to the intrusion of the tourmaline-bearing granites of the West of England.

The blue tourmaline was probably derived from the metamorphosed sedimentary rocks in which it is so common. It is abundant in the Permian Breccias of the centre of Devon. Much of the rutile has probably had the same source.

To summarize, therefore, I put forward the following points:—

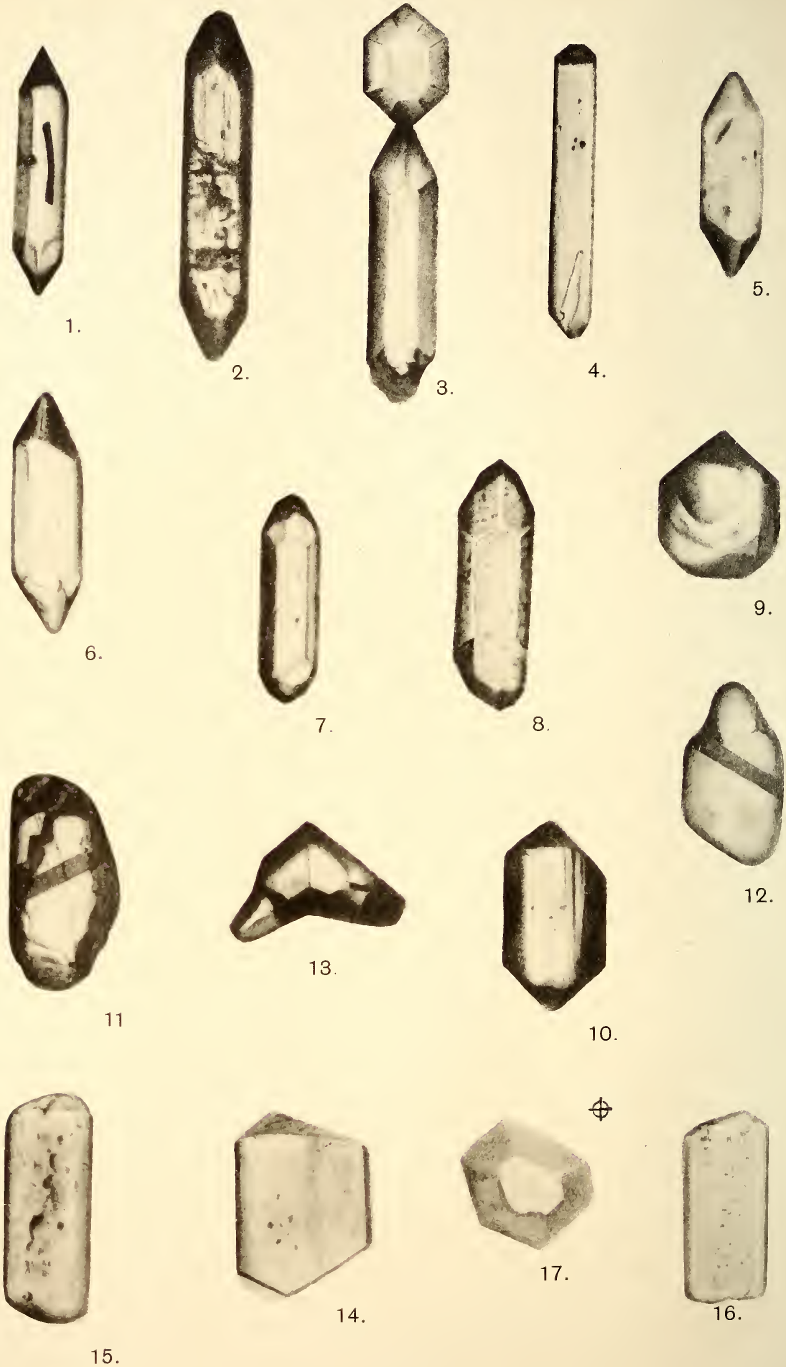
(i) That the distribution of material, and individual mineral species, indicates a main southerly sediment-bearing current, joined by a westerly minor current, which makes itself apparent about 20 miles north of the coast.

(ii) That a mass of material was furnished by a highly metamorphosed area, and that this differed widely from any now exposed in the South-west of England.

(iii) That the probable source of much of the material was the Armorican massif of Triassic times, and the high land of Devon and Cornwall to the west, feeding the southerly and westerly currents respectively.

In conclusion I wish to express my thanks to Mr. Ralph Morgan, of Exeter, for his kindness in supplying me with many samples of New Red Sands from Devon; to Prof. Sollas, for the kindly interest

[1] J. J. H. Teall, 'Brit. Petrogr.' 1888, pp. 386–87.
[2] A. de Lapparent, 'Traité de Géologie' 4th ed. (1900) p. 1004 (map).
[3] A. Lacroix, 'Minéralogie de la France' vol. i (1893–95) p. 6.
[4] Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 383.



Minerals from the Bunter Pebble-Bed.

C. J. Bayzand, del. *Bemrose, Collo.*

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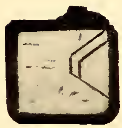
3.



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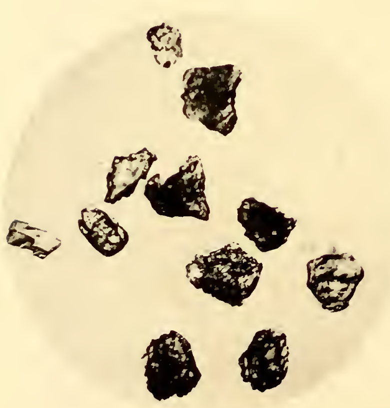

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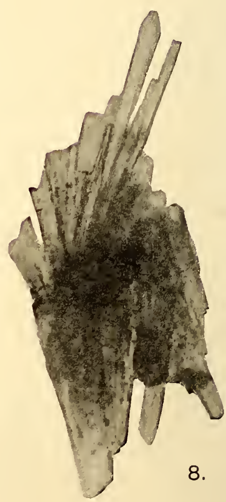


8.

MINERALS FROM THE BUNTER PEBBLE-BED.

C. J. Bayzand, del. *Bemrose, Collo.*

which he has taken in my work; and to Mr. C. J. Bayzand, of the University Museum, Oxford, for preparing the drawings for the plates which illustrate this paper.

EXPLANATION OF PLATES XXXI & XXXII.

Plate XXXI.

Figs. 1, 2, 5, 6, 7, & 8. Zircons showing various forms. × 150 to 200 diameters.
Fig. 3. 'Capped zircon' (from a drawing and photograph by Mr. J. B. Scrivenor). × about 200.
4. Zircon with basal plane (001). From Burlescombe. × about 150.
9. Pink stumpy zircon or xenotime (?). × about 150.
10. Simple crystal of rutile. × about 200.
Figs. 11 & 12. Polysynthetic twins of rutile. × about 150.
Fig. 13. Knee-shaped twin of rutile. × about 150.
Figs. 14–16. Crystals of tourmaline (brown). × about 200.
Fig. 17. Basal section of tourmaline, perpendicular to the optic axis. × about 200.

Plate XXXII.

Figs. 1–5. Tabular crystals of anatase, showing the large base and narrow pyramids. × about 225 diameters.
Fig. 6. Crystal of brookite from the Upper Bunter of Ladram Bay. × 250.
7. Grains of staurolite, from a microphotograph. × 50.
8. Group of rudely radiating blue tourmaline, from the Permian Breccias (from a microphotograph). × about 150.

Discussion.

Prof. Sollas said that the Author had spent much time and labour in working out the material of the Triassic sands: he had determined the minerals, some not always easy to recognize with accuracy; and his generalizations, when they were not positive facts, were at least extremely probable. He had adhered to one horizon in his examination of the sands, and this lent additional force to his conclusions.

Mr. H. B. Woodward remarked that it was always a source of satisfaction to be in harmony with previous observers. According to J. W. Salter, many of the Budleigh-Salterton pebbles were derived from Normandy; while Mr. Ussher had observed that north of Burlescombe the Triassic conglomerates were of local derivation. These views received support from the Author, who had initiated a very important line of research.

Mr. Greenly felt an especial interest in this paper, because among the other problems of Anglesey was one concerning certain 'Red Rocks.' Such evidence as was at present available went to show, on the whole, that these were probably of Triassic age, but the exposures were very limited. The very interesting and novel results obtained by the Author encouraged him to hope that the defects of stratigraphical evidence might yet be supplemented by petrographical data; and that it might, after all, be possible to arrive at satisfactory conclusions concerning the relations of these rocks to the underlying Coal-Measures, and to the Red Rocks of the Vale of Clwyd and the Western Midlands.

Prof. Groom said that he was glad to see so interesting an application of a method of research devised by Prof. Sollas. The mere thickness of beds was an imperfect indication of the source of the material. Thinning might take place either towards, or away from the source; and in many cases the thickness appeared to be a measure of the rate of depression, rather than an indication of proximity to the source of supply. From a consideration of the nature of the materials, the Author had made it probable that the main source of supply of the Lower Triassic beds of South-western England had been the southern part of the Armorican Range, now largely denuded away. He had also recognized the incoming of new materials immediately to the south of the old buried east-and-west ridge which divided the Triassic basin of the Midlands from that of the South-western area, and against which the members of the Trias overlapped on each side. This gentle ridge—a relic of the northern portion of the Armorican Range—although largely covered by Keuper Marls, appeared to have persisted in part to a later date, and it seemed possible that it might have furnished some of the materials of the Triassic deposits in the trough to the south.

The PRESIDENT expressed his pleasure at finding that the study of the finer materials of the English pebble-beds had now begun in earnest, and that the Author had already reached results which were of such value and interest. Hitherto, Midland geologists, who looked upon the Trias as their especial formation, had been content to draw their conclusions respecting the probable source or sources of the Triassic sediments from the study of the pebbles and the larger rock-fragments, and this paper marked a new epoch in this kind of geological research. It was gratifying to note that the Author inferred, from his study of the microscopic materials, the same general direction of south-to-north travel as had long since been inferred for the Triassic pebbles of the South of England by J.W. Salter, Prof. Bonney, and others. Midland geologists, however, claimed that ridges existed in the Midlands in Triassic times, from which some of their local pebble-beds and sandstones had been derived; and it was interesting to see, from the Author's results, that the view of the derivation of all, or practically all, the materials from lost Armorican ridges below the English Channel or in Britanny ought not to be too closely pressed. Indeed, there was much to be said in favour of the view that some of the lost pre-Triassic Midland ridges were made up of rocks of Armorican type.

The AUTHOR thanked the Fellows for their kindly reception of his paper, and referred to the great value of Prof. Sollas's method of mineral separation, by means of which much of his work had been done. With reference to the red rocks of Anglesey mentioned by Mr. Greenly, the Author stated that he had not examined them, but that, as in the West of England, it was possible to draw a broad mineralogical distinction between the Permian, the Pebble-Bed, and the Red Rocks of higher horizons, this might also be possible in other areas. In reply to Prof. Groom, the Author said that he had been so far unable to prove that any characteristic mineral had been derived from the ancient ridge of land to the north.

33. *The* Red Sandstone-Rocks *of* Peel (Isle of Man). By
William Boyd Dawkins, M.A., D.Sc., F.R.S., Professor of Geology in Owens College (Victoria University), Manchester.
(Read May 28th, 1902.)

[Plate XXXIII—Map.]

Contents.

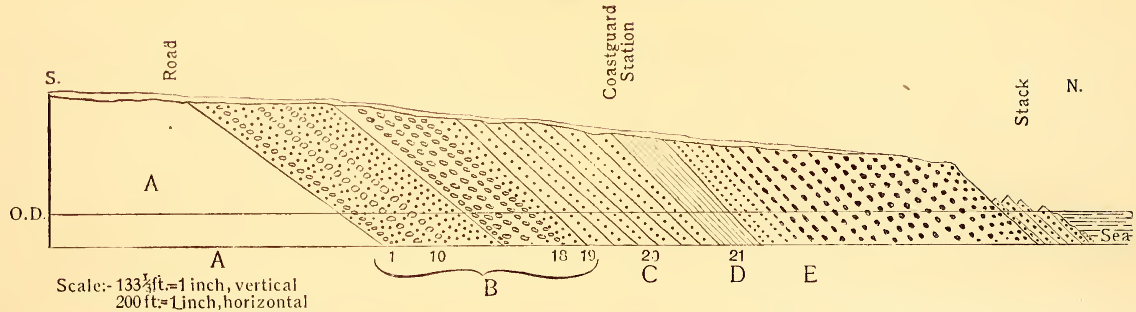
I. Introductory.

The Red Sandstone Series, ranging along the coast eastward from Peel to Will's Strand, is faulted into the Ordovician massif of the Isle of Man, and so covered with Drift that the only clear sections are to be found along the line of cliff, and in the quarries at Ballaquane. There is, therefore, little reason for surprise that it should have been assigned to various geological horizons. It has been referred to the Old Red Sandstone by Cumming, to the Calciferous Sandstones by Mr. Horne, and to the Permian by myself (in a paper read before the Manchester Geological Society in 1894), and by Mr. Lamplugh in 1896 to the Basement Carboniferous. It is so described by him in his Appendix to the British Association Handbook for 1896 (Liverpool), and is so represented in the Geological-Survey map of the island, and in the $\frac{1}{4}$-inch Geological Map of England and Wales, both published in that year. Since 1894, in continuation of my work in mapping the island on the 6-inch scale, I have collected further evidence as to its geological age, and have refreshed my memory by a visit to the most important localities in the Lake District where the Permians can be studied. The results of this enquiry are embodied in the following paper.

II. The Lower Red Sandstones and Brockrams of Ballaquane and Creg Malin.

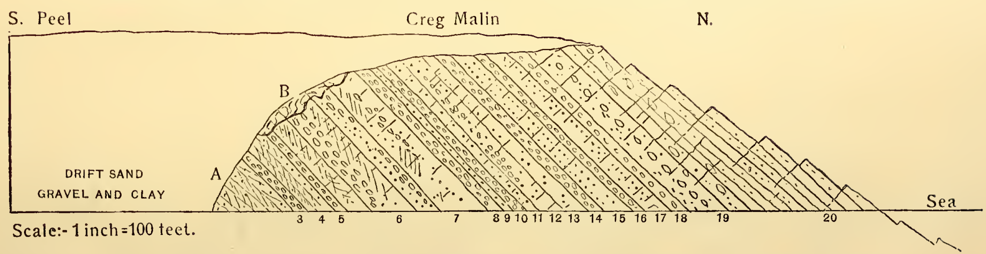
The Red Sandstones exposed in the cliffs at Creg Malin, and in the quarry at Ballaquane, dip at an angle varying from 37° to 46°, away from the Ordovician massif of the island, the exposures in

Fig. 1.—*Section from Ballaquane to Stack.*



[For the Explanation of the letters A–E in the above section, see p. 637.]

Fig. 2.—*Section at Creg Malin.* (A = *Ice-worn, and* B = *Ice-crushed rock.*)



[For the Explanation of the numerals in both the above sections, see pp. 635, 636.]

these two localities extending without a break as far south as the road to Kirk Michael (see Pl. XXXIII). They consist of Red Sandstones containing irregular conglomerates and breccias, more or less chemically altered, known in the Lake District as Brockram. They range under the Drift south of the road at Ballaquane to a distance of 800 feet, where they occur at a watering-place for cattle east of Ballaquane House.

In the Ballaquane Quarries the following section is exposed :—

		Thickness in feet.
19.	Conglomerates and thin sandstones .... about	25
18.	Red conglomerate	1
17.	Dull red sandstone, with pebbles	2
16.	Red conglomerate	2
15.	Bright red sandstone	0½
14.	Red conglomerate, with bright red marlstone-matrix...	3
13.	Dull red sandstone	2
12.	Red conglomerate, irregular	1½
11.	Dull red sandstone, irregular..................................	4
10.	Red conglomerate	1
9.	Dull red sandstone	4
8.	Red conglomerate, irregular	1
7.	Dull red sandstone	60
6.	Dull red sandstone, with thin marls........................	21
5.	Red conglomerate in two layers, irregular	4
4.	Dull red sandstone, mottled grey	30
3.	Red conglomerate, composed of pebbles and angular fragments, irregular..	2
2.	Bright red sandstone, mottled grey	58
1.	Dull red sandstone, with one layer (4 inches) of red marlstone-pebbles, with mica, red shale, and vein-quartz...	73
		295

These strata (fig. 1, p. 634) dip northward at an angle of 37°, and are 385 feet thick, including the unworked beds close to and north of the quarry. If this dip be maintained in those below them, concealed under the Drift to the south, 488 feet must be added, making a total thickness of 873 feet for the Ballaquane Series.

The chief interest in this section centres in the conglomerates and breccias. They consist of the following materials :—

c. Coarse grey micaceous sandstone-pebbles.
r. Red sandstone-pebbles.
c. Purple marlstone, rounded and angular.
c. Purple shale, rounded and angular.
r. Decalcified crinoidal limestone-pebbles.
r. Purple limestone-pebbles.
r. Grey limestone-pebbles.
r. Red chert, angular and rounded.
r. Black chert, angular and rounded.
r. White vein-quartz pebbles.
r. Red quartzite-pebbles.
c. Hæmatite-pebbles.
c. Chalcedony, mostly angular.

[*c* = common ; *r* = rare.]

These materials are irregularly piled together, and the oblong masses lie at various inclinations in the Red Sandstone-matrix, some with their long axes vertical. In fig. 3 I have represented the largest block in the quarry; it consists of purple shale, and measures 12 × 8 inches.

Fig. 3.—*Block of purple shale, Ballaquane Quarries.*

These strata strike towards Creg Malin, where they constitute the cliffs (fig. 2, p. 634). The details are as follows:—

		Thickness in feet.
19.	Conglomerate, breccias, and sandstones	(?)
18.	Conglomerate, with red shale-pebbles and blocks	4
17.	Red sandstone	10
16.	Conglomerate and breccias	4
15.	Red sandstone	10
14.	Conglomerate, with limestone-pebbles	4
13., 12., 11.	Dull red sandstone, with conglomerates and breccias	20
10.	Calcareous breccia (Brockram), with fossiliferous pebbles	4
9.	False-bedded red sandstone	2
8.	Calcareous breccia (Brockram), with fossiliferous pebbles	4
7.	Dull red sandstone, mottled grey, false-bedded	55
6*a*.	Irregular conglomerate, with limestone-pebbles	4
6.	Dull red sandstone, mottled grey, ripple-marked, false-bedded	12
5.	Irregular conglomerate, with limestone-pebbles	4
4.	Dull red sandstone, mottled grey, ripple-marked, false-bedded	30
		167

The three lowest beds of the quarries at Ballaquane are here concealed by the Drift, overlying the rounded, iceworn strata of No. 4. With the exception of No. 6 *a*, all the other beds are identical. The pebbles and breccias of the Brockrams, also, are practically the same. The limestone-pebbles, however, are more abundant, and the fossils which they contain are in a better state of preservation.

III. The Red Sandstones of the Gob and Traie Fogog.

The conglomerates and breccias, described above, dip seaward (see figs. 1 & 2, p. 634, and Pl. XXXIII) under dull red sandstones, with breccias containing blocks great and small of red, micaceous, marlstone and shale, with occasional pebbles of other rocks (No. 20 of figs. 1 & 2). They form the sea-front of the Gob and of Traie Fogog, dipping north 8° west at an angle of 46°. Their thickness, calculated along the line of section, from the north of Ballaquane Quarries to the Coastguard Station, is 325 feet. They in their turn plunge underneath bright red, mottled sandstones (No. 21 of fig. 1, p. 634) with thin marls, at the base of the cliff below the Coastguard Station. These are some 80 feet in thickness, ranging upward as far as the lowest bed of the Stack Series in Lhooby Reeast.

IV. The Upper Sandstones, Brockrams, and Limestones of the Stack Series.

The calcareous conglomerate-series at the eastern end of Traie Fogog presents the following section:—

		Thickness in feet.
7.	Bright red sandstone and calcareous conglomerates, with concretions of dolomite embedded in red paste .	20
6.	Irregular layer of dolomitized limestone and calcareous concretions, with conglomerate and red sandstone ...	8
5.	Red sandy marl, mottled grey ...	12
4.	Conglomerate, mainly of limestone-pebbles, in a red sandy magnesian matrix ...	5
3.	Red sandstone ...	4½
2.	Bright red, mottled marls, with grey calcareous concretions ...	10½
1.	Conglomerate, consisting mainly of limestone-pebbles, in a red sandy magnesian matrix ...	10
		70

The upper stratum, No. 7, passes into a series of ten thin beds of concretionary magnesian limestone, so irregularly distributed in the sandy Brockrams as to render an accurate description impossible. With them thin lenticular sandstones and red marls are so interlaced, that no two sections taken along the line of cliffs from Traie Fogog eastward to Lhooby Reeast agree. They are ripple-marked and sun-cracked, and were therefore accumulated in part between high- and low-water mark. The uppermost beds consist of Brockrams (conglomerates and breccias), plunging into the sea at the Stack, at an angle of 35°.

The total thickness, measured along the line of dip, is 426 feet, and the average dip is 40°, slightly to the west of north; the actual upper boundary is beneath low-water.

V. The Classification of the Rocks.

These rocks form one series, which may be conveniently subdivided as follows:—

			Thickness in feet.
E.	II. The Upper or Stack Series ...		426
	I. The Lower or Peel Sandstone Series...		1278
D.	Bright red sandstone ...about	80	
C.	Dull red sandstones of the Gob and Traie Fogog	325	
B.	Ballaquane and Creg-Malin Beds ...	385	
A.	Drift-covered sandstones ...	488	

The true base of these rocks is concealed by Drift, and is nowhere visible.

VI. The Range of the Peel Sandstones and Stack Series to the North-East along the Coast.

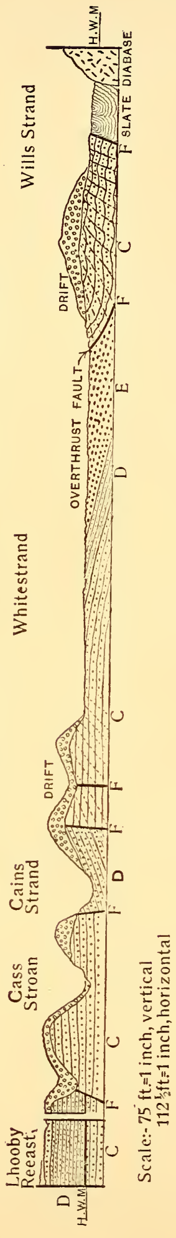


Fig. 4.—*Section along the coast, from Lhooby Reeast to Will's Strand.*

The Stack Series forms the headland to the north-east of Traie Fogog, and ranges as far as Lhooby Reeast, where the easterly trend of the coast brings in again the bright red and variegated beds below (fig. 4, D).

The cliffs and foreshore from Lhooby Reeast, for 1150 feet to the north-east, are formed of bright red sandstone, more or less mottled (fig. 4, D), dipping north 20° west at an angle of 40°. In the little bay south of Cass Stroan, they are faulted against the dull red sandstones with breccias of Traie Fogog (fig. 4, C). Here their dip is 34°, north 18° west, while that of the latter is 10°, north 18° west, the downthrow being to the south-west.

From this fault the dull red sandstones (C) with breccias and conglomerates, in some places sun-cracked and mottled grey, range along the coast with an uniform dip north 18° west, of 14°, as far as the fault in the headland, between Cass Stroan and Cain's Strand. At this point the red variegated sandstones (D) are thrown down against C, and are seen in the cliffs and foreshore of Cain's Strand, as far as the fault marked on the foreshore by a cave. To the north-east of this fault the cliffs are sheared and broken, as far as the south-western headland of Whitestrand Bay, the smashing culminating in a fault full of crushed rock about 20 feet broad. Still farther north-eastward the dull red sandstone-strata are unbroken, and dip gradually underneath the bright red and mottled beds (D). These pass underneath the Stack Series (E), which occupies the foreshore and forms the low cliff extending as far as an overthrust-fault, abruptly cutting them off close to the northern headland. At this point, the dull red sandstones of the lower series (C) rest upon the Stack Beds, and are folded, sheared, and smashed, as far as the southern portion of Will's Strand. Here they dip under the unbroken strata, ending in the north-east in a stack composed of breccia and conglomerate, close to the great fault that crosses the bay diagonally north and south, and throws down the Red Sandstone Series to the west into the black-and-grey soft phyllites of the Ordovician massif. (See fig. 4, p. 638, & Pl. XXXIII.)

VII. The Range of the Rocks Inland.

These rocks are bounded on the north-east by a fault clearly defined in the cliff and foreshore; and on the south-west at Creg Malin, by a reef which (from its being in a right line) probably is a fault-line. Still farther west the Drift-sands, clays, and gravels occupy the whole of the foreshore, and as far as the Ordovician slates on the western side of Peel Harbour, and St. Patrick's Isle. These Drift-deposits have been proved to the depth of 20 feet below the bottom of the harbour, and are of unknown depth. They rise to more than 100 feet above Ordnance-datum inland, filling up the pre-Glacial valley of Peel, and obscuring the exact boundary of the Red Sandstones below. The latter have, however, been struck in a boring south-east of Ballagyr, and occur in the fields south of that place, and east of Ballaquane House. They therefore extend as far as these points, and are so represented in the map (Pl. XXXIII).

There are also two small outliers of red sandstone and conglomerate near Glenfaba Bridge, which rest on the black rotten slate, their actual boundaries being concealed by Drift. That to the north of the bridge is entirely covered with Drift, and is only known from a shaft, 20 feet deep, sunk about the year 1840,[1] through Drift and 2 feet of red sandstone into the blue rotten slate. The second ranges from a fault, close to the south-western abutment of the bridge, over the lower portion of Mr. Corrin's garden, as far as Raggatt, and is proved to be surrounded by black rotten slate, in shafts and borings on the south, west,[2] and east,[3] and by exposures of slate to the north. On the south-east, it is concealed by alluvial sands and gravels.

If the map (Pl. XXXIII) be compared with my preliminary

[1] I am indebted to the late Mr. Robert Corrin and to Mr. Morrison for particulars of this and the following borings and sinkings in search of coal in this area.

[2] Two levels driven into slate by the Foxdale Mining Co., one under Raggatt House, the other to the north, about the year 1830.

[3] A borehole at a distance of 500 feet north-east from the bridge, made about 1864 by Messrs. Robert Corrin, Morrison, & Keown, yielded the following section:—

	Thickness in feet.	
Soil	2	150
Drift-clay, sand, and gravel	88	
Rotten shale	28	
Grey sandstone	2	
'Blue fox-clay' / Rotten shale	30	

The slate was also struck, in a shaft 20 feet deep, close to the south of Glenfaba millwheel, by the same explorers about the same time.

sketch-map, published in 1894 in the Transactions of the Geological Society of Manchester,[1] it will be noted that there are several differences, due mainly to my not having recognized the overthrust-faults at that time. The present map is the result of further examination.

If it be compared with that published by the Geological Survey, it will be found that there are important differences which need explanation. The area in my map is considerably smaller than that of Mr. Lamplugh's, and the direction and position of the south-western boundary-fault are different. With regard to the area inland, I have already pointed out that the southern boundary is concealed by Drift of considerable thickness, and that therefore it cannot be accurately ascertained without further evidence. In my map it is taken to be defined by the two faults and the exposures inland. In Mr. Lamplugh's it is enlarged by the assumption that the two outliers near Glenfaba belong to the main mass of the Sandstone, thrown down to the east by a fault running north 18° east from Glenfaba Bridge, through the Drift-covered area to the middle of Peel Bay. There is no evidence of this fault on the ground, excepting at Glenfaba Bridge, and that is too small an exposure to give its true direction. It will not explain the presence of the Red Sandstone on the west side of the fault, nor will it explain the presence of slate north-east of Glenfaba Bridge, or close to the millwheel. For these reasons I am unable to accept Mr. Lamplugh's map of these rocks.

VIII. Their Permian Age.

Nor can I accept Mr. Lamplugh's identification of the rocks with the Basement Carboniferous of the south of the island, at Langness and elsewhere. The sandy conglomerates resting on the slate of the massif, and dipping under the Carboniferous Limestone in that district, are composed of pebbles of sandstone and vein-quartz, and angular masses of slate stained red. They are derived, without exception, from the sandstones, slates, and phyllites of the Ordovician massif upon which they rest, and against which they abut. There are no chalcedonies, no hæmatites, no cherts, no limestone-pebbles, and the calcareous magnesian element is conspicuous by its absence. The red rocks of the north of the island are composed of materials derived from the waste of cliffs of Carboniferous Limestone, Yoredale Rocks, and of Keisley Limestone, without any trace of the Ordovician massif now visible at the surface. They have been torn away from a shore-line composed of Lower Carboniferous rocks and of limestones of Ordovician age. In the following table I have compiled a list of the materials which occur in the Brockrams of the Peel Sandstone and the Stack Series.

[1] 'Geology of the Isle of Man' Trans. Manch. Geol. Soc. vol. xxii, facg. p. 592.

TABLE OF MATERIALS FORMING THE LOWER BROCKRAMS OF THE PEEL SERIES, AND THE UPPER BROCKRAMS OF THE STACK SERIES.

	Lower Brockrams.		Upper Brockrams.		
	Ballaquane Quarry.	Creg Malin.	Traie Fogog. Lhooby Reeast.	Whitestrand.	Ballaghenny Boring.
Carboniferous Limestone, grey crinoidal ...	...	*	*	*	*
Do. do. red crinoidal ...	...	*	*	*	*
Do. do. pink crinoidal ...	...	...	*	*	*
Do. do. decalcified crinoidal	*				
Carboniferous chert, grey	*	*	*	*	
Do. do. black	*	*	*	*	
Do. do. red	*	...	...	*	
Yoredale shale, grey..................................	*	*	...	*	
Do. do. purple	*	*	*	*	*
Do. marlstone, purple......................	*	*	*	*	*
Do. sandstone, purple......................	*	*	*	*	*
Do. do. grey	*	*	...	*	*
Do. hæmatite	*	*	*	*	*
Do. chalcedony	*	*	*	*	
Micaceous grey sandstone	*	*	*		
Keisley Limestone, pink mottled	...	...	...	*	
Red quartzite	...	*	*		
White vein-quartz	*	*	*	*	

All these materials have been derived from rocks which form the Lower Carboniferous and the Ordovician Series in the Lake District, with the exception of the two last, which may belong to any older pebble-beach. The hæmatites (sometimes botryoidal) and the chalcedonies are especially characteristic, and are, so far as I know, only found together in the Lake District. The Keisley Limestone also is a Lake-District rock, occurring in the neighbourhood of Appleby.

It is, however, unnecessary to go to the Lake District for the source of most of these materials. The borings described in the next following paper (p. 647) reveal that Carboniferous Limestone and Yoredale rocks occur underneath the Glacial Drift covering the north of the Isle of Man; and a comparison of the cores with the pebbles under discussion proves, beyond doubt, that the latter were derived from Lower Carboniferous rocks, then forming cliffs in the north of the island. All the varieties of the pebbles of Carboniferous Limestone and Yoredale shales and sandstones are represented in the borings, with the exception of the decalcified crinoidal limestone. The decalcification of the last-named is doubtless due to its exposure, at the surface, to the attack of the carbonic acid contained in the rain-water.

If there be any doubt as to the post-Carboniferous age of these rocks, it is decided by the examination of the fossiliferous pebbles of both the Lower and the Upper Brockrams. The species which I have identified, by the kind assistance of Mr. E. T. Newton, F.R.S., and Mr. Rhodes, in the Museum of Practical Geology, Jermyn Street, are *Griffithides glaber* and *Chonetes Laguessiana*, from the Lower Brockram of Peel. The latter occurs also in the Upper Brockram of the Stack Series, at Lhooby Reeast. Both are Carboniferous species.

For the identification of a second series of species, of Ordovician age, I am indebted to Mr. Leonard Gill and Mr. F. R. Cowper Reed, M.A., F.G.S. They consist of *Plectambonites quinquecostata*, *Platyceras verisimile*, and *Illænus brevicapitatus* (a variety of *I. Bowmani*). These have been compared by Mr. Reed with the specimens in the Woodwardian Museum at Cambridge; and he identifies the limestone in which they occur with the Keisley Limestone, a rock restricted to one small inlier near Appleby. It is therefore obvious that the cliffs from which the Brockrams were torn were composed of Keisley Limestone, as well as rocks of Carboniferous age in the region of the Isle of Man, and that the Brockrams are, on the whole evidence, post-Carboniferous.

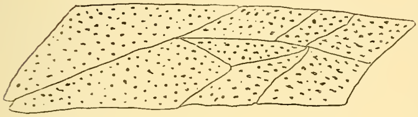
The detailed account of the fossils of the Keisley Limestone in the Manx Brockrams must be reserved for a future paper. It is sufficient to note here that it has contributed largely to the pebbles in the Upper Brockrams at Whitestrand, while it has not as yet been identified in the Lower or Peel Series.

A comparison of the rocks under discussion with the Permian of Barrowmouth near Maryport, and of the Vale of Eden near Appleby and Kirkby Stephen, so well described by Sedgwick, Binney, Eccles, Harkness, Nicholson, and others, proves that the sequence is of the same general order. The section at Barrowmouth shows about 5 feet of Brockram resting, unconformably, upon the waterworn surface, and passing into a Magnesian Limestone about 8 feet thick. In the Vale of Eden the Penrith Sandstones, some 2000 feet thick, contain Brockrams mainly massed in the lower and upper divisions, as is the case with the Peel Sandstones and Stack Conglomerates. They are chiefly composed of materials derived from the break-up of the Carboniferous rocks. The hæmatites, cherts, chalcedonies, and pebbles of Carboniferous Limestone and Yoredale rocks are the same in the Brockrams of both these districts. In Hilton Beck, the Penrith Sandstones dip under a series of marls and sandstones, with one layer of limestone 4 feet thick, and these again underlie Triassic sandstones. Both the Peel Sandstone and that of Penrith represent the Rothliegende, or Lower Permian of the Continent. The Stack Series may be referred either to the concluding phase of that subdivision, or to the beginning of the period of the Magnesian Limestone, so well developed on the eastern side of the Pennine Chain.

IX. The Shearing and Faulting.

These Permian rocks are sheared and faulted to an extraordinary degree, and their presence on the coast-line of the Isle of Man is due to their being let down into the Ordovician massif by the two boundary-faults, to the north and to the south. As we traverse the coast-line from Peel towards Will's Strand, there are two areas which need special notice (fig. 4, p. 638, & Pl. XXXIII): the foreshore and headland, between Cain's Strand and Whitestrand, and those between the latter and Will's Strand. In the first of these, a fault traverses the headland and runs across the foreshore in a direction west 18° north, by which the Gob Sandstones (C) have been thrust over the bright red, mottled sandstones of D. Along this line the rocks are sheared, the planes of shearing intersecting the planes of bedding, and dividing the rock into lenticular and diamond-shaped masses, with surfaces more or less scored or slickensided. Close to the cave on the foreshore, the shearing is parallel to the fault (fig. 5). To the north of this fault the headland is sheared, and is traversed by a second fault (? overthrust), 20 feet wide, full of smashed angular blocks, both great and small. This occupies the foreshore to the south of Whitestrand, where we may observe that the red colour of the rocks has been discharged along the lines of crush. To the north of Whitestrand, the same division of the Peel Sandstone (C) has been thrust over the Stack Series (E) in a southerly direction, along a gentle ascending plain (see fig. 6, p. 644). Here the crushing is most marked, the sandstone being crushed into the marls, and both presenting characteristic lenticular shearing-structure. The whole of the headland on the north is sheared, folded, and broken, up to the northern boundary-fault, the dull red sandstones being folded, and the thin interstratified marls being crushed and squeezed out of their normal position.

Fig. 5.—*Sheared sandstone parallel to the fault, Cain's Strand.*

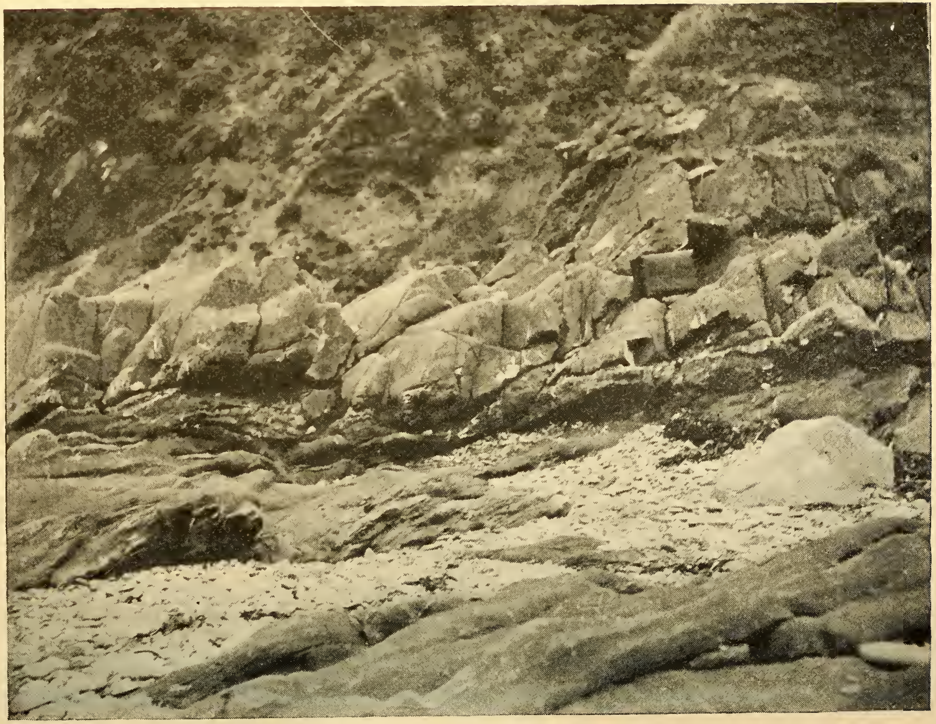


[A length of 8 feet is shown.]

The age of these disturbances is taken by Mr. Lamplugh [1] to be post-Carboniferous and pre-Permian. He assigns it rightly, in my opinion, to the same period as the remarkable overthrust-faults in the Carboniferous Limestone and volcanic rocks of the south of the island. As the rocks under consideration are Permian, the period of the faulting is clearly post-Permian. It belongs probably to the great system of earth-movement, which has left its mark in the Axis of Artois in Northern France, Somerset, South Wales, and Ireland, which took place in the interval between the latest Palæozoic and the earliest Mesozoic rocks. That it is pre-Triassic is proved by the fact that the Triassic rocks, in the borings in the north of the island, overlie these Permian rocks unconformably, occupying the same relation to them as the Triassic to the Permian, on the flanks of the Pennine Chain. These disturbances in the Permian of the Isle of Man are represented in the Upper Eden Valley by the high and irregular dips of

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 22.

Fig. 6.—*Overthrust fault, north of Whitestrand.*



[FF = Fault-line ; C = Gob Sandstones ; E = Stack Series.]

Fig. 7.—*Sheared Gob Sandstones, at the headland north of Whitestrand.*

the rocks of the same age. The only other two periods of disturbance at a later date, in the British Isles, with which these overthrust-faults can be compared, are those of Dorset, belonging to the Cretaceous age,[1] and those of the Isle of Wight and of the South of England, which are post-Miocene and pre-Pliocene.

X. The Probable Source of the Iron in the Red Rocks.

In the course of the examination of the Permian rocks dealt with in this paper, and of those revealed in the borings described in the next following, I have had to consider the question of the origin of the large quantity of iron present in the Permian and Triassic strata. This iron in many cases, both in the Isle-of-Man borings and in the Lake District, has replaced the calcium-carbonate of the Carboniferous and Yoredale Limestones. The idea that it might have been derived from the break-up of the Carboniferous shales was suggested to me by Prof. Lapworth. The large quantity of iron, present not only as sulphide but as carbonate, in the shales of the Yoredale Series, Millstone Grit, and Coal-Measures, is more than sufficient to account for all the iron, when it is considered that several thousand feet of shales have been denuded away, from an area of many hundreds of square miles, in the Northern Counties before the Permian age, and during the time that the Permian and Triassic strata were being accumulated. It is more than sufficient to account for the hæmatites of Barrow and other districts, which have long been recognized as post-Carboniferous. The landlocked seas, of Permian and Triassic age, in the area under consideration, would allow of the accumulation of highly ferruginous rocks in the areas which they now occupy. I do not know of any other hypothesis which will explain the facts. It is very likely that the break-up of the Silurian and Ordovician shales has, in like manner, resulted in the accumulation of iron in the landlocked basins of Old-Red-Sandstone times.

XI. Conclusion.

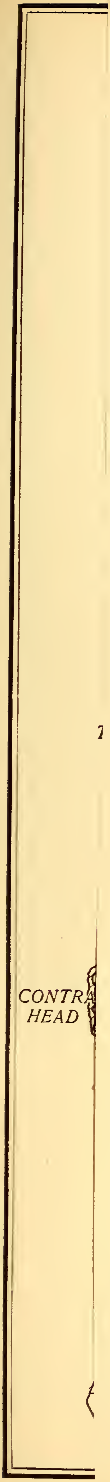
In this paper I have laid before the Society the evidence as to the Permian age of the rocks under consideration. They fall naturally into line with the Permian of England and of the Continent. Their true base is not seen in the Peel District: they are, however, proved, in the borings in the north of the island (described in the next following paper) to rest there unconformably upon the Carboniferous rocks, and to be covered by the same series of Triassic strata as those that overlie the Permian in the adjacent parts of England, in the Lake District, in Lancashire, and in Cheshire.

EXPLANATION OF PLATE XXXIII.

Geological map of the neighbourhood of Peel (Isle of Man), on the scale of 2 inches to the mile.

[For the Discussion, see p. 660.]

[1] A. Strahan, Quart. Journ. Geol. Soc. vol. li (1895) p. 549.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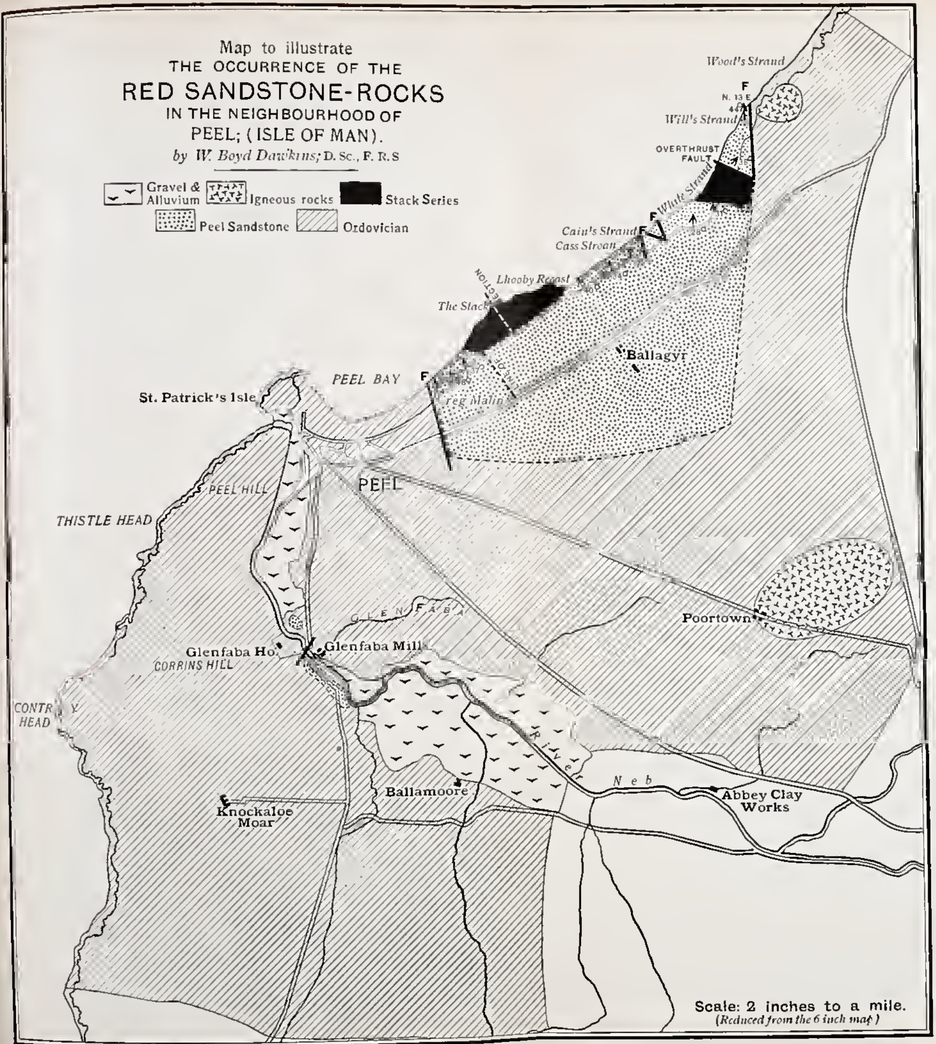

Map to illustrate
THE OCCURRENCE OF THE
RED SANDSTONE-ROCKS
IN THE NEIGHBOURHOOD OF
PEEL; (ISLE OF MAN).
by W. Boyd Dawkins; D. Sc., F. R. S
Gravel & Alluvium
Igneous rocks
Stack Series
Peel Sandstone
Ordovician
Wood's Strand
Will's Strand
OVERTHRUST FAULT
White Strand
Cain's Strand
Cass Stroan
Lhooby Reeast
SECTION
The Stack
Ballagyr
PEEL BAY
St. Patrick's Isle
PEEL
PEEL HILL
THISTLE HEAD
GLEN FABA
Poortown
Glenfaba Ho.
Glenfaba Mill
CORRINS HILL
CONTRARY HEAD
River Neb
Ballamoore
Abbey Clay Works
Knockaloe Moar
Scale: 2 inches to a mile.
(Reduced from the 6 inch map)

34. *The* CARBONIFEROUS, PERMIAN, *and* TRIASSIC ROCKS *under the* GLACIAL DRIFT *in the* NORTH *of the* ISLE *of* MAN. By WILLIAM BOYD DAWKINS, M.A., D.Sc., F.R.S., Professor of Geology in Owens College (Victoria University), Manchester. (Read May 28th, 1902.)

[Map on p. 656.]

CONTENTS.

I. INTRODUCTORY.

THE whole of the Isle of Man, north of a line drawn due west from Ramsey, is covered with a thick mantle of Glacial Drift, forming a plateau rising, in some places, to a height of more than 100 feet above the sea. South of this, obviously a shore-line, the iceworn Ordovician massif of the island rises in a series of precipitous hills, culminating in Snaefell. The contrast, between the northern plain and the southern hills, is so marked, that it raises the question as to whether the Ordovician rocks are continued in the shape of a seaworn plateau, covered by Drift; or whether, in this concealed area, other and newer rocks occur, similar to those surrounding the Ordovician massif of the Lake District, of Carboniferous, Permian, and Triassic age. It was not improbable that the Coal-Measures of Whitehaven might extend beneath the sea in this direction. The question has been solved by a series of six borings, carried on under my advice from 1891 to 1898 by Messrs. Craine, and under the able direction of Mr. John Todd, to whom I am indebted for the journals from which the sections have been prepared. Of the specimens, from which the strata have been identified, some are in the Manchester Museum, Owens College, some in the Museum of Practical Geology, Jermyn Street, London, and some in the possession of the engineer at Ramsey. The borings are all close to the coast-line, starting from a plateau of sand and gravel, at about 20 feet above Ordnance-datum. They have proved that the Carboniferous Limestone, the Yoredale rocks, and the Permian and Triassic Series, lie buried under the Drift in the northern plain.

II. BORING NO. 1, AT LHEN MOAR.

The westernmost of the series is at Lhen Moar, about 270 yards north of 'The Park' on Sheet No. II of the 6-inch Ordnance-map of the Isle of Man. (See also fig. 1, p. 656.)

It presents the following section [1]:—

	Depth. Feet.	Thickness. Feet.
Sand and shingle	12	12
Glacial sand, shingle, and silt	167½	155½
Grey crinoidal Carboniferous Limestone, dipping 40°	233	65½

At this point the boring was stopped, as it was obviously of no use to sink in search of coal below the Carboniferous Limestone. The discovery of this limestone is an important addition to our knowledge of the geology of the north of the island.

III. Boring No. 2, at Ballawhane.

The next boring, in passing north-eastward along the coast, is at Ballawhane, near Blue Point (6-inch Map No. II), at a distance of about 1400 yards from Lhen Moar. It yielded the following section:—

	Depth. Feet	Depth. inches.	Thickness. Feet	Thickness. inches.
Sand and shingle	16	0	16	0
Glacial sand, shingle, silt, and Boulder-Clays	171	0	155	0
TRIASSIC.				
Red micaceous sandstones, with subordinate grey sandstones and thin red marls with occasional pebbles of red marl	544	2	373	2
LOWER CARBONIFEROUS.				
YOREDALE SERIES	679	5	136	3
Red shale, with slickensides	568	2	24	0
Sandy marl, with carbonaceous specks	577	6	9	4
Brown marly crinoidal limestone and conglomerate	578	4	0	10
Pink and grey crinoidal limestone	585	6	7	2
Blue limestone	587	6	2	0
Red earthy limestone	590	6	3	0
Brown, fine-grained sandstone, crushed	602	8	12	2
Crushed red and purple calcareous marls	612	8	10	0
Brown sandy marl	613	2	0	6
Soft purple marl	627	0	13	10
Calcareous sandy red conglomerate, with crinoids	630	9	3	9
Dark shale	633	11	3	2
Purple sandy marl, with conglomerates	656	0	22	1
Grey calcareous marls	664	9	8	9
Dark-grey shale, crushed	679	5	14	8
CARBONIFEROUS LIMESTONE	717	4	37	11
Compact grey limestone, with hæmatite	691	3	11	10
Grey crinoidal limestone, in places converted into hæmatite	697	6	6	3
Grey compact limestone	698	0	0	6
Red limestone	699	0	1	0
Grey crinoidal limestone	706	4	7	4
Grey limestone	714	10	8	6
Mottled grey-and-red crinoidal limestone	717	4	2	6

[1] The details of this section will be found in 'The Geology of the Isle of Man' Trans. Manch. Geol. Soc. vol. xxii (1894) p. 598.

The red sandstones, underneath the Glacial Drift, are identical in their physical characters with the St. Bees Sandstone in Cumberland, and are of Triassic age. They dip at an angle of 8°. The details of this portion of the section are to be found in the paper read before the Manchester Geological Society, already quoted, and also in vol. xxiii, pt. 1 of that Society's Transactions, and therefore need not be repeated here.

The purple, red, and grey shales, marls, and marlstones, below the Triassic strata, are very much sheared and crushed. At depths respectively of 627 and 657 feet from the surface, the boring-tool passed through a conglomerate-breccia, indistinguishable from some of the Permian Brockrams, to which they were referred in the above-quoted paper. The specimens, however, which I have examined in the Museum at Jermyn Street (by the kindness of Mr. Lamplugh) prove that the strata, both above and below, are of Lower Carboniferous age. They are identical with the type of Yoredale rocks which surrounds the massif of the Lake District and ranges far over the adjacent parts of Yorkshire. I can only account for the breccias in these rocks by the hypothesis that they occupy lines of fault, filled with the crushed adjacent rocks of Yoredale age, from the break-up of which the Brockrams elsewhere have been largely constituted. These Yoredale rocks dip at an angle of 35°, at points respectively of 611 feet and 686 feet below the surface.

The thickly-bedded limestones beneath belong to the Carboniferous Limestone, and have been more or less hæmatitized in irregular patches.

IV. Boring No. 3, at Knock-e-Dooney.

The boring at Knock-e-Dooney, near Rue Point (6-inch Ordnance-map, No. II), at a distance of about 1536 yards north-east of that at Ballawhane, traversed the following strata :—

	Depth.		*Thickness.*	
	Feet	inches.	Feet	inches.
Glacial Drift	173	0	173	0
Sand, with stones	16	0	16	0
Sand and shingle	36	0	20	0
Clayey sand, with fragments of coal	76	0	40	0
Sandy clay	101	0	25	0
Clayey sand, with fragments of coal	116	0	15	0
Sand	150	0	34	0
Clayey sand	163	0	13	0
Clayey gravel	173	0	10	0
Triassic Sandstone	605	3	432	3
Red sandstone	181	8	8	8
Grey do.	182	0	0	4
Red do.	186	2	4	2
Grey do.	186	3	0	1
Red do.	189	1	2	10
Grey do.	189	3	0	2
Red do.	191	11	2	8
Grey do.	192	2	0	3
Red do.	195	11	3	9
Grey do.	196	1	0	2

	Depth.		Thickness.	
	Feet	inches.	Feet	inches.
Red sandstone	196	5	0	4
Grey do.	196	7	0	2
Red do.	215	7	19	0
Red shaly sandstone	217	1	1	6
Red sandstone	219	10	2	9
Red do.	227	4	7	6
Grey do.	227	6	0	2
Red do.	248	0	20	6
Grey do.	248	2	0	2
Red do.	252	4	4	2
Grey do.	252	6	0	2
Red do.	262	9	10	3
Grey do.	262	11	0	2
Red sandstone and grey sandy marls	285	4	22	5
Red sandstone	287	10	2	6
Grey do.	287	11	0	1
Red do.	293	1	5	2
Grey do.	293	4	0	3
Red do.	298	8	5	4
Brown sandy shale	298	10	0	2
Red and subordinate grey sandstones, with partings of shale or marl, as above	505	5	206	7
Red sandstone	506	11	1	6
Brown shale	516	11	10	0
Red sandstone	521	6	4	7
Brown shale	529	2	7	8
Red sandstone	541	2	12	0
Brown shale	548	2	7	0
Red sandstone	557	2	9	0
Red gritty marl	583	2	26	0
Red sandstone	584	8	1	6
Brown shale	596	5	11	9
Sandy variegated shale	596	11	0	6
Red sandstone, with carbonaceous specks	605	3	8	4
PERMIAN	662	10	57	7
Red and brown marly sandstones, with Brockram-grains	634	7	29	4
Coarse red sandstone	638	1	3	6
Dark red marlstone	642	1	4	0
Dark red sandstone	646	0	3	11
Dark red marlstone	649	0	3	0
Sandy marl	653	9	4	9
Coarse red calcareous sandstone, passing into Brockram	658	1	4	4
Brockram, with pebbles of crinoidal limestone	660	4	2	3
Coarse red and grey sandstones, with Brockram	662	10	2	6
(?) Fault.				
LOWER CARBONIFEROUS.				
YOREDALE SERIES	945	10	283	0
Purple micaceous sandstones, marls, and shales, grey and black shales with clay-ironstone nodules, crinoidal stems, and sometimes gypsum	790	8	127	10
Grey crinoidal limestone	792	10	2	2
Dark blue and black shales, with clay-ironstone nodules, exhibiting joint-planes filled with gypsum	865	8	72	10
Red, blue, and purple shales, with hæmatite	894	4	28	8

	Depth.		Thickness.	
	Feet	inches.	Feet	inches.
Fine grey sandstone, with clay-ironstone............	908	10	14	6
Black and blue shales, with clay-ironstone and iron-pyrites	945	10	37	0
CARBONIFEROUS LIMESTONE	961	0	15	2
Grey limestone	949	6	3	8
Grey shaly crinoidal limestone	950	4	0	10
Dark shale	951	10	1	6
Grey crinoidal limestone	957	10	6	0
Grey earthy limestone	960	4	2	6
Grey crinoidal limestone, stained red, with *Rhynchonella*..	961	0	(?)	

The Triassic sandstones below the Drift, in this section, are the same as those in the preceding section, and dip at an angle of 7°, as compared with that of 8° at Ballawhane.

The red sandstones, and marlstones, below the Triassic sandstone, are assigned to the Permian age, because they contain conglomerate-breccias, formed of Yoredale rocks and Carboniferous Limestone, embedded in a calcareous paste, and presenting the curious physical characters of the Brockrams of Cumberland and the Vale of Eden. They are identical physically with those which are exposed on the shore to the north-east of Peel, described in the preceding paper (p. 637). Here they are of especial interest, because they rest upon the Carboniferous rocks from which they have been torn.

The Yoredale rocks are of the usual Lake-District type, and like them are more or less hæmatitized. They dip at an angle of 30°, at depths of 675 and 716 feet from the surface.

The Carboniferous Limestone below is of the usual crinoidal type, and is locally stained red.

V. BORING NO. 4, AT BALLAGHENNEY.

The fourth boring, about 3600 yards east and north of the last-described borehole, yielded the following results:—

	Depth.		Thickness.	
	Feet	inches.	Feet	inches.
GLACIAL DRIFT.................................... ...	212	4	212	4
Sand and stones	15	0	15	0
Shingle	42	0	27	0
Sand	78	0	36	0
Clay	112	0	34	0
Sand, gravel, and clay.......................................	138	8	26	8
Sand	211	0	73	0
Gravel	212	4	0	8
TRIASSIC SANDSTONE...........................	956	1	743	9
Red and grey micaceous sandstones, with subordinate layers of marl, as in the preceding section.	649	0	436	8
Red sandstone, with conglomerate	671	3	22	3
Red and grey micaceous sandstones as before......	956	1	284	10
PERMIAN	1040	10	84	9
Red sandy marl	1003	10	47	9
Brown marls and coarse sandstones	1017	10	14	0

	Depth. Feet	Depth. inches.	Thickness. Feet	Thickness. inches.
Brockram: conglomerate, with pebbles of red crinoidal limestone and hæmatite	1018	4	0	6
Sandstone, with Brockram	1021	4	3	0
Red calcareous Brockram and sandy marls, with crinoidal limestone-pebbles	1040	10	19	6
LOWER CARBONIFEROUS.				
YOREDALE SERIES	1281	0	240	2
Red, purple, and grey micaceous sandstones, with subordinate layers of shale, marlstone, and earthy limestone and patches of hæmatite, and containing *Stigmaria*, *Lepidodendron*, and other plants	1209	11	169	1
Sandy purple limestone, with crinoids	1214	5	4	6
Calcareous shale	1217	11	3	6
Red sandstone	1218	3	0	4
Earthy limestone	1219	2	0	11
Grey and purple marlstone	1225	8	6	6
Grey limestone	1229	10	4	2
Purple and grey crinoidal limestone	1232	1	2	3
Purple and grey marlstone, with carbonaceous fragments	1235	5	3	4
Purple and grey marlstone	1242	11	7	6
Purple and grey crinoidal limestone	1243	7	0	8
Shaly sandstone	1245	11	2	4
Purple and grey marlstone, sheared	1246	0	0	1
Compact grey limestone	1255	0	9	0
Earthy red limestone	1260	0	5	0
Earthy red sandy limestone	1262	0	2	0
Purple and grey marlstone, with gypsum	1265	0	3	0
Light purple calcareous sandstone	1270	0	5	0
Purple and grey marlstone	1272	0	2	0
Purple and grey marlstone, with *Productus*	1276	0	4	0
Red crinoidal limestone	1277	0	1	0
Breccia, red sandy calcareous, sheared, probably in the line of fault	1281	0	4	0

The Triassic, Permian, and Yoredale Series are the same as in the preceding section. The last-named dip at an angle of 33° at a depth of 1057 feet from the surface, and at 1070, 1202, and 1243 feet at an angle of 30°.

The Permian strata in both these sections are remarkable for their thinness, and for the absence of the massive lower sandstones of Peel. It must, however, be noted that precisely the same contrast is visible when the Permian rocks of Barrowmouth are compared with those of the Vale of Eden.

VI. Boring No. 5, at Point of Ayre.

The fifth boring, at the Point of Ayre, close to the lighthouse, 3566 yards north-east of No. 4, adds the Triassic marls and a new saltfield to the geology of the Isle of Man. It yields the following section [1]:—

[1] For further details as to this section, see Trans. Manch. Geol. Soc. vol. xxii (1894) p. 600.

	Depth.		*Thickness.*	
	Feet	inches.	Feet	inches.
GLACIAL DRIFT, as before	298	0	298	0
TRIASSIC MARLS	680	0	382	0
Red, brown, and grey gypseous marls, with traces of salt	615	5	317	5
Brine-run	617	11	2	6
Blue and grey marlstone and marl	635	2	17	3
ROCK-SALT	659	2	24	0
Grey marlstone, with salt	663	2	4	0
ROCK-SALT	672	8	9	6
Brown marl	680	0	7	4

VII. BORING NO. 6, AT POINT OF AYRE.

The discovery of salt at Point of Ayre, close to the lighthouse, has been followed up by a second borehole about 400 yards south-east of borehole No. 5. It presents the following section:—

	Depth.		*Thickness.*	
	Feet	inches.	Feet	inches.
Shingle	16	0	16	0
GLACIAL DRIFT	364	0	348	0
Gravel and sand	56	0	40	0
Sand	68	0	12	0
Sand and gravel	105	0	37	0
Hard sand	113	0	8	0
Boulder-Clay	148	0	35	0
Sand	154	0	6	0
Sandy Boulder-Clay	164	0	10	0
Red clay	167	0	3	0
Boulder-Clay	221	0	54	0
Gravel, with shells	222	0	1	0
Sand	229	0	7	0
Muddy sand, with shells	241	0	12	0
Red sand	277	0	36	0
Sand and gravel, with fragments of coal	281	0	4	0
Gravel	316	0	35	0
Coarse clayey gravel	325	0	9	0
Red sand	349	0	24	0
Gravel	355	0	6	0
Clayey sand and gravel, with boulders	364	0	9	0
TRIASSIC MARLS	922	4	557	4
Disturbed marls	545	0	181	0
Red gypseous marls, broken up	429	0	65	0
Brown marl, with gypsum	501	0	72	0
Gypsum and sandy marl	503	0	2	0
Brown and grey gypseous marls	545	0	42	0
Undisturbed saliferous marls	922	4	376	4
Brown marl, with gypsum	548	0	3	0
Brown and grey marl, with gypsum	556	0	8	0
Grey marlstone, with gypsum	569	0	13	0
Brown and grey marl, with gypsum	574	0	5	0
Grey marlstone	576	0	2	0
Brown and grey marl	578	0	2	0
Grey marlstone	586	0	8	0
Brown marl, with veins of gypsum	588	6	2	6
Brown marl, with SALT	589	2	0	8
Brown marl	593	2	4	0
Grey marlstone, with beds of gypsum	595	2	2	0
Grey marlstone, with SALT	595	4	0	2

	Depth.		*Thickness.*	
	Feet	inches.	Feet	inches.
Grey marlstone, with beds of gypsum	596	4	1	0
Brown marl, with veins of gypsum	599	3	2	11
Brown and grey marl, with beds and veins of gypsum	605	3	6	0
Rock-salt (1)	617	9	12	6
Brown and grey marlstone, with salt	620	9	3	0
Rock-salt (2)	629	3	8	6
Brown and grey marlstone, with salt	635	9	6	6
Rock-salt (3)	637	3	1	6
Brown and grey marlstone, with salt	639	6	2	3
Rock-salt (4)	640	6	1	0
Brown and grey marlstone, with salt	646	6	6	0
Rock-salt (5)	647	0	0	6
Brown marl, with salt	652	6	5	6
Rock-salt (6)	656	6	4	0
Grey marlstone, with salt	657	0	0	6
Brown marl	668	6	11	6
Rock-salt (7) with about 50 per cent. of marl	672	2	3	8
Brown marl	679	2	7	0
Rock-salt (8) with about 25 per cent. of marl	682	2	3	0
Brown marl, with about 30 per cent. of salt	683	6	1	4
Rock-salt (9)	684	0	0	6
Brown marl	691	8	7	8
Brown marl, with salt	694	4	2	8
Brown and grey marlstone	700	4	6	0
Rock-salt (10)	702	10	2	6
Blue marlstone	704	2	1	4
Blue marlstone (with about 10 per cent. of salt)	707	0	2	10
Rock-salt (11)	723	0	16	0
Brown marl	724	9	1	9
Rock-salt (12)	726	3	1	6
Brown and grey marl	731	0	4	9
Brown marl, with salt	732	0	2	0
Rock-salt (13)	733	6	0	6
Brown marl	735	6	2	0
Brown marl, with salt	737	0	1	6
Blue marlstone	740	0	3	0
Blue marlstone, with salt	740	8	0	8
Brown and grey marlstone	750	4	9	8
Rock-salt (14)	751	4	1	0
Brown and grey marlstone	755	0	3	8
Rock-salt (15)	755	10	0	10
Rock-salt, with about 20 per cent. of marl	762	2	6	4
Rock-salt	765	0	2	10
Rock-salt, with about 20 per cent. of marl	769	0	4	0
Blue marlstone	770	3	4	3
Brown and blue marl, with salt	782	7	9	4
Rock-salt (16)	784	4	1	9
Brown and blue marl (with about 30 per cent. of salt)	794	6	10	2
Rock-salt (17)	808	6	14	0
Brown and blue marl, with salt and veins of gypsum	824	[illegible]	16	2

	Depth. Feet	Depth. inches.	Thickness. Feet	Thickness. inches.
ROCK-SALT (18) with about 50 per cent. of marl	827	6	2	10
Brown and blue marl, with veins of gypsum	831	10	4	4
ROCK-SALT (19) with about 50 per cent. of marl	833	7	1	9
Brown and blue marl, with SALT and veins of gypsum	835	11	2	4
ROCK-SALT (20)	837	8	1	9
Brown and blue marl, with SALT and beds and veins of gypsum	842	0	4	4
Bottom of 8-inch borehole	842	0		
Commenced with 5-inch borehole	842	0		
Brown and blue marl, with SALT and beds and veins of gypsum	854	2	12	2
ROCK-SALT (21)	859	8	5	6
Brown marl, with SALT	864	2	4	6
Soft brown and blue marl, with SALT and gypsum	877	8	13	6
Soft brown sandy marl, with gypsum	903	0	25	4
Soft brown marly sandstone	904	0	1	0
Brown sandy marl	916	4	12	4
Soft brown marly sandstone	919	8	3	4
Soft brown and grey sandstone	921	2	1	6
Bluish-grey sandstone	922	4	1	2
	922	4	922	4

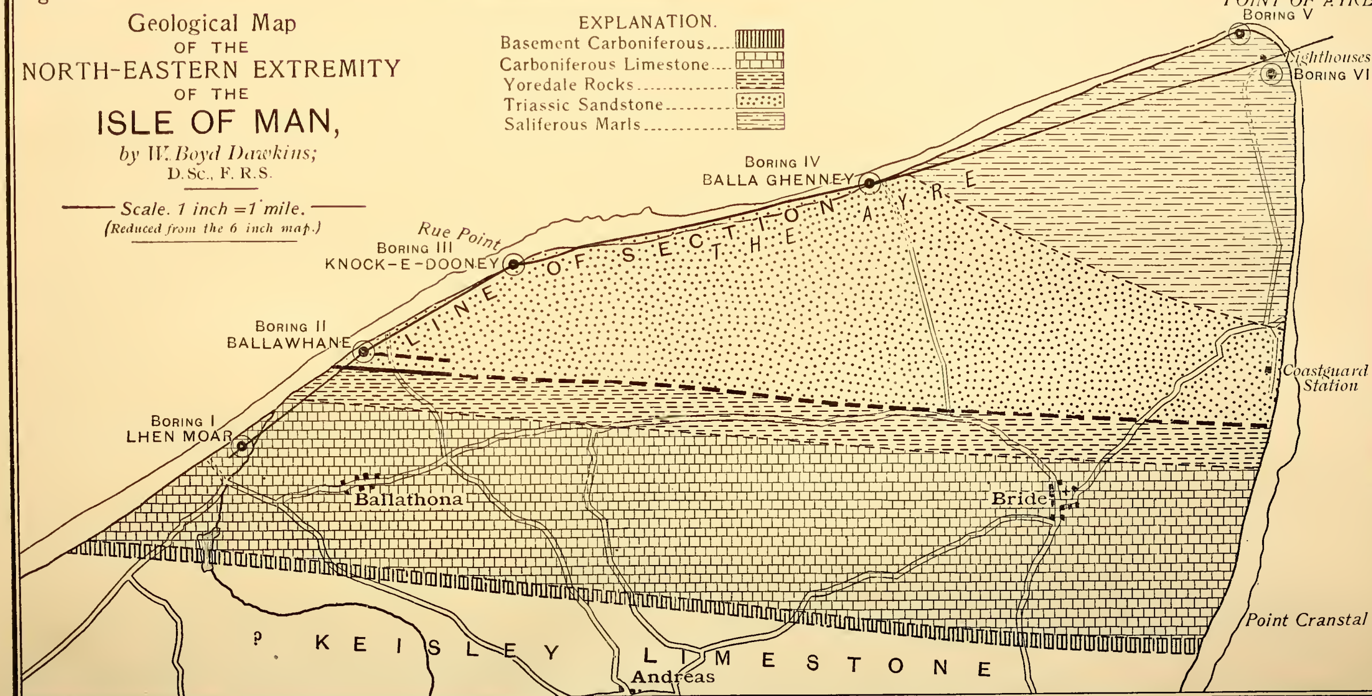
VIII. THE MANX SALTFIELD.

The total thickness of pure rock-salt in this borehole is 76 feet 8 inches; of rock-salt containing 20 per cent. of marl, 10 feet 4 inches; of that containing 25 per cent. of marl, 2 feet; and of that containing 50 per cent. of marl, 8 feet 3 inches. To these must be added marl containing about 30 per cent. of salt, 11½ feet.

The discovery of salt in these two boreholes is likely to be of great commercial value to the island, and is a fitting reward to Messrs. Craine for their persistence in carrying out the boring in search of coal. Looking at the evidence of the other boreholes. I could not advise them to sink deeper, on the chance of striking the Coal-Measures of Whitehaven. These, if they exist at all at this spot, lie buried beneath an unknown thickness of Triassic marls, and not less than 800 feet of Triassic sandstone, and with the additional chance of the occurrence of Permian strata. It is very probable that the Yoredale rocks, and not the Coal-Measures, form the floor, upon which the newer Red Rocks have been deposited in this area.

The unexpected presence of the Saliferous Marls is a link uniting the Triassic strata of the north of the island with those of Barrow on the one hand, and Carrickfergus on the other. It is very probable that these three saltfields belong to one great saliferous basin, underlying the Irish Sea, extending southward and eastward to join that of Fleetwood, and to the south in the direction of the great saltfield of Cheshire. It is now divided from

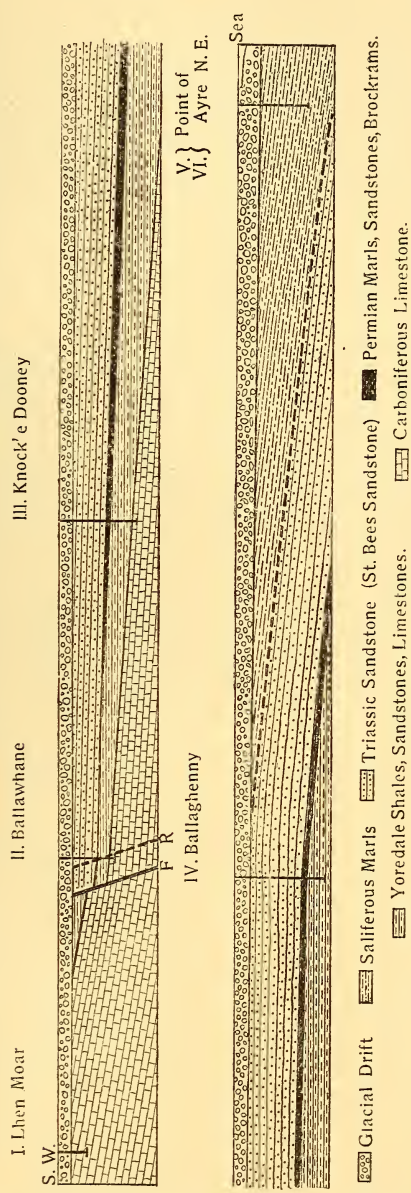
Fig. 1.


Geological Map
OF THE
NORTH-EASTERN EXTREMITY
OF THE
ISLE OF MAN,
by W. Boyd Dawkins;
D.Sc., F.R.S.
Scale. 1 inch = 1 mile.
(Reduced from the 6 inch map.)
EXPLANATION.
Basement Carboniferous
Carboniferous Limestone
Yoredale Rocks
Triassic Sandstone
Saliferous Marls
POINT OF AYRE
BORING V
Lighthouses
BORING VI
BORING IV
BALLA GHENNEY
LINE OF SECTION
THE AYRE
Rue Point
BORING III
KNOCK-E-DOONEY
BORING II
BALLAWHANE
BORING I
LHEN MOAR
Coastguard
Station
Ballathona
Bride
Point Cranstal
? KEISLEY LIMESTONE
Andreas

the last by the anticline of Keuper and Bunter sandstones of the district between Chester, Runcorn, Warrington, and Liverpool. How far the Manx salt-field extends southward under the Drift-covered Point of Ayre remains to be proved.

If the sections of the two boreholes (5 & 6) at the Point of Ayre be compared, it will be observed that the Triassic marls, in that which is farthest to the north, were struck at a depth of 298 feet from the surface, while in the other they were struck at 364 feet. The layers of rock-salt too in the first of these do not agree in their position with those of the second. It must also be noted that the Upper Triassic marls in the southern borehole, No. 6, are disturbed, and present the same physical characters as those of the red marls on the edge of the saliferous basin of Cheshire, and of those ranging from Burton in the direction of Tutbury and Rolleston. In these districts the rock has been disturbed, and the surface let down irregularly, by the solution of the rock-salt, giving rise to some of the Cheshire meres, and causing the surface-drainage to find its way deep into the marls in the latter district. In my opinion, the beds of rock-salt in the northern borehole, No. 5, have been dissolved away from the disturbed-marl area in No. 6, as they rose

Fig. 2.—*Section along the line of borings in the north of the Isle of Man, on the scale of 2 inches to the mile.*



towards the surface in consequence of their northerly dip, letting down the surface to a depth of 65 feet below the normal level of the rocky plateau. In the district of Northwich the upper thick bed of rock-salt, some 80 feet thick, has been carried away by natural solution letting down the pre-Glacial land-surface, and giving room for very thick and abnormal accumulations of Glacial Drift. Many other cases of the same kind have come before me in Cheshire, in the course of various enquiries as to the structure of the Cheshire saltfield. It may be inferred, therefore, that the total thickness of pure salt proved in the two borings is not less than 109 feet 8 inches.

IX. General Conclusions.

When these borings are drawn on the 6-inch scale, and connected together, as in the originals of figs. 1 & 2, they give a clear idea of the sequence of the beds, and of the thickness of the Triassic sandstone. It will be observed that the last-named thickens in a northerly direction. I have already mentioned the presence of a fault in the Yoredale rocks at Ballawhane. A little to the south-west of this there is, in my opinion, another fault, letting down the Triassic sandstones into the Yoredale Series. In no other way am I able to account for the contrast between the sections 1 & 2 at Lhen Moar and Ballawhane.

These borings do not afford sufficient evidence for the construction of an accurate map of the solid geology under the Drift. Both my map, published in the Transactions of the Manchester Geological Society, in 1894, and the map of the Geological Survey, are mere sketches, to be modified by the result of subsequent observation. The accompanying map (fig. 1, p. 656) has been made by the light of the boring at Ballaghenney, which limits the area of the saliferous marls, and considerably enlarges the area of the Triassic sandstones, as shown in my previous map. The Yoredale rocks are also represented, as forming part of the waterworn surface underneath the Drift. A further addition is that of the Basement Carboniferous Beds of the south of the island, which form a thin band at the base of the Carboniferous Limestone, instead of occupying the wide area shown in the Geological Survey-map. The position of this is, of course, hypothetical, and it may, or may not, extend as far south as the point where the rocks of the massif rise abruptly above the plain between Ramsey and Kirk Michael. The Permians are probably faulted down, and covered by the Triassic sandstone, as shown in figs. 1 & 2. They may, however, appear on the eastern side, as shown in the Geological Survey-map.

The increase in the thickness of the formations penetrated in the boreholes is eloquent of the direction of the dip of the strata.

	No. 1. Lhen Moar.	No. 2. Balla-whane.	No. 3. Knock-e-Dooney.	No. 4. Balla-ghenney.	No. 5. Point of Ayre.	No. 6. Point of Ayre.
	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.
Glacial Drift	167 6	171 0	173 0	212 4	298 0	364 0
Saliferous marls (Dip 12°.)	......	......	......	......	382 0+	557 4
Triassic sandstone (Dips 7°, 8°, 10 to 12°.)	......	373 2	432 3	743 9		
Permian Series	......	......	57 7	84 9		
Yoredale Series (Dips 30°, 35°, 33°.)	......	136 3	283 0	240 2+		
Carboniferous Limestone (Dip 40°.)	65 6+	37 11+	15 2			

It is obvious, from the succession of these rocks and their increase in thickness along a north-easterly line, that they all dip in natural order to the north, or away from the Ordovician massif of the island.

It is also clear, from the above table, that they constitute a plateau of marine erosion (fig. 2, p. 657) sloping northward and eastward, and extending from a depth of about 150 feet below Ordnance-datum on the west at Lhen Moar, to a depth of about 343 feet at the Point of Ayre. Were the Glacial Drift resting upon it removed, the sea would occupy the whole of the area north of a line drawn between Ramsey and Kirk Michael. To realize the great thickness of the Drift, it is necessary to add the height of the hills of Drift above the level of the boreholes, which gives a total of not less than about 450 feet, a greater thickness than has been proved elsewhere in the British Isles.

The Carboniferous and post-Carboniferous rocks in the Isle of Man stand in the same relation to the pre-Carboniferous massif as those of the Lake District. The same rocks occur in the same order, dipping away in every direction from the massif, both north and south. Here, as there, they probably form concentric rings, now broken, round the Silurian (and Ordovician) massif, being represented in the south by the Basement Carboniferous and Carboniferous Limestone of Langness and Castletown; in the north by the Carboniferous Limestone, the Permian, and the Triassic sandstones and marls, which have been described in this and the preceding paper. It must further be noted that during the time of the accumulation of the Permian Series in the north of the Isle of Man, the Ordovician grits and phyllites, now forming by far the greater part of the cliffs, were not exposed to the erosion of the sea on the Permian coast-line. The cliffs then in the north of the island were mainly composed of Carboniferous Limestone and Yoredale rocks. This fact is proved not merely by these rocks having been the source from which the Permian strata were derived, but also by their occurrence in the sea-worn plateau underneath the Permian of the north of the island.

These cliffs also (as is proved in the preceding paper) were carved out of Keisley Limestone, a rock which may be expected to occur underneath the mantle of Drift in the north of the island, in its proper place between the Basement Carboniferous and the Ordovician quartzites and sandstones which overlook the buried seaworn northern plateau.

Discussion [on the two foregoing papers].

Mr. Lamplugh, in defending his rendering of the Peel Sandstones on the Geological Survey-map, remarked that he would gladly have accepted the reading of this exceedingly obscure ground given by the Author in his paper of 1895, if this had agreed with the available data. But as he found that important field-evidence in the outcrops around Glenfaba had been overlooked, he was compelled to attempt an independent rendering in accordance with this evidence. The borings in this area, referred to by the Author, were made long ago, and the evidence in regard to them was unsatisfactory. He readily acknowledged that any mapping, under the conditions, could be only approximately correct.

The same remarks applied with even stronger force to the mapping of the northern plain, which was really only a portion of the Irish sea-bottom, made into land by the thick Glacial deposits. For his own part, the speaker had always regretted that it was officially necessary for him to produce a map of the solid rocks underlying this ground; but, given the necessity, nothing more could be done than had been done. In the Memoir now in the press he had recognized the possibility that Silurian rocks might occur in this tract.

He was in accord with the Author in his amended reading of the borings at the northern margin of the island; but he thought that it was due to himself to mention that the error in the Author's previous interpretation of the Ballawhane boring, now so frankly acknowledged, would not have been discovered if the speaker had not himself examined the cores. The Author, in a previous paper, had based far-reaching conclusions on the supposed Peel rocks of this boring, now acknowledged to be Lower Carboniferous.

The speaker's examination of the cores from all the borings had convinced him that no equivalents of the Peel Series had been found in them. The Permian breccias of these borings could be directly correlated with the Permian breccia or Brockram of the Cumberland coast, but this correlation could not be sustained in respect to the Peel rocks. He deprecated the use of the terms 'Brockram' and 'Magnesian Limestone' applied by the Author to parts of the Peel Series, and also the reference of pebbles to the 'Yoredales,' etc., on the basis of general resemblance only. The condition of the limestone-fragments in the Peel Conglomerates was not that of the limestone-fragments in the Brockram of Cumberland and of the northern borings.

As to the Author's insistence that the Peel Series was identical in physical characters with the Permian rocks of the North of England, he would point out that Mr. J. Horne had described the series as closely resembling the Calciferous Sandstone-rocks of the Kirkcudbrightshire coast; and also that the speaker, in visits to mainland-sections referred to by the Author, had failed to find the similarity on which such stress was laid.

He acknowledged the difficulty in fixing the age of the Peel Series, and in this respect congratulated the Author upon his recent most interesting discovery that the majority of the fossils of the limestone-fragments were of Ordovician age. He suspected that the remaining three supposed Carboniferous species would prove to be of the same age. Indeed, it was not impossible that the Peel rocks might eventually prove to be of older date than either the Author or the speaker had hitherto suspected. This would be, to him, a most satisfactory termination of the discussion.

Mr. Marr wished to deprecate the use of Lake-District terminology in the Isle of Man: it was purely local and stratigraphical, and should be confined to the Lake District. He pointed out that fragments of Keisley Limestone had been found in the basal Carboniferous conglomerates of the neighbourhood of Sedbergh.

The Author, in reply, said that he accepted Mr. Lamplugh's explanation of the difference between them—that the work of the Geological Survey in the Isle of Man was 'official,' while that of the Author was a 'labour of love.' At that late hour he would merely remark that the Brockrams under discussion are identical in composition with those of the borings, acknowledged by Mr. Lamplugh to be Permian, and with those of the Lake District accepted by every one as Permian. If any doubt remained, it could be solved by the examination of the specimens on the table from these three sources, and of those in the Museum at Jermyn Street.

35. *A* Descriptive Outline *of the* Plutonic Complex *of* Central Anglesey. By Charles Callaway, D.Sc., M.A., F.G.S. (Read June 11th, 1902.)

[Map on p. 664.]

Contents.

I. Introduction.

Twenty-two years ago, a paper by me on 'Some New Points in the pre-Cambrian Geology of Anglesey' appeared in the Geological Magazine.[1] One section of that paper discussed the 'Continuity of the Granitoid Series with an underlying Gneiss,' and the chief evidence for that continuity was furnished by the Craig-yr-Allor anticline. An ellipsoidal dome of hornblendic and chloritic gneiss in Central Anglesey was described as surrounded by 'granitoidite,' below which it appeared to dip in a quaquaversal manner. As both the gneiss and the granitoid rock were then generally regarded as of sedimentary origin, the inference that the gneiss represented a formation older than the 'granitoidite' appeared to be justified. We now know, however, that these rocks are not metamorphosed sediments, but plutonic masses; therefore they can never have been in stratigraphical sequence. A review of the ground in the light of the new theory of origin has now been undertaken, and the following paper is the result. I include within its scope the acidic rocks, both massive and schistose, which are associated with the gneisses and granite, so as to present a general outline of the structure of the plutonic complex of Central Anglesey. I do not propose to enter into minute petrographical or geognostic details: the former being unnecessary for my purpose, while the latter would be superseded by the expected mapping of Mr. Edward Greenly. Some corrections were made in the old interpretations of the district by the Rev. J. F. Blake[2] in 1888. In

[1] Dec. 2, vol. vii (1880) p. 117.

[2] Quart. Journ. Geol. Soc. vol. xliv (1888) p. 463. Details will be given further on (p. 671).

the previous year, I had communicated to the British Association[1] an outline of the igneous theory of origin; and in 1897 I read to this Society an account of the 'Origin of some of the Gneisses of Anglesey'[2] from evidence obtained in the eastern district.

I have to express my great obligations to Prof. Bonney for his opinion on some of the thin slices of rocks used in this paper; to Prof. Theodore Groom for working out certain microscopic details; and to Mr. Philip Holland for an elaborate chemical analysis of the felsite from which the grey gneiss is derived.

II. The Materials which compose the Plutonic Complex.

In the eastern district, the materials employed in the gneiss-making process are mainly felsite and diorite. These varieties occur also in Central Anglesey; but associated with them is the well-known binary granite (haplite) originally called 'Dimetian' by the late Dr. Hicks. A fourth variety, which occupies an important place in this paper, is the quartz-felsite claimed by that geologist as 'Arvonian.' It forms a part of the same magma as the granite, and must be carefully distinguished from the quartzless felsite, into which it is sometimes intruded in dykes and veins.

(1) The Diorite and its Modifications.

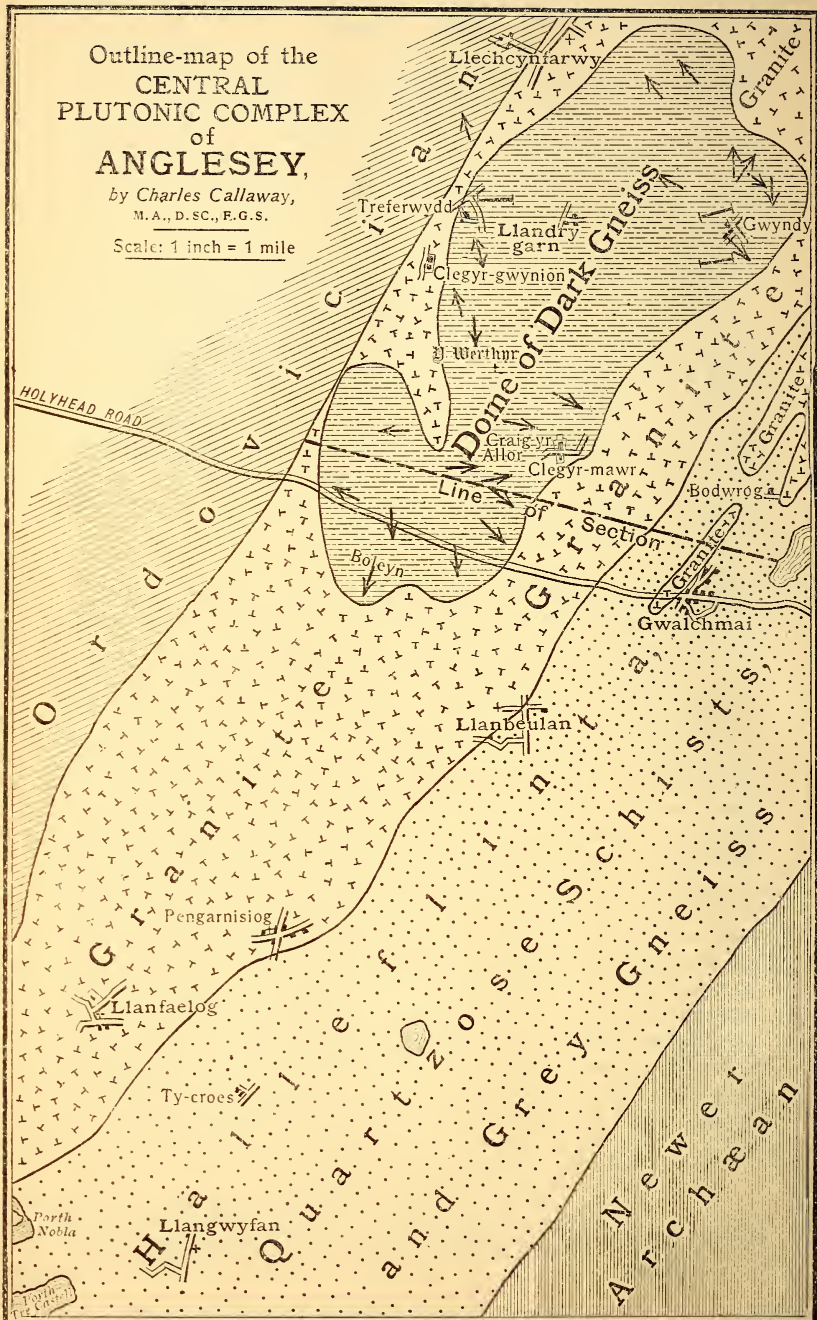
The diorite is well known.[3] It undergoes numerous modifications, of which the following are the most important:—

(*a*) Hornblende-Gneiss.—This rock forms a large proportion of the gneissic dome. It will be more fitly noticed farther on (p. 670, etc.).

(*b*) Decomposed diorite and chlorite-gneiss.—At the southern end of the dome, especially on the Holyhead Road, the diorite is much decomposed. In the old quarry on the south side of the road, near the $\frac{9}{16}$ milestone, it passes into a soft greenish rock, with hardly any granite-veins, and with only a few indistinct traces of foliation. Under the microscope, the latter (579)[4] can hardly be distinguished from a grit. It is composed of angular fragments in a greenish matrix. The fragments are mainly felspar, plagioclase predominating. Hornblende comes next in quantity: it has broken up along the cleavage-planes, and some of it is rather drawn out. Some minute, highly refracting granules, which polarize in brilliant colours, are apparently epidote. Iron-oxides in crystalline forms are scattered through the slide. The groundmass, which is not abundant, is mainly chlorite. This rock is clearly a diorite, which has suffered from crushing and decomposition.

[1] Rep. Brit. Assoc. 1887 (Manchester) p. 706.
[2] Quart. Journ. Geol. Soc. vol. liii (1897) p. 349.
[3] T. G. Bonney, Geol. Mag. 1880, p. 126; J. F. Blake, Rep. Brit. Assoc. 1888 (Bath) pp. 403–406 & Quart. Journ. Geol. Soc. vol. xliv (1888) pp. 479–99.
[4] The numbers between parentheses throughout this paper refer to the slides in my cabinet.

Fig. 1.


Outline-map of the
CENTRAL
PLUTONIC COMPLEX
of
ANGLESEY,
by Charles Callaway,
M.A., D.SC., F.G.S.
Scale: 1 inch = 1 mile
Ordovician
Granite
Granite
Granite
Granite
Granite
Dome of Dark Gneiss
Line of Section
Halleflinta,
Quartzose Schists,
and Grey Gneiss
Newer Archæan
HOLYHEAD ROAD
Llechcynfarwy
Treferwydd
Llandrygarn
Clegyr-gwynion
Gwyndy
Y Werthyr
Craig-yr-Allor
Clegyr-mawr
Bodwrog
Boleyn
Gwalchmai
Llanbeulan
Pengarnisiog
Llanfaelog
Ty-croes
Porth Nobla
Llangwyfan
Porth Tre Castell

About 2 furlongs [1] to the west, on the northern side of the road, is a long section of rock much of which is similar to the last; but some of it is sounder, there is more foliation, and granite-veins are more numerous.

(*c*) Micaceo-chloritic gneiss.—In a quarry on the Holyhead Road, $1\frac{1}{2}$ furlongs east of the $\frac{9}{16}$ milestone, the rock is of a greenish colour and rather micaceous. It is penetrated by veins and small masses of granite. The structure is rather massive, dips being indistinct. A small quarry displays similar rock 100 yards to the west-north-west. Half a mile to the south-west, close to the southern junction with the granite near Boleyn, there is a good quarry-section of rock of the same general type, but it is more micaceous, and displays a clear foliation-dip. A thin slice of this rock (578) shows under the microscope irregular fragments of felspar, in a chloritic groundmass. Several parallel flakes of a white mica cross the field, and part of the chlorite is orientated in the same direction. Some secondary quartz is present. This schist is apparently formed from the diorite, but the rock has undergone partial reconstruction, probably under the influence of the adjacent granite. Prof. Bonney remarks of this specimen that 'the rock was very probably once igneous.'

(*d*) Kersantite and biotite-gneiss.—Biotite is normally developed in the diorite, whenever granite-veins come in abundantly. We thus get a kersantite where the rock is massive, and a biotite-gneiss where foliation is produced. These effects were described by me in 1887,[2] and have been noticed by other writers.[3] The evidence, so far as Anglesey is concerned, will be offered on p. 669.

(2) The Felsite and its Modifications.

I have never succeeded in obtaining a specimen of the felsite in its original state. The least modified specimen has been recognized under the microscope by several experts as a true felsite.[4] A chemical analysis of the rock, taken at a distance of 2 feet from the above in the same unbroken mass, has been kindly made for me by Mr. Philip Holland, F.I.C. It is slightly schistose, and indicates an early stage of the transition from the felsite to mica-gneiss. I have placed by the side of it an analysis of a rhyolite

[1] Localities and distances are taken from the 6-inch Ordnance-map.

[2] Rep. Brit. Assoc. 1887 (Manchester) p. 706. See also Quart. Journ. Geol. Soc. vol. xlv (1889) pp. 478–87 & Geol. Mag. 1894, pp. 217–19. In the Malvern rocks, hornblende is sometimes (at least) changed to black mica, through the intermediate stage of chlorite. I do not know whether chlorite has been changed into biotite in Anglesey, as I have not been able to work out the genesis of the mica so completely as at Malvern.

[3] E. Hill & T. G. Bonney, Quart. Journ. Geol. Soc. vol. xlviii (1892) pp. 128–32, 135–37; J. Parkinson, *ibid.* vol. lv (1899) pp. 440–43, 445; G. A. J. Cole, Trans. Roy. Irish Acad. vol. xxxi (1900) pp. 442, 453 *et seqq.*

[4] Quart. Journ. Geol. Soc. vol. lii (1897) p. 351.

quoted in Geikie's 'Text-book of Geology,'[1] and an analysis of an American obsidian furnished to me by Mr. Holland.

	Granular Felsite, *Y Graig, Gaerwen, Anglesey.*	Rhyolitic Obsidian, *Medicine Lake.* (*U.S.A. Geol. Surv.*)	Rhyolite, *Euganean Hills.* (*Vom Rath.*)
	Per cent.	Per cent.	Per cent.
Silica	73·48	73·51	76·03
Titanic oxide	0·29	...	...
Alumina	14·79	14·42	13·32
Ferric oxide	0·03	0·46	...
Ferrous oxide	1·04	1·49	1·74
Manganous oxide	trace	trace	...
Lime	0·53	1·26	0·85
Magnesia	0·43	0·33	0·30
Potash	4·24	4·29	3·83
Soda	4·40	4·03	5·29
Sulphur-trioxide	0·03	...	...
Phosphorus-pentoxide	0·02	0·04	...
Combined water	0·81	0·40	...
Loss			0·32
	100·09	100·23	101·68

It will be seen from these analyses that the Anglesey felsite does not differ materially from Vom Rath's rhyolite, and is almost identical with the American obsidian.

The felsite, in the first stage of crushing, is converted into the rock originally known in Anglesey as 'hälleflinta.'[2] It then passes progressively into quartzose and micaceous schists, the phenomena being similar to those so well seen at Y Graig,[3] in the eastern district.

The least modified form of the felsite as it occurs in Central Anglesey is the 'hälleflinta' of Hicks. The following slide (1) is from his typical locality (Llanfaelog): it has undergone greater change than the type-specimen from Y Graig. In ordinary light, it is colourless and nearly transparent, irregular clear patches being surrounded by slightly dingy material, and some opacite in small patches is present. The clear spaces prove to be mainly quartz.

The dingy patches are largely composed of minute microliths of white mica lying confusedly intermingled. Some felspar also appears to be present, but I cannot clearly detect crystalline forms amid the tangle of mica. Prof. Bonney writes of it, 'I think it is a devitrified rhyolite (or dacite), with sericite forming from the felspathic constituents.'

A specimen of the 'hälleflinta' (389) from Porth Nobla shows more differentiation. The groundmass consists of water-clear granules of various sizes and definite outline. Some of them are angular, and are evidently the result of fracture, but most of them

[1] 1st ed. (1882) p. 137.

[2] I made some comments on this rock in a previous paper, Quart. Journ. Geol. Soc. vol. liii (1897) p. 350.

[3] *Ibid.* p. 351.

are either roundish or lobe-like. Both quartz and felspar are present. Some of the mica is similar to the last, but it also occurs in small flakes, and in thin strings occupying cracks. The signs of crushing are very apparent. Prof. Bonney concedes this to be similar to (1) but 'affected by pressure.'

A specimen from Gwalchmai (4) has a groundmass of very minute irregular fragments, with microlithic mica intermixed. Scattered through this are large clear patches, some of them with rounded or lobe-like contours, others being angular. Much of this clear material is felspar. Prof. Bonney 'strongly suspects' that this rock is 'the result of crushing *in situ* of either a felsite or a micro-granite.' On the whole he 'inclines to the former opinion.'

These three slides are sufficient to prove an igneous origin for the rocks which bound the central granite on its eastern side. Towards the east, these modified felsites pass little by little into quartzose and micaceous schists. The passage is best seen on the shore near Porth Nobla, and in the district round Gwalchmai. The following are a few selected varieties of this schist.

Quartz-schist (34), Ty-croes.—The quartzose and micaceous constituents are arranged in parallel folia. The former are in rounded and lobate granules of various sizes, the larger being often aggregated into conspicuous lenticles. A little felspar is present. Most of the mica (white) is rather minute, but some of it is in flakes, which, running in lines parallel to the lenticles and one to the other, give the rock a distinctively foliated appearance. Prof. Bonney considers it 'a pressure-modified quartz-felsite or micro-granite,' and recognizes the mica as secondary.

Quartz-schist (25), Gwalchmai.—A rock similar to that last-described, but the schistosity is not so well marked. It is regarded by Prof. Bonney as 'probably of igneous origin.'

Typical mica-schist (461), east of Ty-croes.—Rather fine-grained. The water-clear constituents, which are mostly quartz, are in small lobate granules, and the mica (white) in either fair-sized microliths or flakes, the minerals being evenly arranged in parallel seams. There are few traces of fracture in the slide, the rock evidently having been almost completely reconstructed. Prof. Bonney thinks that the mica 'dates from the structure, which may be the result of crush.' He is unable to decide from the slide whether the schist is igneous or sedimentary in origin; but raises no objection to the former hypothesis, if the field-evidence proves satisfactory. Of this there can be little doubt, since in so many localities schist of a similar type is seen to pass gradually into a rock which he admits to be igneous.

Sound mica-gneiss (498), Porth Trecastell.—The water-clear constituents and the mica (white) are in larger elements than in the last-described slide, and the foliation is very distinct. There is a small proportion of untwinned felspar. A comment is made on this specimen by Prof. Bonney, in terms almost identical with his remark on (461).

It is needless to describe further specimens. That the foregoing, especially (461) and (498), are true crystalline schists will not, I think, be disputed. Prof. Bonney, in commenting on the probable origin of these schists, sometimes suggests micro-granite as an alternative to felsite. I have never seen any mass of micro-granite in Central Anglesey: the granular quartzless felsite, so far as I have observed, being the only source of the schists. However, I must leave the elaboration of the details of the schist-making process to younger workers.

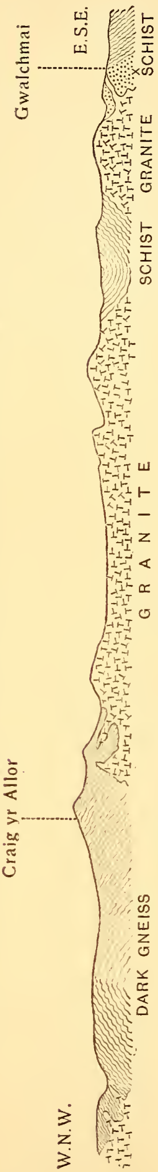


Fig. 2.—*Generalized section across the central complex of Anglesey: distance = 3 miles.*

[At the point marked × the hälleflinta passes into schist.]

Prof. Theodore Groom, D.Sc., has been kind enough to relieve my eyesight by examining the water-clear granules of this series of slides in convergent light, and he permits me to use his diagnoses in the foregoing descriptions.

I have not forgotten that the crystalline limestones included in these schists at Bodwrog and Porth Trecastell may be thought to indicate a sedimentary origin. I have long since, however, come to the conclusion[1] that these limestones are chemical segregations, produced during deformation. They are associated with rotten ferruginous schists, intermixed with quartzose and micaceous bands, and occur in lenticles, varying in dimensions from microscopic films to masses several feet thick. I have not been able to work out in detail the problem of their genesis; but these facts are clearly inconsistent with a sedimentary origin of the schists, and tend, I think, to confirm the view held in this paper.

(3) The Granite (Haplite) and Quartz-Felsite.

These rocks are intruded into the diorite and the felsite after the production of their schistosity, as will be shown later on. The former have never, I believe, been affected by earth-pressures to a material extent.

[1] Rep. Brit. Assoc. 1887 (Manchester) p. 706.

The granite has been more than once described.[1] It is normally a haplite. I suspect that the mica which it sometimes contains is secondary. As compared with the haplite associated with the diorites of Malvern, its felspar is more largely plagioclastic.

The quartz-felsite is of a normal type. Four slides of this rock were described by Prof. Bonney [2] in 1880. One of these (6), which at that time he thought might be a trachyte-tuff, he is now inclined to regard as cataclastic. Two new slides from other localities have also been submitted to him, and identified as of the same class, one of them with a 'granophyric' structure: both of these he considers as probably devitrified glasses. I need hardly remark that the originally vitreous condition of the rock is no proof that it was ever erupted at the surface.

III. The Relations of the Rock-masses.

(1) The Relations between the Diorite and the Granite.

(*a*) The Craig-yr-Allor anticlinal dome.—This ellipsoidal dome of dark gneiss is described in my first Anglesey paper.[3] I have recently reviewed the ground, and inserted on the 6-inch Ordnance Survey-map a large number of additional outcrops of the gneiss and the granite. The result is to confirm amply my original account of the structure of the dome; but the more minute detail shows that the granite has sometimes invaded the area of the gneiss, producing irregularities in the outline of the ellipse. More clearly, however, than ever comes out the main fact that, at the margin of the dome, the gneiss, wherever I have seen it, dips towards the granite. A few additional details will here be given.

The major axis of the ellipse strikes north-east and south-west, in accordance with the general trend of the band of granitic and gneissic rocks which passes diagonally across the island, and is about $3\frac{1}{2}$ miles in length, the breadth of the ellipse being about $1\frac{1}{2}$ miles. The curve of the south-western end (see sketch-map, p. 664) lies south of the Holyhead Road, west of Gwalchmai. Working along this line from east to west, we find in the quarry on the south of the road, just opposite Cerig-y-Cathod, and in the old quarry near the $\frac{9}{16}$ milestone, green altered diorite with traces of schistosity, the dips being a little to the east of south. At Boleyn, the strikes, seen in the road, are due east and west; and, in a field a little farther to the south-west, there is a good section of micaceo-chloritic gneiss (578) p. 665, with clear dip to south-south-west. The granite crops out within 50 yards to the south. The strike of the gneiss, therefore, swings round in a curve, with its convexity facing southward.

On the western side of the ellipse, we begin at the Holyhead Road, where there is a long section of rotten schist dipping to the west-

[1] T. G. Bonney, Quart. Journ. Geol. Soc. vol. xxxv (1879) pp. 306, 307; J. F. Blake, Rep. of Committee on Microscop. Struct. Older Rocks of Anglesey, Brit. Assoc. 1888 (Bath) p. 397.

[2] Geol. Mag. 1880, pp. 125, 126.

[3] *Ibid.* p. 119.

north-westward, and this appears to be the dip at Tai-newydd, a third of a mile to the north-north-east. Clear north-westerly dips are seen to the south-east of Clegyr-gwynion; but a little farther north, around Treferwydd, and in the old quarry south-east of Treferwydd, the dips are only slightly to the west of north. North-westerly dips, however, appear in force to the south-east of Llech-cynfarwy, and the same dip occurs at Rhên-blas, still farther to the south-east.

A furlong east of Rhên-blas, near Pentre'r-felin, hornblendic gneiss crops out at several points with dips to north and north-east. In one quarry, the foliation-strike curves round, so as to give these and the intermediate dips in the same visible mass. We are here at the north-eastern end of the ellipse, for granite comes in immediately to the north-east; and close by, to the east, the gneiss begins its easterly dip.

From the last point, we follow the south-eastern side of the ellipse. East of Gwyndy, there is a fine section of the gneiss, apparently plunging to the east-south-east below the granite. Exposures then become rare, until we approach the Craig-yr-Allor area. Here the outcrops of gneiss and granite are almost countless. North and north-east of Clegyr-mawr, the dip is usually a little to the south of east. Around Craig-yr-Allor, it is sometimes east or even a little to the north of east; but, as we come round towards our starting point, it becomes east-south-easterly and finally south-easterly, thus connecting with the south-south-easterly dips on the Holyhead Road. The angle of dip in this series of sections varies between low and high; but the majority of them are described in my note-book as 'moderate,' that is, from 40° to 50°.

Within the ellipse, towards its north-eastern end, is an area in which the gneiss is contorted, with strikes deviating not much from east and west. These are seen at Treferwydd and at several points to the south, as far as Tai-newydd. I do not know whether they are continuous across the ellipse by way of Llandrygarn; but east of that hamlet and north of Gwyndy, east-and-west strikes are common. I have never observed these strikes reaching as far as the marginal junction with the granite.

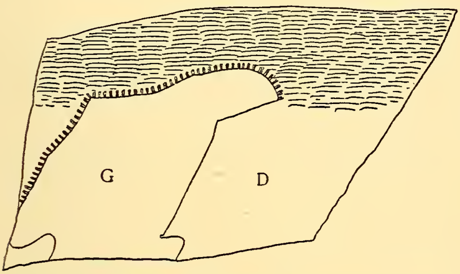
Granite appears sporadically in masses within the Craig-yr-Allor ellipse; but it is not necessary to my purpose that I should anticipate Mr. Greenly's expected map. My paper, however, would be hardly intelligible without an outline-map, which also includes the acidic rocks to the east of the ellipse (fig. 1, p. 664). It will be seen from the dips inserted in this map, that the foliation in the dark gneiss indicates a domical structure, and that at the margin the dips are uniformly in the direction of the surrounding granite.

(*b*) The foliation of the dark gneiss.—I have retained the descriptive term 'dark' before 'gneiss,' because the colour is due to more than one cause. It is usually produced by the presence of either hornblende or biotite, but frequently chlorite appears in abundance. Epidote and iron-oxide are sometimes present.

The gneiss is 'simple,' when it is merely the diorite or one of its modifications that has acquired a schistose structure; and 'complex,' when the simple variety is interbanded with granite-veins. The latter is an example of 'primary injection,'[1] as distinguished from a gneiss of 'secondary injection,' in which the injected matter is a product of decomposition, as in the case of some of the gneisses of Eastern Anglesey.[2]

The first stage in the process of gneiss-formation is the production of schistosity in the diorite. Much of the diorite is schistose; but, even in hand-specimens, the foliated diorite may be sometimes seen passing gradually into the massive rock. The granite does not share in the foliation; for, whether the veins cut across the foliation or run with it, the granite remains massive. Fig. 3 shows this very clearly. It represents a hand-specimen, on one side of which the diorite is distinctly foliated, light-coloured lines of felspar alternating with the dark hornblende. A vein of the haplite cuts obliquely across the foliation, but is itself quite unfoliated. It has slightly fused the diorite at the junction, fresh crystals of hornblende forming a sort of fringe to the vein.

Fig. 3.—*Granite-vein in diorite.* (*About $\frac{1}{4}$ nat. size.*)



D = Diorite passing upward into hornblendic gneiss.
G = Haplite, containing epidote. At its upper margin its constituents are interfelted with the hornblende of the diorite.

Schistosity in the diorite produced by pressure was first noticed as occurring at Gaerwen, in a paper read by me before the British Association at Manchester in 1887 (p. 706 of Report). In the following year, the Rev. J. F. Blake presented his Report on Anglesey rocks, and described[3] the phenomena in some detail. He states that at Gaerwen the constituent minerals of the diorite have been more or less pulled out into lenticles, and that the rock is sometimes 'crowded with mylonitic lines.' The term 'shearing' is applied by him to the process which the diorite has undergone. With these descriptions I entirely agree. A series of six slides in my collection shows the change from diorite to schist

[1] Prof. C. R. Van Hise indicates my 'primary injection' by the term 'injection,' and my 'secondary injection' by the word 'cementation,' Princip. of N. Amer. Precambr. Geol. 16th Ann. Rep. U.S. Geol. Surv. 1894-95 (1896) pp. 666-68, 684-88. But surely there is 'injection' in both cases.
[2] Quart. Journ. Geol. Soc. vol. liii (1897) pp. 355-57.
[3] Rep. Brit. Assoc. 1888 (Bath) p. 405.

very clearly: the progressive deformation of the hornblende, and the alteration of the felspar, being the most prominent features in the transformation.

I came to the Craig-yr-Allor diorite with this information in mind. This rock sometimes shows some parallelism of its constituents anterior to crushing, as Prof. Bonney remarks in his notes to me. But this is not the most marked character of the schistose diorite. Four slides (373–376) illustrate this point. They were taken from the same mass of diorite in Craig-yr-Allor, at distances of a few feet one from the other. The first (373) was selected as a comparatively sound diorite, and the others as illustrating the progressive change that takes place in it as a shear-zone is approached.

(373) In parts of the slide the hornblende is aggregated into irregular folia, and a little of it is chloritized.

(374) The rock from which this slide was taken contains some veins of granite. The structure is distinctly schistose, flakes of chlorite being drawn out into parallel seams. These flakes often coincide with cracks (shear-planes), which are further accentuated by iron-oxide. A little quartz appears.

(375) Taken from a point nearer to a plexus of granite-veins. The structure is similar to that last-described, but there is more chlorite and less hornblende.

(376) Within a plexus of granite-veins, large and small, with a general parallelism. The diorite contains little hornblende, but abundance of chlorite in roughly parallel flakes. Associated with the chlorite is some brown mica and a larger proportion of white mica. Much of the latter is in minute flakes orientated with the chlorite, and apparently formed contemporaneously with it. A part of the felspar-crystals contains white mica, but in smaller elements, some of it in microliths. Shear-planes in this slide are very marked, running parallel to the foliation. They often pass through a flake of chlorite, and biotite sometimes occurs in the chlorite just at the shear-plane, a feature that I have often observed in the Malvern gneisses. Prof. Bonney agrees that the characters shown in this slide are not inconsistent with the theory of the action of a haplite on a pre-existing diorite.

The facts seen in this series of slides are in close agreement with the descriptions of my second Malvern paper.[1] The Anglesey diorite resembles the medium-black variety (No. 3) at Malvern, the granite in both localities is a haplite, and the contact-effects of the haplite upon the diorite are similar.

The second stage in the process of gneiss-formation is the injection of granite-veins and the production of contact-effects. These points, anticipated in the description of the last slide (376), must now be discussed.

Nearly everywhere throughout the gneissic ellipse, the diorite and its modifications are penetrated by granite-veins. Their frequency

[1] Quart. Journ. Geol. Soc. vol. xlv (1889) pp. 478–87.

seems to follow no law, for while they increase in number towards the margin in the area south-east of Llechcynfarwy and in the section east of Gwyndy, I did not observe them at all in the schist south-west of Boleyn, although the junction with the granite is within 50 yards, and they are not numerous in the quarries south of the Holyhead Road. They vary in thickness between a foot or more and a line or less. They occasionally cut across the schistosity of the diorite, either directly or obliquely; but generally they coincide with it, as if it had provided the planes of least resistance. Fig. 4 shows a combination of the two.

Fig. 4.—*Granite-vein in foliated diorite, Craig-yr-Allor.*

Where the veins are few in number, contact-effects may be very slight. Sometimes, however, fusion is produced at the contact, with aggregation of fresh hornblende, as in fig. 3 (p. 671). Or the fusion may have proceeded for some distance into the diorite. In this intermediate zone, the granite and diorite are intermixed, hornblende (and perhaps black mica) in aggregates being immersed in a granitic groundmass. Large phenocrysts of hornblende also occur away from the diorite, scattered in a granitic magma. Some of these are corroded at the margin, where they are in contact with quartz. How far the felspars of the two magmas are intermixed I have not ascertained.

Abundance of granite-veins in the diorite is usually (indeed, so far as I saw, invariably) accompanied by the generation of black mica, and the number of veins appears to be in direct ratio to the quantity of the mica produced. Where the veining is very close all the hornblende has disappeared. When the veins lie in the planes of shearing in the diorite, they are parallel one to the other, and the result is a banded gneiss, seams of quartz and felspar (the haplite) alternating with seams of biotite and felspar (the modified diorite).

I have not succeeded in obtaining microscopic specimens showing the details of the production of this banded gneiss. This defect appears to be due to the degree of fusion which the granite has caused in the diorite. Sharp lines of contact between the diorite and the invading granite I have not been able to observe, so that it is impossible to determine exactly in my slides how much of a specimen is diorite and how much granite. We have therefore to rely mainly upon field-evidence. We know that the diorite has been often cut by parallel and closely approximated planes of division, and we know that an invading granite is much more likely to penetrate these than to flow in the direction of a fluxion-structure in a solid rock. We find in the field that the granite-banding normally coincides with the direction of shearing in the diorite, and we may fairly infer that the injection has followed the pre-existing shear-planes.

Some of the best sections of the banded gneiss occur in the old quarry north of the site of Y Werthyr. The beds here lie in a gentle anticline, and the granite-veins bear a larger proportion to the diorite than in any other Anglesey locality known to me. They attain a maximum thickness of 6 inches, but most of them are much thinner. In one variety of the gneiss, there are six veins, with interfoliated micaceous films, in the thickness of 1 inch. Under the microscope this rock (577) is seen to consist mainly of felspar and quartz, the latter predominating. Twinned and untwinned felspars are in about equal proportion. The slide is crossed by two interrupted films of intermixed biotite and chlorite, with a minute proportion of white mica. Discontinuous cracks coincide with the films, and may be the partial survivals of the original shear-planes along which the granite was forced. Both the quartz and the felspar are moulded to the flakes of mica and chlorite. The felspar of the original diorite would seem to have been incorporated with the haplite.

Another specimen of gneiss from this quarry exhibits signs of crushing subsequent to the final consolidation. The thin slice (575) is traversed by four subparallel cracks (shear-planes), which pass with an undulating course from side to side. One of these is filled almost from end to end with chlorite. The others are occupied partly by chlorite, and partly by opaque brown matter and biotite. The opaque matter, presumably iron-oxide, is confined to the cracks; but the mica often extends for some distance on each side of them. The rock in the bands between the cracks is mostly felspar and quartz. The seams of mica and chlorite have apparently yielded readily to pressure, and hence are traversed by the shear-planes.

Another variety of the banded gneiss is nearly all granite, the intervening films of mica being so thin as to be just perceptible to the naked eye. Superficially this rock suggests the gneiss of secondary injection seen south of the Wych at Malvern.[1] In that example, the granite is sheared, and infiltration-products, sometimes changed into black mica, lie between the lenticles of haplite. In this case, it is the diorite which has been sheared, and the granite has been injected along the planes of fracture, so that the injection is primary.

The behaviour of the granite-veins is well seen in this quarry in strike-sections, some of them running for several yards with uniform thickness, others thinning out more rapidly. Here and there in the quarry the veins are fewer and less regular, but the general mass of diorite has been so densely charged with the haplite that no hornblende could be detected in it.

I do not think that any original biotite occurs in the Craig-yr-Allor district. This mineral makes its appearance so uniformly in

[1] Quart. Journ. Geol. Soc. vol. xlv (1889) pp. 496–98.

proportion to the abundance of granite-veins, that the relation between them of cause and effect may fairly be inferred.

Compressive forces seem to have affected the district repeatedly. Before the diorite had consolidated, an imperfect fluxion-structure was produced. After solidification, the diorite was sheared, and granite was injected along the planes of discontinuity. Subsequently to the secondary consolidation, shearing took place along the seams of the softer minerals.

(*c*) The dark gneiss originally a xenolith of diorite.—The mass of diorite the modifications of which gave rise to the gneisses of the Craig-yr-Allor area is seen in plan to be entirely surrounded by granite, and as it is almost everywhere penetrated by granite-veins it must be underlain by the granite, probably at no great depth. It must once have been of much greater vertical thickness, for it has been exposed to intermittent denudation ever since the early part of the Ordovician [1] Period. It was therefore at one time a huge block of diorite, immersed in granite. It may, of course, have been continuous under the granite with other masses of diorite. Before the granitic intrusion, the diorite must have acquired its schistose structure. Whether the domical arrangement of the schistosity was produced in one period by expansion under constraint, or resulted from two linear forces acting simultaneously or successively, I have not sufficient material to determine.

This insulation of a diorite-mass is no new phenomenon. Isolated blocks and masses of the diorite appear in the felsite 7 miles to the south-east, in the Llangaffo district.[2] As early as 1885, I showed [3] that the granite of Northern Donegal contains xenoliths of hornblendic, micaceous, and quartzose schists. Two years later I described [4] how granite invades the diorite of County Galway, forcing its way along the joints, and carrying away with it isolated blocks of the diorite. In this way pseudo-conglomerates were formed in Western Galway, and a gneissic rock near Galway town. Recently, Prof. G. A. J. Cole [5] has recognized similar phenomena in Eastern Tyrone and Southern Donegal, and he considers that the relations described as existing between the granite and various xenoliths 'will probably be found to prevail throughout the whole of North-west Ireland' (*op. cit.* p. 467).

Several other writers [6] have noted the occurrence in the British area of xenoliths in plutonic magmas; but I am not aware of any other example of an insulated mass on so large a scale.

[1] Conglomerates of at least Llandeilo age contain fragments of diorite in Anglesey, as well as pebbles of the haplite, T. G. Bonney, Quart. Journ. Geol. Soc. vol. xl (1884) pp. 585, 586. See also H. Hicks, *ibid.* pp. 187–96.

[2] Quart. Journ. Geol. Soc. vol. liii (1897) p. 355.

[3] *Ibid.* vol. xli (1885) pp. 22?–24, 227.

[4] *Ibid.* vol. xliii (1887) pp. 518–24.

[5] Trans. Roy. Irish Acad. vol. xxxi (1900) pp. 431 *et seqq.*

[6] J. A. Phillips, Quart. Journ. Geol. Soc. vol. xxxvi (1880) p. 1; E. Hill & T. G. Bonney, *ibid.* vol. xlviii (1892) p. 127; A. Harker, *ibid.* vol. lii (1896) p. 320; J. Parkinson, *ibid.* vol. lv (1899) p. 430 & vol. lvi (1900) p. 320.

(2) The Relations between the Felsite and the Granite.

The introduction of the new theories of metamorphism also compels a new reading of the band of acidic rocks which forms the eastern member of the central complex. Dr. Hicks's interpretation placed the granite (Dimetian) at the base, followed on the east by quartz-felsites and hälleflinta (Arvonian), which were succeeded by schists (Pebidian). In 1879, I formed the opinion that the quartz-felsite and the hälleflinta did not rank as a distinct formation, and that they were separated from the schist to the east by a fault, which appeared to be necessitated by the old hypothesis. Unhampered by this preconception, it is not difficult to arrive at the following results:—

(*a*) The quartz-felsite forms part of the same magma as the granite.
(*b*) The hälleflinta (modified felsite) and associated schists are penetrated by the granite and the quartz-felsite in masses and veins.

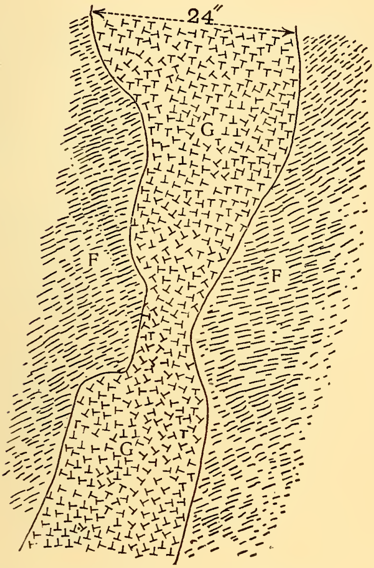
(*a*) The quartz-felsite forms part of the same magma as the granite.—In 1879, I stated that the quartz-felsite occurs in the granite, and passes without a break into it at two localities, Pengarnisiog (north-east of Ty-croes) and between Tai-newydd and Tyn-rhos (north of Gwalchmai). Recently, I have observed a similar passage at the farm of Pen-yr-argae (south-west of Gwalchmai). Sometimes the quartz-felsite forms distinct veins in the granite: this is seen to the north-west of Gwalchmai, in the Pen-clegyr ridge, and a little to the west of Plas-einion.

(*b*) The modified felsite and associated schists are penetrated by the granite and the quartz-felsite in masses and veins.—In my descriptions under this head, I will include the rocks on the same line of strike to the south-west.

Porth Nobla.—On the seashore a little to the west of this small bay, there is an irregular intrusion of the granite in the modified felsite (389) p. 666. Near at hand to the east, the felsite is more compressed, and is penetrated by numerous granite-veins, which have been rather flattened by the pressure. A little farther east, the veins are still more abundant, and are squeezed into thin seams, giving in association with the schists the appearance of a banded gneiss.

South-west of Gwalchmai.—At the last 'e' of Pen-yr-argae, the granite is very clearly seen to pierce the felsite in veins. One of these is shown in fig. 5, p. 677. Near at hand to the east and north-east, the quartz-felsite is very conspicuous, cropping out in numerous crags, being easily recognized at a distance by its creamy tint. It shows no trace of schistosity; but is extremely jointy, so that, though hard and sound, good hand-specimens of it are difficult to obtain. It penetrates the felsite, which is of a greenish colour, and is more or less schistose, passing towards the east and south into the well-marked series of quartzose and micaceous schists, which lies to the south of Gwalchmai. Most of the intrusions of quartz-felsite were near the granite-mass north of Pen-yr-argae, so that they doubtless proceed from the granite in the normal manner. They occur in dyke-like masses, forming linear crags running parallel to the associated schistose felsite; that is, east and west in the fields immediately east of Pen-yr-argae, and north-east and south-west a little farther to the north-east. One of the dykes was observed to terminate in thin veins penetrating the schist. Several of the crags that trend north-east and south-west have schist dipping south-eastward clinging to their north-western face.

Fig. 5.—*Vein of granite in felsite, north-east of Pen-yr-argae.*



[G = Granite; F = Felsite.]

North-west of Gwalchmai.—A band of granite runs for more than half a mile in a northerly direction from Gwalchmai, cropping out a little to the north-west of the Post Office, and forming a scarp overlooking the western side of the road to the north. At the southern end of the scarp, the quartz-felsite is very clearly seen to vein the granite, and both granite and quartz-felsite send veins into the felsite.

West of this granitic ridge lies a band of the schistose felsite. It is about 2 furlongs broad, and is bounded on the west by the granite-mass which limits the eastern margin of the gneissic ellipse, the junction between the two being near Plas-einion. It lies in a complex synclinal fold, striking north-east and south-west, in accordance with the general trend of the crystalline rocks of Central Anglesey. It is very well seen at Plas-einion, with a contorted dip to the south-east, which, as we go eastward, soon changes to the north-west, and this dip is maintained up to the junction with the granite of Gwalchmai. This schist appears to be almost free from intrusive veins.

East of Gwalchmai, the felsite becomes more and more distinctively schistose. It is frequently penetrated by small granite-veins,[1] as at Porth Nobla. Two thin slices (377 & 378) of this gneiss were submitted to Prof. Bonney. They are from the field east of Bodwrog Church, and are very near to the granite, on which the church stands. Prof. Bonney considers them 'a kind of mica-gneiss,' which may have once been a felsite or micro-granite, and

[1] Mr. Greenly observes that in Central Anglesey 'quartzose and micaceous schists' are penetrated by granite-veins (Geol. Mag. 1896, p. 495).

he observes :—'I think much, at any rate, of the mica is secondary.' On my calling his attention to the granite-veins, he writes that he suspects the 'coarser parts' of the slides 'to represent rolled-out veins.' The injection of these schists with granite-veins thus gives rise to a banded gneiss, of a less common type than the injection of granite or felsite into a basic rock.

It will be noticed that the relations of the granite to the felsite and grey gneiss are similar to those described as existing between the granite and the rocks of the hornblendic dome. Into the non-schistose felsite, the granite is intruded irregularly, as into the diorite; but where the felsite is modified into schist, the granite-veins are usually lenticular. It seems clear that the schistosity of the grey gneiss had been acquired previous to the intrusion of the granite and quartz-felsite. The posteriority of the granite to the gneiss is seen in the old quarry at Treflyn, east of Gwalchmai. Here a rather massive vein of haplite[1] is intrusive in the schist. The former is unusually coarse, the pinkish-red felspar being strongly differentiated from the quartz: it does not display the slightest evidence of pressure.

That the quartz-felsite is younger than the felsite is well seen at Pen-yr-argae. The dykes of the former trend with the schistosity of the felsite, as if they had been intruded along the planes of least resistance. But the quartz-felsite is absolutely free from schistosity, as I have previously pointed out.

(3) The Relations between the Felsite and the Diorite.

The felsite does not appear in contact with the diorite in the central complex, except at the extreme southern end at Porth Gwyfen.[2] Their relations are more clearly seen in the eastern gneissose band. The felsite distinctly veins the diorite at Y Graig (north-west of Gaerwen) and in the railway-cuttings near Llangaffo. It is at the latter locality that the grey gneiss (modified felsite) encloses isolated blocks and dyke-like masses of the diorite. It may fairly be concluded that the diorite is older than the felsite, and therefore the oldest rock in Central Anglesey.

The following would seem to have been the sequence of events in the central complex. Diorite was first consolidated. It was then penetrated by masses and veins of felsite, and blocks of it were isolated from the main mass (or masses), and floated off into the felsite. The consolidation of the felsite was the next stage. Earth-pressures then affected both diorite and felsite, producing schistosity. A granitic magma, usually haplite, sometimes quartz-felsite, then invaded the area, penetrating the diorite and the felsite in large masses, and sending into them countless veins, which commonly

[1] This granite is cut by a dyke of basalt, but it has been no part of my purpose to notice rocks which do not affect my special enquiries.

[2] Quart. Journ. Geol. Soc. vol. liii (1897) p. 354.

found their way along planes of schistosity, giving rise to banded gneisses.

Fig. 2 (p. 668) is a generalized section across the central complex, showing the relations of the granite to the gneisses and schists.

IV. Summary of Results.

(1) The central complex of Anglesey was originally composed of diorite, felsite, and granite.

(2) The diorite has been modified into an elliptical dome of dark gneiss, namely, into simple gneisses by pressure, and into complex gneisses by pressure *plus* granitic intrusion.

(3) The intrusion of the granite into the diorite has often produced fusion at the contact, sometimes with the generation of biotite in the diorite.

(4) The diorite and dark gneiss form an insular mass surrounded by granite.

(5) The felsite has been modified into quartzose and micaceous schists and gneisses, by pressure, and into banded gneisses by the addition of granitic intrusions.

(6) The quartz-felsites of the area are a part of the granitic magma.

(7) Both diorite and felsite were modified into gneisses and schists prior to the intrusion of the granite and quartz-felsite, which are not foliated.

36. *The* Point-de-Galle Group (Ceylon): Wollastonite-Scapolite Gneisses. By Ananda K. Coomáraswámy, Esq., B.Sc., F.L.S., F.G.S. (Read June 18th, 1902.)

[Plate XXXIV—Map.]

I. Introduction.

Prof. A. Lacroix[1] has recorded the existence of wollastonite- and scapolite-bearing rocks in Ceylon. The specimens examined by him can hardly, however, have come from Galle, as they contain garnet, a mineral never found in the rocks of the Galle Group described below. It seems therefore probable that rocks allied to those of Galle, but differing from them in petrological details, will be found elsewhere in Ceylon.

I have on a former occasion[2] given a short description of the Galle rocks, and am now able to supply a more detailed account of the rocks and to describe their field-relations. There are excellent exposures at Galle, within the Fort on the western side, between the Signal flagstaff and the north-western bastion; outside the Fort below the north-western bastion; and south-west of the Victoria Park near the remains of an old powder-magazine. All these exposures can be easily visited in the course of one whole day spent at Galle.

II. General Description.

The Galle rocks differ from normal types belonging to the Charnockite Series in the following ways:—

(1) The presence of wollastonite, scapolite, and sphene.
(2) The existence of definite dykes and segregation-veins crossing the foliation.
(3) The absence of garnet, hypersthene, mica, and original hornblende, and bands of 'granular quartz-rock.'
(4) Somewhat coarser grain.

But resemble them closely in

(1) The variability of chemical and mineralogical composition.
(2) The conspicuous mineral-banding (foliation).
(3) Common strike (about 10° west of north).
(4) The petrological characters of the acid types (especially as regards the felspars).
(5) The local tendency to graphic structures.

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[1] 'Contributions à l'Étude des Gneiss à Pyroxène et des Roches à Wernerite' Bull. Soc. Minéral. Franç. vol. xii (1889) p. 269 & pl. xii, fig. 2.

[2] 'Ceylon Rocks & Graphite' Quart. Journ. Geol. Soc. vol. lvi (1900) p. 602.

The chief rock-types may be briefly tabulated as follows, though numerous transitions from one type to another occur:—

BASIC	1. Pyroxene-sphene-scapolite rock. Specific gravity=3·34.
INTERMEDIATE.	2. Rocks composed of pyroxene, scapolite, wollastonite, and graphite, iron-ores, and sphene, often with subordinate felspars or quartz.[1] Specific gravity=2·99, 2·92.
	3. Similar rocks, with abundant orthoclase-microperthite, or quartz, or both. Specific gravity=2·90, 2·83, etc.
ACID	4. Rocks formed of orthoclase-microperthite, orthoclase, oligoclase; with very little pyroxene, sphene, graphite; often rather coarser-grained than types 2 & 3. Specific gravity=2·64, 2·60.
	5. Coarse-grained quartzofelspathic rocks of granitoid aspect.

Types 1, 2, & 3 have usually a granular structure, types 4 & 5 a granulitic structure. Types 2, 3, & 4 form the main part of the exposures.

There are also (6) acid rocks composed of felspars, quartz, and little augite, iron-ores, apatite, zircon, etc., occurring as dykes crossing the foliation; and (7) coarse wollastonite-orthoclase-quartz-pegmatites.

The acid types (4 & 5) are of somewhat later origin than the basic, and though generally interbanded, behave on the whole in an intrusive manner towards them. The latest-formed dykes and segregation-veins (6 & 7) crossing the foliation are also of an acid type.

Foliation.—The alternation of grey and white rocks of types 4 & 5 with green and green-and-white rocks of types 2 & 3 produces a conspicuous banding. (Fig. 1, p. 682; see also Quart. Journ. Geol. Soc. vol. lvi, 1900, p. 602, fig. 2.) At the junctions of the different bands there is a gradual but rapid change from one type to the other. Quartz, when present, is usually in individuals elongated parallel to the foliation; flakes of graphite are similarly oriented, and when locally abundant may even produce a plane of parting. The general strike varies little. Occasionally sharp contortions are to be found, the axes of the sharp folds being parallel to the strike. These local sharp folds are the result of pressures acting during consolidation.

Dykes and segregation-veins.—A few dykes of normal charnockite-like type are found, crossing the foliation at right angles or obliquely. Such dykes are from 1 to 4 feet wide, and consist of grey and greenish-grey rock, not especially coarse-grained, in which very fine-grained orthoclase-microperthite is a predominant mineral, with quartz, a little augite, and sometimes apatite, sphene, and iron-ores as accessory minerals. They have a specific gravity varying from 2·62 to 2·67. One such dyke showed traces of a banded structure parallel to the edges. At the junctions with the matrix,

[1] In most cases, not quite all the minerals mentioned occur in the same slide.

the minerals interlock, and chilled edges are not found, showing the contemporaneous character of these ‘dykes,’ which are similar both to normal charnockites and to the acid varieties of the Galle Group.

Fig. 1.—*Foliation in the Point-de-Galle Group, Galle Fort: alternation of lime-silicate-pyroxene and quartzofelspathic types of rock.*

[At × × the specimen, figured in Quart. Journ. Geol. Soc. vol. lvi (1900) p. 603, was obtained; and at × the rock figured in the present paper, fig. 7, p. 688.]

More characteristic are the coarse pegmatite-patches and intrusive veins crossing the foliation (type 7). In these the component elements attain a large size and are frequently idiomorphic, with the exception of the wollastonite, which occurs in large masses moulding the other minerals (except pyrite, which however is rare in these veins). In such segregation-veins the minerals wollastonite, orthoclase, and quartz predominate, pyroxene being present in less quantity. Calcite and apophyllite occur occasionally, but may be secondary. The largest wollastonite-individual measured 36 × 15 inches; quartz 11 × $5\frac{1}{2}$ inches; orthoclase 24 inches in greatest diameter; a hexagonal prism of quartz, embedded in wollastonite, had a 3-inch prism side. The pyroxenes do not exceed a few inches in diameter, and are not always present. Scapolite was not found in the veins. Some veins consist almost entirely of wollastonite; one such, 2 to 4 inches wide, was noted on the shore between the Eolus and north-western bastions. Occasionally in these pegmatite-veins druses are found, partly filled with calcite. When weathered out, these sometimes yield idiomorphic orthoclase or apophyllite.

Weathering.—The felspars are generally very slightly cloudy, and not quite so fresh as in most of the inland charnockites. The scapolite exhibits often a fibrous structure due to incipient decomposition. The rocks generally speaking are, however, very fresh. In some specimens the wollastonite has been replaced by a minute quartz-calcite mosaic.

Relation to the Charnockite Series.—It will be seen from the map that the rocks of the Galle Group occupy a belt or zone with normal members of the Charnockite Series on each side. No actual junctions are exposed, and probably no sharp contact could be recognized, even if complete exposures were to be seen. Probably there is rather a gradual transition; bands of acid rocks in the Galle Group are quite like acid members of the Charnockite Series, showing the close connection between the two groups of rocks.

III. Notes on the Minerals.

Wollastonite,—never idiomorphic, but moulding other minerals; by no means always present; occasionally replaced by a quartz-calcite mosaic. Very large individuals in segregation-veins. It is interesting to note that Prof. Lacroix emphasizes the original character of the wollastonite in his Ceylon rocks, which, though probably not from Galle, are of very similar type.

Scapolite (wernerite),—constantly with small rod-and-lath-like inclusions parallel to the vertical axis. When decomposed has a cloudy look and fibrous structure. More frequently present than wollastonite. Never in large individuals, and not found in segregation-veins. Like the wollastonite, evidently an original mineral; often accompanying quite fresh felspars.

A graphic intergrowth of scapolite and orthoclase-microperthite (fig. 2, p. 684) occurred at the junction of a small quartz-felspar-pyroxene vein with a green-and-white wollastonite-scapolite-pyroxene rock. It is interesting to compare this intergrowth with the intergrowths of scapolite and diopside, and scapolite and orthoclase, which were found in a variety of rock included in the crystalline limestone of the Hakgala district.[1]

Felspars,—usually orthoclase, with very minute microperthitic structure; often showing a peripheral zone of intergrowth with very fine vermicular quartz. Perhaps microcline-microperthite is sometimes present. The microperthitic structure is usually very fine; in other cases, the plagioclase-inclusions are larger and distinctly twinned. Large and small idiomorphic orthoclase-individuals, without inclusions, occur in the segregation-veins. Some from a drusy cavity were kindly examined by Mr. Richard Graham, who

[1] A. K. Coomáraswámy, 'Crystalline Limestones of Ceylon' Quart. Journ. Geol. Soc. vol. lviii (1902) p. 409.

Fig. 2.—*Intergrowth of scapolite and orthoclase-microperthite, near the junction of a small vein with a more basic type of rock.* (×12½.)

[1 = Quartz ; 3 = Orthoclase-microperthite ; 16 = Scapolite, with fibrous decomposition-products.]

Fig. 3.—*Microscope-section of a rock illustrating type 1.* (×12½.)

[14 = Sphene ; 16=Scapolite ; 20=Pyroxene.]

says that 'the forms present are too rough to measure except with the hand-goniometer; they are probably

m(110), *b*(010), *z*(130), *c*(001), *o*($\bar{1}$11), *n*(021), *y*($\bar{2}$01), ? *d*(241);'

the combinations *mbzcony*, *mbconyd*, *mbcon* being noted. 'Sections || *b* give an extinction of about 5° and positive bisectrix central.'

Plagioclase is not very common in separate individuals, and when present is usually referable to oligoclase (in one case labradorite). The felspars, in appearance and behaviour, much resemble those of the Charnockite Series in general.

Augite,—pale sea-green in sections, dark bottle-green macroscopically, probably always belonging to the hedenbergite group.[1] Cleavage well developed. Extinction-angles over 40°. Occasionally replaced by amphibole, chlorite, calcite, etc., but usually fresh. Rare in segregation-veins, where individuals do not exceed a few inches in diameter. On one individual (moulded by calcite) from a small pegmatite-patch, Mr. Richard Graham determined the forms *m*(110), *a*(100), *b*(010), *o*($\bar{2}$21), and *u*(111).

Quartz,—irregular elongated individuals in the acid rocks, the elongation parallel to the foliation. Large idiomorphic individuals in the segregation-veins. Often opalescent in the coarse quartzo-felspathic rocks. No quartz-veins occur.

Sphene,—usually present, but never idiomorphic except where moulded by wollastonite in local pegmatitic patches.

Graphite,—generally present in small flakes, as an original mineral. Rare in more acid types, and not noted in segregation-veins. One very thin vein of graphite was observed following a line of very slight disturbance.

Iron-ores,—pyrite most usual; magnetite, more or less titaniferous, also occurs.

Zircon and apatite rarely observed.

Apophyllite,—small idiomorphic individuals in a drusy cavity in a segregation-vein. The forms *a*(100), *c*(001), *p*(111) have been identified by Mr. Graham.

The order of crystallization of some of the minerals is not very clear. Sphene, graphite, zircon, apatite, and iron-ores are the earliest; wollastonite is usually the last mineral to crystallize. When augite, felspars, quartz, and scapolite are present together, the structure is generally granular.

IV. Other Localities in Ceylon.

Rocks perhaps allied to those of Galle were brought up from the shaft of a graphite-mine at Nilhene (Baddegama district). Specimens composed of augite, scapolite, orthoclase, quartz, wollastonite, graphite, sphene, iron-ores, and calcite in various proportions were

[1] See chemical analysis, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 604.

Fig. 4.—*Microscope-section of rock illustrating type 2.* (×12½.)

[14 = Sphene; 16 = Scapolite; 20 = Pyroxene; 29 = Iron-ores;
47 = Wollastonite; 47 *a* = Quartz and calcite replacing wollastonite.]

Fig. 5.—*Another rock illustrating the same type as above.* (×12½.)

[6 = Plagioclase; 14 = Sphene; 21 = Amphibole; 49 = Calcite;
54 = Graphite.]

found, and have been briefly described by me in a former paper.[1] A quartz-calcite-micropegmatite occurred in one variety. No information concerning the field-relations of these rocks is available.

Rocks evidently similar to the Galle type occurred in a small exposure on the shore at Pittiwela, a few miles north of Galle. Specimens from this locality consisted of augite, scapolite, and sphene. The small exposure seemed to be quite isolated on the sandy shore.

Some charnockite-limestone contact-rocks in Ceylon resemble rock-types occurring at Galle, as, for example, the scapolite-augite rock with sphene, which occurs associated with crystalline limestone at Herimitigala[2]; but the contact-rocks, on the whole, are of a rather different type, the absence of wollastonite being especially noticeable,

Prof. Lacroix's specimens indicate the existence of wollastonite- and scapolite-gneisses in some other parts of Ceylon.

V. Conclusions.

The Galle Group includes a series of rocks allied to, and part of, the Charnockite Series in Ceylon. Like those of that series, it is clear that the Galle rocks must be classed as orthogneisses, for they have evidently consolidated from a magmatic condition. The wollastonite and scapolite are original minerals, and certainly not decomposition-products from felspars or other minerals. They are often associated with felspars which are in a perfectly fresh condition. This original character of wollastonite and scapolite in some gneisses rich in lime is well recognized. Wollastonite has even been found as an original mineral in eruptive rocks.

Possibly the richness in lime of some of the Galle rocks is due to the total absorption of a large mass of limestone (whether originally of sedimentary origin or otherwise) by a portion of the Charnockite Series. It may, however, have been an original character of the magma. Scapolite-pyroxene rocks are sometimes found at the junction of limestone and charnockite in Ceylon.[3] Wollastonite has not, however, been found in such situations. If the absorption-theory be accepted, the lime-silicate minerals must be regarded as endomorphic contact-minerals. In any case, the Galle rocks seem to show clear indications of progressive differentiation from basic to acid types; the coarse segregation-veins seem to be the last product of such a process. There is no reason to regard the graphite-flakes as other than original and crystallized from the magma.

That the Galle rocks have not suffered from deforming earth-movements since their complete consolidation is evidenced by their microscopic characters, and by the segregation-veins and dykes which

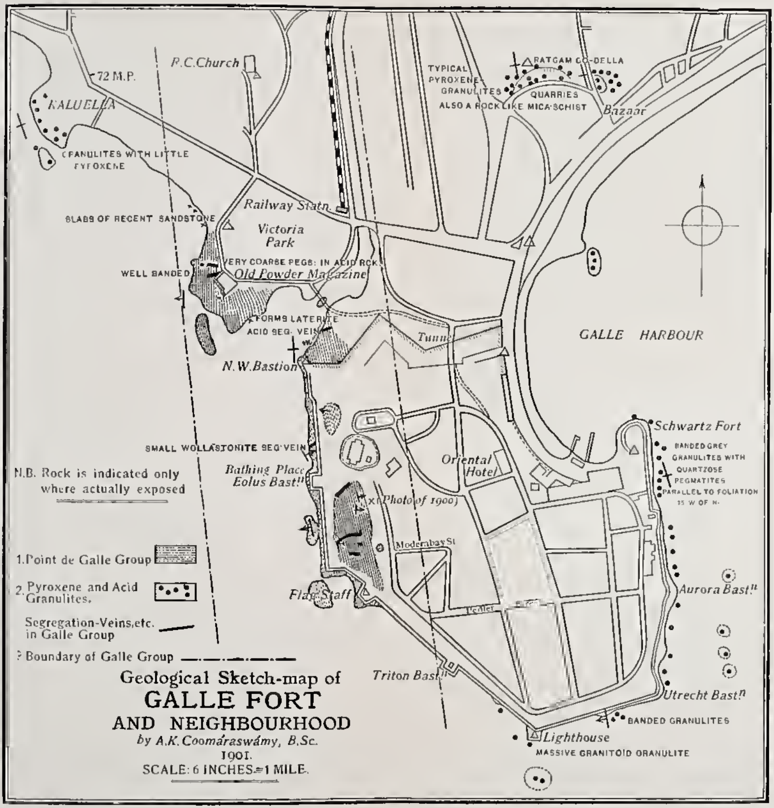
[1] 'Ceylon Rocks & Graphite' Quart. Journ. Geol. Soc. vol. lvi (1900) p. 602.
[2] 'Crystalline Limestones of Ceylon' *ibid.* vol. lviii (1902) p. 407.
[3] *Ibid.* pp. 405 *et seqq.*

Fig. 6.—*Microscope-section of rock illustrating type 3.* (×12½.)

[3 = Orthoclase-microperthite; 14 = Sphene; 16 = Scapolite; 20 = Pyroxene; 29 = Iron-ores.]

Fig. 7.—*Microscope-section of rock illustrating type 4.* (×12½.)

[1 = Quartz; 3 = Orthoclase-microperthite (and orthoclase?); 54 = Graphite
×× = Direction of foliation.]


Geological Sketch-map of
GALLE FORT
AND NEIGHBOURHOOD
by A.K. Coomáraswámy, B.Sc.
1901.
SCALE: 6 INCHES = 1 MILE.
N.B. Rock is indicated only where actually exposed
1. Point de Galle Group
2. Pyroxene and Acid Granulites.
Segregation-Veins, etc. in Galle Group
? Boundary of Galle Group
R.C.Church
72 M.P.
KALUELLA
GRANULITES WITH LITTLE PYROXENE
TYPICAL PYROXENE GRANULITES
ALSO A ROCK LIKE MICA-SCHIST
QUARRIES
Bazaar
Railway Statn.
SLABS OF RECENT SANDSTONE
Victoria Park
VERY COARSE PEGS: IN ACID RCK.
WELL BANDED
Old Powder Magazine
FORMS LATERITE
ACID SEG. VEIN
Tunnel
GALLE HARBOUR
N.W.Bastion
Schwartz Fort
BANDED GREY GRANULITES WITH QUARTZOSE PEGMATITES PARALLEL TO FOLIATION
SMALL WOLLASTONITE SEG'VEIN
Oriental Hotel
Bathing Place
Eolus Bast.n
x (Photo of 1900)
Flag Staff
Aurora Bast.n
Triton Bast.n
Utrecht Bast.n
BANDED GRANULITES
Lighthouse
MASSIVE GRANITOID GRANULITE

are never sheared or distorted, while the interlocking of the minerals at their junction with the matrix and their actual mineral composition, manifest their contemporaneous character and close connection with other rocks of the Galle Group.

EXPLANATION OF PLATE XXXIV.

Geological sketch-map of Galle Fort and neighbourhood, on the scale of 6 inches to the mile, showing the localities where wollastonite-scapolite gneisses are exposed.

Discussion.

Prof. Groom asked whether it was not possible that some of the splendid gneisses described by the Author had been formed by the intrusion of the more acid materials, along planes of foliation of a schist produced by the shearing of a solid rock.

The Author thanked the Fellows for the kind way in which they had received his paper. In reply to Prof. Groom, he said that he thought the mineral-banding of the Galle rocks was a true fluxion-foliation. There was no evidence of foliation in the basic portions of the rocks, previous to the introduction of the more acid portions. Basic lenticles included in more acid rock were common in the Charnockite Series, and there were transitions from these through pinched bands to ordinary mineral-banding. Simple mineral-banding was chiefly conspicuous at Galle, and this seemed to point to the squeezing of a 'schlierig' rock in the course of consolidation, during which there was perhaps a successive introduction of basic and acid types, the final residuum forming segregation-veins.

37. Alpine Valleys *in* Relation *to* Glaciers. By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S. (Read June 11th, 1902.)

[Plate XXXV—Sections.]

Evidently faith in the excavating power of glaciers will not become extinct in the lifetime of Prof. W. M. Davis, for he has recently credited them with the making of not only the Alpine lakes, but also no small part of the valleys.[1] They have produced, in his opinion, similar effects in Central France also and in Norway. Into these countries, though I know both fairly well, I cannot follow him without making an undue demand on the Society's patience, so I shall restrict myself to the Alps, and in doing this shall say very little about the Ticino Valley, which in Prof. Davis's paper occupies a prominent position. That I pass over (although, as it happens, my own ideas on this subject assumed a more definite form during a stay in one of its 'hanging valleys' four years ago) because I found that my friend and successor, Prof. Garwood, had devoted some time last summer to testing Prof. Davis's hypotheses in the place of their nativity, and was no nearer being a convert than myself. So I have ceded that region to him, and select for my purpose one or two other districts with which I am not less familiar, and apparently more so than Prof. Davis, whose method of dealing with this intricate problem does not strike me as satisfactory: for, so far as I can discover, he did little more than travel through the Alps by one or two frequented routes. But a problem of this kind cannot be solved without examining the upper as well as the lower parts of valleys, and contemplating the mountains from their peaks as well as from their bases. Under these circumstances, I think that we are entitled to demand facts and reasons in support of assertions, and to demur when we find the latter treated as valid foundations in the construction of an hypothesis.

A thorough discussion of Prof. Davis's paper would be tedious to the Society, for I should have to take it section by section, and insert with tiresome iteration either a 'not proven' or a *non sequitur*, so I will restrict myself to one of his hypotheses, with which, in my opinion, his whole position stands or falls. A very common type in Alpine valleys, according to his observations, is represented in Pl. XXXV, fig. 3, no. I. The more open part above the dotted line AB he maintains to be pre-Glacial, and the narrower one below to be the work of glaciers in the Ice-Age.[2] The first of these positions I do not dispute, though I attach a rather different sense to the words; the latter, I hope to show, cannot be harmonized with the facts.

[1] 'Glacial Erosion in France, Switzerland, & Norway' Proc. Boston Soc. Nat. Hist. vol. xxix (1900) pp. 273–322.

[2] For his arguments I must refer the reader to his paper, but I think that all familiar with the subject will easily infer them from my own.

To save time, I will describe in some detail a single Swiss valley in the Pennine Alps; for then it will suffice to mention briefly numerous others which lead to similar conclusions. At Visp a river bearing the same name joins the Rhone. The area which it drains includes some of the highest peaks and largest glaciers in the Pennine Alps; to the east of it indeed we must travel on the water-shed as far as the Bernina group, before we find a summit which reaches 12,000 feet. The Visp River is formed by the union of two great torrents, so that its plan on the map is a reversed Y, the western arm being fed by the glaciers around Zermatt, the eastern by those of the Saasthal; these torrents unite, each flowing in a deep gorge, near the village of Stalden. This is perched on the top of a rocky step—perhaps 400 feet high—in the floor of the valley, which afterwards remains fairly level and less contracted, though with steep and craggy mountains on either side, till it enters that of the Rhone. Measured on the map,[1] it is about 8 miles from the junction of the torrents to Saas Grund.[2] The chief ascent in this part of the valley-floor ends at Balen (4985 feet), some $2\frac{1}{2}$ miles below Saas Grund, the rise being about 1500 feet in the first half and 900 feet in the second. From Balen it continues gradual, rising about 650 feet in rather more than 7 miles,[3] and the valley is much more open. Below Balen, the valley as a whole takes the form given in Pl. XXXV, fig. 3, no. II; higher up this is less well marked, although hanging valleys are sometimes conspicuous.

The most remarkable of these, that in which the popular resort Saas Fee (5900 feet) has sprung up during the last quarter of a century, is reached by a steep rocky ascent from Saas Grund (5125 feet), which brings us to the comparatively level floor of an upland basin enclosed by a vast horseshoe of snowy mountains, which attain a greater elevation on the western than on the eastern side. Beginning with the Mittaghorn (10,330 feet), the crest runs on to the Egginerhorn (11,080 feet), after which it is interrupted by a snow-saddle, not quite 9900 feet high. From that it again rises to more than its former elevation, and culminates in the Allalinhorn (13,235 feet). Thence for a long way it practically keeps above 12,500 feet,[4] the Alphubel itself reaching 13,803 feet. Then comes the mass of the Mischabelhörner, the highest peak of which almost attains 15,000 feet, the gaps at first being about 1000 feet lower. The crest, after the Nadelhorn (14,220 feet), begins to decline, but it is now outside the limit of the Fee basin. All the drainage from the inner side of this horseshoe passes by Saas Fee, and most of its snowfields combine to form the broad ice-

[1] Unless expressly stated, all horizontal distances mentioned in this paper are thus measured.
[2] The ancient village on the bed of the valley.
[3] Thus the ascents may be roughly given:—first, 550 feet a mile; then, about 325 feet a mile; and lastly, for rather more than half the whole distance, under 100 feet a mile. (See Pl. XXXV, fig. 1.)
[4] The lowest pass, the Alphubel Joch, just south of that summit, is 12,475 feet.

curtain designated the Fee Glacier. If the Allalinhorn, and still more the Alphubel, were not snowy mountains, we might regard the higher passes, or 12,500 feet, as the upper limit of the névé which supplies the glacier; but as it is, we will estimate this as 13,000 feet.

How far is this huge corrie a cause, how far a consequence of this mass of névé and glacier? Let us see what would be the result of a rise of temperature of from 6° to 7° Fahr. The effect on the glacier would be the same as lowering the whole district by 2000 feet. The smaller glaciers would then disappear, the larger be greatly reduced in volume. But suppose the rise to be 10° Fahr., equivalent to an imaginary lowering of 3000 feet; then the principal peaks would range from over 10,000 to under 12,000 feet, and the neighbouring passes would be about 9500 feet. The district, in fact, would resemble the Lepontine Alps, from Monte Leone to about the Ofenhorn.[1] A further rise of 4° might be roughly represented by taking off another 1000 feet. Then, with only two peaks in the Alps overtopping 11,000 feet, with the higher Pennine passes, such as are mentioned above, at 8500 feet, and most of those in the Oberland well below the snow-line, though a few small glaciers[2] might linger around Monte Rosa and Mont Blanc, these would hardly rise above 'the second order,' and over a large part of the Alps there would not be so much as a snowfield; for the snow-line would then correspond with what is now 12,000 feet, or only a little below the top of the Wetterhorn or the Cima di Jazi. Thus during the Oligocene and most of the Miocene Period, when the temperature, according to the accepted authorities, was distinctly higher than at present, probably some 16° Fahr. in the earlier part, glaciers cannot have taken any real share in the sculpturing of the Alps, and even permanent snow-beds could only lend a little help in a few of the highest regions. At the beginning of the Pliocene Period, when the last great series of movements was dying away, the snow-beds probably had attained some size, and glaciers had formed under the shadow of the higher peaks, which may even have reached their present limits soon after the middle of the Pliocene Period. Thus in Oligocene and Miocene ages, to speak in general terms, glaciation in the Alps was a negligible quantity, its effects coming gradually into play in the Pliocene. But for some time many districts would be little affected, because with a temperature 6° or 7° Fahr. higher than at present there would not be a glacier left between the Simplon and the Maloja Passes, and even in the Oberland every one of the great ice-streams would have vanished, for then permanent snow could only begin at what is now 10,000 feet. On the other hand, if the temperature were lowered by the same amount, glaciers would

[1] We can realize the change by (say) estimating Saas Fee at 3000 feet, the Schwarzberg-Weissthor as 8850 feet, and Monte Rosa itself as only 12,227 feet, or hardly equal to the Mont Velan.

[2] As I have pointed out ('Ice-Work, present & past' Internat. Sci. Series, 1896, pt. iii, ch. 1, pp. 232–33) glaciers in the Alps begin to form about 1000 feet higher than the snow-line.

begin to form at 7000 feet, and the extent of the ice-streams would be enormously increased. For instance, in the valley above Saas Grund a field of névé would extend down from the Monte-Moro Pass to below the Mattmark Inn, and in the Oberland a continuous snowfield would cover the upper part of the Gemmi Pass.

These conclusions are inevitable, if we believe the climate of Europe to have been warmer than now in Oligocene, Miocene, and early Pliocene times, especially in the first and second. They may, however, be questioned on the ground that the Alps were then more elevated than at the present time, and have since been greatly lowered by 'denudation.' This objection demands an answer. No doubt a great mass of material has been removed; valleys have been carved out in rock-masses once continuous; their floors have been much lowered; but is there any evidence that the height of the crests has been very materially diminished? Suppose the Alps—say at the outset of the Oligocene—to be beginning to rise, and their watershed to correspond on the whole with that of the Pennines. No sooner did that emerge, than streams would begin to run northward and southward. Some might trace for themselves independent parallel furrows; most of them would combine in groups, like the branches and trunk of a tree, as we can see when the tide retreats from a shelving, sandy shore. Suppose subordinate folds to be presently developed on the north and south of the main one; then streams would be caught by the intervening troughs, and valleys of strike [1] be formed. But the water in places would escape through a gap in the crest of the subordinate fold, for it is very probable that this would not keep at the same level in every part. These outlets, as the rising continued, would probably become less numerous, so the water would ultimately escape from the central range (as at the present day) by very few gaps.[2] This would be the early history of the great strike-valleys of the Upper Rhine, Reuss, and Rhone—that extraordinary trough of (mostly) Mesozoic rock now divided into three by the comparatively low watersheds of the Oberalp and the Furka.[3] The rising in the Swiss Alps was not marked till, at any rate, after Bartonian times, and must have been going on during the earlier part of the Oligocene. The great conglomerate-masses of the Nagelfluh, now generally referred to the Upper Oligocene, prove denudation to have then become active, and that which now forms the Rigi indicates the course of the Reuss through the Bernese Oberland to have been already determined, although the crystalline rocks, which we now see rising from beneath the Mesozoics and later sedimentaries at

[1] I prefer the old terms 'dip-valleys' and 'strike-valleys' to the more modern 'consequent' and 'subsequent,' as on the whole more expressive. 'Obsequent,' another new term, ought not, I believe, to bear the meaning given to it.

[2] Four: the Rhone, the Reuss, the Rhine, and the Inn.

[3] Oberalp Pass (6710 feet), Furka Pass (7990 feet): probably it may be traced over the Forclaz (4937 feet) and the Col Ferret (8343 feet), where, however, it is deranged by the massif of Mont Blanc.

Erstfeld, could have been but rarely exposed. But, it may be asked, does not this fact prove the crest at the watershed (now of crystalline rocks) to have been higher by the thickness of the vanished sedimentaries? That, I think, would not follow, for we must remember that during this age the northern flank of the Central Alps would more closely resemble the corresponding part of the Tyrol at the present day: namely, an outer range of sedimentaries, like the Austro-Bavarian Alps, and a central one (the watershed) of crystalline rocks in which, however, remnants of the others were then more abundant. The Lepontine Alps, during the formation of the Nagelfluh, may very well have been rather higher than at present, but probably not much; nor is such a difference necessary, since the Reuss can still transport similar materials to the level of the Lake of Lucerne, and even an addition of 2000 or 3000 feet to the altitude of the range would leave it inferior to the present Oberland.[1] The final uplift of this range,[2] with its complicated folds and thrust-faults, and the elevation of the Nagelfluh to a frontier-zone of mountains, sometimes rising above the 5000-foot contour-line, may be ascribed to the series of movements which closed the Miocene Period and made a land-region of this part of Europe. That, of itself, would retard the outflow; but as there is no more change in the physiography of the Alpine Rhine, Rhone, and Reuss than what the rock-structures themselves can explain, we may conclude that the rivers had already sufficient erosive power to keep open their outlets, and that the central axis of the Alps was not much higher than it is at the present day.

The Alps, however, may have been lowered by actual subsidence; and this objection is more difficult to meet. Indeed, though I see no reason for supposing that the difference in level between the crest of the Pennine Chain and the mouth of its lateral valleys, such as the Vispthal, has materially altered, I should think it probable that the slope of the great trunk-valleys, into which these discharge, such as the Rhone above St. Maurice, has been diminished, and that the great lakes, at any rate, lie in a zone of rather recent subsidence. This movement, however, I think, has not so much affected the Alps as a whole as the relative level of certain parts, and is not likely, even on the former supposition, to have lowered their crest by more than 1000 or at most 1200 feet. If so, a correction of some 3° or 4° Fahr. must be applied to the temperatures which I have used. But as we do not know when, if at any time, to apply this correction, or, in other words, at what epoch the Alps reached their greatest altitude, it seemed to me simpler to reason from the existing state of things, instead of suggesting possible modifications of uncertain value.

[1] The Pizzo Rotundo is 10,490 feet above sea-level; the St. Gotthard Pass 6935 feet.

[2] The effects are conspicuous in the Mont-Blanc massif, and from it as far as Dauphiné.

Returning to the Fee Alp, we find that its comparatively level bed is some 6000 feet above the sea, and the ascent from it to the passes is fairly rapid. It is, in fact, a gigantic corrie with rocky steps and slopes generally not less than 6000 feet high (see Pl. XXXV, fig. 2). At the present time, and at least ever since the Glacial Epoch, the floor (nearly half a league long) has been raised by accumulation rather than lowered by denudation.[1] But its rocky lip is notched by a gorge, which begins just below Saas Fee, deepens rapidly, and continues to within a short distance of the junction of its torrent with the Visp, to which, indeed, this is almost equal in volume.

Let us now examine the main valley (see Pl. XXXV, fig. 1). As already said, it exhibits no marked change in level above this junction, though it becomes rather narrower. After about 3 miles from Saas Grund, beyond the Zermeiggern chalets (5630 feet) it begins to ascend more rapidly, taking the form of a glen with steep rocky slopes on either side, the western one being the more precipitous. At the Distel Alp (4 miles) we have reached 7120 feet, and then ascend to the Monte-Moro Pass (9130 feet).[2] No high peaks are in the immediate neighbourhood of this Pass, though I believe such to have existed at the time when the Saasthal was mainly excavated[3]; on the eastern side also they are comparatively low for some distance, but we find them on the west and north-west. The Schwarzenberg Glacier is the first worth naming which sends its waters to the Visp, and it reaches the floor of the valley near the Mattmark Inn (6965 feet) below the Distel Alp. The Allalin and the Hochlaub Glaciers come next: the former, which is by far the larger, reaching the floor of the V-shaped valley. Both of these are enclosed at their heads by precipitous walls, culminating in the Strahlhorn, Rimfischhorn, and Allalinhorn. The entrance of the Schwarzenberg Glacier does not affect the level of the valley-floor; it is very slightly steepened for a short distance below the Allalin Glacier, and not perceptibly changed by the third one.

On the eastern side, the more notable valleys are, the Furggenthal, a long glen leading to the Antrona Pass (9330 feet), and rather similar in form to the main one, the floor of which is at a lower level, as might be expected from a comparison, even at the present day, of the two torrents. Then comes the Almagell glen, running up to the Portjen Grat (12,008 feet) and the Zwischbergen Pass (10,657 feet): shorter, more distinctly a hanging valley, and drained by a larger torrent, leaping down a rocky wall in which, however, it has nowhere cut more than a slight gash.[4] North of

[1] We pass great domes of ice-worn rock just before entering the village of Saas Fee, but the valley-bed is then concealed for a time under pastures masking slopes of débris.

[2] The first stage has an average rise of about 370 feet a mile, the second of 1000 feet.

[3] See Alpine Journ. vol. xiv (1889) p. 224.

[4] That is, so far as can be seen from Almagell. I once came down the valley in descending from the Weissmies, but that was 20 years ago, and so I do not very distinctly remember more than that it was uninteresting.

this are other lateral valleys, the beds of which are more or less separated from that of the main one by a steep ascent, but exhibit less strongly marked characters than those already mentioned. Above them, this spur reaches its greatest elevation in the Weissmies, Laquinhorn, and Rossbodenhorn—all overtopping 12,000 feet, and looking down on the deep trench of the Simplon Pass (6590 feet).

To the west of Visp, three valleys only, the Val d'Anniviers, the Val d'Hérens, and the Val de Dranse, descend from the watershed of the Pennines to the great trench along which the Rhone flows to Martigny. In the first the stream issues from a deep gorge, the floor of the valley being nearly 1200 feet above that of the Rhone. The rise in the next 4 miles is not quite 1000 feet; in the next 2 miles, to Mission, near the junction of the Val de Zinal and the Val de Moiry, it is about 280 feet; after that the floor of the former rises almost 600 feet in nearly a mile[1]; then the ascent for about 3 miles to Zinal (5505 feet), and for some distance beyond it, is rather gentle, not more than 200 feet a mile. The Val d'Hérens is roughly similar. At the mouth is a steep drop and a gorge, but as the valley is more V-shaped, it is not easy to give exact figures. The entry, however, of the western and smaller branch—the Val Moiry—does not seem to produce very much effect. The V-like outline, in fact, continues till we approach Evolena (4520 feet), where a valley, rather short, brings the drainage from the Ferpecle Glacier. This produces no apparent effect on the depth of the valley, which, however, is distinctly broadened at the junction. From Haudères (4747 feet), where the torrents unite, to beyond Arolla (6570 feet)—well over 3 miles—the ascent is steeper and generally steady; but, after running nearly level from below Arolla to some little way up the Colon Glacier, the usual rapid ascent takes place to rather high passes and peaks.[2] The Dranse Valley consists of at least three tributaries, and drains a large mountain-area, but as I believe its story to be complicated by the upheaval of the Mont-Blanc range, I shall merely say that it enters the Rhone Valley at Martigny, after descending a steep-sided V-shaped rocky glen, which is glaciated almost down to the level of the river.

East of the Simplon Pass, the topography of the Rhone Valley and its tributaries becomes less simple, and the dominant features can alone be noticed. A short distance above Brieg the drainage of the great Aletsch Glacier, which occupies a kind of hanging valley, issues from the grand gorge of the Massa to join the Rhone.[3] About 2 miles beyond this (and so not due to that glacier), a distinct step occurs in the floor of the main valley between Moril and Lax, after

[1] These figures are not quite accurate, for they are taken from villages above the stream, which is running in a deep notch or gorge, but their only error is to exaggerate slightly the drop from the junction of the valleys.

[2] The lowest pass, Col de Colon, is 10,270 feet above sea-level. Some of the peaks are about 12,700 feet.

[3] All the valleys from the Oberland to the west of this are more or less 'hanging valleys,' the torrents from them issuing from a gorge or very steep-sided V.

which only two tributaries—the Binnenthal and the Eginenthal—descend from the actual watershed on the south: the former being in its upper part a valley of strike, in its lower, where it is more or less a gorge, one of dip. The Eginenthal, on the contrary, is fairly open at its mouth, and the rise for a considerable distance is comparatively gentle (rather over 300 feet a mile), till at last an abrupt ascent (at least 2300 feet) leads to the Gries and Nufenen Passes. But the outlines of this valley, if we attribute great effects to glacial erosion, would oblige us to admit that the snowfields near the Gries Pass (which now are, and, so far as we can tell, always have been, of minor importance), aided by the absolutely petty contingent from the Nufenen Pass,[1] plunged at once precipitately downward and excavated the comparatively open Eginenthal. In other words, the smaller ice-stream of the Eginenthal was more effective than the larger one of the Binnenthal. The head of the main valley is also rather anomalous, for its trough seems to extend in a direct line to the Furka Pass: the Rhone Glacier occupying a glen more immediately connected with the Oberland massif. This also is a kind of hanging valley; for, from just below Gletsch (5755 feet) to near Obergestelen (4450 feet) is a rather steep and rocky descent—that is to say, the valley in which a glacier would appear late and vanish early is a more important physical feature than that where a rather large one still remains.[2]

The Bernese Oberland, as already stated, was probably more affected than the Pennines and Eastern Alps by the second great set of movements: these, however, so far as we can tell, did not so much initiate features, as intensify those the outlines of which had been already sketched. But the valleys, especially in the upper parts of the region, are probably on the whole more modern than in corresponding parts of the Pennines.[3] So a few words may be said about one of the principal Oberland valleys, that of the Upper Aar.[4] This river may be said to rise from a glacier formed by the union of ice-streams descending from beneath the Berglistock, the Schreckhorn, and the Finsteraarhorn, between which are passes about 11,000 feet

[1] The Nufenen Pass is just over 8000 feet above sea-level; the Gries slightly higher, but the glacier crossed on the way to it comes from a rather large névé occupying a kind of strike-trough between ridges from 10,000 to 11,000 feet in altitude.

[2] It is worth notice that the sudden steepening in the descent of the Rhone Glacier is but a little higher than the top of the Grimsel Pass, also approached by a steep ascent from Gletsch. It may also be worth noting, that below Martigny, the Val de Trient, with the steep ascent to Salvan and the famous gorge through which that torrent descends to the Rhone Valley, indicates the water to be far more effective than the vanished glacier as an erosion-agent.

[3] This may partly account for the fact that 'beheaded valleys' seem more common on the watershed of the Alps than elsewhere. Hanging valleys, so far as I remember, are rare, except when the water is discharged into the trench of the Rhone.

[4] The larger rivers have cut their own paths, like the Lutschine, the Linth, and the Aar, the last being barred rather than 'stepped' at the Kirchet. There are slight steps at the entrances of the tributary Urbachthal and Gadmenthal.

above the sea. The ascent to these is commonly a rocky wall, some 800 feet high, but the slope of the névé below is generally not rapid and that of the ice-stream almost gentle; for a considerable length of the glacier lies between rather over 8000 feet and rather under 7000 feet above sea-level. From its foot (about 6200 feet) the valley retains its dominant features for perhaps $2\frac{1}{2}$ miles, except that it tends to become narrower, its bed being rather flat and stony. Near the Grimsel Hospiz (6160 feet), famous for the surrounding roches moutonnées, the Aar turns sharply from north-east to north-north-west, and begins a rapid descent for about 1500 feet through the Upper Haslithal. In section, this part of the valley is a regular **V**, cut completely in crystalline rocks, which, as is well-known, are wonderfully ice-worn, and the marks of the glacier may be traced in places to within 2 or 3 yards of the torrent. A rise in temperature of 10° would probably efface the Unter-Aar Glacier, and give us in its place a rather trench-like valley, at the head of which the rock-wall of the Strahleck would rise from a snow-bed of very moderate size. If, then, this upper trench, now mostly occupied by glacier, be the work of the ice, so must be the lower part below the Grimsel. Yet that is a regular **V**: its buttresses, though wonderfully moulded by ice-action, still retain the ridges characteristic of sculpture by ordinary meteoric forces, and shallow glens may be occasionally seen on either side, descending from the mountain-crests. Though the ice has nowhere left its mark on the Alps more conspicuously than here, it has not been able to obliterate the leading lines of a waterworn valley.

It would be easy to multiply instances from other parts of the Alps. These exhibit varietal differences, according to the nature of the rocks; and the physical features of the limestone-districts differ in some respects from those of the crystalline. But, speaking of the latter only (in order to avoid too much complexity), I may say that all the valleys, small and large, in the lower as well as the higher districts, are shaped on the same general pattern, the superimposed effects of ice becoming more conspicuous as we get farther from the sea-level, and nearer to their heads. The evidence, so far as I can read it, indicates that the isolation of a tributary from the principal valley—in other words, the conversion of the former into a 'hanging valley,' depends upon whether the latter could become the path of a powerful, and especially of a glacier-fed torrent—that is, it is very much a question of the forces and of the environments. In the Cottian Alps, from which glaciers have practically disappeared and where the streams are generally clear, rock-gorges, so far as I remember, are not as a rule conspicuous. But in Dauphiné, in all the great mountain-mass connecting its central peaks with the Aiguilles of Mont Blanc, throughout the valleys and passes of Switzerland, and in the Tyrol (of all which I can speak from personal knowledge), I have observed only varietal distinctions, together with many common features which appear to me inexplicable on any hypothesis of ice-excavation; and have not found one which does not harmonize with the work of heat and cold, of rain and rivers, guided, of course, by the results of earth-movements.[1]

Personal examination of every part of the Alps, of the Pyrenees, the Apennines, Scandinavia, Auvergne, and many other hill- or mountain-regions, has led me to the following conclusions:—

(1) That the action of permanent snow is more conservative than destructive.

(2) That the erosive effect of a glacier is at a minimum beneath a comparatively level névé, such as is often found at the base of a rock-wall, not seldom from 300 to 600 or 700 feet high.

(3) That cirques, corries, and bowl-like heads of valleys are mainly the work of water, their forms depending on local circumstances: they are made on a small scale by rain and its runlets, on a larger by streams.[2] They are not restricted to glaciated regions, though permanent snow-beds, other things being equal, favour the formation of the first and second. The principal cirques in the Alps exist in regions where the peaks do not rise so high as 11,000 feet, and are sometimes considerably below this; their floors are not at very high levels—under rather than over 4000 feet. In other words, cirques occur on the grandest scale where the ice would have the smallest extension, the shortest duration, and the least erosive action.

(4) That while running water is very obviously competent (with the requisite environment) to carve out cliffs on a grand scale, no proofs have been brought to show that a glacier can do this on any but a small scale. Indeed, in all cases that I have seen, it appeared more probable that the ice had only modified a cliff already in existence, than that it had hewn one out by itself. We need also something better than vague assertions about 'broken-bedded valleys' before we can regard it as proved that a glacier can hew its rocky floor into great steps. We may fairly appeal to the Unter-Grindelwald Glacier, for its ice-curtain has been partly withdrawn during the last 40 years; when we examine the steps which it has exposed, these appear to have preceded the ice, and to have had only their edges rounded off by it. Indeed, my imagination will not enable me to picture a glacier in the act of cutting steps in a subjacent mass of rock.

Again, the obstacles which projecting rocks, or ridges like those of Sion, present to Prof. Davis's excavating glaciers, cannot be

[1] The features of the Saxon Switzerland are often thoroughly Alpine. There are little gorges in the glens leading to the Elbe, and lines of castellated summits, which in a photograph might be taken for scenes in the Dolomites, yet these are seldom more than about 1500 feet above sea-level, so that glaciers, if ever they formed in this region, would be very short-lived.

[2] See my paper on 'The Formation of Cirques' Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 312. During the 30 years which have elapsed since that paper was written, I have revisited some of these cirques, have examined many others, great and small, and have been continuously observing the forms of valleys, and I am more than ever convinced that I have rightly interpreted the teaching of Nature. Such contours as are represented by Mr. Harker (Trans. Roy. Soc. Edinb. vol. xl, pp. 232–41) are to be found associated with, but are not characteristic of, glacial action.

removed by merely stating that they may be masses left by the ice, as islands are by running water. He ought at least to show some reason—such as the occurrence of unusually hard material, for their escape from the oppressor. Now certain of these I know, especially that at Sion, and venture to say that he will find this difficult.

Again, a wonderful faith in 'strong glacial erosion' is required before we can believe the upper part of the Gasterenthal to have been excavated by a glacier. I have ventured to maintain that the far humbler Kirchet presents serious difficulties[1]; and how any such hypothesis is to fit the widening of the valley above the Klus on the Landquart, or the step down to Klosters from the valley in which Davos lies—a region even now with few and small glaciers—to mention no other cases, passes my comprehension.

(5) Beheaded valleys, the executioners of which, as has been proved at the Maloja Pass, have been the ordinary meteoric agents (working in this case from the Italian side of the Alps, where fluviatile erosion would be more active than on the northern side), are more common on the main range, because there these agents have been longest at work.[2]

(6) When not thus beheaded, a valley commonly expands in its uppermost part (though occasionally it keeps the furrow-form to but a little below a pass). This expansion is somewhat on the corrie-type, a 'wall,' or at any rate a steep rise, forming the last portion of the ascent. As the rills gather into streams, and these into rivers, the valley becomes more V-like, the slope of the sides steepening as the torrent increases in erosive strength: so the Y-type (where the rocks are unchanged) probably indicates a rather rapid increase in the power of the torrent.[3]

(7) In all parts of the Alps we can trace, beneath the undulating contours impressed by the glaciers, the ordinary features due to other meteoric agencies. The broader outlines of the valleys, whether those at higher elevations, which are still occupied by névé and glacier, or those at lower, which are either bare or merely patched by one or two snow-beds,—valleys, in short, which snow and ice have occupied since Pliocene times, as well as those which they only invaded in the Ice-Age,—are in all cases practically identical, provided the rock is similar.

I have been obliged to speak rather dogmatically, because if every statement were fully proved, the details would be so numerous

[1] Alpine Journ. vol. xix (1899) p. 29.

[2] See Alpine Journ. vol. xiv (1889) pp. 224–32, for details. The crest of the Pennines at the head of both branches of the Vispthal affords, as there explained, wonderful instances of this process. I have little or no doubt that the snowfields on the Monte-Moro Pass, and others in that neighbourhood, were once much more extensive and rose to a greater elevation.

[3] I may refer for details to the chapters on mountains and valleys (pp. 55–157) in the 'Scientific Study of Scenery' London, 1900, by my friend Mr. J. E. Marr, from which I should differ at most on one or two points of detail.

as to become wearisome. These can be produced, if necessary. So I venture to conclude this communication, already somewhat prolix, by a brief statement of the ideas concerning the valley-sculpture of the Alps, which have gradually developed themselves in my mind from a study not of books, but of Nature, in the course of visits, which are now 30 in number. This sculpture began in Oligocene ages, when the central axis, which still forms the watershed, dominated greatly over the ranges north and south; it continued through most of the Miocene, though it was at its maximum, at any rate in the transport of materials, when the Nagelfluh pebble-beds were deposited; for during these periods the rainfall on the Alps, owing to the different arrangement of sea and land, was probably heavier than it is at the present time. At first there were no glaciers, for some time not even permanent snow-beds. Then denudation—peak- and valley-sculpture alike—was of the ordinary kind, which became more active as the temperature slowly declined. The Miocene Period, as it approached its end, would witness two changes: (*a*) the beginning of the second great Alpine uplift; (*b*) a marked extension in the area permanently covered by snow, and thus the formation of real glaciers.[1] This second change would restrict, or even arrest the action of small streams in the upper glens, and would intensify that of the main torrents; in other words, there would be less rake-scratching in the upland glens, and more furrow-cutting in the valleys. The latter process would become more conspicuous during the Pliocene, as the glaciers continued to increase in size; but it must be remembered that, as the ice occupied more and more of a valley-floor, it would protect the newly-annexed territory from other agencies than the ice-plane.[2] In a system of valleys, denudation would be checked on the whole in the higher tributaries, and intensified in the principal channels of discharge. This would lead to the formation of 'hanging valleys,' and as they developed the torrents from them would acquire a plunging force and begin to cut gorges.[3] This process in many cases has continued ever since, though perhaps it might slacken in the higher regions when the ice had a very great extension: for at the present day the torrents which flow from glaciers are much reduced in volume during the winter. That season I presume may be regarded as a temporary relapse into the climatal conditions of the Ice-Age.[4] Therefore I maintain that not only does Prof. Davis's hypothesis derive little

[1] This would be when the mean temperature of the Alpine region (supposing the height to be the same) was 6° or 7° Fahr. higher than it is at the present day.

[2] The main sub-glacial torrent, especially if it had already cut a gorge, would of course continue to deepen this.

[3] It is worth noting that in the Alps when streams at the present day are fed by lakelets or snow-beds, gorges, as a rule, are insignificant or absent; the great gorges, at any rate in the crystallines, are the paths of glacial torrents.

[4] The streams would have great erosive force during inter-Glacial times (when the Deckenschotter and the great valley-gravels were formed); but, so far as I can judge, the glaciers would even then extend beyond their present limits, and thus the districts with which I have been chiefly concerned may have been more or less covered by snow or ice all through the Glacial Epoch.

support from facts, but also the Alpine valleys are almost wholly pre-Glacial. The upper and broader parts—say those higher than 800 feet, more or less, above the present beds[1]—are chiefly pre-Pliocene work; the narrower (V-like parts) below were formed in part of that Period; the gorge-cutting dates from later Pliocene onwards; while the superficial moulding, some shallow tarns in special situations, the *roches moutonnées* and the general smoothing, are the work of the Ice-Age. Many upland valleys were cut down to the curve of no-erosion at an early date—perhaps even by the beginning of Pliocene times; though in others denudation might be again started by the change in level which closed the Miocene Period. Except for the cutting of gorges and the destruction of peaks and crests, denudation in the Alpine regions now proceeds with comparative slowness,[2] and many streams over the greater part of their course are actually raising, instead of lowering their beds.

EXPLANATION OF PLATE XXXV.

Fig. 1. Section along the bed of the Visp, from the Monte-Moro Pass to near Visp, on the scale of $\frac{5}{8}$ inch to the mile.

2. Section across the Saas Valley, from Grundberg to the Alphubel, on the scale of $1\frac{1}{4}$ inches to the mile.

These sections have been constructed from the contour-lines in the 'Topographischer Atlas der Schweiz,' without any attempt to indicate cliffs or minor irregularities. As the second one crosses the Visp very obliquely, it materially diminishes the lower slope on either side. From Saas Grund to Saas Fee is a really steep ascent; in other words, the true section of this part of the valley is more V-like than it appears in the diagram.

3. I. Section of glaciated valley, according to Prof. W. M. Davis.

II. Section of glaciated valley, according to the author.

AB = Bed of pre-Glacial valley; C = Glacial valley;

QR = Highest level of glacier.

[For the Discussion, see p. 716.]

[1] It is impossible to give a very precise figure—according to circumstances, it may be more or considerably less.

[2] In the latter case I should think that it was most generally active from rather under 8000 to over 9000 feet. Above this limit, generally speaking, only cliffs are exposed, the slopes being protected by snow.

Fig. 1.- Slope of the bed of the Vispthal, from the Monte-Moro Pass to near Visp.

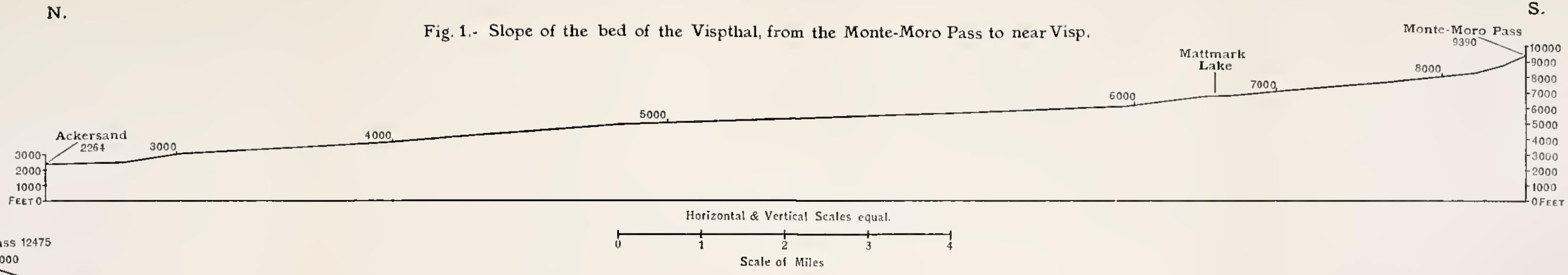


Fig. 2.- Section across the Saas Valley.

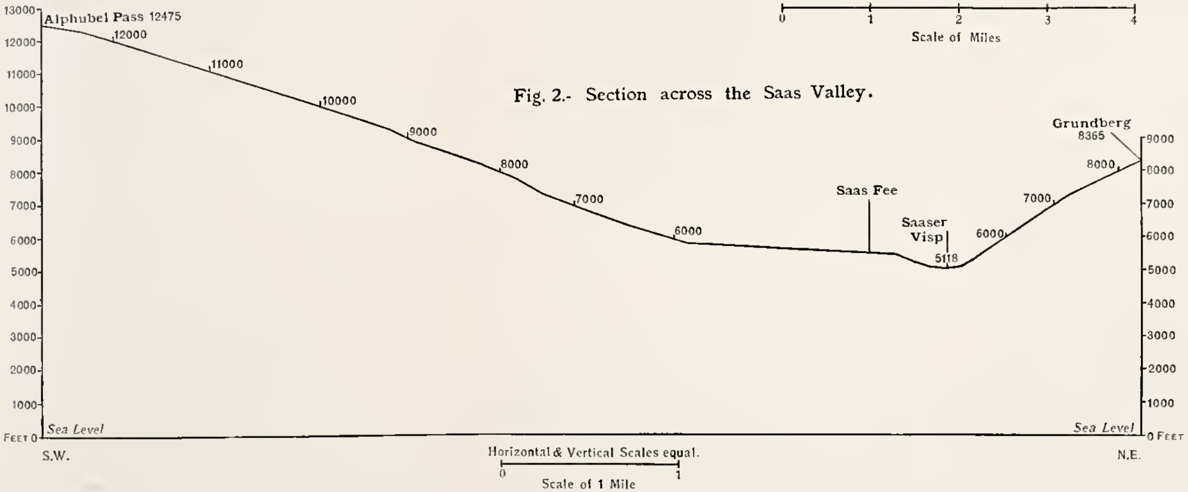
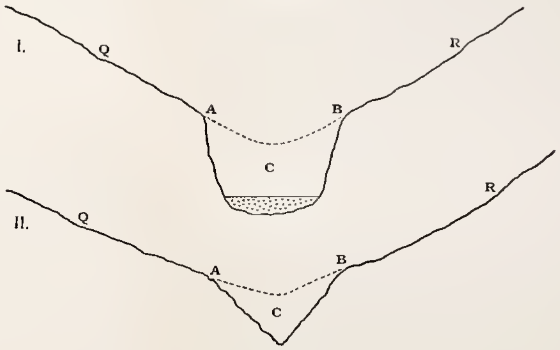


Fig. 3.- Sections of glaciated valley.



38. *On the* Origin *of some* Hanging Valleys *in the* Alps *and* Himalayas.

By Prof. E. J. Garwood, M.A., F.G.S. (Read June 11th, 1902.)

(Plates XXXVI–XL.)

Contents.

I. Introduction.

During my visit to the Eastern Himalayas in 1899, I was much struck by the discordance of certain of the tributary valleys to the main valleys which they feed in the district of Jongri, near the south-eastern foot of Kabru. While making a plane-table survey of this district, I arrived at certain conclusions with regard to the origin of these valleys, which I have already published in the journal of a kindred Society.[1] I was, therefore, much interested when my attention was drawn to a paper by Prof. W. M. Davis on 'Glacial Erosion in the Valley of the Ticino,'[2] in which the hanging valleys in the lower part of the Val Ticino are attributed to the over-deepening of the main valley by ice. His theory of their origin may be briefly stated in the following paragraph taken from the paper above cited:—

> 'The deepening of a glaciated valley for a good part of its length is thus seen to be a general result of glacial erosion; it is accompanied throughout by discordant or hanging lateral valleys, and the production of a lake in the distal portion of such a valley is but a subordinate result of glacial action.' (*Op. cit.* p. 152.)

This theory of the origin of hanging valleys is diametrically opposed to the one at which I had arrived, from a study of similar valleys in the Sikhim Himalayas. Coming as it does, however, from one of our foremost exponents of drainage-problems, it deserves most careful consideration.

I propose, therefore, first to consider all the evidence available with regard to the possible modes of formation of the hanging valleys which occur in the Val Ticino itself, and afterwards to bring to bear on the question any evidence from similar phenomena in other districts, with which I am acquainted, which may tend to throw light on the origin of the Ticino valleys.

[1] Geogr. Journ. vol. xx (1902) p. 13.

[2] 'Appalachia' vol. ix (1900) pp. 136-56 w. figs. & pls. xv–xvi.

In the first place, I feel that I owe to Prof. Davis an apology for entering as a critic into a field of research which he has made so peculiarly his own. I should like to urge, however, as an extenuating circumstance that, though I have written little, I have lived a large portion of my life among the glaciers of the Alps, and in particular in the neighbourhood of the St. Gotthard range. Had Prof. Davis selected any other district but the Val Ticino, I should most likely not have considered myself justified in criticizing his facts and conclusions; but with the Val Ticino I have had a long and intimate acquaintance, having traversed it on an average twicea year for upwards of twenty years, either on foot, in coach, or by train, and have a personal knowledge of nearly every gully and lake between Airolo and the Lago Maggiore.

Under these circumstances, I feel bound to suggest an alternative origin, for the discordant lateral valleys which Prof. Davis has described, from that which he has advocated—a theory as to their origin which has been considerably strengthened by a study of the hanging valleys which I have met with in Sikhim and elsewhere.

II. Hanging Valleys of the Val Ticino.

To the accuracy of the facts stated in Prof. Davis's excellent description of the main features of the Val Ticino between Giornico and Biasca I can fully testify. The basal cliffs, the gentler slope forming benches above, and the open character of the valley below Biasca are familiar features; and I quite agree with him that

'the benches seem to be the remnants of the slower slopes of an ancient wide-open valley, in whose floor the present cliff-walled deeper valley has been eroded; and this supposition is confirmed when it is found that the high-standing lateral valleys are systematically related to the ancient rather than to the modern valley-floor.' (*Op. cit.* p. 146.)

But when we come to the statement (*op. cit.* p. 147) that

'The famous corkscrew tunnels . . . . are therefore to be regarded, along with the stone posts of the grape-arbours in the vineyards about Biasca, as indirect consequences of glacial action,'

we have reached the gist of the matter, and I must join issue; for I cannot admit that this assumption of the over-deepening of the lower portion of the valley by direct ice-erosion is at all borne out by the facts of the case, even if we adopt Prof. Davis's own line of argument, although, as I shall endeavour to show, ice has, in my opinion, been probably the indirect cause of the formation of the hanging valleys, but in a very different manner from that advocated by Prof. Davis.

Let us review the evidence brought forward to support the theory that the lower portion of the main valley below the benches and below the mouths of the hanging valleys has been entirely excavated by ice. This evidence rests on two facts: (1) the steep character of the main-valley wall below the level of the hanging valleys; and (2) the absence of

'overlapping profiles, entering the valley from one side and the other alternately, and concealing the more distant parts of the valley-floor.' [1]

The first of these arguments does not by itself afford any evidence of overdeepening by ice, as we have plenty of instances of river-gorges with inaccessible sides and subparallel walls. No one, for instance, imagines that the cañons of Colorado or the gorge of the Via Mala owe their origin to overdeepening by ice; and this Prof. Davis would be the first to admit. It is, therefore, on the second statement—that the characteristic 'crossing spurs' are absent from the Val Ticino—that the ice-excavation theory relies, supported by the presence of the hanging valleys and the steeper grade of the main-valley walls beneath.

Now, the hanging valleys described by Prof. Davis are all situated a short distance above or below Biasca, and his description of the valley's characteristics is entirely drawn from this portion of the Val Ticino. The valleys below Biasca are complicated by the results of the additional drainage from the Val Blenio; and as the portion above Biasca contains three of Prof. Davis's typical valleys, namely, the Val d'Ambra, the Val Nadro, and the Val Cramosina, I propose to confine myself to a description of the features of the Valle Leventina between Airolo and Biasca. For here we have but one main valley, running between two parallel ranges, which receives no sudden access of drainage at any portion of its course, the conditions under which any of its features were produced being consequently the same throughout.

If we examine the entire length of this valley, we find that the hanging valleys are by no means confined to the three just above Biasca, before mentioned, but occur at intervals right up to Piotta, 3 miles below Airolo, where the torrent of La Foos [2] plunges from the lake of Ritom in the Val Piora, by far the largest hanging valley in the district. Farther up again, the Val Tremola, draining the St. Gotthard Pass, though partly cut back, comes under this category; and higher still, in the Val Bedretto, the trench-like appearance of the valley and the precipitous character of the lateral streams are very marked features for a considerable distance. Among others, I may cite the Val Piumogna opposite Faido, and the Val Chironico above Giornico. Both of these are every whit as discordant in their relation to the Valle Leventina as those mentioned near Biasca, and whatever theory we adopt as to the mode of formation of one must apply equally to all.

I do not wish here to discuss the faulted character of the valley-floor above Faido, as I do not think that this has influenced the formation of hanging valleys, except to hasten the deepening of

[1] See Prof. Davis's paper, 'Glacial Erosion in the Valley of the Ticino' Appalachia, vol. ix (1900) p. 142.
[2] Misprinted 'Foss' on the section and map, Pl. XXXVI.

main valleys, especially perhaps above Airolo where the softer Jurassic beds have been let in.

A glance at the accompanying map (Pl. XXXVI) shows that, although the valley between Biasca and Giornico is fairly open, this is by no means the case above the latter village; and, instead of the trough-like character described by Prof. Davis as typical of a valley overdeepened by ice, we have exactly the features shown in fig. 1 of his paper[1] as characteristic of a water-cut valley, spur after spur overlapping in the distance, while the river winds sharply between its rocky walls. Thus, through Monte Piottino, the valley makes a double rectangular turn, necessitating two of the famous spiral tunnels above Faido, and similar overlapping profiles occur near Lavorgo, below Faido (see Pl. XXXVII, figs. 1 & 2, and explanation). Between these points, immediately opposite Faido, lies the hanging valley of Piumogna. Higher up again, nearer Airolo, we have two undoubted river-gorges, near Madrano and Brugnasco respectively, the former being so cañon-like in character that for both road and railway it has been necessary to resort to tunnelling (Pl. XXXIX, fig. 1).

We see, then, that the Valle Leventina shows all the features typical of a valley excavated by water, especially as regards the steeper basal trench represented in fig. 3 of Prof. Davis's paper.[2] The more open portion, near Biasca, presents no features inexplicable by ordinary river-erosion, and the width of its floor is undoubtedly increased by the deposition of shingle washed down from the upper valley, giving a much flatter character to the section than it would otherwise possess. The only abnormal features, therefore, are the hanging valleys, and these occur equally in the upper portion of the Valle Leventina, where (as we have seen) sections of the basal trench of the main valley between them are undoubtedly river-gorges as shown above. There is, then, no direct evidence that the overdeepening of the main valley, which has resulted in the production of the discordant lateral valleys, is due to erosion by ice; and it remains to account for the presence of these valleys by the ordinary process of river-excavation.

Now, all that would be required to produce the discordance in question would be an acceleration of the main Ticino River without a corresponding acceleration of its tributaries. This would immediately be produced were an elevation to take place at the upper end of the Val Ticino, whereby the grade of the valley should be perceptibly increased, while the lateral valleys were merely tilted sideways. That such an elevation has taken place I have, for some time past, considered as the only explanation possible of certain other phenomena in the district. Most of these do not directly bear on the subject in hand, although I think that the hanging valleys are but incidents connected with much larger problems of drainage on the southern side of the Alps, of which the formation of the Italian lakes constitutes an integral part.

[1] 'Glacial Erosion in the Valley of the Ticino' Appalachia, vol. ix (1900) p. 142. [2] *Ibid.* p. 146.

There are, however, three important facts which bear directly on the point at issue. The first of these is the striking manner in which many of the lateral tributaries enter the Ticino by gorges which point up stream. It was when seeking a solution of this curious phenomenon, that the idea of an elevation of the upper end of the district first occurred to me as the only possible explanation of the tilting of these gorges from their original vertical position. Another significant fact is the manner in which the drainage of the Val Piora has collected at its lower end to form Lago Ritom; and the third is the past history of the drainage of the Val Piumogna, opposite Faido.

The question of the origin of the group of lakes in the neighbourhood of the Val Piora is one which I must leave till another occasion; but it seems probable that, should an elevation of the upper end of the Val Ticino have taken place as postulated, there would be a tendency for the drainage to collect at the lower end of the Val Piora, until such time as a gorge should be cut down to a sufficient depth to drain off the accumulated water. That this result would be indefinitely delayed may be expected, when we remember that, on the first formation of the lake, all the transported fragments by which the work must be effected would be deposited at the upper end of the lake to form the delta on which the farm-buildings of Campo now stand, and only clear water would lap over into the old channel: the resulting fall has gradually cut back a gorge in the old valley below, but has not, as yet, appreciably affected the level of the lake above.

The direction of the ancient drainage of the Val Piumogna is another instance bearing on this question. In former times, the river appears to have drained westward from the hamlet of Dalpe by Prato, entering the Ticino where Morasco now stands, being headed off by the rocks of Monte Piottino so as to enter the Ticino up stream. This old depression is a conspicuous feature, and was the line followed by the old Roman road which climbed over Monte Piottino, past Prato and Cornone, to avoid the river-gorge below. After the elevation, the river was diverted to the east at right angles to its former course, and now falls in a series of cascades into the Ticino opposite Faido; the relics of the lake thus formed are seen in the deposit of alluvium in the valley above the fall.[1]

The questions now remain, When did this elevation take place? and to what was it due?

One point seems perfectly clear, namely, that it originated at all events before the last occupation of the valley by ice. This is shown, not only by the polished sides of the overdeepened portion of the main valley, but also by the rounded edges of the hanging valleys where these debouch into the Valle Leventina. The steep rock-walls on the western bank of the Ticino below Faido, however, are deceptive in this respect: the smooth slabs over which the

[1] See K. von Fritsch, 'Geognostische Karte des Sanct Gotthard' Beitr. z. Geol. Karte d. Schweiz, vol. xv (1873).

rivulets cascade, which at first sight seem to point to great glacial erosion, are in reality due to planes of foliation in the gneiss. This is proved by the manner in which many of these smooth surfaces pass under the overlying slabs, while the truncated edges of these beds are sharp and angular, although they face up stream. In many cases, also, as under Calonico Church, the recent rock-falls from the surface of these slabs can be seen below.

This elevation may possibly have been initiated in pre-Glacial times as a final stage in the orogenic uplift in the late Pliocene Period. I, however, incline to the belief that the hanging valleys were produced during the warmer inter-Glacial Periods, the existence of which in the Alps, first suggested fifty-five years ago by Collomb, has been now clearly demonstrated by the researches of James Geikie, Penck, Blaas, Bœhm, and others. Thus Prof. Penck[1] attributes an excavation of 720 feet in the valley of the Iller to river-erosion, during the mild period antecedent to the last advance of the Iller Glacier.

So far as I am aware, no lignite-deposits of this age have been recorded from the Val Ticino; but should any occur, I would expect to find them on the upper benches above Faido, between Mairengo and Calpiogna, and on the corresponding plateau between Dalpe and Prato. Possibly the lake-deposits mentioned above might contain remains of this inter-Glacial flora, while the presence of a fragment of a lower bench at 816 metres may indicate a succession of at least two former valley-floors.

One fact which seems to be more and more clearly established every year, is the tendency shown by all glaciated districts to undergo elevation as their covering of ice melts away. I need only recall the raised beaches of Spitsbergen, Franz-Josef Land, Norway, and North America, leaving out of account for the moment the Himalayas and the Alps themselves. One of the most interesting points recorded in a recent report of the Norwegian Geological Survey, is the coincidence of the greatest post-Glacial rise with the area of the greatest depression below the axis of the inland ice.[2] If this rise be accepted also for the Alps, after the maximum period of glaciation was passed, we have at once a solution of the problem of the hanging valleys. As the ice melted back, torrents of water would be discharged from the fronts of the retreating glaciers, and, as the country rose, the main river would rapidly deepen its valley, while the lateral valleys would not only remain at their former grade, but would also continue to be occupied for some time longer by ice—a fact well illustrated in the Alps nowadays. The hanging valleys thus initiated would be prevented from immediately establishing an accordant grade with the main valley; and the longer

[1] Jahresb. d. Geogr. Gesellsch. München, 1886, pt. ii. See also Penck & Brückner, 'Die Alpen im Eiszeitalter' Leipzig, 1901–02; A. Rothpletz, 'Ein geologischer Querschnitt durch die Ost-Alpen' Munich, 1894; & A. P. Coleman, Geol. Mag. 1902, p. 59.

[2] Norges Geol. Undersög. No. 28 (1900); & N. O. Holst, Sveriges Geol. Undersökn. ser. C, No. 180 (1899) p. 113.

their glaciers remained, the longer would this result be delayed: only the mouth of the valley being cut back into a gorge by the water flowing from the glacier, while the curve of erosion of the gorge would flatten gradually as the ice retreated.

On this supposition, then, those lateral valleys which have been longest freed from their protective covering of ice should have established the most accordant grade with the main valley; and this indeed we find to be the case. There are no true hanging lateral valleys remaining on the left bank of the Ticino, which faces west and south (with the exception of the Val Piora, the preservation of which has been already explained), while those found on the right wall face north and east, and it is in these that the ice will have been the last to melt: the head of the Val Piumogna being still occupied by a glacier.

In this way we see how ice could be indirectly responsible for the hanging valleys, and how we can explain their marked occurrence in glaciated regions, without attributing, as Prof. Davis has done, the overdeepening of the main valleys to direct erosion by ice.[1]

Before referring to the support that this explanation appears to receive from other districts, I would point out that there is one piece of evidence which seems strongly to favour the contention that the overdeepened floor of the Val Ticino was effected by water-erosion, and not by ice. If we attribute the overdeepening to ice-erosion, the action of the glacier should have been more marked at the lower end of the valley, near Biasca, than in the middle portion, near Airolo.[2] If, on the other hand, the overdeepening be due to an acceleration of the velocity of the river consequent on the elevation of the upper end of the district, we should expect the results to be greatest in the middle portion, and less marked at the lower end of the valley where the effects of elevation died away.

If, now, we construct a section along the present floor of the Val Ticino, from Airolo to Biasca, and restore the old floor before the overdeepening took place, using for this purpose the present position of the mouths of the hanging valleys between Airolo and Biasca, we find that there is a regular decrease in the respective heights of the hanging valleys, above the present thalweg of the Ticino, showing that the greatest amount of excavation has taken place in the floor of the old valley in its middle portion, and that the amount of overdeepening gradually decreases in the lower portion.[3] The heights are approximately shown on the accompanying diagram, drawn to the true scale of 1 : 50,000 (Pl. XXXVI, longitudinal section along the Valle Leventina). This appears to me conclusive evidence in favour of water having been the chief agent of erosion, and not ice. The Val Ticino, therefore, does

[1] Reusch, Norges Geol. Undersög. No. 32 (Aarbog for 1900).
[2] Prof. Davis attributes the excavation of the Lago Maggiore below to ice-erosion.
[3] It is here also that marked deposition commences.

not (in my opinion) furnish any evidence that the overdeepening of the main valley, and the consequent formation of hanging lateral valleys, has been due to the direct action of ice. On the contrary, the facts appear to point to the deepening of the old Ticino valley by water, consequent upon an epeirogenic uplift of the upper end of the district in inter-Glacial times.[1]

Although the evidence adduced in the foregoing pages appears to me conclusive, I am acquainted with two other districts exhibiting the characteristic features of hanging valleys which strongly confirm this view. The first is the Val Bregaglia, the second the Jongri district of the Sikhim Himalayas.

III. Hanging Valleys of the Val Bregaglia.

At the upper end of the Val Bregaglia, in close proximity to the Maloggia Pass, we have three hanging valleys in different stages of development—the Albigna, the Val Marozzo, and the gorge of the Orlegna, which drains the Forno Glacier and the Valley of La Tajeda. The Albigna Valley is occupied throughout its upper portion by the Albigna Glacier; but a short level tract of ground strewn with alluvium intervenes, between the end of the glacier and the cascade by which the water from the melting ice plunges into the gorge of the Pian dei Buoi below. No one who has ascended this gorge is likely to forget the severe character of the ascent, nor the detour necessitated by the precipitous nature of the fall: it is in every respect similar to the ascent to Dalpe from Faido, and the traveller is forcibly reminded of the Val Piumogna, in the Ticino Valley.

That this precipitous descent from the Albigna Glacier to Casaccia is due to the overdeepening of the main valley, has not, I think, been denied; and there can be little doubt that it has been effected by the vigorous encroachment of the Maira, on the water-parting between the Val Bregaglia and the Upper Engadine. If this water-parting were once situated farther down the Val Bregaglia, nearer Vico Soprano, as has been suggested,[2] the Albigna and Forno valleys on the south, and the Val Marozzo on the north, must once have formed tributaries of the Inn, and not of the Maira; and this supposition is borne out by the general trend and present relative elevation of these valleys.

As the steeper-graded Maira River cut back its water-parting, the drainage from the Albigna Valley would first be captured and compelled to flow westward, then that of the Val Marozzo, and, lastly, that of the Val Forno, the waters of the two last-named

[1] Since writing the above, my attention has been called to a note in the Bull. Soc. Géol. France, ser. 3, vol. xxviii (1900) p. 1003, by M. W. Kilian, who, on theoretical grounds, comes to much the same conclusion as that enunciated above.

[2] A. Heim, Jahrb. d. Schweiz. Alpenclub (1879–80) p. 429; T. G. Bonney, Geol. Mag. 1888, p. 540; & C. S. Du R. Preller, *ibid.* 1893, p. 448.

being chiefly responsible for the present cliff-like wall of the Maloggia.

These three valleys, belonging as they do to the high-level Engadine drainage-system, have been left far above the deeply-cut Val Bregaglia, and their streams have not yet had time to adjust their floors to accordant slopes with that of the Maira, into which they fall by precipitous cascades.

I do not think that the overdeepening which has produced these hanging valleys at the upper end of the Val Bregaglia can by any possibility be attributed to excavation by ice; for whence did the glacier come? Obviously not from the hanging valleys themselves, or how are we to account for their truncated mouths? And there is no gathering-ground for snow in the district other than the Engadine Valley beyond the precipitous wall of the Maloggia itself, the formation of which by ice I do not think the wildest advocate of ice-erosion would suggest. We have here, then, a group of hanging valleys the uppermost of which, the Forno, is in process of formation before our eyes by river-action: these are situated at the head of a glacial cul-de-sac, and cannot therefore be attributed to the over-deepening of the main valley by ice.

The river issuing from the Albigna Glacier has cut back the gorge forming the Pian dei Buoi; but the waterfall is still very steep, and no gentler grade can be established so long as the general high level of the Albigna Valley is maintained by the presence of the glacier. And this protected valley, like the hanging valleys of the Val Ticino, again faces north-east. The Val Marozzo, on the other side of the Val Bregaglia, although its drainage was captured by the Maira after that of the Val Albigna, has no protective glacier, and has already established a more gentle slope for its gorge, and the same is the case with the Orlegna. Thus we again have the lesson enforced, that it is rivers that erode their valley-floors and glaciers that relatively protect them.

IV. Hanging Valleys of Jongri-Sikhim.

In the Jongri district of the Sikhim Himalaya we find hanging valleys of the Ticino type, which appear undoubtedly to owe their origin to river-excavation. There the original easterly drainage, initiated as a consequence of the uplift of the Kangchenjunga range, is being gradually obliterated and diverted by the direct-flowing rivers subsequently developed along the line of strike parallel to the range. These subsequent rivers, running as they do more directly to the plains than the original easterly streams, have a higher graded slope, and consequently greater erosive powers; with the result that those flowing near the centre of uplift have gradually cut their valleys back and captured, one by one, the head-waters of the original eastward-flowing streams. This is especially noticeable in the case of the Praig Chu and the Chakchurong Chu—two subsequent streams which occupy deep gorges on either side of the Jongri plateau. There can be little doubt that these streams have eaten their way back from the south, and intercepted one of the old eastward-flowing rivers, capturing its head-waters in the process: these are represented by the present hanging valleys of the Kang La and its neighbours. The drainage from these glens falls by torrents and precipitous cascades into the valley of the Chakchurong, 2000 feet below; and so abrupt is the change in level from the glens to the main valley, that the traveller is occasionally obliged to depend, in the more literal sense of the word, on the branches of the dwarf rhododendrons that clothe the precipitous ledges.

It may be asked, Why have these streams not cut down their valleys to an accordant grade with the new valley below? The answer appears to be the same as in the case of the Val Ticino: first, because there has been an epeirogenic uplift in inter-Glacial times; and, secondly, because the higher glens have been, till recently, filled with ice which has *protected* the valley from river-erosion.

That an upward movement of this description has taken place since the formation of the range seems well attested by the observations of the Indian geologists on the Himalayan range generally,[1] from which it would appear that this movement is still in progress. For fuller proofs of the formation of these Jongri valleys by river-erosion I must refer to my notes in the 'Geographical Journal' already published,[2] merely pointing out that here also we have the hanging valleys preserved only on the eastern flanks of the range; a fact which I would again attribute largely to their preservation by the glaciers which, till recently, filled these valleys, and still occupy the upper glens.

V. Hanging Valleys of a Different Type.

In the above descriptions I have confined myself to typical hanging valleys, produced by the overdeepening of the floor of the main valley; but I should not, on this account, wish it to be inferred that I would attribute all similar valleys to this cause. There are other types of hanging valley due to other causes than those described above. Two of these types stand out prominently, and I have met with many examples in the course of my wanderings in the Alps and Arctic regions.

The first of these is to be found bordering inland sheets of water, such as the Swiss and Italian lakes. Some of these, it may be urged, were formed contemporaneously with those described above and afterwards submerged; and it is possible that those at the Flüelen end of the Lake of the Four Cantons come under this category, and are continuations of the series in the Valley of the Reuss, of which the Erstfelder Thal is a conspicuous example. The majority, however, seem to owe their origin to a different cause, and to have

[1] 'Manual of the Geol. of India' 2nd ed. (1893) p. 485. See also W. T. Blanford, Phil. Trans. Roy. Soc. vol. cxciv B (1901) p. 335.

[2] Geogr. Journ. vol. xx (1902) p. 13.

originated since the lakes were in existence and, indeed, to be directly due to the presence of the waters of the lake.

In these occurrences we have exactly what we might expect. A stream draining the hillside that borders a lake will, of necessity, gradually deepen its bed, and at the same time cut back its head-waters—in fact, establish its curve of erosion. The possible depth of this erosion will be limited by the level of the lake, below which no erosion can take place, but, on the contrary, deposition. While the lake remains at the same level, therefore, the stream is continually engaged in flattening the grade of its valley-floor, while below the level of the lake the old steeper grade is preserved. Should the level of the lake be lowered by erosion at its exit, the contrast of slope between the portions of the lateral valley formerly above and below the lake-surface respectively, will afford all the characters of a hanging valley. If this lowering of the lake be gradual, a gorge will be established cutting back into the lateral valley, for it must always be remembered that the adjustment of two discordant valleys can only take place from below, causing the incision to travel backwards at a steep, though diminishing angle.

I would specially emphasize this law of readjustment, as it accounts for the effects of even a gradual lowering of the lake being visible for long afterwards in the tributary valleys, and also for long after the ice melted. Such a condition of things is well seen round the Italian lakes, especially the Lake of Como, as at Bellano, Menaggio, Varenna, and Argenio, and at Ostenno on the Lago di Lugano. The gorges already cut back by the readjustment are locally known as 'oridos.' Thus we have the Orido of Bellano, Orido of Ostenno, etc. In this case, then, it is not by the overdeepening of the main valley, that lateral hanging valleys and oridos are produced, but on account of its protection by the water of the lake.

The remaining type, to which I should like to allude, is also produced independently without any overdeepening of the main valley, and is only found in glaciated districts. These valleys are frequently connected with cirques, into which they merge at their upper end. They are produced in the first place by corrie-glaciers, which are gradually extended backward. A corrie-glacier of this character originates apparently in the following way:—The snow which falls in winter above the snow-line lodges more readily in the flatter portions of water-gullies formed in summer, and will tend to accumulate there, protecting the surface beneath from frost and water-action, while the rock-wall behind will continue to disintegrate, allowing more snow to accumulate each year, so that in time the flatter portion will extend backward into the hillside. In this way an upland glen filled with ice is gradually formed. I noticed many hanging glaciers of this description in Spitsbergen, and, though less common, they undoubtedly exist also in the Alps.[1]

[1] See Quart. Journ. Geol. Soc. vol. lv (1899) pl. xliv.

VI. General Conclusions.

The questions opened up by a discussion of the origin of the hanging valleys in the Alps are very wide, but I have confined my description to those types which have been attributed to direct excavation by ice; and, in the majority of cases cited, the whole question seems to turn on the relative power of excavation possessed by ice as contrasted with water. Having lived among glaciers most of my life, and for some years past having taken the greatest interest in all problems connected with ice, I must express my firm conviction that ice, far from hastening the erosion in a valley previously occupied by a river, appears to me in every case that can be tested to retard the erosion of its floor, and may therefore even be described as a protective agent. Here I am only repeating what has often been expressed before by those best acquainted with ice and snow. Mr. D. W. Freshfield, some years ago,[1] in an admirable essay on the subject, which has been too often overlooked, summed up the question most tersely:—

> 'I believe that a careful inspection of mountain-valleys shows conclusively the very limited extent of ice-action as a quarrier or excavator. And I would urge all who consider water, as compared with ice, "the weaker agent," to measure their respective performances at Grindelwald and Rosenlaui, where between the superficially ice-abraded rocks the torrent has carved for itself a bed hundreds of feet deep. . . . We find that where a barrier presents itself to a glacier furnished with a strong subglacial torrent, the tendency of the ice is to pass over the barrier, the tendency of the water to cut through it. The one acts as sandpaper, the other as a saw. . . . So far as I can see, U-shaped valleys are not V-shaped—or trench-like—valleys broadened by ice, but V-shaped valleys are U-shaped valleys deepened by water-action.'

Here we have an exact description of what has really taken place in the Val Ticino. Prof. Heim, again, sums up in a similar manner when he remarks that 'glaciation is equivalent to relative cessation of valley-formation.'[2] It is to this cause that I would attribute the existence of the hanging valleys of the Ticino and Jongri type as described above, the lateral valleys being protected by glaciers, while the main valley was being deepened by water.

If we examine the termination of glaciers at the present day, they are seen to rest invariably on a more or less raised platform, because of the protection which they afford to the ground underneath. In the Arctic regions I have seen glaciers advancing over loose beach-material and picking it up in places, but doing no excavation; indeed, they are unable to push forward their ice-débris, and advance almost entirely by the shearing of the upper layers over those below. Take the case of the Upper Grindelwald Glacier, or any icefall, the glacier does not dig itself out a course: it simply falls over. The Rhone-Glacier icefield is, curiously enough, cited by Prof. Davis as a hanging valley due to excavation

[1] 'Note on the Conservative Action of Glaciers' Proc. Roy. Geogr. Soc. vol. x (1888) pp. 785, 787.

[2] 'Handbuch der Gletscherkunde' 1885, p. 397. See also T. G. Bonney, 'Do Glaciers Excavate?' Geogr. Journ. vol. i (1893) pp. 481–99.

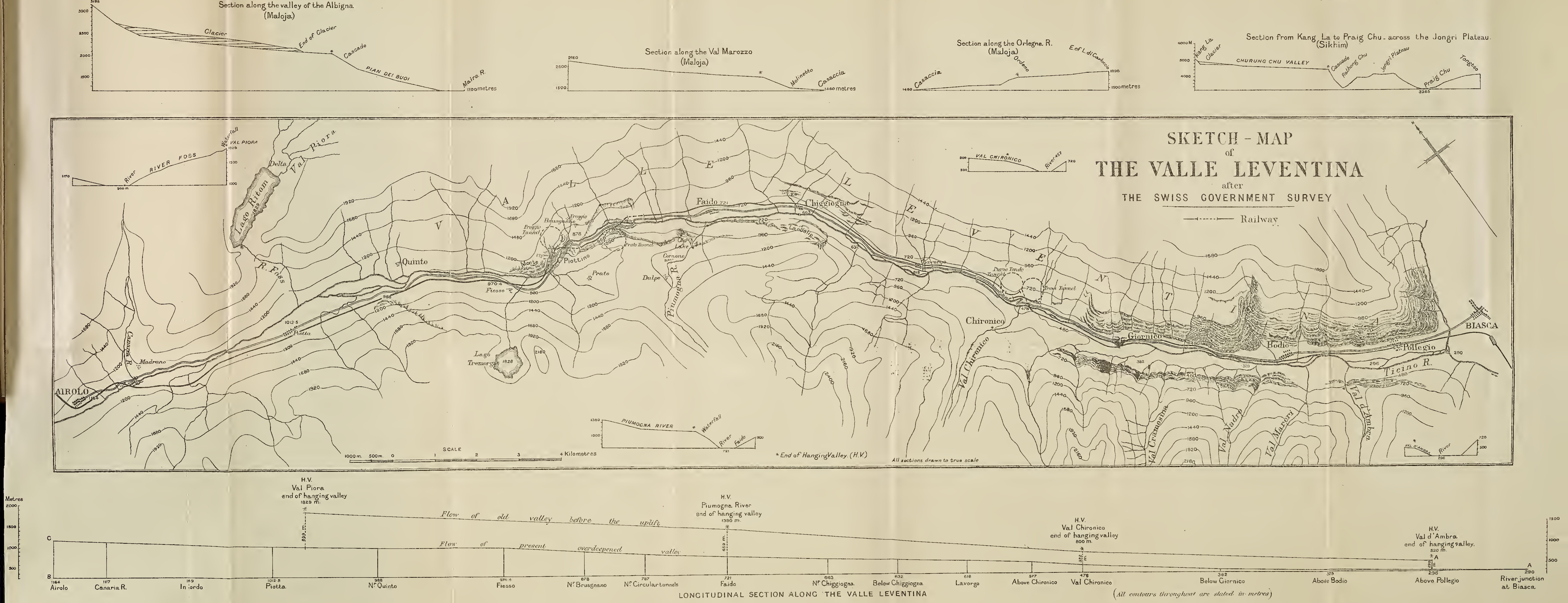

Section along the valley of the Albigna. (Maloja)
Glacier
End of Glacier
Cascade
PIAN DEI BUOI
Maira R.
1200 metres
Section along the Val Marozzo (Maloja)
Molinetto
Casaccia
1460 metres
Section along the Orlegna R. (Maloja)
Casaccia
Ordeno
E of L. di Cavloccio
1500 metres
Section from Kang La to Praig Chu - across the Jongri Plateau. (Sikhim)
Kang La
Glacier
CHURUNG CHU VALLEY
Cascade
Jongri Plateau
Praig Chu
Tongtso
SKETCH - MAP
of
THE VALLE LEVENTINA
after
THE SWISS GOVERNMENT SURVEY
Railway
VAL CHIRONICO
River 457
VAL PIORA
Waterfall
RIVER FOSS
River
Lago Ritom
Delta
Val Piora
R. Foss
Canaria R.
Madrano
AIROLO
Piotta
Quinto
Fiesso
Monte Piottino
Prato
Lago Tremorgio
Dalpe
Piumogna R.
Faido
Chiggiogna
Lavorgo
Chironico
Val Chironico
Giornico
Bodio
Pollegio
BIASCA
Ticino R.
Val Cramosina
Val Nadro
Val Marori
Val d'Ambra
V A L L E L E V E N T I N A
PIUMOGNA RIVER
Waterfall
Faido
SCALE
1000 m. 500 m. 0 1 2 3 4 Kilometres
* End of Hanging Valley. (H.V.)
All sections drawn to true scale
VAL d'AMBRA
River
Metres
H.V. Val Piora end of hanging valley 1829 m.
H.V. Piumogna River end of hanging valley 1390 m.
H.V. Val Chironico end of hanging valley 800 m.
H.V. Val d'Ambra end of hanging valley. 520 m.
Flow of old valley before the uplift
Flow of present overdeepened valley
1164 Airolo
1117 Canaria R.
Piotta
988 Nr Quinto
974.4 Fiesso
878 Nr Brusgnano
787 Nr Circular tunnels
721 Faido
663 Nr Chiggiogna
632 Below Chiggiogna
616 Lavorgo
577 Above Chironico
476 Val Chironico
382 Below Giornico
325 Above Bodio
296 Above Pollegio
290 River junction at Biasca
LONGITUDINAL SECTION ALONG THE VALLE LEVENTINA
(All contours throughout are stated in metres)

Fig. 1.—*Gorge of Monte Piottino, from above Fiesso.*

Fig. 2.—*Overlapping profiles below Faido.*

THE GORGE OF LA FOOS, FROM VAL PIORA.

by ice,[1] but the ice which formed it must have come down the valley now occupied by the icefall. Therefore, Why the icefall? Why was the barrier not degraded?

Mr. Harker, in his admirable description of the glaciation of Skye, alludes to the weight of the ice and the grinding of the ground-moraine. A great deal of excavating work has been attributed to ground-moraine; but, as a matter of fact, there is very little material at the bottom of the ice. Most of it is carried englacially in an ice-sheet, and not between the ice and the valley-floor.

In many places it is possible to study the relative action of ice and running water, occupying the same valley and working side by side. Fig. 2 in Pl. XL, for instance, which is from a photograph taken in Hornsund Bay (Spitsbergen), shows a gorge cut down by the water running under the ice, and the ice moulding itself down into the gorge. The gorges which terminate many of the glaciers of Switzerland have been thus produced; the gorge at the end of the Aletsch Glacier has been cut down by the subglacial river, and the same phenomenon is well seen at the end of the Mer de Glace and elsewhere.

The question of the excavation of lake-basins by ice I must leave to another occasion, though Prof. Davis considers that they are intimately bound up with the origin of the hanging valleys. I hope, however, to have shown that, so far as the districts described above are concerned, there is no proof that the over-deepening of the main valley, and the consequent production of 'hanging' lateral valleys, has been the result of ice-excavation, and that the marked occurrence of these valleys in glaciated districts can possibly be accounted for in quite another way.

EXPLANATION OF PLATES XXXVI–XL.

Plate XXXVI.

Map and longitudinal section of the Valle Leventina, together with sections of the chief hanging valleys to which allusion is made. The map shows the various characteristics on which emphasis is laid in the text. The sections are all drawn to the true scale of 1 : 50,000, except that across the Jongri Plateau which is on the scale of 1 : 100,000. The asterisks denote the lower terminations of the hanging valleys.

Plate XXXVII.

Fig. 1 shows the river-gorge of Monte Piottino and the old river-level above on the right, which exactly corresponds with the mouth of the Val Piumogna.

Fig. 2 illustrates the overlapping character of the profiles below Faido.

Plate XXXVIII.

Photograph of the gorge of La Foos, from the edge of the Val Piora, looking down into the Valle Leventina.

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[1] 'Glacial Erosion in France, Switzerland, & Norway' Proc. Boston Soc. Nat. Hist. vol. xxix (1900) pp. 273–322.

PLATE XXXIX.

Fig. 1. The river-gorge below Airolo, with relics of the older benches.
2. View of the mouth of the Albigna Valley and waterfall, from the Maloggia.

PLATE XL.

Fig. 1. The upper cascade of La Foos, draining Lago Ritom, Val Piora.
2. The end of an Arctic glacier, Hornsund (Spitsbergen), showing a hanging valley protected by ice, with water-cut gorge and subglacial water-channel, into which ice has moulded itself. This illustration shows clearly the superior erosive power of water over ice, when both occupy the same valley.

DISCUSSION [ON THE TWO FOREGOING PAPERS].

The PRESIDENT congratulated the Fellows upon the lucid manner in which the whole subject had been presented and discussed by Prof. Bonney, and upon the fine series of illustrative lantern-views exhibited and described by Prof. Garwood. The subject was one of such conspicuous interest from several aspects, and the phenomena apparently admitted of so many interpretations, that it was little to be wondered at that scientific opinion was so divided upon the question. It was very pleasant, however, to find that lifelong workers in the Alps like Prof. Bonney and Prof. Heim, who had so many years ago described the classic examples of the Maloja, were still fully agreed in ascribing the differential denudation which had originated the Alpine examples almost wholly to the action of running water; and at the same time to find that Prof. Garwood concurred with Dr. Reusch in ascribing many of the Norwegian examples of hanging valleys to the preservative action of ice and snow. While he himself fully agreed with Prof. Bonney that the differences in level between the main valley and these lateral valleys was a matter of differential denudation by water-action, he could hardly follow him when he carried back the date of the main valleys in which they occur to the Middle Tertiary age. The suggestion made by Prof. Garwood, that the main valley had been subsequently deepened owing to increase in erosive power due to regional tilt was, he thought, novel and very plausible. The examples of associated main and lateral 'hanging valleys' which he had himself seen both in the Alps and in Norway, had led him to the opinion, that while running water had probably accomplished the erosion of both, yet the distinction between them was in some way connected with the physical conditions of the Ice-Age. The ice possibly aided in bringing about the differential denudation, not perhaps as an eroding agent, but, as in the case of the Matterhorn, as a transporting agent—the local conditions enabling it to act here as a local remover, and there as a local preserver of disintegrated material.

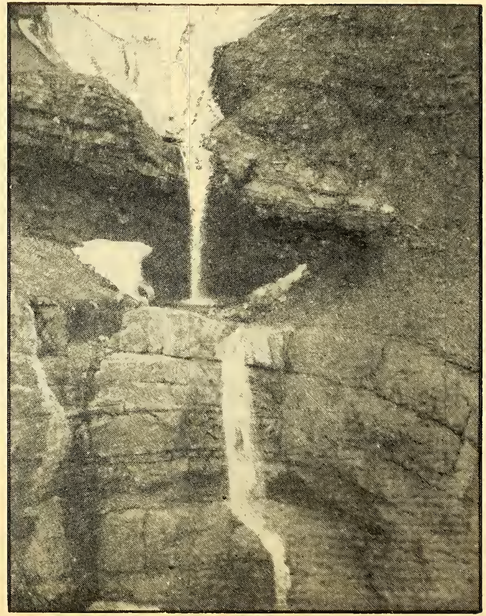
Mr. MARR considered that he had hardly a right to speak upon these papers, as he knew nothing of the district described; but he had long been interested in 'hanging valleys' in the Lake District. He would like to know how Prof. Davis, in the case of certain valleys

Fig. 1.—*The river-gorge below Airolo, with relics of the older benches.*

Fig. 2.—*View of the mouth of the Albigna Valley and waterfall, from the Maloggia Pass.*

Fig. 1.—*Upper cascade of La Foos.*

Fig. 2.—*The end of an Arctic glacier: Hornsund (Spitsbergen).*



with overlapping spurs which he had described, had ascertained that the partial destruction of the spurs was due to ice, and not to water. In the Lake District, he (the speaker) believed that the hanging valleys were often due to differences in rock-structure, especially to the existence of gigantic brecciation along the main valleys, though many other structures produced their effects. He wished to emphasize the importance of carefully studying each case (as had been done by the Authors), for many valleys which were not really 'hanging valleys' appeared, at first sight, to simulate them; and, indeed, he believed that detailed study of various different districts was necessary before the intricate question of the formation of these valleys could be finally solved.

Mr. Mackinder agreed with the previous speaker that we should first study special cases, and then generalize. But if we accept the general idea of a difference of erosive power as the cause of the contrast between the main and the 'hanging' valleys, then the hanging valleys should diminish in scale towards the upper part of the main valley, unless indeed there should be a hanging valley at the head of the main valley. Perhaps this might be so in some cases.

Mr. Lamplugh remarked that, whatever objection might be taken to the methods and conclusions of Prof. Davis, his work, at any rate, deserved credit for having stimulated fresh investigation on all sides. He agreed with Mr. Marr that hanging valleys might be formed in different ways, and therefore required separate study. In the examples best known to him, the explanation given by the present Authors, that the trunk-valleys had been deepened mainly by stream-erosion, was fully adequate. At the same time, it must not be forgotten that there were proofs that the land-surface had sometimes been pared down by ice-action, though perhaps not so much in confined valleys as in more open ground.

Gen. McMahon, as an illustration of the small power of erosion possessed by a glacier, instanced a case in the Upper Spiti Valley, in the Central Himalayas, at an elevation of 14,000 feet, of a small spur composed of thin splintery slates, running into the valley at right angles to the course of a glacier, which once filled the valley. The crest of this thin ridge was rounded, beautifully polished, and grooved and striated by ice-action, showing that the glacier had ridden over it, in its passage downward, but had been unable to remove this barrier.

Prof. Bonney, in replying, remarked that he had avoided appealing to the effect of uplift (though he was quite prepared to admit that it might have occurred), because he wished to see the results of less hypothetical causes. He fully endorsed Prof. Garwood's remarks about the Maloja and other parts of the Engadine. The President was quite right in attributing the explanation of the structure of the Inn Valley to Prof. Heim. In fact, it had been independently published by him and by the speaker, but the former had priority. He thought that the President had a little misunderstood (probably owing to his remarks about the Oberland) what he had said about the main and side valleys; he believed their formation to be simultaneous, but the main stream would be more energetic, because it was augmented by the lateral ones. Mr. Marr was quite right as to the importance of study of individual instances, but the speaker had examined a very large number, for he had been at work on such questions for fully forty years, and in the Alps the rock-masses were on a larger scale than in English hill-countries, so that explanations of lines of weakness would not so generally apply in the former as in the latter. To Mr. Mackinder, he observed that the floors of the hanging and the main valley did become nearer in going up the latter, but he could not see how a hanging valley should occur at its head, for there could not be any differential motion to cause it. To Mr. Lamplugh, he replied that inferences from the action of moving masses of ice upon a soft material were not of much value when transferred to hard rock; personally, he did not feel gratitude for papers written after hurried journeys. He had preferred to spend about ten years in examining these valleys, for he did not believe that science was benefited by hasty generalizations.

Prof. Garwood, in reply to Mr. Lamplugh, said that he had tried to avoid too much generalization on glacial erosion, as it was a large subject, and had confined his views to the four districts described in the paper. He quite agreed with him that the surfaces of upland districts were liable to have the disintegrated material removed by ice, and the solid rock grooved and polished, and he pointed out in his paper that this had happened in the Val Ticino since the overdeepening of the main valley. He thanked the Fellows for their reception of his paper.

39. *On the* Jurassic Strata *cut through by the* South Wales Direct Line *between* Filton *and* Wootton Bassett.

By Prof. Sidney Hugh Reynolds, M.A., F.G.S., and Arthur Vaughan, Esq., B.A., B.Sc., F.G.S. (Read June 18th, 1902.)

Contents.

I. Introduction.

A paper like the following, dealing with a newly-exposed section, does not require any long introduction, and naturally the number of previous communications on the subject is limited. We know of only two, namely:—Mr. H. B. Woodward's account in the 'Summary of Progress of the Geological Survey for 1898,' pp. 188–94, and the Rev. H. H. Winwood's Report on the Excursion of the Geologists' Association to the new Great Western Railway-line from Wootton Bassett to Filton, Proc. Geol. Assoc. vol. xvii (1901) p. 144.[1]

II. The Liassic Sections West of Sodbury Tunnel.

1. The Main Section.

(*a*) The White Lias.

Resting directly upon a thin bed of typical Cotham Marble is a compact, cream-coloured limestone, about 1 foot thick; this bed forms a marked horizon, not only by reason of its peculiar texture, but also on account of the levelness of its surface. It represents the 'White Lias' of the Somerset area and, in particular, the 'Sun-Bed' of the Radstock district.

(*b*) The *Ostrea*- and *Torus*-Beds.

Immediately above the Sun-Bed is a series of limestones and subordinate shales, forming a total thickness of about 5 feet. Although no specimen of *Psiloceras planorbis* was found, the horizon of these beds is well marked zonally by *Ammonites Johnstoni* (=*Amm. torus*), which is not uncommon in the upper strata. The series is, however, chiefly characterized by *Ostrea liassica* and its

[1] We are much indebted to Mr. A. W. Manton, the agent for Messrs. Pearson, and to the contractors, for facilities in the examination of the specimens preserved in the office near the Cross Hands, Old Sodbury, and to Mr. C. E. Grierson, the engineer for the Great Western Railway, for the loan of a map of the line.

numerous mutations which abound throughout, but especially towards the base.

The following is a complete list of the fossils that we have obtained from these beds :—

Ammonites (Psiloceras) Johnstoni, Sow.=*Amm. torus*, d'Orb.
Amberleya (?) sp.
Ostrea liassica, Strickl., and mutations.
Pecten aff. *calvus*, Goldf., and allied species.
Pecten cingulatus (?) Phil.
Avicula cygnipes, Y. & B.
Lima gigantea, Sow.
Pholadomya glabra, Ag.
Pleuromya Crowcombeia, Moore.
Pseudodiadema lobatum, Wright.
Pseudodiadema sp.

Palæontological Notes.[1]

Pecten cingulatus (?) is an oval form with small equal wings; the cast shows two sharp ruts diverging from the sides of the beak.

The mutations of *Ostrea liassica* are chiefly towards the form of *O. ungula*, and are brought about by the deepening of the large valve at the front, in such a manner that its border becomes semicylindrical and nearly at right angles to the plane of the rest of the valve.

(*c*) The *Cidaris*-Shales and *Lima*-Beds.

The succeeding 35 feet is made up of a series of thick shales, separated by a few conspicuous limestone-bands.

The most interesting palæontological feature of this series is the prevalence of small echinids in the shales. Long pin-like spines, with portions of the test, crowd the shales throughout the middle 10 feet, and extend downward into the shales of the *Ostrea*-Beds below, where they are by no means uncommon. So far as we are able to judge, the commonest forms in the lower shales are two species of *Pseudodiadema* (*Ps. lobatum*, Wright, and *Ps.* sp.). In the middle 10 feet, where the spines occur in multitudes, the predominant form is a species of *Cidaris*, near *C. Edwardsi*, Wright, but probably distinct.

Very common in the shales of this series, and extending down into the shales of the *Ostrea*-Beds, is a small *Pecten* of the type of *P. calvus*, Goldf.

Mineralogically the shales are gypseous; the uppermost 4 feet of shale abounds in small selenite-crystals, while the surfaces of the lower shales are speckled all over with minute gypseous aggregates.

The complete list of fossils obtained from this series is as follows :—

Ostrea ungula, Rœmer.
Pecten calvus, Goldf., and allied species (*P. subulatus*, *P. textilis*, *P. multifurcatus*, etc.).
Lima gigantea, Sow., small and large.
Lima pectinoides (?) Sow.
Cardinia Listeri, Sow., and mutations (*C. ovalis*, *C. hybrida*).
Modiola hillanoides, Chap. & Dew.
Unicardium cardioides, Phil.
Macrodon hettangiensis, Terq.
Cidaris sp., aff. *C. Edwardsi*, Wright.
Pseudodiadema sp.
Pentacrinus sp.
? Plant-remains.

[1] The determination of the fossils has been carried out by one of us only (A. V.).

Palæontological Note.

The Pectens, so common in the shales, exhibit several characters in common. They are all orbicular in form, have the front wing double the size of the hind one, and appear almost smooth to the naked eye. With a lens, however, fine radial and concentric striæ are rendered visible; this ornament is quite clear to the unaided eye in *P. textilis*, Rœm., is distinct with a lens in *P. calvus*, Goldf., while in *P. subulatus*, Münst., the radials are very indistinct. *P. multifurcatus*, Tate, has closely-punctated radials, which curve outward as they diverge (much after the fashion of *P. rigidus*, Sow.).

(*d*) The *Angulatus*-Beds.

The uppermost 17 feet of our first vertical section is characterized by a thick series of clayey shales, having three nodular limestone-beds at the base and capped, at the top of the section, by several bands of nodular limestone separated by thin clay-partings. The whole series is very fossiliferous, and its geological horizon is well-marked by *Schlotheimia angulata* and its mutations. Of these mutations the flattened and close-ribbed form characterizes the middle shales; while the thicker form, with more widely-spaced and taller ribs, occurs in the uppermost nodular limestone-bands, where it is associated with *Ammonites (Vermiceras) Conybeari*.

It is worth noting that the association of a species of *Schlotheimia* with *Amm. Conybeari* at the top of the *Angulatus*-zone is common throughout the Bristol district (as, for example, at Keynsham, where *Schlotheimia Charmassei* and *Amm. Conybeari* occur together).

Rhynchonella calcicosta was found in the uppermost beds, but is of rare occurrence. In this association we see another point of resemblance with the same horizon near Bristol; but, whereas in the Sodbury district *Rh. calcicosta* is very uncommon, near Bristol it occurs in thousands.

The most abundant of all the fossils in this series of beds is an oyster (*Ostrea irregularis*, Münst.) which exhibits a most puzzling variation of form. The unattached valve is always flat, with the beak slightly curved, the attached valve always deep and convex, but the area of attachment differs greatly in size and position in different individuals. When this area is large and flat the species resembles *O. ungula*, but there is a complete transition from such forms to that of a typical *Gryphæa*, with incurved beak and deep, regularly convex, lower valve. No typical specimen of *Gryphæa arcuata* was found in the beds, but the oyster now under discussion undoubtedly occurs on the same horizon as that at which *Gr. arcuata* is so abundant in the Bristol district; moreover, an oyster of identical form is found associated with *Gr. arcuata* at several localities near Bristol. We are inclined to regard this oyster as a mutation of a species of *Gryphæa*, but not identical with *Gr. arcuata*.

The complete list of fossils obtained from the *Angulatus*-beds is as follows:—

Ammonites (Schlotheimia) angulatus, Schloth., with three distinct mutations.
Amm. (Vermiceras) Conybeari, Sow.
Pleurotomaria anglica, Sow.
Gryphæa sp. (*Ostrea irregularis*, Münst.), with numerous mutations towards the form of *O. ungula*.
Lima gigantea, Sow. (Small.)
L. punctata, Sow.
Lima Hermanni, Voltz.
L. hettangiensis, Terq.
Modiola hillanoides, Chap. & Dew.
Unicardium cardioides, Phil.
Pholadomya glabra, Ag., and allied species (cf. *Ph. Fraasi*).
Gresslya Galathea (?) Ag. (Badly preserved casts.)
Rhynchonella calcicosta, Quenst.

Vertical Section of the lowest Zones of the Lower Lias west of Sodbury Station.

			Feet	Ins.	Feet.
Nodular limestones with clay-partings.	*Amm. Conybeari.* *Amm.* aff. *angulatus.*	....			3
Thick shales, with nodular limestone-beds.	*Ostrea irregularis* very abundant, and fragments of *Amm. angulatus.*	Shale	3	0	$14\frac{1}{2}$
		Nodular limestone...	0	3	
		Shale	8	0	
		Three beds of nodular limestone, with shale-partings ...	2	3	
		Shale	1	0	
Thick shales, with several thin, but prominent, bands of limestone.	*Cidaris* sp. and *Pecten* spp. very abundant: *Lima gigantea.*	Limestone	0	4	$35\frac{1}{12}$
		Shale	4	0	
		Limestone	0	6	
		Shale, with a nodular limestone-band..................	5	6	
		Limestone	0	4	
		Shale, with a nodular limestone-band	1	3	
		Limestone	0	4	
		Shale	4	0	
		Limestone	0	6	
		Shale	4	3	
		Limestone	0	6	
		Shale	1	10	
		Limestone	0	3	
		Shale	6	0	
		Limestone	0	4	
		Shale	2	3	
		Limestone	0	4	
		Shale	1	4	
		Limestone	0	6	
		Shale	0	9	
Two thick limestone-beds.	*Ammonites Johnstoni*	....			2
Thin flaggy limestones, separated by thin shales.	*Ostrea liassica*, *Modiola minima*, and *Pleuromya.*	....			3
The White Lias (Sun-Bed), with Cotham Marble at the base		....			2

(e) The *Bucklandi*-Beds.

East of the site of the new Sodbury station, the cutting had already been earthed in for some 400 yards at the time of our visit; the beds thus concealed may, with practical certainty, be assigned to the zone of *Ammonites Bucklandi.*

That *Gryphæa arcuata* occurs in great abundance in these beds may be deduced from the numerous groups of closely-packed valves belonging to this species, which were to be seen outside a row of cottages near the new station. The fossils, we were informed, came from these beds. Of the truth of this assertion there is strong negative evidence, in the fact that we have found no such packed masses of the species either in the beds above or below.

(*f*) The *Turneri*-Shales.

The first exposure that we were able to examine was immediately west of the first bridge, which lies east of the new station. Higher beds were exposed to the east of the bridge in drainage-cuttings; and, about 300 yards east of the bridge, a fault, with a downthrow of 30 feet towards the west, enabled us to examine beds a little below those exposed just west of the bridge.

Lithologically, this series of beds consists of a very uniform succession of shales (7 or 8 feet thick) separated by thin limestone-bands (3 or 4 inches thick). There are also several impersistent limestone-bands, made up of separate nodules; these nodules assume the most varied forms, such as ovoid, spherical, club-shaped, dumbbell-shaped, etc. A great number of these nodules exhibit the usual concentric-shell structure, and are undoubtedly ordinary concretions. In many others, however, this structure is apparently absent; and since, when examined *in situ*, they are seen to have a conspicuous lamination parallel to that of the shales in which they lie, it is possible that such nodules may be those portions of an originally continuous sheet which have offered the greatest resistance to the solvent action of water. Throughout the series, the shales are perfectly fissile, and can be split into laminæ as thin as paper.

Palæontologically, the whole series is characterized by the abundance of *Ammonites (Arnioceras) semicostatus* and its mutations. *Arietites Turneri* is not uncommon, and there are at least two species belonging to the genus *Coroniceras*, one of which is nearly allied to *Amm. (Coroniceras) Bucklandi.* These ammonites occur in great profusion, in a crushed state, on the surfaces of the shale-laminæ; but they are also found in considerable numbers, either as solid fragments, or firmly embedded in limestone-nodules.

In the lowest beds of this series, single specimens of *Gryphæa arcuata* are fairly plentiful, and the species occurs somewhat rarely near the top, where it is associated with *Waldheimia (Zeilleria) indentata. Belemnites acutus* was found at more than one level.

The shales crowded with crushed ammonites of the *semicostatus*- and *Turneri*-types immediately call to mind the similar series at Lyme Regis; while the occurrence of typical *Arietites Turneri* firmly embedded in limestone-nodules suggests the precisely similar form from Barrow (near Bristol). The association of *Ammonites semicostatus, Zeilleria indentata, Gryphæa arcuata,* and *Belemnites acutus* recalls the '*Spirifer*-Bank' of Radstock, and in particular of Paulton; but the general differences between the two districts are very considerable. Throughout the Lias of Radstock brachiopods are abundant, whereas, in the Sodbury cutting, the very reverse is noticeably the case. Lithologically also the two areas are strikingly dissimilar: in the Radstock area the zones are of no great thickness, and are chiefly limestones with subsidiary clays; in the Sodbury district the zones are of very considerable thickness, and are chiefly shales with very subsidiary limestones.

The complete list of fossils from this series is as follows:—

Belemnites acutus, Mill.
Ammonites (Arnioceras) semicostatus, Y. & B., and its mutations.
Amm. (Arietites) Turneri, Sow.
Amm. (Coroniceras) spp.
Amm. (Agassizoceras) Sauzeanus (?) d'Orb.
Gryphæa arcuata, Lam.
Pecten aff. *textorius*, Schloth.
Waldheimia (Zeilleria) indentata, Sow.

Palæontological Notes.

So many different ammonites have gone under the specific name of *semicostatus*, that it is necessary to indicate with some precision the particular form to which the name is here applied. The ribs are straight, sharp, and close-set; their upper edges are horizontal and end abruptly in a vertical edge. The rim is square and provided with a sharp central keel, flanked by two deep furrows. The mutations are produced by the greater or less spacing of the ribs. These are the chief characters upon which we have had to rely for determining the solid whorl-fragments. The crushed specimens sometimes exhibit quite clearly the Arnioceratan character of smooth early whorls; but in most cases the centre is indistinct, and the only characters clearly defined are the straightness of the ribs and the slow rate of whorl-increase. In such cases, it is impossible definitely to identify even the genus.

Arietites Turneri occurs in solid fragments of the typical Barrow form, but even in the crushed state it can be identified by the forward sweep of the ribs, as they approach the rim.

The ammonites referred to in our list as *Coroniceras* spp. are solid fragments, kindly identified for us by Mr. S. S. Buckman, F.G.S.

Agassizoceras Sauzeanum (?) is doubtfully so named from a fragment of a whorl. This exhibited a square cross-section; straight, well-spaced, strong ribs ending in prominent points; and a flat rim, provided with a low, rib-like keel unflanked by furrows. Many of the crushed specimens probably belong to this form.

Belemnites acutus is quite typical; short and almost perfectly conical, with a narrow apical angle.

Pecten aff. *textorius*, Schloth.—In the right valve of this species, as figured by Goldfuss, the ribs resemble slender rods having rings set along them at intervals (after the *P. vimineus*-pattern); but, in our specimen, the ribs are sharply angular and finely serrated. On the other hand, *P. acutiradiatus*, Münst., with which our specimen has sometimes been identified, is more transverse and has its sharp angular ribs quite smooth.

Waldheimia (Zeilleria) indentata is of the typical Radstock form.

(*g*) The *Oxynotus*-Beds.

Proceeding eastward, we found the section completely obscured, until we reached a point about 200 yards from the mouth of the tunnel; here the cutting has vertical walls, and the beds are well exposed. They consist of a series of shales and thin limestone-bands, precisely similar in character to those of the *Semicostatus*-Beds already described. At first the dip is very inconsiderable, but there is a marked easterly dip in the neighbourhood of the tunnel-entrance.

The beds of this series contain few fossils, though crushed ammonites are not uncommon in the shales. They are doubtfully referred to the species *Ammonites densinodus*, Quenst., but the absence of any solid fragments that clearly exhibit the rim renders accuracy of determination impossible.

Avicula (Oxytoma) inæquivalvis, Sow. is not uncommon.

(*h*) The *Armatus*- and *Jamesoni*-Beds.

Just at the mouth of the tunnel, these beds are well exposed in the steep bank on the south of the line.

Lithologically, they consist of thick shales separated by thin limestone-bands precisely similar in general character to the beds below. Palæontologically, the beds at the base contain numerous badly-preserved ammonites, the commonest form being a species of *Deroceras* closely allied to *D. armatus*; while *Ammonites carusensis* is not uncommon, in a pyritized and somewhat crushed state. Throughout the series a crushed form, probably *Ammonites densinodus*, is common in the shales.

Towards the top of the section fossils are very common, though as a rule poorly preserved; we have determined the following species:—

Ammonites Scipionianus (?) d'Orb.
Belemnites penicillatus, Sow.
B. clavatus, Blainv.
B. longissimus, Mill.
B. acutus, Mill.
Belemnites aff. *grandævus*, Phil.
B. aff. *paxillosus*, Schloth.
Rhynchonella aff. *Thalia*, d'Orb.
Waldheimia (Zeilleria) numismalis, Lam.

Palæontological Notes.

The determination of the belemnites, as is usually the case with this group, was a matter of considerable difficulty. This difficulty arises from three main causes: firstly, the fact that, while we have to rely almost entirely upon the shape of the guard and the nature of the apical grooves, the mutations of form are continuous and almost endless, and the extent to which a groove is pronounced may vary from a deep rut to the most inconspicuous depression; secondly, the difference of opinion among students of the group as to the exact connotation of the specific names; and lastly, the fact that there are undoubtedly very many forms, or stages in mutation, which require new names. For these reasons, we have been content in most cases to employ the name given, in the monograph on belemnites published by the Palæontographical Society, to the species most like the one that we had to determine.

Fig. 1.—*Cutting, chiefly in Lower Lias, east of Lilliput, Chipping Sodbury.*

The association of the paxillose type of belemnite with the acute brevicones is very characteristic of this horizon.

Rhynchonella aff. *Thalia* is very common, but usually badly preserved; it is one of the *lineata*-group, and was kindly determined for us by Mr. J. W. D. Marshall.

VERTICAL SECTION OF THE *ARMATUS*- AND *JAMESONI*-BEDS WEST OF THE TUNNEL (OLD SODBURY).

			Feet	Ins.	Feet.
Shales, with thin beds of nodular limestone.		*Belemnites* spp. *Waldheimia numismalis* *Rhynchonella* aff. *lineata*			6
Thick shale, with a few thin limestone-bands.	*Am. densinodus* (?)	Shale	4	6	30⅔
		Limestone	0	3	
		Shale	7	3	
		Limestone	0	3	
		Shale, with one thin band of nodular limestone	9	0	
		Limestone	0	5	
		Shale	9	0	
Thin pyritous limestone and shale		*Amm.* aff. *armatus.* *Amm. raricostatus.*			2

2. The Lilliput Cutting (south-west of Chipping Sodbury).

A very small exposure of Lower Lias is seen on the south side of the Lilliput cutting, at the western end of the ridge of Carboniferous Limestone there cut through. The beds are much disturbed, being, with the underlying Cotham Marble, faulted and bent into the form of an U. The section is considerably obscured by talus, but the following beds can be made out:—

	Thickness in feet.
Thinly-bedded limestone, with shaly partings. (*Ostrea*-Beds.) ..	3 seen.
Sun-Bed	1⅓
Cotham Marble	—

3. The Lower Lias of Stoke Gifford.[1]

The lowest beds of the Lower Lias crop out in the cutting immediately east of Stoke Gifford. Owing to a very slight westerly dip, the greatest total thickness occurs near the western end of the cutting; but no beds above the sub-zone of *Ammonites torus* are shown at any point.

The White Lias.

The White Lias is represented by a single bed (the 'Sun-Bed') which directly overlies a bed of very characteristic Cotham Marble. In the character of the Cotham Marble, and in the reduction of the White Lias to a single bed, the development at Stoke Gifford is strikingly similar to that west of Sodbury Tunnel already described. In this connection, it is interesting to notice that, at New Clifton (near Bristol), which lies in the same Jurassic area as

[1] This section lies about 3 miles west of the main Sodbury section, near the western termination of the line.

Stoke Gifford, but close to its southern border, the White Lias includes, between the Sun-Bed and the Cotham Marble, a small number of thin limestone-beds precisely similar in character to the beds of the thick White-Lias series seen in the neighhourhood of Bath and Radstock.

The *Ostrea*-Beds.

These include about 4 feet of thin limestone-beds, separated by subsidiary shales.

Pleuromya Crowcombeia, *Ostrea liassica*, *Modiola minima*, *Pholadomya glabra*, and *Lima punctata* occur abundantly. The character of the various beds and the vertical distribution of these fossils in them is almost identically the same as at New Clifton and Kelston.

The *Planorbis*-Beds.

These consist of two or three thin limestone-beds, capped by a red ferruginous clay. *Ammonites planorbis* is very common, especially in the uppermost limestone-layer which is thin, extremely irregular, and much iron-stained. The spines of small echinids can be seen, weathered out on the surfaces of the limestones.

The *Torus*-Beds
(including part of the *Lima*-Beds).

These form the top of the section, and only a thickness of about 2 feet is shown. They consist of a lower series of white rubbly limestones, in which *Ammonites torus* is very common; a middle thick clay; and an upper series of hard limestones, in which large specimens of *Lima gigantea* abound.

The following is a complete list of the fossils found in the Lower Lias of the Stoke-Gifford cutting, assigned to their respective horizons:—

TORUS-SUB-ZONE. 2 feet.	Hard limestones. Clay. Rubbly white limestones.	*Ammonites Johnstoni*, Sow. = *Amm. (Psiloceras) torus*, d'Orb. *Lima gigantea*, Sow. *L. hettangiensis*, Terq. *Rhynchonella calcicosta*, Quenst.
PLANORBIS-BEDS. 10 inches.	Red clay. Thin limestones.	*Ammonites (Psiloceras) planorbis*, Sow. *Lima gigantea*, Sow. *L. punctata*, Sow. *Pseudodiadema (?)*
OSTREA-BEDS. 4 feet.	Limestone-beds, with subsidiary shales.	*Ostrea liassica*, Strickl. *Lima valoniensis*, Dum. *Modiola minima*, Sow. *Pleuromya Crowcombeia*, Moore. *Pholadomya glabra*, Ag.
SUN-BED. 7 inches.		
COTHAM MARBLE.		

Palæontological Notes.

Rhynchonella calcicosta.—This seems to differ but very slightly from the typical form which occurs so abundantly in the *Angulatus*- and Lower *Bucklandi*-Beds of Keynsham (near Bristol); it is, however, more flattened.

Pseudodiadema (?)—The small echinid-spines are here placed under this genus, because they exactly resemble the spines found on the same horizon at New Clifton, where they are associated with portions of the test.

III. The Sodbury Tunnel.

This tunnel extends for a distance of about $2\frac{1}{2}$ miles, from Old Sodbury to near Acton Turville. Starting on the west in the *Jamesoni*-Shales of the Lias, it emerges on the east through the massive limestones of the Great Oolite, piercing in its course every intermediate horizon.

Our knowledge of the beds through which the tunnel passes has been chiefly obtained from a careful examination of the material that has been brought up, partly from the boring of the shafts themselves, but mainly from the boring of the tunnel. A few surface-exposures have aided in confirming some of our conclusions.

We have also derived very valuable assistance from the specimens collected at the surface, when the shafts were in course of construction. The specimens are labelled with the approximate depth, in each shaft, at which rocks of that particular kind were encountered. By the kindness of the engineer (Mr. Grierson) and the agent (Mr. Manton) we have been afforded every facility for examining these specimens, as well as for studying the geological section constructed from them by the late engineer to the section (Mr. Katzenstein).

The exact determination of the vertical succession has, however, been a matter of very considerable difficulty.

In the first place, since rocks of almost identical character recur again and again at very different horizons, it becomes impossible to assign a block, found on the tips and containing definite fossils, to its correct horizon, unless the labelled specimens of identical nature contain fossils. The fossils themselves have consequently to be employed to determine the vertical succession, by assuming the same zonal sequence as in neighbouring districts. The value of the work is, in such cases, reduced to the mere registration of the occurrence of particular species in a particular kind of rock.

In the second place, rocks of well-marked lithological character, and common on the tips, contain no fossils and cannot be matched by any of the rock-specimens preserved from the shaft-borings; their position is therefore entirely problematical, and can only be assumed to be the same as that of similar rocks from other districts. We shall consequently, in all cases of doubt, state the data on which our surmises are founded.

(*a*) The *Capricornus*-Zone and Marlstone.

Lithologically, this series consists of clays and sandy beds containing many nodules, with an occasional band of fossiliferous limestone. In the limestones *Ammonites capricornus* occurs somewhat plentifully, as also does *Avicula inæquivalvis*. At the base of the series, almost immediately above the *Numismalis*- and Belemnite-Shales, a specimen of *Lytoceras* (aff. *fimbriatum*) has been found.

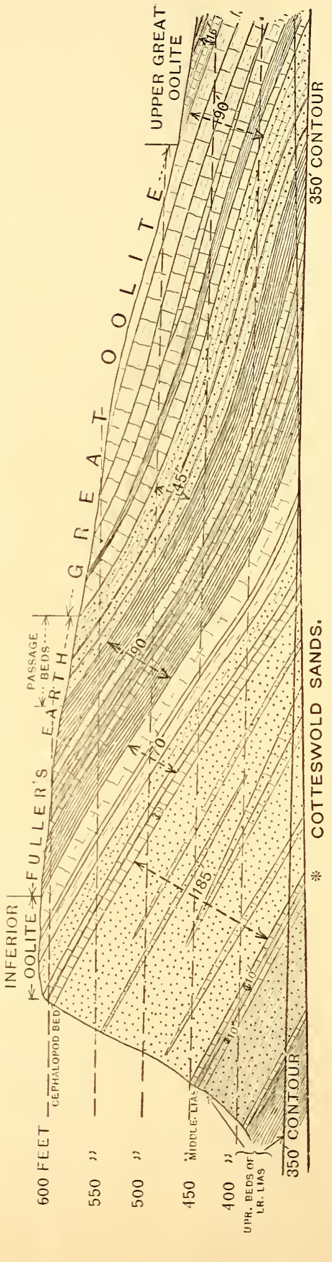


Fig. 2.—*Section through Sodbury Tunnel.* (*The asterisk* (*) *marks the 10 feet of Upper Lias.*)

[Horizontal scale: 1 inch = 2000 feet; vertical scale = 10 times the horizontal.]

This series is capped by a considerable thickness (at least 10 feet) of (i) sandy, (ii) marly, and (iii) ironshot limestones, all of which are very rich in fossils.

(i) In the hard sandy beds *Avicula inæquivalvis* and *Cucullæa* sp. are abundant, associated with a small, convex, smooth *Pecten*; *Ammonites capricornus* occurs in these beds, and good specimens can be obtained.

(ii) In the marly limestone-beds specimens of *Ostrea irregularis?* (an oyster of the vesiculose type) form an actual oyster-bed; and with this oyster are associated mutations of *Cardinia Listeri*.

(iii) The Marlstone (ironshot limestones).—Lithologically, this is the typical marlstone of the district, and consists of a coarsely ironshot, marly, limestone, blue when freshly brought to the surface, but becoming brown on exposure to the air. It contains *Pecten æquivalvis* abundantly, *Modiola scalprum* commonly, and *Rhynchonella tetrahedra* very rarely.

In the absence of any definite information as to the vertical succession of these three types of limestone, we are inclined to think, from their similarity to beds in the series below (*Capricornus*-Beds), that the sandy beds, with *Avicula inæquivalvis*, *Cucullæa* sp., and *Ammonites capricornus*, occur at the base of the limestone-beds; while there seems no doubt that the ferruginous beds with *Pecten æquivalvis* and *Modiola scalprum* (the Marlstone) occur at the top.

As no ammonites occur in the ferruginous beds, they can only be doubtfully assigned to the *Margaritatus*-Zone, from analogy with other districts.

Adopting this succession, the following is a list of the fossils that we have collected from these beds, assigned to their different matrices, arranged in descending sequence:—

(iii) The Marlstone. (? Zone of *Ammonites margaritatus*.)	*Belemnites* aff. *ilminsterensis*, Phil. *Pecten æquivalvis*, Sow. *Pecten* sp. *Modiola scalprum*, Sow. *Gryphæa cymbium*, Lam. *Cardium truncatum*, Sow. *Cypricardia* sp. *Rhynchonella tetrahedra*, Sow. *Pentacrinus* sp.
(ii) *Ostrea*-Bed	*Ostrea irregularis (?)* Münst. *Cardinia Listeri*, Sow. & mutations.
(i) Sandy limestone-beds. (? Zone of *Ammonites capricornus*.)	*Ammonites (Amblycoceras) capricornus*, Schloth. *Avicula (Oxytoma) inæquivalvis*, Sow. *Cucullæa* sp. *Gervillia* sp. *Goniomya* sp. *Pecten* sp. *Pinna folium*, Y. & B. *Pleuromya costata*, Y. & B. *Unicardium cardioides*, Phil.

Palæontological Notes.

In the sandy limestones:—

Pecten sp. has already been alluded to as a small smooth *Pecten* of the *calvus*-type, but somewhat more convex. No complete specimens have been seen, though it is abundant in fragments.

Avicula inæquivalvis is of the typical form named *sinemuriensis* by Oppel; it is extremely abundant.

Cucullæa sp. is very characteristic of this bed, and a chance fracture of a large block may reveal as many as fifty specimens completely covering the surface. In size and contour it seems to differ from any form previously figured. The nearest figure is that of *C. bilineata*, Moore, but the hinge-line in our species is much longer and the radial striæ are never obvious, even in young forms.

In the Marlstone:—

Pecten sp. is a large *Pecten*, with both the ribs and the intermediate spaces sharply angular. This may be a mutation of *P. æquivalvis*, in some specimens of which the ribs in the left valve are markedly angular, but it is in that case a very extreme form.

Belemnites aff. *ilminsterensis* is a long, cylindrical, slowly-tapering, tripartite belemnite.

(*b*) The Upper Lias.

Lithologically, there are three distinct types of rock, all of which contain ammonites characteristic of this horizon.

(1) A very compact, cream-coloured marl.

In this bed, which is 2 or 3 feet thick, *Ammonites falcifer* is abundant, small *Rhynchonellæ* are not infrequent, and *Belemnites* aff. *vulgaris* occurs occasionally.

(2) A very compact, marly limestone charged with angular, jaspery fragments.

In this bed, which is of about the same thickness as (1), *Ammonites communis* (and in particular one of its mutations, *Amm. Holandrei*) is extremely abundant; well-grown specimens of *Amm. Levisoni* also occur, while young forms of this, or an allied species of Hildoceratan ammonite, are plentiful. *Rhynchonella Moorei* occurs sparingly. In all probability we must assign to this horizon a very curious breccia, containing angular fragments embedded in a deeply-stained matrix.

(3) A pyritous bed containing very numerous specimens of *Ammonites bifrons*. The majority of the specimens are fragmentary, rounded, and pyritized.

The total thickness of the Upper Liassic beds probably does not exceed 10 feet.

The following is a list of the fossils which we have obtained from these beds, without distinction of matrix:—

Ammonites (Dactylioceras) communis, Sow. and its mutation, *Amm. Holandrei*, d'Orb.
Amm. (Hildoceras) bifrons, Brüg.
Amm. (Hildoceras) Levisoni, Simps.
Amm. (Harpoceras) falcifer, Sow.
Belemnites aff. *vulgaris*, Y. & B.
Pecten sp.
Rhynchonella Moorei, Dav.
Rhynchonella sp.
Drift-wood is very common in the pyritous bed.

Palæontological Notes.

The ammonite of the *communis*-group, alluded to above as *Ammonites Holandrei*, d'Orb. is the mutation so common at Stoke, near South Petherton.

Amm. falcifer, Sow. is the species figured as *Amm. serpentinus* in Wright's monograph on the 'British Lias Ammonites' (Pal. Soc.).

Rhynchonella sp. is a small form of the type of *Rh. calcicosta*; we have not found enough specimens to ensure its determination.

(*c*) The Cotteswold Sands.

Lithologically, the Cotteswold Sands consist of a very thick series of micaceous sands, containing lenticular bands of hard sandy limestone which occur at very irregular vertical intervals. These bands die out rapidly in both directions, so that the hard beds encountered in one shaft are not usually the continuations of those met with in the next, but occur at different depths and at different intervals in the sand series. The total thickness of the sands can be estimated with considerable accuracy, for they are capped by the Cephalopod-Bed and lie immediately upon the Upper Liassic Series. Both these horizons are accurately determined by the labelled specimens obtained from the boring of the temporary shaft, just at the top of the escarpment (Shaft No. 6). Making a small correction for dip (estimated as shown below), the total thickness of the sand series is 185 feet.

The sands themselves contain no fossils, but the hard beds are, as a rule, extremely fossiliferous. On account of the exact lithological similarity of the beds at different depths, the relative horizons of the fossils derived from them cannot possibly be inferred.

Ammonites of the *striatulus*-group occur on at least two different levels, for there are rock-specimens at the office which contain this form, but indicate by their labels very different depths below the top of the sands. We have also found this ammonite in a small exposure, at the side of the path that forms a short cut from Old Sodbury to the Cross Hands. *Ammonites radians* is very common in certain of the hard beds, but, so far as we know, is not associated with *Amm. striatulus*.[1]

The following is a complete list of the fossils that we have obtained from the hard sandy beds; it is impossible, however, to determine the relative vertical positions which they occupy in the series:—

Ammonites (Grammoceras) striatulus, Sow., and its mutations, in particular *Amm. toarcensis*, d'Orb.
Amm. (Dumortieria) radians, Rein. (see footnote).
Amm. (Grammoceras) fallaciosus, Bayle, and a mutation.
Amm. (Haugia) Eseri, Oppel.
Amm. (Harpoceras) subplanatus, Oppel.
Pholadomya fidicula, Sow.
Ph. aff. *Heraulti*, Ag.

Palæontological Notes.

All the specimens of ammonites from these beds have been submitted to Mr. S. S. Buckman, F.G.S., who has very kindly confirmed or corrected their identification.

[1] The bed containing *Ammonites radians* is placed by Mr. Buckman in the Cephalopod-Bed (see note on p. 736).

Ammonites striatulus occurs of two very distinct types: the one, with rounded whorl-sides, nearly resembles *Amm. striatulus*, Sow.; the other, with flat sides, is exactly similar to the form so common at Wootton-under-Edge, and is *Amm. toarcensis*, d'Orb.

Amm. radians is the *radians* of Buckman, but not of Wright. *Amm. fallaciosus* is the *radians* of Wright.

(*d*) The Cephalopod-Bed.

Capping the sands is a bed, or rather a series of beds, about 10 feet thick, and very uniform in character throughout.

Lithologically, this rock is a compact marl, coarsely ironshot and often to such an extent as to resemble linseed-meal. It was encountered in the three successive shafts numbered 6, 5, & 4; and very characteristic specimens of it, labelled with the depth at which they occurred, are preserved from each of these shafts. We are thus enabled to determine very accurately the average dip of the strata in the neighbourhood of the Cross Hands. A simple calculation indicates an easterly dip of about 3·5°.

The rock is crowded with fossils throughout its entire thickness.

Three separate palæontological horizons can be easily, and invariably, distinguished:—

(1) The *Lima*-Bed, characterized by the abundance of specimens of a very large, flattened *Lima* of the *Etheridgei*-type, as well as by numerous other lamellibranchs which are identical with, or remarkably similar to, common Inferior-Oolite forms.

(2) The Belemnite-and-*Cynocephala*-Bed, a thick bed, crowded with *Rhynchonella cynocephala* and with tripartite belemnites.

(3) The Opalinid-Bed, a softer bed, in which ammonites of the Opalinid-type are so common that, in places, the rock is entirely composed of them. In this bed, as in the *Lima*-Bed, Oolitic forms of lamellibranchiata abound, associated with a few forms of more Liassic aspect.

The following is a complete list of the fossils which have been obtained from these beds, assigned, so far as possible, to the particular horizon from which they were derived.

Since there is no direct evidence of succession, these three fossiliferous beds are arranged in descending vertical series by comparison with the sections contained in Mr. Buckman's paper on the Cotteswold Sands.[1] (In many characters, however, the *Lima*-Bed bears a much closer resemblance to the Opalinid-Bed than it does to the Belemnite-and-*Cynocephala*-Bed; in particular, we may note the abundance of Oolitic lamellibranchs in both the first-named beds and their absence from the last.)

[1] 'On the Cotteswold, Midford, & Yeovil Sands, etc.' Quart. Journ. Geol. Soc. vol. xlv (1889) p. 440.

3) The Opalinid-Bed. Horizon of *Ammonites opalinus.*	*Ammonites (Lioceras) opalinus*, Rein. and several mutations. *Amm. (Grammoceras) aalensis*, Ziet. *Amm. (Pseudolioceras) compactilis*, Simps. *Astarte* sp. *Pecten* aff. *demissus*, Phil. *Gresslya abducta*, Phil. *Ceromya bajociana*, d'Orb. *Cardium* aff. *truncatum*, Sow.[1] *Lima punctata*, Sow. *Goniomya v-scripta*, Sow.[1]
(2) The Belemnite- & *Cynocephala*-Bed. Horizon of *Ammonites Moorei.*	*Ammonites (Dumortieria) Moorei (?)* Lyc. *Belemnites* aff. *Voltzii*, Phil. *B.* aff. *tripartitus*, Schloth. *Rhynchonella cynocephala*, Rich. *Terebratula punctata*, var. *haresfieldensis*, Dav.
(1) The *Lima*-Bed. Horizon of *Ammonites dispansus.*	*Ammonites (Grammoceras) dispansus*, Lyc. *Amm. (Dumortieria)* sp. nov. *Bel.* aff. *tripartitus*, Schloth. *Lima Etheridgei*, Wr. *Astarte lurida (?)* Sow. *Cœlastarte* sp. *Opis trigonalis*, Sow.

Palæontological Notes.

For the correct naming of the ammonites we are again much indebted to Mr. Buckman's kind assistance. *Ammonites (Dumortieria)* sp. was returned by him with the following note:—

'This is altogether new to me. I have not seen any species with so many coils in the umbilicus, and at the same time so thin.'

The Opalinid ammonites belong mostly to the mutation with moderately open umbilicus.

The name *Belemnites* aff. *tripartitus* is employed to cover long, tripartite belemnites which are nearly cylindrical in form.

Belemnites aff. *Voltzii* (probably = *B. compressus, conicus* of Quenstedt) is employed to cover a large group of conical, compressed forms marked by three deep apical grooves. There seems, however, to be a complete passage from this type into the cylindrical form just noticed.

Astarte sp.—This species occurs somewhat commonly, and excellent specimens may be obtained from the Opalinid-Bed. Though resembling *A. elegans*, Sow. in its marking and lunule, it differs in being larger and of rectangular form.

Rhynchonella cynocephala, Rich.—The form common at Sodbury is separated from the typical *Rh. cynocephala* by Mr. Buckman, under the name of *Rh. cynoprosopa*.

[1] We are much indebted to the kindness of Mr. J. W. Tutcher, for the loan of these and several other specimens, from his very fine collection.

Note on the Cephalopod-Bed and Sands.

From the similarity of the hard sandy beds in which *Ammonites radians* occurs to those which contain *Amm. striatulus*, we had regarded this ammonite as characterizing one of the hard beds in the sands below the Cephalopod-Bed. We were apparently strengthened in this conclusion by the absence of any rocks of similar character, from among the very numerous labelled specimens of the Cephalopod-Bed preserved at the office. All the specimens had the typical ironshot character, and included fossils from the three beds already enumerated.

Mr. Buckman, however, informs us that he is convinced that the *Radians*-Bed should be placed in the Cephalopod-Bed, and suggests the following descending vertical sequence :—

Opalinid-Beds.........	Ironshot.
Cynocephala-Beds ...	
Radians-Beds	Sands.
(*Lima* &) *Dispansus*-Beds	Ironshot.
Striatulus-Beds	Sands.

He cites the following section from North Stoke (near Bath) to illustrate the occurrence of sandy beds below the horizon of *Ammonites opalinus* and above that of *Amm. dispansus*. This section, not previously published, is here given by Mr. Buckman's kind permission :—

SECTION AT NORTH STOKE, 1895, by MR. S. S. BUCKMAN, F.G.S.

		Feet	Inches.
UPPER *TRIGONIA*-GRIT.	Ironshot earthy stone and marl. *Terebratula subsphæroidalis*, Upton.	0	6
RADIANS-BEDS.	Yellowish-grey sandstone. *Dumortieria, Lithodomus.*	1	3
	Yellow sands and some rock. Hard grey sand-rock. Fragments of *Dumortieria* or *Catulloceras*.	1	4
	Sands	1	6
DISPANSUS-BEDS.	Yellowish ironshot earthy stone. *Grammoceras dispansum*; *Hammatoceras* aff. *insigne*; *Lytoceras* aff. *Germainei*.	1	1
	Yellowish-brown marl. *Grammoceras dispansum.*	0	3
STRIATULUS-BEDS.	Yellow sands much concealed	4	6
	Yellow sands. *Lytoceras* aff. *Germainei*.	1	6
	Sands	0	11
	Yellow sand-rock.	0	8
	Yellow sands.		

(e) The Inferior Oolite.

Lying, as it does, between the well-marked Opalinid-Bed and the clays of the Fullers' Earth, the thickness of the Inferior Oolite is easily estimated (from the labelled specimens) to be about 70 feet. The vertical succession of the different beds which make up this thickness cannot, however, be very definitely stated. The total thickness of the series is approximately the same in the two shafts numbered 5 & 4 (that is, in the permanent shaft near the Cross Hands, and in the temporary one which lies about 200 yards farther east); but the lithological character of the rocks in the two borings does not absolutely correspond at corresponding levels. The following general summary is, nevertheless, applicable equally to either shaft, the beds being arranged in descending order:—

		Thickness in feet.
Globata- and Coralline Beds.	Blue, yellow, and white oolite (the oolitic character as a rule strongly and uniformly marked).	25
Trigonia-Grit.	Very fossiliferous, compact limestones, with *Trigonia costata* and *Rhynchonella spinosa*.	10
	Coarsely granular, yellow limestone, full of comminuted shells, but with no determinable fossils.	5
	Oolitic limestones of varied texture, with some soft sandy beds, and, at the base, a compact fossiliferous limestone.	25 to 30

The following is a complete enumeration of the different types of rock, belonging to the Inferior Oolite, which are met with on the tips.

(1) A pure white limestone, which is very uniformly and conspicuously oolitic.

This contains few fossils, but, by breaking up some scores of blocks, *Terebratula globata* was found to be not uncommon in it, and *Rhynchonella subtetrahedra* occurs sparingly. In places this oolite becomes blue or yellow, and the change of colour often occurs quite suddenly in a single block. In a large block, which exhibited the change from white to yellow, the yellow portion was seen to be made up entirely of a thick mass of *Thamnastræa*.

(2) A sandy and fine-grained blue limestone, in which *Terebratula globata* is quite common and, with it, *Rhynchonella subtetrahedra*, as well as a much-branched species of *Cladophyllia (?)*. This rock is consequently on about the same horizon as the last. Judging by the matrix alone, a specimen of *Collyrites ovalis*, which we obtained, came from this bed.

(3) A deep yellow-stained limestone, containing abundant fossils embedded in a very compact matrix.

In this rock the external impressions of costate *Trigoniæ* are extremely abundant, and perfectly typical specimens of *Rhynchonella spinosa* have been obtained from it. It is undoubtedly on the same horizon as a compact blue limestone which contains the same fossils, and of which labelled specimens from the boring of Shaft No. 4 are preserved.

(4) A very compact, splintery, yellow limestone, containing numerous specimens of a well-marked species of *Montlivaltia*, intermediate between *M. lens* and *M. Delabechei*. Since the greater part

of the interior of the corals has been filled in with calcite, the rock has a very characteristic appearance, and is easily recognized. Apart from the *Montlivaltia*, we have been unable to find in the rock any fossils that can be definitely determined.

(5) A very soft, yellow, sandy rock crumbling into a loose sand.

There is little doubt that this rock is only a softer representative of the one just described, for a fine specimen of the same *Montlivaltia* has been obtained from it. Here also occur a *Terebratula* of *perovalis*-like aspect and *Rhynchonella hamponensis*.

(6) A bed very similar to (3), the *Trigonia*-grit, in texture, and, like it, full of fossils.

Here we found *Cœlastarte excavata*, *Trigonia*-casts, and a fragment of the outer whorl of an ammonite. This fragment was submitted to Mr. Buckman, who suggested that it might belong to a species allied to *Cylicoceras undatum*, which occurs in the *Opaliniformis*-Zone. Assuming that this determination is approximately correct, this bed would occur at the very bottom of the Inferior Oolite.

The following is a complete list of the fossils that we have obtained from the different beds of the Inferior Oolite, grouped under the several matrices from which they were derived. The beds are arranged in a definite descending order, although this is done with considerable hesitation.

GLOBATA- and CORALLINE BEDS	*Terebratula globata*, Sow. *Rhynchonella subtetrahedra*, Dav. *Collyrites ovalis*, Leske. *Thamnastræa* aff. *mettensis*, E. & H. *Cladophyllia* sp.
TRIGONIA-GRIT	*Trigonia costata*, Sow. *Lima pectiniformis*, Schloth. *Rhynchonella spinosa*, Schloth. *Belemnites* sp. (a canaliculate fragment).
The *MONTLIVALTIA*-BED, partly compact, partly soft.	*Montlivaltia* sp. *Terebratula* sp. *Rhynchonella hamponensis*, Buckm.
COMPACT BED	*Hinnites abjectus*, Phil. *Cœlastarte excavata*, Sow. *Gresslya abducta*, Phil. *Pholadomya fidicula*, Sow. *Trigonia* sp. *Ammonites* sp. (*? Cylicoceras undatum*, Buckm.) *Rhynchonella subringens*, Dav.

Palæontological Notes.

The *Montlivaltia* sp. has twenty-four long septa, with twenty-four shorter intermediates, and lastly, a complete cycle of forty-eight still shorter septa. The base is almost flat, but more convex than in the typical *M. lens*, while the epitheca does not appreciably invest any portion of the sides (as it does in *M. Delabechei*). The base has a small central depression, and is covered with a concentrically-wrinkled epitheca.

Average diameter = 25 to 30 millimetres; height = 12 to 14 mm.

The brachiopods have been examined by Mr. J. W. D. Marshall, who has kindly compared them with specimens from his large collection of Jurassic brachiopods. The specimen of *Terebratula* from the *Montlivaltia*-bed has also been submitted to Mr. Buckman, who acknowledges its *perovalis*-like aspect, but points out that it is contrary to all experience that this species should occur with *Rhynchonella hamponensis*.

Rhynchonella subringens.—Only two specimens of this shell were found; they also were submitted to Mr. Buckman, who regards them as indisputable evidence of the Pea-Grit horizon. He points out that the presence of that horizon at Sodbury indicates a slight syncline, which he had already surmised on other evidence.

(*f*) Fullers' Earth and Passage-Beds.

Rocks belonging to the Fullers'-Earth Series were met with in all the shafts east of the Cross Hands, and the lower beds are exposed at the surface in a small cutting close to the first permanent shaft (No. 5). Our knowledge of the vertical succession is derived, partly from this cutting, but, in the main, from the set of specimens obtained from the shafts and preserved in the Great Western Railway-office at the Cross Hands.

The following section is constructed from an examination of the rock-specimens derived from Shaft No. 4, which is the only shaft that penetrates the whole series of beds intermediate between the oolitic limestones of the Great Oolite above, and those of the Inferior Oolite below.

		Thickness in feet.
Great Oolite.	Coarse-grained oolitic limestone.	
(?) Passage-Beds.	Compact sandy limestone, with thin clays	36
Fullers' Earth.	Clay and shale, full of *Ostrea acuminata*	28
	Argillaceous limestone .... about	10
	Clay, with *Ostrea acuminata*	27
	Compact blue limestone, with *Terebratula globata* and *Ostrea acuminata*	5
	Shale	24
Inferior Oolite.	Oolitic limestone (*Globata*-Beds).	

The uppermost beds in this section (coarse-grained oolitic limestone) may be unhesitatingly assigned to the Great Oolite Series.

The lowermost (*Globata*-Beds) are those already described as the top beds of the Inferior Oolite. On palæontological grounds alone, these basal limestones should probably be grouped rather with the Fullers' Earth, than with the Inferior Oolite; for *Terebratula globata*, which characterizes them, occurs of identical form in the clays above, where it is associated with *Ostrea acuminata*. Again, the corals which occur in these limestones are of Bathonian, rather than Bajocian types. In many respects these limestones bear a strong resemblance to the top (or Coralline) beds of Dundry Hill, where *T. globata*, of the typical Fullerian form, occurs associated with corals very similar to those found in our tunnel-section.[1]

The Sandy Limestone-Beds (Passage-Beds).

The exact horizon of these hard beds cannot be definitely settled from the actual rock-specimens preserved from this shaft (No. 4), for these specimens contain no fossils. Rocks of exactly similar texture, however, occur at several levels in the shafts farther east, and it seems certain that these thick limestone-beds pass laterally into a series of alternating clays and hard limestones, in which the relative thickness of limestone and clay varies considerably from point to point. This deduction is based on the fact that, in each of the shafts farther east (numbered 3 & 2), there is a thickness of about 40 feet of clays and hard limestones, which occupy a position exactly analogous to that of the hard sandy limestones of Shaft No. 4: for they rest upon clays full of *Ostrea acuminata*, and are capped by beds of massive oolitic limestone. The specimens of these beds derived from Shafts No. 3 and No. 2 contain fossils at more than one horizon, so that, from these specimens, the stratigraphical position of this series can be approximately determined.

Palæontologically, these sandy limestone-beds seem to bear a closer relationship to the Great Oolite than to the Fullers' Earth, for large specimens of *Pholadomya deltoidea* (very similar to the common Cornbrash form) are common, while no specimen of *Terebratula globata* or *Ostrea acuminata* was found in them.

These beds probably occupy the same horizon as the Stonesfield Slate, but they do not bear a close resemblance to that series, either in lithological or palæontological characters: for the limestone, though sandy, is not fissile and the faunal facies is very distinct. We have simply designated them 'Passage-Beds' in our tunnel-section.

The Fullers' Earth.

This consists of a thick series (about 90 feet), mainly of clays and shales. When traced laterally, the lithological character is very inconstant, for the clays pass, on the one hand, into shales, and, on the other, into beds of hard shelly marl. In the middle of the series, however, there are one or more beds of argillaceous limestone which mark a fairly constant horizon.

The clays and marls are crowded with *Ostrea acuminata*, while *Avicula echinata*, *Terebratula globata*, *Rhynchonella varians* (of the

[1] Mr. J. W. D. Marshall permits us to state that he has found typical Fullers'-Earth fossils in what appears to be a pocket at the western end of Dundry Hill (*Ornithella cadomensis*, *Rhynchonella varians*, *Terebratula globata*, etc.); and one of us has also obtained there a specimen of *Ostrea acuminata*.

typical Fullers'-Earth form) and *Rhynchonella* sp. (described below) occur plentifully, at certain horizons. A *Pecten* of the *vagans*-group is not uncommon.

The following is a complete list of the fossils obtained from the Fullers' Earth and Passage-Beds, arranged in descending order:—

Passage-Beds (45 feet).	Hard sandy limestones, with subsidiary clays.	*Pholadomya deltoidea*, Sow. *Ph.* aff. *Heraulti*, Ag. *Trigonia pullus (?)* Sow. *Avicula (Pseudomonotis) echinata*, Sow. *Cypricardia* sp. *Ammonites (Perisphinctes) gracilis*, J. Buckm. *Trichites* sp. *Pecten* aff. *demissus*, Phil. Crustacean.
Fullers' Earth (90 feet).	Clays, shales, and marls, with a fairly constant middle series of argillaceous limestones (10 feet).	*Ostrea acuminata*, Sow. *Avicula (Pseudomonotis) echinata*, Sow. *Pecten* of the *vagans*-group. *Isocardia* sp. *Terebratula globata*, Sow. *Rhynchonella varians*, Schloth. *Rh.* sp. *Waldheimia (Ornithella) ornithocephala*, Sow.[1]

Palæontological Notes.

Waldheimia (Ornithella) ornithocephala is non-elongate in form. The straight central portion of the frontal margin is very short ($\frac{1}{3}$), compared with the width of the test.

Rhynchonella sp.—This form has a very *concinna*-like aspect, the perforation not being closed below by the deltidial plates. Mr. Buckman considers it to be a new species, quite distinct from both *Rh. concinna* and *Rh. obsoleta.* Its mutations take place (1) in form, as shown by a tendency towards greater elongation, rarely towards greater transversity; (2) in increased coarseness of ribbing.

Ammonites (Perisphinctes) gracilis, J. Buckm.—Our specimens seem to agree with the figures given in the 'Great-Oolite Mollusca.' The strongly marked ruts at intervals, the nature of the ribbing, and the open umbilicus, mark the species out as a close relative of *Amm. (Perisphinctes) Martinsi*, d'Orb.; but the flattened sides, straight ribs, and narrow rim make it worthy of a distinct name.

Pecten of the *vagans*-group.—Form elongate; beak-angle less than 90°. Right valve: four broad ribs, each bisected by a groove, separated one from the other by three broad valleys; valve convex. Left valve: ribs (about seven) unequally spaced, low, and cylindrical, crossed at unequal intervals by scaly annulations; valve flat.

[1] Several specimens found at Shaft No. 2 were kindly given to us by Mr. T. F. Sibly.

IV. The Great-Oolite Series east of Sodbury Tunnel.

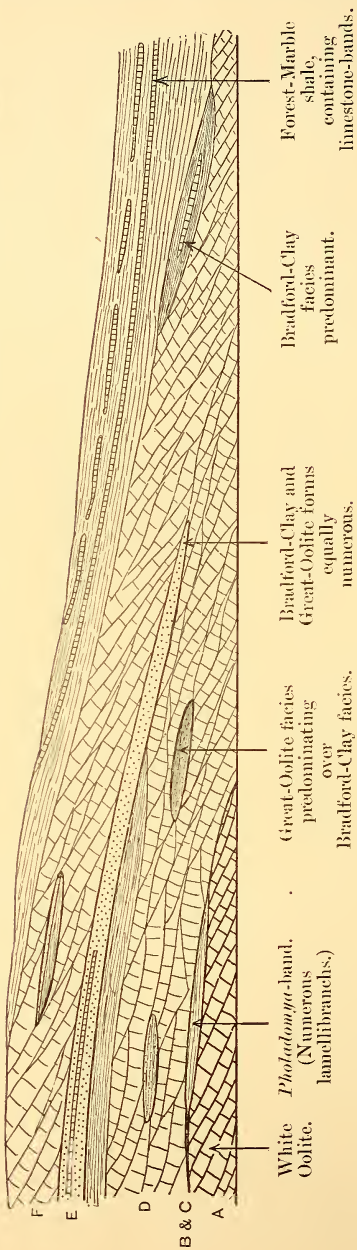


Fig. 3.—*Cutting east of Sodbury Tunnel. (Horizontal scale: 1 inch = 150 yards; vertical scale exaggerated.)*

As here defined, the Great-Oolite Series is taken to include all the beds which lie between a compact, sandy, non-oolitic limestone below, and a thick shale-series above. The sandy limestones below are those which we have already discussed under the Fullers'-Earth Series as Passage-Beds, and the shales above undoubtedly belong to the Forest-Marble Series.

This definition affords a ready means of marking off the Great Oolite from the beds above and below; but, since the basis on which it rests is purely lithological, it applies only to the particular area with which we are dealing.

In the actual section, as seen in the magnificent cutting east of the tunnel, nothing could be more clearly marked than the junction of the massive limestone-beds with a thick series of shales above: yet, if a hand-specimen is taken from one of the upper beds of the massive limestone-series, and compared with another specimen taken from one of the ledge-like limestone-bands in the shale-series above, the similarity of the two specimens both lithologically and palæontologically is very striking.

The whole series exceeds 100 feet in thickness, and consists essentially of much-jointed beds of massive limestone; the strata are false-bedded and wedge-bedded throughout, as well as traversed by several master-joints. At all depths in the series the massive limestones have a tendency to pass laterally into sandy beds or clays, which strike the eye, when viewing the section, as lenticular masses embedded in a matrix of jointed false-bedded limestone. When standing at any particular point in the cutting, east of the tunnel-mouth, it would be easy to exaggerate the stratigraphical importance of these clays and sands. For example, in the vertical face which contains the mouth of the tunnel, a very conspicuous thick band of dark clay is seen at a short distance above the roof of the tunnel, resting upon massive limestone-beds which continue

Fig. 4.—*The eastern end of Sodbury Tunnel.*

to the floor, and capped by a prominent sandy bed. Traced laterally however, this clay and its capping of sand die out completely, to be replaced by limestones, continuous in all respects with those above and below, but containing the same fossils as were found in the clay and sand.

As another example, we may take the following:—At a short distance from the mouth of the tunnel, and some 30 feet below the clay just referred to, occurs a very characteristic sandy clay, as black as coal. Traced towards the tunnel this passes into a brown sand, and ultimately into massive limestones; but, under all conditions, the horizon is well-marked by large specimens of *Pholadomya deltoidea*, which occur abundantly along this particular level.

Of the palæontology of the lower beds we have no record, for the rock-specimens from the shafts contain no fossils. But from the upper beds, which are exposed in the cutting to the east of the tunnel-mouth, we have obtained an extensive series of fossils. These have been collected at different times during the making of the cutting, so that the section has been examined almost bed by bed. Again, the dip, which is variable both in direction and amount (a south-easterly dip of 7·5° was measured at one point), has always an easterly direction, and brings each bed in succession down to the floor of the cutting, so that it can be easily examined.

The following is a detailed account of the section taken near the mouth of the tunnel, but generalized, so as to apply, with more or less accuracy, to the whole expanse of Great Oolite.

(i) Lithology of the Section immediately East of the Tunnel.

			Thickness in feet.
Forest Marble.		Thick shales or clays containing two or more separated bands of limestone, which jut out like parallel ledges......	
Upper Great Oolite.	F.	A thick mass of limestones, false-bedded, wedge-bedded, and much jointed, with occasional lenticular bands of dark clay.	about 15
	E (2).	Sandy layer, thickest just at the mouth of the tunnel, but thinning out rapidly eastward; it can, however, be traced, though much attenuated, to the point at which it disappears below the floor of the cutting.	about 6 (where thickest).
	(1).	Lenticular band of dark clay; this is about 4 feet thick at the tunnel, but thins out very rapidly eastward and dies out entirely before reaching the floor of the cutting.	
	D.	A thick mass of limestone, false-bedded, wedge-bedded, and much jointed, with occasional lenticular bands of sand and dark clay. This group rests upon a more or less persistent thin sandy layer.	about 25
Great Oolite (White).	C.	Massive, fine-grained, white oolitic limestone (unfossiliferous)..	3
	B.	Lenticular band of black clay, passing laterally into sand, but ultimately merging into the general limestone-mass.	about $2\frac{1}{2}$
	A.	Massive, fine-grained, white oolitic limestone (unfossiliferous)..	to base.

(ii) Palæontology of the Section.

(*a*) Upper Great Oolite, Groups F to D.

Most of the limestone-beds in Groups F and D have a very coarse oolitic structure, and are crowded with shells largely fragmentary. Polyzoa abound in certain layers, and can be picked out in hundreds from the crumbled surfaces. Of most common occurrence are slender branching species belonging to the genera *Heteropora*, *Ceriopora*, and *Multiclausa*.

Cidaris-spines are not uncommon, and small gasteropoda, especially small specimens of *Trochus*, occur plentifully.

Rhynchonella obsoleta, *Terebratula maxillata*, and *Lima cardiiformis* occur throughout the whole series of beds, but are especially abundant at certain levels in the series marked D. In a lenticular sandy layer, about the middle of Group D, we found the following:—

Group D.

Lithodomus sp.	*Rhynchonella obsoleta*, Sow.
Lima cardiiformis, Sow.	*Terebellaria ramosissima*, Lamx.
Trichites nodosus, Lyc.	*Cidaris* sp.
Pecten vagans, Sow.	*Acrosalenia* sp.
Terebratula maxillata, Sow.	*Cladophyllia* sp.
Waldheimia (Eudesia) cardium, Lam.	*Peronidella* sp.

From the sandy and clayey beds, marked E, and especially from the limestone-beds which are developed in the sandy layer at certain points, we obtained the following fossils :—

Group E.

Belemnites sp.	*Waldheimia (Ornithella) digona*, Sow.
Mytilus furcatus, Goldf.	*W. (Eudesia) cardium*, Lam.
Ostrea Sowerbyi, Lyc.	*Rhynchonella obsoleta*, Sow.
O. gregaria, Sow. (rare).	*Berenicea Archiaci*, Gregory.
Corbula sp.	*Cidaris* aff. *bradfordensis*, Wr.
Cucullæa aff. *concinna*, Phil.	*Isastræa limitata*, Lamx.
Terebratula aff. *bradfordensis*, Walker.	*Cladophyllia Conybeari (?)* Ed. & H.

Some 300 yards east of the tunnel-mouth, an extremely fossiliferous horizon occurs, at the very top of Group F. Here, separated by a thin clay from the main mass of false-bedded limestones, is a sandy limestone crowded with fossils. This limestone and the clay beneath it pass laterally, when followed westward, into the uppermost beds of Group F. The clay must be regarded, therefore, as only another instance of the development of lenticular clay-bands, so characteristic of the series.

The commonest fossils at this horizon are :—

Group F.

Avicula (Oxytoma) costata, Sow. (very abundant).	*Rhynchonella obsoleta*, Sow.
Pecten lens, Sow.	*Rh. concinna*, Sow.
P. vagans, Sow.	*Waldheimia (Ornithella) digona*, Sow.
Lima cardiiformis, Sow.,	*Terebratula maxillata*, Sow.
and numerous lamellibranchs.	*T. bradfordensis*, Walker.

(β) Great Oolite (white oolite), Groups C to A.

These consist of massive, fine-grained, white oolitic limestones which include non-persistent layers of fossiliferous clay and sand (B) near the top.

The limestones are not highly fossiliferous, but the horizon B is marked by a very distinctive assemblage of fossils.

Terebratula maxillata and *Rhynchonella obsoleta* occur sparingly; but the horizon is characterized by the abundance of casts of lamellibranchs. These belong to the genera *Pholadomya*, *Pleuromya*, *Unicardium*, and *Cypricardia (?)*; the large casts of *Pholadomya deltoidea* may be almost said to form a continuous layer.

There is a striking change in the faunal facies, as we pass from the White-Oolite Series below to the beds of the Upper Great Oolite. On the other hand, the Upper Great Oolites are characterized throughout by very uniform assemblages of fossils. We may note, however, a gradual increase in the forms characteristic of the Bradford Clay as we pass upward in the series. In Group D (see vertical section below) the brachiopods are represented by typical transverse specimens of *Terebratula maxillata*, large *Rhynchonella obsoleta*, and an occasional example of *Waldheimia cardium*. At the horizon E, though *T. maxillata* still occurs of the typical form, it is largely replaced by a form, more elongate, less maxillated, and with a beak so truncated that the margin of the perforation lies in a plane sloping backward. *Waldheimia digona* enters this horizon, and is not uncommon. *Rhynchonella obsoleta* is very common, and *Waldheimia cardium* occurs sparingly (large specimens of *Lima cardiiformis* abound at this horizon). At the top of Group F, *Terebratula bradfordensis* occurs of quite typical character, and it is associated, as at Bradford-on-Avon, with *Waldheimia digona*. Here also *Avicula costata* is quite as abundant as at Bradford-on-Avon.

It is important to note that we have been unable to find any specimens of *Dictyothyris coarctata* and of *Apiocrinus*; but, with this reservation, it would be utterly impossible to separate the top beds of the Upper Great Oolite from the Bradford Clay, on palæontological grounds. On account of the perfectly continuous faunal sequence, we have found it impossible to separate a 'Bradford-Clay' horizon, and have consequently grouped the whole of the upper series of beds under the title of 'Upper Great Oolite,' being content to point out that the uppermost beds are homotaxial with the clay at Bradford-on-Avon.

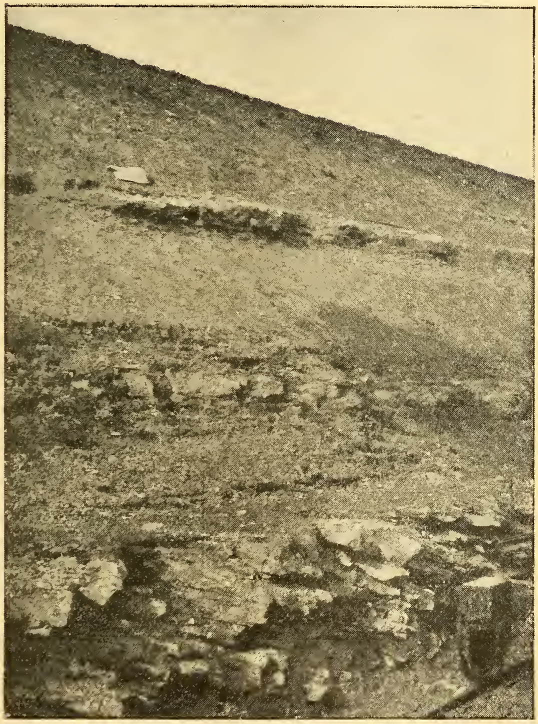
Generalized Vertical Section of the Great Oolite and Forest Marble east of the Tunnel (near Acton Turville).

		Thickness in feet.
Shales and clays containing two thick limestone-bands. (Forest Marble.)	*Waldheimia digona* and *Avicula costata* especially abundant towards the base.	to top of section.
F. Massive wedge-bedded limestones, with lenticular sandy bands.	*Rhynchonella obsoleta.* *Terebratula bradfordensis.* *Waldheimia digona.* *Avicula costata.*	about 5
E. Dying out eastward. — Sand, with sandy limestone-bed. Sandy clay.	*Lima cardiiformis.* *Rhynchonella obsoleta.* *Terebratula* aff. *bradfordensis* *T. maxillata.* *Waldheimia digona.* *W. cardium.*	about 6
D. Massive wedge-bedded limestones, with several lenticular sandy bands.	*Lima cardiiformis.* *Terebratula maxillata.* *Rhynchonella obsoleta.* *Waldheimia cardium.*	about 24
Thin sandy parting, variable in thickness		1
C. White oolitic limestone, with few fossils		3
B. Lenticular sandy band, of very variable thickness.	*Pholadomya deltoidea*, abundant.	3
A. Massive white oolitic limestone, with few fossils		to base of section.

V. THE FOREST MARBLE AND THE CORNBRASH.

The Forest Marble crops out south-west of Badminton, a few yards west of the eastern end of the big tunnel, and extends thence eastward as far as Bradfield Farm, south-east of the village of Norton, a distance of 6½ miles. As regards the extent of country that it occupies, and the number and size of the cuttings opened in

Fig. 5.—*Cutting about 650 yards east of Sodbury Tunnel.*



Forest Marble.

Clay, with hard band. Bradford-Clay facies predominating over Great - Oolite facies.

Wedge-bedded Upper Great Oolite.

it, the Forest Marble is undoubtedly the most important deposit cut through by the line.

The Forest Marble maintains throughout its typical character, as beds of variable shale alternating with compact shelly, oolitic, limestone, or hard sandy limestone with doggers. It shows great lateral variability, the limestone-bands being all lenticular deposits, not traceable for any great distance. The shelly limestones jut out like ledges in the shales, and have their surfaces covered with fossils, among which species of *Pecten* are common. When broken across, the limestone-slabs are seen to be made up of parallel layers of closely packed shells. On the surfaces of such slabs we recognized the following fossils: *Pecten lens*, *P. annulatus*, *P. rigidus*, *P. vagans*, *Ostrea Sowerbyi*, *Rhynchonella* (mutation of *Rh. concinna*).

The lowest beds of the Forest Marble seen overlying the Great Oolite immediately east of Sodbury Tunnel are:—

		Thickness in feet.
2.	Shale, with limestone-band 2 feet thick in places	8
1.	Shale, which, when followed eastward, develops a prominent band of shelly limestone 1 to 3 feet thick	18
	GREAT OOLITE. Compact, false-bedded, shelly oolite.	

The above series is cut off by a fault with a downthrow to the east, at a point due south of Badminton Farm. East of this fault shales are seen, and at the point where the road between Badminton and Acton Turville crosses the line, a limestone-band is seen coming on below; this may be the upper of the two bands which were cut off by the fault. Embankments or shallow cuttings, showing no continuous series of exposures, extend from this point until the big cutting due south of Alderton is reached.

Immediately west of Alderton Tunnel there is a section of Forest Marble, showing predominating clays or shales and subsidiary limestones, as follows:—

		Feet	Inches.
8.	Clay or shale	15	0
7.	Impersistent limestone	0	6
6.	Blue clay	30	0
5.	Hard, blue, oolitic limestone	0	6
4.	Clay	3	0
3.	Hard, blue, oolitic limestone	0	9
2.	Blue sandy clay	2	3
1.	Compact oolitic limestone, weathering yellow, to base of section	8	0
		60	0

At the eastern end of Alderton Tunnel there is a fine section through the Forest Marble, which is traversed by three faults with slight downthrows to the east. The section immediately east of the tunnel is as follows:—

		Thickness in feet.
3.	Thinly-bedded limestone, false-bedded at the base	10
2.	Blue clay and shale, with a hard band near the top and a more persistent hard band near the base	20
1.	Hard limestone to base of section	10

The above section shows predominating limestones and subsidiary clays. The lowest beds some 200 yards to the east pass into shale; the limestone at the top also thins out eastward, and is replaced by shale.

The cutting which commences east of Alderton Tunnel extends almost continuously as far as Bradfield Farm, and affords a splendid section of the Forest Marble. This shows the usual great lateral variability and frequent false-bedding. Several small faults cut through the beds to the east of the Fosseway, but the beds as a rule show little disturbance. In the neighbourhood of the Fosseway and Furleaze Farm they are approximately horizontal; when, however, a point due south of the village of Norton has been reached, the dip is 10° south-eastward.

A general section of the Forest Marble here is as follows :—

	No.	CORNBRASH.	Thickness in feet.
FOREST MARBLE.	8.	Shale	20
	7.	Hard compact sandy limestone with doggers, alternating with irregular bands of loose sand, the sand predominating in the middle of the series	15
	6.	Shelly limestone	5
	5.	Compact oolitic shelly limestone, very variable	1 to 6
	4.	Shale	25
	3.	Hard, very shelly band (typical Forest Marble)	3
	2.	Shale	10
	1.	Limestone, sometimes sandy, sometimes oolitic	1 to 3

Band 3 in the above section, which is full of *Pecten vagans* and *P. lens*, is very prominent. Its westernmost outcrop is due south of Townleaze Barn.

At a point nearly half a mile west of Bradfield Farm, the Cornbrash is seen coming on above the Forest Marble, and an excellent section of it is exposed in the cutting as far as the farm, as well as in a road-cutting leading to Hullavington Station.

The cutting west of Bradfield Farm shows the following section of Cornbrash :—

		Thickness in feet.
3.	Thinly-bedded, reddish, flaggy limestone	4
2.	Loose yellowish clay	4
1.	Limestone, rubbly at the top but chiefly thin-bedded, compact, and shelly, with abundant *Ostrea Sowerbyi*	3
	FOREST MARBLE to base of section.	

Fossils are, as usual, very plentiful in the Cornbrash; we obtained :—

Echinobrissus clunicularis, Llwyd. (Very common.)
Pseudodiadema versipora, Ag.
Acrosalenia hemicidaroides, Wright.
A. spinosa. Ag.
Terebratula intermedia, Sow.
Waldheimia (Ornithella) obovata, Sow.
Rhynchonella concinna, Sow.
Avicula (Pseudomonotis) echinata, Sow. (Very common.)
Ostrea Sowerbyi, Lyc. (Very common.)
Modiola sp.

VI. THE OXFORD CLAY AND THE CORALLIAN.

The westernmost outcrop of the Middle Oolites is near Kingway Barn, whence they extend as far as the end of the line at Wootton Bassett, a distance of some 10 miles. By far the greater part of this distance is occupied by the Oxford Clay, the Corallian being seen only in Wootton Bassett station-yard. Unfortunately our examination of these beds was delayed till they were very much earthed-in and overgrown.

The Callovian is seen in a cutting which traverses the northern end of Bincombe Wood, between Rodbourne and Kingway Barn.

Mr. H. B. Woodward[1] notes that the beds seen here are all referable to the Kellaways division, and consist of 20 feet of clay with septaria, overlain by 10 to 20 feet of sandy and loamy beds. The only bed exposed at the time of our visit was a brown sandy clay, which yielded :—

Modiola bipartita, Sow.	*Ammonites (Proplanulites) Kœnigi*, Sow.
Trigonia sp. cf. *irregularis*, Seebach.	*Amm. (Stephanoceras) coronatus*, Brüg.
Ostrea aff. *Sowerbyi*, Lyc. (Abundant.)	
Belemnites obeliscus, Phil.	

We obtained also *Ammonites* (*Stephanoceras*) *gowerianus*, Sow. from a neighbouring embankment. *Amm.* (*Cardioceras*) *modiolaris*, Llwyd, we did not find, but numerous specimens of it and of *Amm. Kœnigi* were to be seen in the neighbouring railway works-office at Kingway Barn, and we were informed that they came from this cutting.

Farther east, for a distance of 4 miles, no other exposures were met with, the line consisting of a series of big embankments chiefly formed of Forest Marble brought from the long cuttings east of the tunnel. Immediately west of the road leading from Little to Great Somerford, brown unfossiliferous sand is exposed at several points. This is noted by Mr. Woodward (*loc. cit.*), and the sand is ascribed to the Callovian.

The next exposures occur in a cutting about $1\frac{1}{2}$ miles east of Somerford Station. The sides of the cutting were very much overgrown at the time of our visit, but in little drainage-trenches Lower Oxford Clay (*Ornatus*-Zone) of a very shaly type was exposed, containing :—

Avicula aff. *Münsteri*, Goldf.	*Ammonites (Cosmoceras) Jason*, Rhein.
Modiola (?)	*Amm. (C.) ornatus*, Schloth.
Cerithium (?)	*Amm. (C.) Elizabethæ*, Pratt.

Although there are other cuttings, we saw no more exposures until a point due south of Brinkworth Rectory was reached. Here, in a patch of clay still not earthed-in, we obtained :—

Gryphæa dilatata, Sow. (Very common.)	*B. obeliscus (?)* Phillips.
Avicula aff. *Münsteri*, Goldf.	*B. Oweni*, Pratt.
Isoarca (?)	*Ammonites (Quenstedtoceras) Lamberti*, Sow.
Belemnites hastatus, Blainv.	*Amm. (Q.) Mariæ*, d'Orb.
B. hastatus var. *gracilis*, Phillips.	*Amm. (Q.) Sutherlandi*, Sow.
B. sulcatus, Miller.	*Amm. (Cardioceras) cordatus*, Sow.

This assemblage of fossils shows that the beds are of Upper Oxford-Clay age. Further earthed-in cuttings extend as far as a point south of Callowhill Farm; and after that embankments begin, and extend as far as Wootton Bassett.

On the south side of the cutting, at the bridge for the road between Chippenham and Swindon, west of Wootton Bassett Station, there is a good section showing the Corallian with the underlying top of the Oxford Clay. The section is as follows :—

[1] Mem. Geol. Surv. 'Summary of Progress for 1898' p. 189.

			Thickness in feet.
Corallian.	4.	Clay, with hard bands not markedly pisolitic, the hard bands predominating at the top ....seen	20
	3.	Hard pisolite, with a thin irregular band of black clay sometimes pisolitic	4
	2.	Pisolitic clay	1
	1.	Stiff dark-blue Oxford Clay with *Thracia*, becoming more sandy above	9½

Cidaris florigemma and *Ostrea* sp. were common in all the beds above the Oxford Clay. *Thecosmilia annularis*, *Chemnitzia*, and *Belemnites abbreviatus* (Mil.) also occurred in the Corallian.

The beds near the bridge on both sides of the line have only a slight south-easterly dip, but a few yards to the east the dip is as much as 15°, the direction being south 15° east. There was not enough evidence to enable us to determine whether this was due to flexure, or to a fault which is shown here in the 1-inch Geological Survey map, but of whose presence we obtained no other evidence.

VII. Summary and Conclusions.

The following seem to us to be the most noteworthy points about the section that we have examined :—

(i) The thickness of the Lower Lias (about 200 feet to the top of the *Capricornus*-Zone) as compared with that in the districts farther south; and its remarkably shaly character, limestone being predominant only at the base.

(ii) The presence of the three zones of the Upper Lias in a thickness of about 10 feet, and the pyritous condition of the fossils in the *Bifrons*-Zone.

(iii) The great thickness of the Cotteswold Sands (185 feet), and the occurrence at several horizons of hard sandy beds containing *Ammonites striatulus*, as previously noted by Mr. S. S. Buckman.

(iv) The occurrence of four ammonite-zones (*fide* Mr. Buckman) in an exceptionally fossiliferous Cephalopod-Bed.

(v) The recognition of the Pea-Grit horizon in the Sodbury district.

(vi) The presence of an oolitic limestone of considerable thickness, containing fossils of Fullers'-Earth type, and forming a passage-bed between the Inferior Oolite and the Fullers' Earth.[1]

(vii) The occurrence of a thick series of sandy limestones at the top of the Fullers'-Earth Series, probably on the same horizon as the Stonesfield Slate.

(viii) The character of the upper beds of the Great Oolite, which consist of wedge-bedded oolitic limestones containing a series

[1] Somewhat similar passage-beds are described in Mem. Geol. Surv. 'Jurass. Rocks' vol. iv (1894) pp. 129 & 232.

of lenticular patches of clay and sand, with a fauna resembling that of the Bradford Clay.[1]

(ix) The great thickness and monotonous character of the Forest Marble.

(x) The characteristic development of the usual zones of the Oxford Clay.

Discussion.

The Rev. H. H. Winwood regretted that so many papers were crowded into one evening, necessarily restricting discussions often of great importance. However admirable an abstract might be, yet in the absence of the writers of the papers it was impossible adequately to appreciate their work. In the present instance he was debarred from asking several questions respecting the conclusions resulting from the careful work of the Authors on the railway-line cut through these most interesting Jurassic strata. He would, however, suggest that further evidence was required, than the finding of *Terebratula digona*, to establish the existence of Bradford Clay in the Acton-Turville section. He hoped that the term 'Cotteswold Sands' would give place to the old name 'Midford Sands'; and called attention to the fact that a large amount of water (owing to the sinking of Shaft No. 6 through the Oolites to the Lower Liassic Clays) now ran westward instead of eastward, suggesting that this might affect the head-sources of the Avon at no great distance, near Didmarton.

The Rev. J. F. Blake said that he could only comment on the paper from a general point of view, not having been able to visit the section; but this he was glad to do, as it was important to have on record this continuous section along a new line, by such competent observers, who appeared to have obtained ample data for the discussion of the sequence.

If the paper, as read, told of all the principal fossils obtained, it was remarkable how varying a development the lower part of the Jurassic Series showed from place to place. The fossils might occur in their right order, but it was impossible to contend that all the zones were distinguishable. Above the *Bucklandi*-Beds the series seemed incomplete, and the Middle Lias showed no *Spinatus*-Beds; and, what was more remarkable, there were no *Serpentinus*-Beds in the Upper Lias, which yielded only *Ammonites communis* and *Amm. bifrons*. Then, in the Inferior Oolite, there was only the lowest zone of *Amm. opalinus*.

With regard to the beds above the Inferior Oolite, it did not appear whether the so-called Great Oolite represented the true Oolite of Bath, or was only correlated with it; and the speaker felt that too little was known of the distinctive faunas of this part, to permit of the separation of a Bradford Clay and Forest Marble, except by position and lithology.

[1] This feature has been previously noted in the Minchinhampton district, Mem. Geol. Surv. 'Jurass. Rocks' vol. iv (1894) pp. 271–72, and in the Corsham district, *ibid.* p. 356.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LVIII.

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

Vol. LVIII. FEBRUARY 18th, 1902. **No. 229.**
PART 1.

THE

QUARTERLY JOURNAL

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1902.

Wednesday,	February (*Anniversary*, Feb. 21st) ...	26
,,	March	12–26
,,	April	16–30
,,	May	14–28
,,	June	11–25

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Vol. LVIII. Part 2. MAY 15th, 1902. **No. 230.**

C. A. White

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TO BE HELD AT BURLINGTON HOUSE.
Session 1902–1903.

1902.

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„ December 2–17

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CONTENTS.

PAPERS READ.

[No. 232 will be published next November. The List of Geological Literature added to the Society's Library during 1901 will be issued separately to the Fellows at an early date.]

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Vol. LVIII. NOVEMBER 29th, 1902. **No. 232.**
Part 4.

C. A. White

THE

QUARTERLY JOURNAL

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GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

[With Ten Plates, illustrating Papers by Mr. Thomas, Prof. Boyd Dawkins, Mr. Coomáraswámy, Prof. Bonney, and Prof. Garwood.]

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LONGMANS, GREEN, AND CO.

PARIS:—CHARLES KLINCKSIECK, 11 RUE DE LILLE.
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