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 SIXTIETH.

1904.

LONDON:

LONGMANS, GREEN, AND CO.

PARIS: CHARLES KLINCKSIECK, 11 RUE DE LILLE.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

MDCCCCIV.

# List

OF THE

## OFFICERS

OF THE

# GEOLOGICAL SOCIETY OF LONDON.

Elected February 19th, 1904.

### President.

John Edward Marr, Sc.D., F.R.S.

### Vice-Presidents.

Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Edwin Tulley Newton, Esq., F.R.S.
Horace Bolingbroke Woodward, Esq., F.R.S.

### Secretaries.

Robert Stansfield Herries, Esq., M.A.
Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.

### Foreign Secretary.

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

### Treasurer.

William Thomas Blanford, C.I.E., LL.D., F.R.S.

### COUNCIL.

The Rt. Hon. the Lord Avebury, P.C., D.C.L., LL.D., F.R.S., F.L.S.
Francis Arthur Bather, M.A., D.Sc.
William Thomas Blanford, C.I.E., LL.D., F.R.S.
Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S.
Prof. Edmund Johnstone Garwood, M.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Prof. Theodore Groom, M.A., D.Sc.
Alfred Harker, Esq., M.A., F.R.S.
Robert Stansfield Herries, Esq., M.A.
Prof. John W. Judd, C.B., LL.D., F.R.S.
Prof. Percy Fry Kendall.
Philip Lake, Esq., M.A.
Prof. Charles Lapworth, LL.D., F.R.S.
Bedford McNeill, Esq., Assoc.R.S.M.
John Edward Marr, Sc.D., F.R.S.
Prof. Henry Alexander Miers, M.A., F.R.S.
Horace Woollaston Monckton, Esq., F.L.S.
Edward Tulley Newton, Esq., F.R.S.
George Thurland Prior, Esq., M.A.
Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.
The Rev. Henry Hoyte Winwood, M.A.
Horace Bolingbroke Woodward, Esq., F.R.S.

---

### Assistant-Secretary, Clerk, Librarian, and Curator.

L. L. Belinfante, M.Sc.

### Assistants in Office, Library, and Museum.

W. Rupert Jones. Clyde H. Black.
Alec Field.

# TABLE OF CONTENTS.

PROCEEDINGS.

# LIST OF THE FOSSILS DESCRIBED AND FIGURED IN THIS VOLUME.

| Name of Species. | Formation. | Locality. | Page |
|---|---|---|---|
| | **Foraminifera.** | | |
| *Nummulites distans*, var. pl. xxv, figs. 5 & 6 | Eocene | Vernitza | 293–94 |
| —— *Dufrenoyi*, pl. xxv, figs. 1–4 | | | 292–93 |
| —— *Heberti (?)* | | | 294 |
| —— *variolaria (?)* | | | 294 |
| | **Madreporaria Aporosa.** | | |
| *Cladocora* cf. *articulata* | Middle Eocene | Gorgona Deré | 290 |
| *Trochocyathus*, sp. | | Vernitza | 290 |
| | **Madreporaria Fungida.** | | |
| *Cycloseris* cf. *Perezi*, pl. xxiv, figs. 26 & 27 | Middle Eocene | Vernitza | 290 |
| | **Arachnida.** | | |
| *Eoscorpius sparthensis*, sp. nov., figs. 2 & 3 | Middle Coal-Measures | Sparth Bottoms | 395–97 |
| | **Lamellibranchiata.** | | |
| *Anomia* sp., pl. xviii, fig. 1 | Rhætic | Sodbury | 201 |
| *Avicula contorta* | | | 202–203 |
| *Cardinia concinna* aff. *regularis*, text-fig. 4 & pl. xviii, fig. 4 | | | 204–205 |
| *Cardium cloacinum*, fig. 6 | | | 207–208 |
| —— *protractum*, pl. xxiv, fig. 19 | Miocene | Gherme Tepé | 282–83 |
| —— *rhæticum* | Rhætic | Sodbury | 208 |
| *Corbicula semistriata*, pl. xxiv, figs. 21–23 | Oligocene | Masatly | 287 |
| *Corbula*, sp. | | Keshan | 287–88 |

| Name of Species. | Formation. | Locality. | Page |
|---|---|---|---|
| | **Lamellibranchiata** (*continued*). | | |
| *Didacna crassa*, pl. xxiv, figs. 1 & 2 | Pliocene | Gallipoli | 280 |
| *Dreissensia polymorpha*, pl. xxiv, fig. 3 | Pliocene | Gallipoli | 280 |
| —— *rimestiensis*, pl. xxiv, figs. 7 & 8 | Miocene | Teke-keui | 281 |
| —— *Tschaudæ*, pl. xxiv, fig. 4 | Pliocene | Gallipoli | 280 |
| *Fimbria subpectunculus* | Middle Eocene | Tzenguerli Deré | 289–90 |
| *Mactra podolica*, pl. xxiv, figs. 16–18 | Miocene | Heraklitza, &c. | 282 |
| *Modiola sodburiensis*, sp. nov., pl. xviii, figs. 3 & 3 *a* | Rhætic | Sodbury | 203 |
| —— *minima* | Rhætic | Sodbury | 204 |
| *Pecten valoniensis*, pl. xviii, figs. 2 & 2 *a* | Rhætic | Sodbury | 202 |
| *Pleurophorus elongatus*, fig. 5 | Rhætic | Sodbury | 205–207 |
| *Plicatula cloacina*, sp. nov., text-fig. 3 & pl. xviii, fig. 5 | Rhætic | Sodbury | 202 |
| *Prosodacna* cf. *stenopleura*, pl. xxiv, figs. 9 & 10 | Miocene | Teke-keui | 281 |
| *Spondylus subspinosus*, pl. xxiv, figs. 24 & 25 | Middle Eocene | Tzenguerli Deré | 289 |
| *Unio Delesserti*, pl. xxiv, fig. 14 | Miocene | Potamina Deré | 283 |
| | **Gasteropoda.** | | |
| *Lyrcæa Bonelli*, pl. xxiv, figs. 5 & 6 | Miocene | Teke-keui | 281 |
| *Melania* cf. *Escheri*, pl. xxiv, fig. 11 | Miocene | Potamina Deré | 283 |
| *Melanopsis costata*, pl. xxiv, fig. 15 | Miocene | San Stefano | 283 |
| —— cf. *fusiformis* | Oligocene | Keshan | 286–87 |
| —— *incerta*, pl. xxiv, figs. 12 & 13 | Miocene | Potamina Deré | 284 |
| | **Ammonoidea.** | | |
| *Olcostephanus Pallasianus*, var. nov., fig. 3 & pl. xii | Kimeridge Clay | Chippinghurst | 60–61 |
| *Perisphinctes biplex*, pl. x | Kimeridge Clay | ? | 57–58 |
| —— *plicatilis*, fig. 1 & pl. ix | Upper Corallian | ? | 55–57 |
| —— *variocostatus*, fig. 2 & pl. xi | Ampthill Clay | Hawnes | 58–60 |
| | **Elasmobranchei.** | | |
| *Edestus minor*, fig. 1 | Coal-Measures | Indiana | 2 |
| —— *triserratus*, sp. nov., fig. 2 & pl. i | Coal-Measures | Nettlebank (Staffs.) | 3 *et seqq.* |
| *Ptychodus decurrens*, pl. xv & text-fig. | Lower Chalk | Glynde | 133–35 |

| Name of Species. | Formation. | Locality. | Page |
|---|---|---|---|
| | **Teleostei.** | | |
| *Diplomystus marmorensis*, sp. nov., pl. xxiv, fig. 28 ...... | Miocene ........ | Sarkeui ......... | 284–85 |
| | **Sauropterygia.** | | |
| *Plesiosaurus* cf. *bibractensis*... | White Lias .. | Westbury-on-Severn ...... | 359 |
| | **Ungulata.** | | |
| *Anthracotherium* cf. *minus*, pl. xxiv, fig. 20 .................. | Oligocene ...... | Masatly ......... | 286 |

# EXPLANATION OF THE PLATES.

## Erratum.

Plate XXXIII, *for* 'Glenmhaire' *read* 'Glen Mhairc.'

## PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES,

### BESIDES THOSE IN THE PLATES.

---

# PROCEEDINGS

OF THE

# GEOLOGICAL SOCIETY OF LONDON.

## SESSION 1903-1904.

November 4th, 1903.

Sir ARCHIBALD GEIKIE, D.C.L., D.Sc., F.R.S., Vice-President, in the Chair.

Lieut.-Col. George Lyon Tupman, F.R.A.S., Hillfoot Observatory, Harrow; and Richard Hansford Worth, Esq., Assoc.M.Inst.C.E., 4 Seaton Avenue, Plymouth, were elected Fellows of the Society.

The List of Donations to the Library was read.

The SECRETARY announced the presentation, by Sir John Evans, K.C.B., D.C.L., F.R.S., For.Sec.G.S., of a photogravure-portrait of himself.

The following communications were read :—

1. 'Metamorphism in the Loch-Lomond District.' By E. Hubert Cunningham-Craig, Esq., B.A., F.G.S.[1]

2. 'On a New Cave on the Eastern Side of Gibraltar.' By Henry Dyke Acland, Esq., F.G.S.

The following specimens, etc. were exhibited :—

Rock-Specimens, Microscope-Sections, and Lantern-Slides, exhibited by E. H. Cunningham-Craig, Esq., B.A., F.G.S., in illustration of his paper.

Specimens from the Cave at Monkey's Quarry, Gibraltar, and Photographs of the Cave, exhibited by H. D. Acland, Esq., F.G.S., in illustration of his paper.

[1] Communicated by permission of the Director of H.M. Geological Survey.

Specimens of 'Palæofractured' Flint from the excavations now in progress in the Mall, S.W., exhibited by the Rev. H. H. Winwood, M.A., F.G.S.

A Concretion from Vancouver Island (B. C.), exhibited by T. W. Reader, Esq., F.G.S.

Sheet 317 (Chichester) of the Geological-Survey colour-printed 1-inch Drift-Map, presented by the Director of that Survey.

Three Sheets of the $\frac{1}{75,000}$ Map of the Geological Survey of Austria-Hungary, presented by the Director of that Survey.

---

November 18th, 1903.

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

William Nobbs Harrop, Esq., Koh-i-Noor Mine, Kanowna (Western Australia), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Notes on Upper Jurassic Ammonites, with special reference to Specimens in the University Museum, Oxford: No. I.' By Miss Maud Healey. (Communicated by Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S., F.G.S.)

2. 'On the Occurrence of *Edestus* in the Coal-Measures of Britain.' By Edwin Tulley Newton, Esq., F.R.S., V.P.G.S.[1]

The following specimens and photographs were exhibited:—

Specimens of *Edestus Heinrichsii*, N. & W., from the Coal-Measures of Illinois, exhibited by Dr. A. Smith Woodward, F.R.S., F.L.S., F.G.S.; and a specimen of *Edestus triserratus*, sp. nov., from the Coal-Measures of Smallthorne (North Staffs), exhibited by the Director of H.M. Geological Survey, in illustration of the paper by E. T. Newton, Esq., F.R.S., V.P.G.S.

Photographs exhibited by Prof. W. J. Sollas, D.Sc., LL.D., F.R.S., F.G.S., in illustration of the paper by Miss Maud Healey.

Specimen of *Ammonites variocostatus* from the Corallian of Osmington, exhibited by the Rev. J. F. Blake, M.A., F.G.S.

---

[1] Communicated by permission of the Director of H.M. Geological Survey.

December 2nd, 1903.

Sir ARCHIBALD GEIKIE, D.C.L., D.Sc., Sec.R.S., Vice-President, in the Chair.

Paul Brühl, Esq., Professor of Physical Science, Civil-Engineering College, Sibpur, near Calcutta; Donald Fraser Campbell, Esq., 36 Oakley Crescent, Chelsea, S.W.; John Chadwick, Esq., C.E., Richmond House, Bletchley (Bucks); Maurice Deacon, Esq., Whittington House, Chesterfield; Henry Dewey, Esq., Clerk to the Geological Survey, Bembridge, Broomhouse Road, S.W.; J. A. Foote, Esq., P.O. Box 3203, Troyville, Johannesburg (Transvaal); Benjamin Atherton Hampson, Esq., Hampson's Buildings, Smith Street, Durban (Natal); William Taylor Heslop, Esq., Manager, St. George's Colliery, Halting Spruit (Natal); Henry Home, Esq., C.E., Biggleswade (Bedfordshire); Henry Kidner, Esq., 8 Derby Road, Watford; Hugh John Melliss, Esq., B.A., 30 Denning Road, Hampstead, N.W.; John Pollard, Esq., M.Inst.M.E., Hall Croft, Bradford Road, Wakefield; Robert Heron Rastall, Esq., B.A., Christ's College, Cambridge; Charles Howard Sidebotham, Esq., Assoc.R.S.M., 91 Manchester Road, Southport; George Howlett Tipper, Esq., B.A., Geological Survey of India, Calcutta; Charles Herbert Wilson, Esq., Mining Engineer, Port Darwin (Northern Territory of South Australia); and Offen Charles Witherden, Esq., Port Darwin (Northern Territory of South Australia) were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Notes on the Garnet-bearing and Associated Rocks of the Borrowdale Volcanic Series.' By the late Edward Eaton Walker, Esq., B.A., B.Sc. (Communicated by J. E. Marr, Esq., M.A., F.R.S., F.G.S.)

2. 'A Contribution to the Glacial Geology of Tasmania.' By Prof. J. Walter Gregory, D.Sc., F.R.S., F.G.S.

The following specimens, etc. were exhibited:—

Rock-specimens from the Borrowdale Volcanic Series, exhibited by J. E. Marr, Esq., M.A., F.R.S., F.G.S., in illustration of the paper by the late E. E. Walker, Esq., B.A., B.Sc.

Photographs of Northern Tasmania, exhibited by Prof. J. W. Gregory, D.Sc., F.R.S., F.G.S., in illustration of his paper.

Geological Survey of Egypt: Maps of the Surface-Deposits of Mersa Matru, and Ras Allen Rum, by J. Ball, on the scale of $\frac{1}{25,000}$, 1903, presented by the Director of that Survey.

December 16th, 1903.

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

Edward William Handcock, Esq., 32 Quarry Hill, Tonbridge; John Flesher Newsom, Ph.D., Associate-Professor of Geology & Mining in the Stanford University, California (U.S.A.); and Edward Payne, Esq., Royal Colonial Institute, Northumberland Avenue, W.C., were elected Fellows; and Prof. Anton Koch, of Budapest, and Prof. Albrecht Penck, of Vienna, were elected Foreign Members of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Igneous Rocks associated with the Carboniferous Limestone of the Bristol District.' By Prof. Conwy Lloyd Morgan, LL.D., F.R.S., F.G.S., & Prof. Sidney Hugh Reynolds, M.A., F.G.S.

2. 'A Description of some Rhætic Sections in the Bristol District, with Considerations on the Mode of Deposition of the Rhætic Series.'[1] By A. Rendle Short, Esq., B.Sc., M.B., B.S. (Communicated by Prof. S. H. Reynolds, M.A., F.G.S.)

The following specimens and maps were exhibited:—

Rock-Specimens, Microscope-Sections, Photographs and Lantern-Slides, exhibited by Prof. C. Lloyd Morgan, LL.D., F.R.S., F.G.S., & Prof. S. H. Reynolds, M.A., F.G.S., in illustration of their paper.

Specimens exhibited in illustration of the paper by A. Rendle Short, Esq., B.Sc., M.B., B.S.

Copies of three new colour-printed Geological-Survey maps:—New Series, Sheet 248, Pontypridd (Drift) by A. Strahan, etc.; and Sheet 263, Cardiff (Solid & Drift) by A. Strahan, etc., presented by the Director of that Survey.

---

January 6th, 1904.

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

Reginald Francis Duke, Esq., A.M.I.M.E., 'Banyana,' Littlehampton; William Norman-Bott, Ph.D., F.C.S., Royal Societies' Club, St. James's Street, S.W.; and Hugh Whittall, Esq., Mining Engineer, Constantinople, were elected Fellows of the Society.

[[1] Read under the title of 'The Rhætic Beds of England.']

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: G. T. Prior, Esq., M.A., and F. W. Rudler, Esq., I.S.O.

The List of Donations to the Library was read.

Mr. J. Lomas, in exhibiting a piece of faulted slate from the volcanic slates of Ulpha in Cumberland, said that the thin band showing faults was very limited. The movements being confined to this one strip, must be due to changes in the bed itself and have no relation to larger movements. On tracing the faults on one slab, cutting along the fractures, and reconstructing so that a well-defined band was continuous, it was found that a horizontal shrinkage of 1 in 6 had taken place. The faulting may be due to the cooling and shrinking of an ash deposited at a high temperature, or the closer packing of the particles as the mass settled down. Similar small faults may often be observed in Glacial sands ; and in this case they are obviously due to movements consequent on a closer packing of grains.

Mr. N. F. Robarts referred to the flint-implements which he exhibited, on which he invited criticism, as Plateau or Eolithic implements from the valley of the Wandle, some of which were obtained from the highest parts of the North Downs, in Surrey, at an altitude of 800 feet. The implement exhibited, which was of distinct Palæolithic type, was from Croydon. He also exhibited implements from the gravel at Mitcham, on behalf of Mr. A. J. Hogg.

Mr. Clinch remarked that, after a careful examination of the so-called 'implements' found in the gravel at Mitcham, he was unable to see upon them any traces of human handiwork or of wear arising from use by man. In his opinion they had been shaped entirely by natural forces. He was glad, however, to see on the table a typical Palæolithic implement, much rolled and drift-worn, which had been found at Thornton Heath.

Mr. A. M. Bell acknowledged the working on some eoliths exhibited, especially on one of the hollow scraper-forms, but saw no reason to think them of earlier age than the ochreous and worn Palæolithic implement which was also shown. Probably, in fact, that implement was older than any eolith exhibited—certainly it was much more rolled and altered than the majority of them.

The following communications were read:—

1. 'On a probable Palæolithic Floor at Prah Sands (Cornwall).' By Clement Reid, Esq., F.R.S., F.L.S., F.G.S. and Eleanor M. Reid, B.Sc.

2. 'Implementiferous Sections at Wolvercote (Oxfordshire).' By Alexander Montgomerie Bell, Esq., M.A., F.G.S.

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

Implements made of Vein-Quartz, from the Ancient Floor at Prah Sands (Cornwall), exhibited by Clement Reid, Esq., F.R.S., F.L.S., F.G.S., and Eleanor M. Reid, B.Sc., in illustration of their paper.

A series of Flint and Quartzite-Implements from Wolvercote (Oxfordshire), Limpsfield (Surrey), and other localities; Lantern-Slides of two sections at Wolvercote; and Microscopic Preparations of Plant-Remains from the River-Gravel, exhibited by A. M. Bell, Esq., M.A., F.G.S., in illustration of his paper.

Implements from the Narrows, Yadkin River, Montgomery Co., North Carolina (U.S.A.), exhibited by E. T. Newton, Esq., F.R.S., V.P.G.S.

Vegetable Remains in Flint from Sunningdale (Berkshire), exhibited by E. A. Martin, Esq., F.G.S.

---

January 20th, 1904.

Sir ARCHIBALD GEIKIE, D.C.L., D.Sc., Sec.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The SECRETARY announced that the Council had communicated the following resolution of sympathy to Mrs. Etheridge :—

'That the Council desire to place on record their great regret at the death of Mr. ROBERT ETHERIDGE, F.R.S., formerly President of this Society, who did so much during his long life to advance Geological Science and to promote the interests of the Society.'

The CHAIRMAN read the following letters for the first time, in accordance with Sect. XI, Art. 8 of the Bye-Laws :—

'January 20th, 1904.

'To the Secretary, Geological Society, Burlington House, W.

'SIR,

It is intended on the part of the Council to move :—

(1) That Bye-Laws, Sect. XII, Art. 3, and Sect. XII, Art. 4, 1° be repealed.

(2) That the following new Bye-Law be enacted, to be called Sect. IX, Art. 12 *a*, to come between Arts. 12 & 13 of Sect. IX: Persons not belonging to the Society, if introduced by Fellows or Foreign Members, may be present at General Meetings, subject to such regulations as the Council may make from time to time.

(3) That the following alteration be made in Bye-Laws, Sect. XIX, Art. 1: That the words "subject to such regulations as the Council may make from time to time" be added after the words "General Meetings of the Society" at the end of line 4.

Signed on the part of the Council,

ARCH. GEIKIE.'

'January 20th, 1904.

'To the Secretary, Geological Society, Burlington House, W.

'SIR,

It is intended on the part of the Council to move:—That Bye-Laws Sect. XIV, Art. 4, and Sect. XXI, Art. 6 be repealed.

Signed on the part of the Council,

ARCH. GEIKIE.'

The following communications were read:—

1. 'On the Jaws of *Ptychodus* from the Chalk.' By Arthur Smith Woodward, LL.D., F.R.S., F.L.S., F.G.S.

2. 'On the Igneous Rocks at Spring Cove, near Weston-super-Mare.' By William S. Boulton, Esq., B.Sc., A.R.C.S., F.G.S.

The following specimens were exhibited:—

Jaws of *Ptychodus decurrens*, Ag., from the Lower Chalk of Glynde (Coll. Henry Willett); a Photograph of the Dentition of *Ptychodus Mortoni*, Mantell, from the Upper Cretaceous of Kansas (U.S.A.), and Specimens of Recent Forms, exhibited by Dr. A. Smith Woodward, F.R.S., F.L.S., F.G.S., in illustration of his paper.

Specimens of Igneous Rocks from Spring Cove, near Weston-super-Mare, exhibited by W. S. Boulton, Esq., B.Sc., A.R.C.S., F.G.S., in illustration of his paper.

---

February 3rd, 1904.

Sir ARCHIBALD GEIKIE, D.C.L., D.Sc., Sec.R.S., Vice-President, in the Chair.

Edward C. Banbery, Esq., Summerville, West Bank Avenue, Lytham (Lancashire); William John Barnett, Esq., 35 Harley Street, Cavendish Square, W.; Henry John Wolverton Brennand, Esq., B.A., M.B., F.C.S., 203 Macquarie Street, Sydney (N.S.W.); Basil Elmsley Coke, Esq., 2nd Lieut. Royal Engineers, Elphinstone Barracks, Plymouth; George Walter Grabham, Esq., B.A., Geological Survey Office, 28 Jermyn Street, S.W.; Baird Halberstadt, Esq., Pottsville, Pennsylvania (U.S.A.); the Rev. Benjamin Oriel, B.Sc., 2 First Avenue, Oldfield Park, Bath; Robert Lionel Sherlock, Esq., B.Sc., Assoc.R.C.S., 136 Windleshaw Road, St. Helen's; and Andrew George Stenhouse, Esq., Whitelee, Newhaven Road, Leith, were elected Fellows of the Society.

The List of Donations to the Library was read.

The CHAIRMAN read, for the second time, in accordance with Sect. XI, Art. 8 of the Bye-Laws, the two letters addressed to the Secretary (pp. vi-vii); and notice was given of a Special General Meeting to be held on February 24th, at 7.30 P.M.

The following communications were read:—

1. 'On a Deep-Sea Deposit from an Artesian Boring at Kilacheri, near Madras.' By Prof. H. Narayana Rau, M.A., F.G.S.

2. 'The Rhætic Beds of the South-Wales Direct Line.' By Prof. Sidney Hugh Reynolds, M.A., F.G.S., & Arthur Vaughan, Esq., B.A., B.Sc., F.G.S.

The following specimens, etc. were exhibited:—

Microscope-Sections of Radiolarian Rock from Kilacheri, exhibited by Prof. H. Narayana Rau, M.A., F.G.S., in illustration of his paper.

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

## *ANNUAL GENERAL MEETING,*

February 19th, 1904.

Sir ARCHIBALD GEIKIE, Sc.D., D.C.L., Sec.R.S., Vice-President, in the Chair.

BEFORE commencing the business of the Meeting, the CHAIRMAN read the following letter, which had been addressed to him by the President:—

'February 9th, 1904.

'Dear Sir ARCHIBALD,

'Please kindly convey to the Council, the Officers, and the Fellows of the Geological Society my sincere regrets that I am not yet well enough to attend the Anniversary Meeting, and personally thank them for the honour which they paid me in making me their President, and for their unfailing goodness to me during my tenure of office.

'I shall also be grateful if you will congratulate on my behalf the new President and the Recipients of Medals and Awards; and assure the Fellows of my constant sympathy with, and faith in, the continued progress of the Society, and of my hope to be soon once more amongst them as a fellow-worker.

'Thanking Mr. TEALL and yourself for your great kindness in taking over my Presidential work for me during my illness, and so relieving me of all responsibility,

'I remain, dear Sir Archibald,
'Sincerely yours,
CHARLES LAPWORTH.'

'Sir ARCHIBALD GEIKIE, D.C.L., Sec.R.S.

It was unanimously resolved that a telegram should be sent from the Fellows in General Meeting assembled, thanking the President for his message and wishing him a speedy restoration to health.

### REPORT OF THE COUNCIL FOR 1903.

The Society continues to be in a generally-flourishing condition. The Number of Fellows has undergone but little change: during the past year 46 Fellows were elected (2 less than in 1902, and 6 less than in 1901), of whom 33 paid their Admission-Fees before the end of the year. Moreover, 16 Fellows, who had been elected in the previous year, paid their Admission-Fees in 1903, the total accession of new Fellows during the past twelve months amounting therefore to 49.

Deducting from this number a loss of 53 Fellows (30 by death, 13 by resignation, and 10 by removal from the List, under Bye-Laws, Sect. VI, Art. 5), it will be seen that there is a decrease in the Number of Fellows of 4 (as compared with an increase of 6 in 1902, and a decrease of 4 in 1901).

This brings the total number of Fellows down to 1254, made up as follows:—Compounders 287, Contributing Fellows 930 (exactly the same number as in 1902), and Non-Contributing Fellows 37.

Turning now to the Lists of Foreign Members and Foreign Correspondents, we have to deplore the loss of two of the former in 1903 (Prof. J. P. Lesley and Prof. A. Renard). One Foreign Correspondent also died (Herr F. Karrer). The vacancies thus created (and one in the List of Foreign Correspondents left over from 1902) were in part filled by the transfer of Prof. A. Penck and Prof. A. Koch from the list of Correspondents to that of Members, and by the election of Prof. C. Klein, and Dr. E. E. A. Tietze as Foreign Correspondents. But there still remained on December 31st, 1903, two vacancies in the list of Foreign Correspondents.

With regard to the Income and Expenditure of the Society during the past year, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—

The total Receipts, including the Balance of £61 7*s.* 8*d.* brought forward from the previous year, amounted to £3003 0*s.* 9*d.*, being £75 14*s.* 11*d.* less than the estimated Income.

The total Expenditure during 1903 amounted to £2810 13*s.* 10*d.*, being £206 14*s.* 2*d.* less than the estimated Expenditure for that year.

The Estimates laid before the Fellows at the last Annual General Meeting were exceeded chiefly in the case of the Library (£42 12*s.* 5*d.*). On the other hand, the Expenditure incurred in connexion with the Museum-Catalogue was £37 15*s.* 3*d.* less, and that incurred in connexion with the Quarterly Journal was £229 2*s.* 1*d.* less, than the estimated Expenditure.

During the past year the Council have had under consideration certain suggested alterations in the method of selecting Papers for Publication, and in the rules with regard to the admission of Visitors to General Meetings. The result of these deliberations will be laid before the Fellows at a Special General Meeting, to be summoned at an early date.

The Council have to announce the completion of Vol. LIX and the commencement of Vol. LX of the Society's Quarterly Journal.

Reference is made in the Report of the Library-and-Museum Committee to Mr. C. Davies Sherborn's manuscript Card-Catalogue of the Library. It is hoped that Fellows will make use of this Catalogue for finding references to literature on the subjects of their study. Mr. Sherborn has also undertaken to continue during the current year the preparation of the catalogue-slips for the International Catalogue of Scientific Literature.

Since Easter 1903, the state of health of the President has been such as to preclude him from coming to London, to guide the deliberations of the Council or to take the chair at the Evening Meetings. These duties were undertaken during three months of the past Session by Mr. Teall, and during so much of the present Session as has now elapsed, by Sir Archibald Geikie. The Council feel sure that the Fellows will join with them in the fervent hope that Prof. Lapworth may be speedily restored to health, and that he may soon be able again to take an active share in the proceedings of the Society.

The first Award from the Daniel-Pidgeon Fund was made, on May 27th, 1903, to Dr. Ernest Willington Skeats, who, having been engaged in the investigation of coral-reef deposits, proposed to visit the dolomite-districts of the Tyrol, and collect specimens for analysis and microscopic study, in continuation of his previous researches.

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

The Wollaston Medal is awarded to Prof. Albert Heim, For.Memb.G.S., in recognition of the value of his researches concerning the mineral structure of the Earth, and more especially of his contributions towards the elucidation of the structures of mountain-masses in general, and the Alps in particular.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Prof. George Alexander Louis Lebour, M.A., M.Sc., in recognition of the importance of his contributions to our knowledge of the Carboniferous rocks of the North of England.

The Lyell Medal, together with a sum of Twenty-Five Pounds from the Lyell Geological Fund, is awarded to Prof. Alfred Gabriel Nathorst, For.Memb.G.S., in recognition of his valuable work in investigating the floras of the various geological periods.

The Balance of the Proceeds of the Wollaston Donation-Fund is awarded to Miss Ethel Mary Reader Wood, M.Sc., as an acknowledgment of the value of her contributions to the study of the Graptolites and the rocks in which they occur, and to encourage her in further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Dr. Arthur Hutchinson, M.A., as an acknowledgment of the ability of his memoirs on mineralogical subjects, and to encourage him in further work.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Prof. Sidney Hugh Reynolds, M.A., in recognition of the value of his contributions to our knowledge of the Palæozoic rocks of Ireland, and the geology of the Bristol district and to encourage him in further work.

The other moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. Charles Alfred Matley, as an acknowledgment of the value of his work in elucidating the geology of the Island of Anglesey, and to encourage him in further researches.

A sum of Twenty Guineas from the Proceeds of the Barlow-Jameson Fund is awarded to Mr. Hugh John Llewellyn Beadnell, in recognition of his important memoirs on the topography and geology of the Oases and other districts of the Libyan Desert, and of his valuable collections of vertebrate remains in Egypt during the last three years, and to encourage him in further investigations.

## Report of the Library-and-Museum Committee for 1903.

The Additions made to the Library during the past twelve months have fully maintained, both in number and interest, the standard of former years.

During 1903 the Library received by donation 156 Volumes of separately-published Works, 301 Pamphlets and detached Parts of Works, 280 Volumes and 51 detached Parts of Serial Publications, and 18 Volumes of Newspapers. To these must be added 36 back Volumes of the American journal 'Science,' presented by Prof. Watts.

The total number of accessions to the Library by Donation is thus found to amount to 490 Volumes, 301 Pamphlets, and 51 detached Parts.

The number of Maps presented by various Donors is again very considerable. No less than 179 Sheets of Maps were received, 106 of which came from the Ordnance-Survey Department.

Although the task of selection from among the numerous donations mentioned in the foregoing paragraphs is not unattended with difficulty, your Committee may perhaps be allowed to direct special attention to the following:—Dr. Tempest Anderson's 'Volcanic Studies'; Mr. Mellard Reade's 'Evolution of Earth-Structure'; the 4th edition of Sir Archibald Geikie's 'Text-Book of Geology' (in two volumes); M. de Lapparent's 'Abrégé de Géologie'; M. P. H. Fritel's 'Paléontologie'; Prof. G. de Lorenzo's work on the great Pleistocene Lakes of Southern Italy; the first part of M. F. Delafond's work on the Coal-Measures and Permian of Blanzy and Le Creusot; the fourth part of Prof. Gosselet's Geology of the North of France; 'Outlines of the Geology of Japan' published by the Government of that Empire; the Geological Survey Memoirs on the Isle of Man, on North Arran and South Bute, on the Cheadle Coalfield, and on the country around Leicester, Reading, Salisbury, Chichester, Torquay, and Dublin; also the second volume of the 'Cretaceous Rocks of England.' Moreover, numerous publications were received from the Geological Survey and Mines Departments of Canada, Newfoundland, Nova Scotia, British Columbia, Natal, the Transvaal, the various States of the Australian Commonwealth, India, Egypt, the United States, Portugal, Austria-Hungary, Prussia, Sweden, and Russia; from the Imperial Department of Agriculture for the West Indies; and from the French Ministry of Public Works. A copy of the voluminous Report on the Asphalt-Industry of Trinidad was presented by the Colonial Office.

In addition to the Ordnance-Survey maps mentioned in a preceding paragraph, 8 Sheets of Maps were received from the Geological Survey of England and Wales; and 21 Sheets from the Geological Survey of Japan. Dr. Wheelton Hind and Mr. J. T. Stobbs presented a copy of their 'Chart of Fossil Shells found in connexion with the Seams of Coal and Ironstone of North Staffordshire.'

Sir John Evans presented a photogravure portrait of himself, and Col. F. T. N. Spratt-Bowring, R.E., presented a framed portrait of the late Admiral Spratt: these have been added to the Society's collection of Portraits of Eminent Geologists.

The preparation of a set of electrotype reproductions of the Medals in the gift of the Council was entrusted to Mr. Frank Bowcher, the designer of the Prestwich Medal, and these have now been framed and may be inspected at the Society's Apartments.

The Books, Maps, etc., enumerated above were the gift of 163 Personal Donors; 128 Government Departments and other Public Bodies; and 157 Societies and Editors of Periodicals.

The Purchases, made on the recommendation of the standing Library Committee, included 63 Volumes and 11 Parts of separately-published Works; 43 Volumes and 15 Parts of Works published serially; and 50 Sheets of Maps.

A set of the second series of photographs and the corresponding lantern-slides, issued by the Geological Photographs Committee of the British Association, was subscribed for, and is now deposited in the Library.

The total Expenditure in connexion with the Library during the past year was as follows:—

| | £ | *s.* | *d.* |
|---|---|---|---|
| Books, Periodicals, etc. purchased.......... | 75 | 13 | 7 |
| Binding of Books and Mounting of Maps.... | 166 | 18 | 10 |
| Total | £242 | 12 | 5 |

or £42 12*s.* 5*d.* more than the sum set apart for these purposes in the Estimates. This excess is largely due to the necessity of overtaking certain arrears of binding which had accumulated during recent years.

The rearrangement of the Library authorized by the Council has been in progress during the year, and excellent work has been done by the Assistant-Clerk (Mr. Black) and the Junior Assistant (Alec Field). The Assistant-Librarian (Mr. W. R. Jones), in the meantime, has been engaged in making a current Card-Catalogue and in preparing the Map-Catalogue and the Record of Geological Literature. Much, however, remains to be done before the arrangement of the books and the binding can be considered as brought thoroughly up to date. In this matter there is every reason to believe that good progress will continue to be made in the current year.

Mr. C. Davies Sherborn supplies the following details with regard to the progress of the new Card-Catalogue of the whole Library, upon which he is engaged:—

'The 1880 Catalogue has been mounted, cross-referenced, and arranged in cabinets up to "Humboldt"; and all "Serials," "Academies," "Surveys," "Reports," etc. included therein have been also roughly sorted into cabinets. This statement applies also to the "Additions made to the Library" from 1880 to 1888. It will be impossible to press-mark the cards until further progress is made; but the subject- and locality-cards should already be of considerable utility, as, for example, "Caves," "Vesuvius," "Gold," etc.'

## Museum.

Messrs. J. F. Walker & G. W. Lamplugh presented a series of Fossil Brachiopoda from the fossiliferous band at the top of the Lower Greensand at Shenley Hill, near Leighton Buzzard, figured in Plates XVI–XVIII, Quart. Journ. Geol. Soc. Vol. LIX (1903), which illustrate the paper dealing with the above-mentioned stratum.

A specimen of the Volcanic Ash which fell in Barbados, as a result of the eruption of the St. Vincent Soufrière, on March 22nd, 1903, was presented by Sir Daniel Morris, K.C.M.G., Imperial Commissioner of Agriculture for the West Indies.

For the purpose of study and comparison the Collections were visited on 34 occasions during the year, the contents of about 63 drawers (from 43 cabinets) being thus examined. Moreover, the permission of the Council having been duly obtained, about 122 specimens were lent to various investigators.

No expenditure, beyond that involved in the publication of the Museum-Catalogue, was incurred in connexion with the Museum during the year 1903.

---

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

### I. Government Departments and other Public Bodies.

American Museum of Natural History. New York.
Athens.—Observatoire National d'Athènes.
Australian Museum. Sydney (New South Wales).
Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.
——. Kaiserlich-Königliches Naturhistorisches Hofmuseum. Vienna.
Bavaria.—Königliches 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.
——. Naturwissenschaftliche Landesdurchforschung. Prague.
British Columbia.—Department of Mines, Victoria (B.C.).
—— ——. Bureau of Provincial Information, Victoria (B.C.).
British Guiana.—Department of Mines. Georgetown.
British South Africa Company. London.
California University. Berkeley (Cal.).
Cambridge (Mass.).—Museum of Comparative Zoology, Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
——, High Commissioner for. London.
Cape Colony.—Department of Agriculture: Geological Commission. Cape Town.
Chicago, University of.
——. 'Field' Columbian Museum.
Christiania, University of.
Denmark.—Danmarks Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dijon.—Académie des Sciences, des Arts & des Belles Lettres.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works: 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 an der Saale.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. India Office. London.
——. Ordnance Survey. Southampton.
Holland.—Departement van Kolonien. The Hague.
Hull.—Municipal Museum.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
India.—Geological Survey. Calcutta.
——. Surveyor General's Office. Calcutta.
Iowa Geological Survey. Des Moines (Iowa).
Ireland.—Department of Agriculture & Technical Instruction. Dublin.
Italy.—Reale Comitato Geologico. Rome.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Jassy, University of.
Kansas.—University Geological Survey. Lawrence (Kan.
Kingston (Canada).—Queen's College.
London.—City of London College.
——. Patent-Office Library.
——. Royal College of Surgeons.
——. University College.
Maryland Geological Survey. Baltimore (Md.).
Metz.—Académie des Lettres, Sciences, Arts & Agriculture.
Mexico.—Instituto Geologico. Mexico City.
Michigan College of Mines. Houghton (Mich.).
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Montana University. Missoula (Mont.).
Munich.—Königliche Bayerische Akademie der Wissenschaften.
Mysore Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
Natal.—Department of Mines. Pietermaritzburg.
Nebraska.—Geological Survey. Lincoln (Neb.).
Newfoundland.—Geological Survey. St. John's (N.F.).
New Jersey Geological Survey. Trenton (N.J.).
New South Wales, Agent-General for. London.
——. Department of Lands. Sydney.
——. Department of Mines & Agriculture. Sydney.

New South Wales.—Geological Survey. Sydney.
New York Museum. Albany (N.Y.).
New Zealand.—Department of Mines. Wellington.
Norway.—Geologiske Undersögelse. Christiania.
Nova Scotia, Agent-General for. London.
——. Department of Mines. Halifax (N.S.).
Padua.—Reale Accademia di Scienze, Lettere & Arti.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Peru.—Ministerio de Fomento. Lima.
Pisa, Royal University of.
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.
Rhodesian Museum. Bulawayo.
Rome.—Reale Accademia dei Lincei.
Russia.—Comité Géologique. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
South Australia, Agent-General for. London.
——. Geological Survey. Adelaide.
——. School of Mines & Industries. Adelaide.
South Wales & Monmouthshire, University College of. Cardiff.
Spain.—Comision del Mapa Geológico. Madrid.
St. Petersburg.—Académie Impériale des Sciences.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tokio, Imperial University of.
——. College of Science.
Toronto, University of.
Transvaal Mines Department. Pretoria.
Turin.—Reale Accademia delle Scienze.
United States Geological Survey. Washington (D.C.).
——. Department of Agriculture. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, University of.
——. Mineralogical & Geological Institute.
Victoria (Austral.), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington, State of (U.S.A.).—Geological Survey. Tacoma (Wash.).
—— (D.C.).—Smithsonian Institute.
West Indies, Imperial Agricultural Department for the. Bridgetown (Barbados).
Western Australia, Agent-General for. London.
——. Department of Lands. Perth (W.A.).
——. Department of Mines. Perth (W.A.).
——. Geological Survey. Perth (W.A.).
——. Victoria Public Library. Perth (W.A.).
Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).

## II. Societies and Editors.

Adelaide.—Royal Society of South Australia.
Alnwick.—Berwickshire Naturalists' Club.
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.
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. 'Zeitschrift für Praktische Geologie.'
Berne.—Schweizerische Naturforschende Gesellschaft.
Bordeaux.—Société Linnéenne.
Boston (Mass.) Society of Natural History.
Boston (Mass.).—American Academy of Arts & Sciences.
Brooklyn (N.Y.) Institute 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.
Buenos Aires.—Instituto Geografico Argentino.
——. Sociedad Científica Argentina.
Buffalo (N.Y.) Society of Natural Sciences.
Caen.—Société Linnéenne de Normandie.
Calcutta.—'Indian Engineering.'
——. Asiatic Society of Bengal.
Cambridge.—Philosophical Society.
Cape Town.—South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chicago.—'Journal of Geology.'
Christiania.—'Nyt Magazin for Naturvidenskaberne.'
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 Society.
Darmstadt.—Verein für Erdkunde.
Douglas.—Isle-of-Man Natural History & Antiquarian Society.
Dresden.—Naturwissenschaftliche Gesellschaft.
——. Verein für Erdkunde.
Edinburgh.—Royal Physical Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Falmouth.—Royal Cornwall Polytechnic Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Geneva.—Société Physique & d'Histoire Naturelle.
Genoa.—Giornale di Geologia pratica.
Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Gloucester.—Cotteswold Naturalists' Field-Club.
Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.
Halifax (N.S.).—Nova Scotian Institute of Science.
Helsingfors.—Geografiska Förening i Finland.
——. Meddelanden från Industristyrelsen i Finland.
Hereford.—Woolhope Naturalists' Field-Club.
Hertford.—Hertfordshire Natural History Society.
Hobart.—Royal Society of Tasmania.
Hull Scientific & Field-Naturalists' Club.
Kiev.—Société des Naturalistes.
Lausanne.—Société Vaudoise des Sciences Naturelles.
Lawrence.—'Kansas University Bulletin.'
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.'
——. Sociedad geografica.
Lisbon.—Sociedade de Geographia.
Liverpool Geological Society.
——. Literary & Philosophical Society.

London.—'The Academy.'
——. 'The Athenæum.'
——. British Association for the Advancement of Science.
——. British Association of Waterworks Engineers.
——. 'The Chemical News.'
——. Chemical Society.
——. 'The Colliery Guardian.'
——. East India Association.
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining & Metallurgy.
——. Iron & Steel Institute.
——. 'The Iron & Steel Trades' Journal.'
——. 'Knowledge.'
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'Nature.'
——. Palæontographical Society.
——. 'The Quarry.'
——. Royal Agricultural 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.
——. 'The South-Eastern Naturalist' (S.E. Union of Scientific Societies).
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester Geological Society.
——. Literary & Philosophical Society.
Melbourne.—Australasian Institute of Mining Engineers.
——. Royal Society of Victoria.
Mexico.—Sociedad Científica 'Antonio Alzate.'
Moscow.—Société Impériale des Naturalistes.
New Haven (Conn.).—'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'
Newcastle-upon-Tyne.—Institution of Mining Engineers.
——. North-of-England Institute of Mining & Mechanical Engineers.
Northampton.—Northamptonshire Natural History Society.
Ottawa.—Royal Society of Canada.
Paris.—Commission Française des Glaciers.
——. Société Française de Minéralogie.
——. Société Géologique de France.
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Mineria.
——. Société Scientifique du Chili.
Scranton (Pa.).—'Mines & Minerals.'
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
——. Société Impériale des Naturalistes.
Stockholm.—Geologiska Förening.

Stuttgart.—'Centralblatt für Mineralogie, Geologie & Paläontologie.'
——. 'Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.'
——. Oberrheinischer Geologischer Verein.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. 'Zeitschrift für Naturwissenschaften.'
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Vienna.—'Berg- & Hüttenmännisches Jahrbuch.'
——. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Biological Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
York.—Yorkshire Philosophical Society.

## III. Personal Donors.

Adams, F. D.
Ameghino, F.
Ami, H. M.
Anderson, T.
Arber, E. A. N.
Arçtowski, H.

Barré, O.
Bascom, F.
Beecher, C. E. (the late).
Bistram, A. von.
Blake, the Rev. J. F.
Blake, W. P.
Blanckenhorn, M.
Bonney, T. G.
Borredon, G.
Bourcart, E.
Brown, H. Y. L.
Brown, J. A. (the late).
Bullen, the Rev. R. A.
Bush, L. P.

Cadell, H. M.
Carez, L.
Cayeux, L.
Chapman, F.
Choffat, P.
Clark, J. E.
Cole, G. A. J.
Collins, J. H.
Coomáraswámy, A. K.
Cordovey, M.
Credner, H.
Cumings, E. R.

Dall, W. H.
Davis, W. M.
Dervis, V.
Dewalque, G.
Dollfus, G. F.
Duparc, L.

Eaton, G. F.
Emmons, S. F.
Evans, Sir John.

Fouqué, F. (the late).
Fox, H.
Fritel, P. H.
Fritsch, A.

Garwood, E. J.
Gaudry, A.
Geikie, Sir Archibald.
Gilpin, E., jun.
Gordon, M. M. O.
Gosselet, J.
Grayson, H. J.
Guppy, R. J. L.

Hamilton, A.
Hamling, J. G.
Hargreaves, T. S.
Harmer, F. W.
Hatch, F. H.
Hawell, the Rev. J.
Herz, O.
Hill, the Rev. E.
Hind, W.
Hoek, H.
Holland, T. H.
Holmes, T. V.
Hopkinson, J.
Hovey, E. O.
Howley, J. P.
Hudleston, W. H.
Hull, E.
Hutton, F. W.

Issel, A.

Jentzsch, A.
Jones, T. R.
Jordan, H. K.

Kalecsinski, A. von.
Kewitsch, —.
Kirsopp, J., jun.
Koch, A.
Kœnen, A. von.
Kříž, M.

Lacroix, A.
Lambe, L. M.
Lambert, J.
Lamplugh, G. W.
Lapparent, A. de.
Lebour, G. A.
Liebisch, Th.
Lobley, J. L.
Lomas, J.
Longe, F. D.
Lorenzo, G. de.
Louis, D. A.
Lupsa, I. F.
Lyman, B. S.

Manck, A. V.
Manson, M.
Marbut, C. F.
Marr, J. E.
Meli, R.
Mennell, F. P.
Meunier, St.
Mojsisovics, E. von.
Monckton, H. W.
Morris, Sir Daniel.
Mourlon, M.
Mrazec, L.
Müller, E. C.

Nares, Sir George.
Newton, E. T.
Newton, R. B.

Pachundaki, D. E.
Packard, A. S.
Parkinson, H.
Parkinson, J.
Pauw, L. F. de.
Pearce, F.
Perner, J.
Prinz, W.

Reade, T. M.
Renevier, E.
Richthofen, Baron F. von.

Rigaux, E.
Rowe, A. W.

Sacco, F.
Sauvage, H. E.
Sawyer, A. R.
Schardt, H.
Schopp, H.
Seward, A. C.
Shaw, F. G.
Sheppard, T.
Sherborn, C. D.
Shoolbred, J. N.
Skeats, E. W.
Small, E. W.
Somervail, A.
Spratt-Bowring, F. T. N.
Steinmann, G.
Stephens, T.
Stobbs, J. T.
Stromeyer, C. E.

Talbot, M.
Thomson, A. G. M.
Thompson, B.
Thoulet, J.
Thresh, J. C.
Toula, F.
Traquair, R. H.
Twelvetrees, W. H.

Uhlig, V.

Vaughan, A.
Vidal, L. M.

Walker, J. F.
Watts, W. W.
Whitaker, W.
Willis, B.
Wiltshire, E. W.
Woodward, A. S.
Woodward, H.
Woodward, H. B.
Worth, R. H.

Zeiller, R.

## Comparative Statement of the Number of the Society at the Close of the Years 1902 and 1903.

| | Dec. 31st, 1902. | | Dec. 31st, 1903. |
|---|---|---|---|
| Compounders | 289 | ...... | 287 |
| Contributing Fellows | 930 | ...... | 930 |
| Non-contributing Fellows | 39 | ...... | 37 |
| | 1258 | | 1254 |
| Foreign Members | 40 | ...... | 40 |
| Foreign Correspondents | 39 | ...... | 38 |
| | 1337 | | 1332 |

*Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1902 and 1903.*

| | | | |
|---|---|---|---|
| Number of Compounders, Contributing and Non-contributing Fellows, December 31st, 1902 | | | 1258 |
| *Add* Fellows elected during the former year and paid in 1903 | | | 16 |
| *Add* Fellows elected and paid in 1903 | | | 33 |
| | | | 1307 |
| *Deduct* Compounders deceased | | 7 | |
| Contributing Fellows deceased | | 21 | |
| Non-contributing Fellows deceased | | 2 | |
| Contributing Fellows resigned | | 13 | |
| Contributing Fellows removed | | 10 | |
| | | — | 53 |
| | | | 1254 |
| Number of Foreign Members and Foreign Correspondents, December 31st, 1902 | | 79 | |
| *Deduct* Foreign Members deceased | 2 | | |
| Foreign Correspondents deceased | 1 | | |
| Foreign Correspondents elected Foreign Members | 2 | | |
| | — | 5 | |
| | | 74 | |
| *Add* Foreign Members elected | 2 | | |
| Foreign Correspondents elected | 2 | | |
| | — | 4 | |
| | | — | 78 |
| | | | 1332 |

## Deceased Fellows.

*Compounders* (7).

Bell, M., Esq.
Corfield, Prof. W. H.
Gatty, Dr. C. H.
Hutchinson, Maj.-Gen. A. H.
Justen, F. W., Esq.
Mason, J., Esq.
Vicary, W., Esq.

*Resident and other Contributing Fellows* (21).

Aveline, W. T., Esq.
Barnes, J. H., Esq.
Brown, J. A., Esq.
Carter, J., Esq.
Close, the Rev. M. H.
Collins, A. L., Esq.
Crick, W. D., Esq.
Etheridge, R., Esq.
Exton, Dr. H.
Griffith, N. R., Esq.
Haughton, T. J., Esq.
Jennings, A. V., Esq.
Mellors, P., Esq.
Nicholson, Sir Charles.
Percy, C. M., Esq.
Pirbright, Lord.
Poppleton, R. D., Esq.
Powell, J. H., Esq.
Thomas, W., Esq.
Ward, T., Esq.
Winbolt, J. S., Esq.

*Non-contributing Fellows* (2).

Gavey, G. E., Esq.
Whinfield, E. W., Esq.

## Deceased Foreign Members (2).

Lesley, Prof. J. P.
Renard, Prof. A.

## Deceased Foreign Correspondent (1).

Karrer, Herr F.

---

## Fellows Resigned (13).

Bates, T. L., Esq.
Edwards, W. B. D., Esq.
Goss, H., Esq.
Hay, R., Esq.
Leach, R. E., Esq.
Lewis, G., Esq.
Parker, H., Esq.
Parkinson, James, Esq.
Percival, Dr. G.
Pilling, the Rev. S.
Platnauer, H. M., Esq.
Pruen, J. A., Esq.
Solly, R. H., Esq.

---

## Fellows Removed (10).

Bainbridge, C. E., Esq.
Bilgrami, Syed Ali.
Burr, W. T. G., Esq.
Cheadle, W. W., Esq.
Davies, H., Esq.
Derasari, D. P., Esq.
Maclean, H., Esq.
Smith, W. H., Esq.
Streeten, F. E., Esq.
Waterman, W. J., Esq.

---

*The following Personages were elected Foreign Members during the year 1903:—*

Prof. Albrecht Penck, of Vienna.
Prof. Anton Koch, of Budapest.

*The following Personages were elected Foreign Correspondents during the year 1903:—*

Prof. Carl Klein, of Berlin.
Dr. Emil Ernst August Tietze, 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 Prof. Charles Lapworth, retiring from the office of President.

That the thanks of the Society be given to Prof. H. A. Miers and Mr. J. J. H. Teall, retiring from the office of Vice-President.

That the thanks of the Society be given to Dr. R. Logan Jack, Lieut.-Gen. C. A. McMahon, Prof. H. G. Seeley, Prof. W. J. Sollas, and Mr. J. J. H. Teall, retiring from the Council.

That the thanks of the Society be given to Mr. J. J. H. Teall and Sir Archibald Geikie, Vice-Presidents, for having successively fulfilled the duties of the President during his long illness.

---

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.—1904.

### *PRESIDENT.*

John Edward Marr, Sc.D., F.R.S.

### *VICE-PRESIDENTS.*

Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Edwin Tulley Newton, Esq., F.R.S.
Horace Bolingbroke Woodward, Esq., F.R.S.

### *SECRETARIES.*

Robert Stansfield Herries, Esq., M.A.
Prof. William Whitehead Watts, M.A., M.Sc.

### *FOREIGN SECRETARY.*

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

### *TREASURER.*

William Thomas Blanford, C.I.E., LL.D., F.R.S.

---

### *COUNCIL.*

The Rt. Hon. the Lord Avebury, P.C., D.C.L., LL.D., F.R.S., F.L.S.
Francis Arthur Bather, M.A., D.Sc.
William Thomas Blanford, C.I.E., LL.D., F.R.S.
Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S.
Prof. Edmund Johnstone Garwood, M.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Prof. Theodore Thomas Groom, M.A., D.Sc.
Alfred Harker, Esq., M.A., F.R.S.
Robert Stansfield Herries, Esq., M.A.
Prof. John Wesley Judd, C.B., D.Sc., LL.D., F.R.S.
Percy Fry Kendall, Esq.
Philip Lake, Esq., M.A.
Prof. Charles Lapworth, LL.D., F.R.S.
Bedford McNeill, Esq., Assoc.R.S.M.
John Edward Marr, Sc.D., F.R.S.
Prof. Henry Alexander Miers, M.A., F.R.S.
Horace Woollaston Monckton, Esq., F.L.S.
Edwin Tulley Newton, Esq., F.R.S.
George Thurland Prior, Esq., M.A.
Prof. William Whitehead Watts, M.A., M.Sc.
The Rev. Henry Hoyte Winwood, M.A.
Horace Bolingbroke Woodward, Esq., F.R.S.

# LIST OF

# THE FOREIGN MEMBERS

## OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1903.

| Date of Election. | |
|---|---|
| 1874. | Prof. Albert Jean Gaudry, *Paris.* |
| 1877. | Prof. Eduard Suess, *Vienna.* |
| 1880. | Prof. Gustave Dewalque, *Liége.* |
| 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.*). (*Deceased.*) |
| 1888. | Prof. Eugène Renevier, *Lausanne.* |
| 1888. | Baron Ferdinand von Richthofen, *Berlin.* |
| 1889. | Prof. Ferdinand A. Fouqué, *Paris.* (*Deceased.*) |
| 1889. | Geheimrath Prof. Karl Alfred von Zittel, *Munich.* (*Deceased.*) |
| 1890. | Geheimrath Prof. Heinrich Rosenbusch, *Heidelberg.* |
| 1891. | Prof. Charles Barrois, *Lille.* |
| 1893. | Prof. Waldemar Christofer Brœgger, *Christiania.* |
| 1893. | M. Auguste Michel-Lévy, *Paris.* |
| 1893. | Dr. Edmund Mojsisovics von Mojsvár, *Vienna.* |
| 1893. | Prof. 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.* (*Deceased.*) |
| 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 Tœrnquist, *Lund.* |
| 1901. | Dr. Alexander Petrovich Karpinsky, *St. Petersburg.* |
| 1901. | Prof. Alfred Lacroix, *Paris.* |
| 1903. | Prof. Albrecht Penck, *Vienna.* |
| 1903. | Prof. Anton Koch, *Budapest.* |

## LIST OF

# THE FOREIGN CORRESPONDENTS

## OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1903.

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.* (*Deceased.*)
1890. Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Kiel.*
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, Geneva.*
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.*
1896. Prof. S. L. Penfield, *New Haven, Conn.* (*U.S.A.*).
1896. Prof. Johannes Walther, *Jena.*
1897. M. Louis Dollo, *Brussels.*
1897. M. Emmanuel de Margerie, *Paris.*
1897. Prof. Count H. zu Solms-Laubach, *Strasburg.*
1898. Dr. 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.*). (*Deceased.*)
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Göttingen.*
1899. Prof. Franz Lœwinson-Lessing, *St. Petersburg.*
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.*
1902. Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1902. Prof. Samuel Wendell Williston, *Chicago, Ill.* (*U.S.A.*).
1903. Prof. Carl Klein, *Berlin.*
1903. Dr. Emil Ernst August Tietze, *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. The Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. The Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. The Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Prof. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. Henry C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. Thomas H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Studer.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. William Thomas Blanford.
1884. Prof. Albert Jean Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Des Cloizeaux.
1887. Mr. John Whitaker Hulke.
1888. Mr. Henry B. Medlicott.
1889. Prof. Thomas George Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John Wesley Judd.
1892. Baron Ferdinand von Richthofen.
1893. Prof. Nevil Story Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie.
1896. Prof. Eduard Suess.
1897. Mr. Wilfrid H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Prof. Grove Karl Gilbert.
1901. Prof. Charles Barrois.
1902. Dr. Friedrich Schmidt.
1903. Prof. Heinrich Rosenbusch.
1904. Prof. Albert Heim.

# 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 Wesley Judd.
1874. Dr. Henri Nyst.
1875. Prof. L. C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. Robert Etheridge, Jun.
1878. Prof. William Johnson Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay Heatley Traquair.
1882. Dr. George Jennings Hinde.
1883. Prof. John Milne.
1884. Mr. Edwin Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Mr. Benjamin Neeve Peach.
1888. Dr. John Horne.
1889. Dr. Arthur Smith Woodward.
1890. Mr. William A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville Adelbert Derby.
1893. Mr. John George Goodchild.
1894. Mr. Aubrey Strahan.
1895. Prof. William W. Watts.
1896. Mr. Alfred Harker.
1897. Dr. Francis Arthur Bather.
1898. Prof. Edmund J. Garwood.
1899. Prof. John B. Harrison.
1900. Mr. George Thurland Prior.
1901. Mr. Arthur Walton Rowe.
1902. Mr. Leonard James Spencer.
1903. Mr. L. L. Belinfante.
1904. Miss Ethel M. R. Wood.

# AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

## 'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1873. Mr. William Davies.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. The Rev. W. B. Clarke.
1878. Prof. Hanns Bruno Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. The Rev. Peter B. Brodie.
1888 Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. Waldemar C. Brögger.
1892. Prof. A. H. Green.
1893. The Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustaf Lindstrœm.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. { Mr. Benjamin N. Peach. / Dr. John Horne. }
1900. Baron A. E. Nordenskiœld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.
1903. Dr. Charles Callaway.
1904. Prof. George A. Lebour.

# 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. Govier Seeley.
1876. Dr. James Croll.
1877. The Rev. John F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James Walker Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. Thomas Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Mr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward B. Wethered.
1891. The Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. Griffith J. Williams.
1894. Mr. George Barrow.
1895. Mr. Albert Charles Seward.
1896. Mr. Philip Lake.
1897. Mr. Sydney S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Mr. Thomas H. Holland.
1903. Mrs. Elizabeth Gray.
1904. Dr. Arthur Hutchinson.

# AWARD OF THE PROCEEDS

OF THE

## 'DANIEL-PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

## DANIEL PIDGEON, F.G.S.

'The annual interest to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1903. Dr. Ernest Willington Skeats.

# 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. Govier Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. Henry A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. Thomas Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. Edwin Tulley Newton.
1894. Prof. John Milne.
1895. The Rev. John F. Blake.
1896. Dr. Arthur Smith Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Dr. John Edward Marr.
1901. Dr. Ramsay Heatley Traquair.
1902. { Prof. Anton Fritsch.
Mr. Richard Lydekker.
1903. Mr. Frederick William Rudler.
1904. Prof. Alfred G. Nathorst.

# AWARDS

OF THE

## BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. Henry A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. The Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. Alfred J. Jukes-Browne.
1886. Mr. David Mackintosh.
1887. The Rev. Osmond Fisher.
1888. Dr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. M. Louis Dollo.
1890. Mr. Charles 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.
1903. Mr. Sydney S. Buckman.
1903. Mr. George Edward Dibley.
1904. Dr. Charles Alfred Matley.
1904. Prof. Sidney Hugh Reynolds.

# AWARD OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

## SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three (or every six) years in providing a Gold Medal . . . to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology.'

1903. John Lubbock, Baron Avebury.

## 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 Charles Marsh.
1879. Prof. Edward Drinker 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 Johnson Sollas.
1895. Mr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. E. David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.

## 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. William M. Hutching
1904. Mr. Hugh J. Ll. Beadnell.

*Estimates for*

INCOME EXPECTED.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Compositions | | | | 134 | 0 | 0 |
| Due for Arrears of Admission-Fees | 75 | 12 | 0 | | | |
| Admission-Fees, 1904 | 200 | 0 | 0 | | | |
| | | | | 275 | 12 | 0 |
| Arrears of Annual Contributions | 150 | 0 | 0 | | | |
| Annual Contributions, 1904, from Resident and Non-Resident Fellows | 1770 | 0 | 0 | | | |
| Annual Contributions in advance | 50 | 0 | 0 | | | |
| | | | | 1970 | 0 | 0 |
| Sale of Quarterly Journal, including Longmans' Account | | | | 150 | 0 | 0 |
| Sale of Transactions, General Index, Library-Catalogue, Museum-Catalogue, Hutton's 'Theory of the Earth' vol. iii, Hochstetter's 'New Zealand,' and List of Fellows | | | | 5 | 10 | 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 |
| Returned Income-Tax, from April 1901 to April 1903 | | | | 41 | 0 | 0 |
| | | | | £2927 | 18 | 0 |

*the Year 1904.*

## EXPENDITURE ESTIMATED.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| House-Expenditure: | | | | | | |
| Taxes | | 15 | 0 | | | |
| Fire-Insurance | 15 | 0 | 0 | | | |
| Electric Lighting and Maintenance | 40 | 0 | 0 | | | |
| Gas | 12 | 0 | 0 | | | |
| Fuel | 35 | 0 | 0 | | | |
| Furniture and Repairs | 30 | 0 | 0 | | | |
| House-Repairs and Maintenance | 30 | 0 | 0 | | | |
| Annual Cleaning | 15 | 0 | 0 | | | |
| Tea at Meetings | 20 | 0 | 0 | | | |
| Washing and Sundry Expenses | 35 | 0 | 0 | | | |
| | | | | 232 | 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 | 150 | 0 | 0 | | | |
| Junior Assistant | 52 | 0 | 0 | | | |
| House Porter and Upper Housemaid | 94 | 10 | 0 | | | |
| Under Housemaid | 48 | 18 | 0 | | | |
| Charwoman and Occasional Assistance | 10 | 0 | 0 | | | |
| Accountants' Fee | 10 | 10 | 0 | | | |
| | | | | 876 | 13 | 0 |
| Office-Expenditure: | | | | | | |
| Stationery | 30 | 0 | 0 | | | |
| Miscellaneous Printing, etc. | 45 | 0 | 0 | | | |
| Postages and Sundry Expenses | 80 | 0 | 0 | | | |
| | | | | 155 | 0 | 0 |
| International Catalogue of Scientific Literature | | | | 60 | 0 | 0 |
| Library (Books and Binding) | | | | 200 | 0 | 0 |
| New Fittings for Map-Room | | | | 30 | 0 | 0 |
| Museum | | | | 5 | 0 | 0 |
| Publications: | | | | | | |
| Quarterly Journal, including Commission on Sale | 900 | 0 | 0 | | | |
| Record of Geological Literature | 140 | 0 | 0 | | | |
| List of Fellows | 35 | 0 | 0 | | | |
| Postage on Journal, Addressing, etc. | 90 | 0 | 0 | | | |
| Abstracts, including Postage | 110 | 0 | 0 | | | |
| Library-Catalogue | 93 | 10 | 0 | | | |
| | | | | 1368 | 10 | 0 |
| | | | | £2927 | 18 | 0 |

W. T. BLANFORD, *Treasurer.*

*January 28th, 1904.*

*Income and Expenditure during the*

RECEIPTS.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| To Balance in the hands of the Bankers at January 1st, 1903 .............. | 56 | 15 | 11 | | | |
| ,, Balance in the hands of the Clerk at January 1st, 1903 .............. | 4 | 11 | 9 | | | |
| | | | | 61 | 7 | 8 |
| ,, Compositions .............................. | | | | 171 | 17 | 0 |
| ,, Admission-Fees: | | | | | | |
| Arrears .......................... | 94 | 10 | 0 | | | |
| Current .......................... | 201 | 12 | 0 | | | |
| | | | | 296 | 2 | 0 |
| ,, Arrears of Annual Contributions .... | 151 | 4 | 0 | | | |
| ,, Annual Contributions, 1903 ........ | 1760 | 17 | 0 | | | |
| ,, Annual Contributions in advance .... | 55 | 2 | 6 | | | |
| | | | | 1967 | 3 | 6 |
| ,, Publications: | | | | | | |
| Sale of Quarterly Journal *: | | | | | | |
| ,, Vols. i to lviii * .................... | 99 | 0 | 11 | | | |
| ,, Vol. lix * ............................ | 68 | 12 | 2 | | | |
| | | | | 167 | 13 | 1 |
| ,, Transactions .......................... | | 10 | 0 | | | |
| ,, Ormerod's Index .................... | | 5 | 6 | | | |
| ,, General Index ........................ | 1 | 2 | 6 | | | |
| ,, Record of Geological Literature ... | | 16 | 6 | | | |
| ,, List of Fellows ........................ | | 12 | 0 | | | |
| ,, Museum-Catalogue .................. | 2 | 13 | 3 | | | |
| ,, Library-Catalogue .................... | | 5 | 0 | | | |
| ,, Hochstetter's 'New Zealand' ...... | | 2 | 0 | | | |
| ,, Hutton's 'Theory of the Earth' vol. iii ................................ | | 18 | 0 | | | |
| | | | | 7 | 4 | 9 |
| ,, Dividends (less Income-Tax):— | | | | | | |
| £2500 India 3 per cent. Stock.... | 70 | 18 | 7 | | | |
| £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference-Stock ................ | 14 | 2 | 7 | | | |
| £2250 London & North-Western Railway 4 per cent. Preference-Stock .......... | 84 | 15 | 0 | | | |
| £2800 London & South-Western Railway 4 per cent. Preference-Stock .......... | 105 | 9 | 4 | | | |
| £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference-Stock .................. | 48 | 15 | 7 | | | |
| £267 6*s*. 7*d*. Natal 3 per cent. Stock | 7 | 11 | 8 | | | |
| | | | | 331 | 12 | 9 |
| | | | | £3003 | 0 | 9 |

* Due from Messrs. Longmans & Co., in addition to the above, on Journal, Vol. lix, etc. ...... £65 9 6

*Year ended December 31st, 1903.*

PAYMENTS.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| By House-Expenditure: | | | | | | |
| Taxes | | 15 | 0 | | | |
| Fire-Insurance | 15 | 0 | 0 | | | |
| Electric Lighting and Maintenance | 46 | 17 | 8 | | | |
| Gas | 14 | 3 | 10 | | | |
| Fuel | 58 | 12 | 9 | | | |
| Furniture and Repairs | 37 | 3 | 2 | | | |
| House-Repairs and Maintenance | 21 | 0 | 6 | | | |
| Annual Cleaning | 9 | 9 | 6 | | | |
| Tea at Meetings | 19 | 16 | 5 | | | |
| Washing and Sundry Expenses | 33 | 18 | 11 | | | |
| | | | | 256 | 17 | 9 |
| ,, Salaries and Wages: | | | | | | |
| Assistant Secretary | 350 | 0 | 0 | | | |
| ,, half Premium Life-Assurance | 10 | 15 | 0 | | | |
| Assistant Librarian | 150 | 0 | 0 | | | |
| Assistant Clerk | 141 | 15 | 0 | | | |
| Junior Assistant | 52 | 0 | 0 | | | |
| House Porter and Upper Housemaid | 87 | 19 | 0 | | | |
| Under Housemaid | 48 | 19 | 6 | | | |
| Charwoman and Occasional Assistance | 8 | 14 | 0 | | | |
| Accountants' Fee | 10 | 10 | 0 | | | |
| | | | | 860 | 12 | 6 |
| ,, Office-Expenditure: | | | | | | |
| Stationery | 29 | 3 | 0 | | | |
| Miscellaneous Printing, etc. | 43 | 14 | 11 | | | |
| Postages and Sundry Expenses | 78 | 5 | 7 | | | |
| | | | | 151 | 3 | 6 |
| ,, International Catalogue of Scientific Literature | | | | 60 | 0 | 0 |
| ,, Library (Books and Binding) | | | | 242 | 12 | 5 |
| ,, Prestwich Fund: Advance for Dies and Legal Expenses | | | | 34 | 10 | 0 |
| ,, Publications: | | | | | | |
| Commission on Sale of Quarterly Journal | 13 | 11 | 2 | | | |
| Paper, Printing, and Illustrations | 612 | 9 | 0 | | | |
| Postage and Addressing | 77 | 6 | 7 | | | |
| Stitching and Covering back Numbers | 44 | 17 | 9 | | | |
| Record of Geological Literature | 138 | 16 | 0 | | | |
| List of Fellows | 36 | 2 | 0 | | | |
| Abstracts, including Postage | 114 | 15 | 11 | | | |
| Library-Catalogue | 104 | 14 | 6 | | | |
| Museum-Catalogue | 62 | 4 | 9 | | | |
| | | | | 1204 | 17 | 8 |
| ,, Balance in the hands of the Bankers at December 31st, 1903 | 176 | 12 | 9 | | | |
| ,, Balance in the hands of the Clerk | 15 | 14 | 2 | | | |
| | | | | 192 | 6 | 11 |
| | | | | £3003 | 0 | 9 |

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

F. W. RUDLER,
G. T. PRIOR, } *Auditors.*

W. T. BLANFORD, *Treasurer.*

*January 28th, 1904.*

## *Statement of Trust Funds: December 31st, 1903.*

### 'Wollaston Donation-Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1903 | 31 | 17 | 1 | By Award to Mr. L. L. Belinfante, and Medal | 31 | 17 | 1 |
| ,, 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, 1903 | 30 | 8 | 10 |
| | £62 | 5 | 11 | | £62 | 5 | 11 |

### 'Murchison Geological Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1903 | 20 | 12 | 8 | By Award to Dr. Charles Callaway | 15 | 15 | 0 |
| ,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture-Stock | 37 | 13 | 8 | ,, ,, Mrs. Elizabeth Gray | 22 | 15 | 10 |
| | | | | ,, Cost of Medal | | 17 | 0 |
| | | | | ,, Balance at the Bankers', December 31st, 1903 | 18 | 18 | 6 |
| | £58 | 6 | 4 | | £58 | 6 | 4 |

### 'Lyell Geological Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1903 | 53 | 1 | 3 | By Award to Mr. Frederick William Rudler | 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 | 11 | 0 | ,, ,, Mr. Sydney S. Buckman | 21 | 15 | 0 |
| | | | | ,, ,, Mr. George Edward Dibley | 21 | 15 | 1 |
| | | | | ,, Cost of Medal | 1 | 1 | 0 |
| | | | | ,, Balance at the Bankers', December 31st, 1903 | 50 | 1 | 2 |
| | £119 | 12 | 3 | | £119 | 12 | 3 |

### 'Barlow-Jameson Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1903 | 8 | 4 | 6 | By Balance at the Bankers', December 31st, 1903 | 21 | 9 | 0 |
| ,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture-Stock | 13 | 4 | 6 | | | | |
| | £21 | 9 | 0 | | £21 | 9 | 0 |

## 'Bigsby Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1903 | 9 | 4 | 1 | By Medal, awarded to Dr. Henry M. Ami | 12 | 3 | 2 |
| ,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock | 5 | 19 | 2 | ,, Balance at the Bankers', December 31st, 1903 | 3 | 0 | 1 |
| | £15 | 3 | 3 | | £15 | 3 | 3 |

## 'Geological Relief Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1903 | 9 | 15 | 0 | By Balance at the Bankers', December 31st, 1903 | 13 | 14 | 0 |
| ,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock | 3 | 19 | 0 | | | | |
| | £13 | 14 | 0 | | £13 | 14 | 0 |

## 'Prestwich Trust Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1903 | 17 | 0 | 9 | By Medal, awarded to Lord Avebury | 20 | 0 | 0 |
| ,, Dividends (less Income-Tax) on the Fund invested in £591 1*s.* 4*d.* India 3 per cent. Stock | 16 | 15 | 7 | ,, Part Cost of Die | 10 | 0 | 0 |
| | | | | ,, Balance at the Bankers', December 31st, 1903 | 3 | 16 | 4 |
| | £33 | 16 | 4 | | £33 | 16 | 4 |

## 'Daniel-Pidgeon Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1903 | 14 | 6 | 7 | By Award to Dr. Ernest Willington Skeats | 28 | 13 | 2 |
| ,, Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock | 28 | 18 | 3 | ,, Balance at the Bankers', December 31st, 1903 | 14 | 11 | 8 |
| | £43 | 4 | 10 | | £43 | 4 | 10 |

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

W. T. BLANFORD, *Treasurer*.

*January 28th, 1904.*

F. W. RUDLER,
G. T. PRIOR, } *Auditors.*

## *Statement of the Society's Property: December 31st, 1903.*

| Property. | £ | s. | d. |
|---|---|---|---|
| Due from Messrs. Longmans & Co., on account of Quarterly Journal, Vol. LIX, etc. | 65 | 9 | 6 |
| Balance in the Bankers' hands, December 31st, 1903: | | | |
| On Current Account | 176 | 12 | 9 |
| Balance in the Clerk's hands, December 31st, 1903 | 15 | 14 | 2 |
| Funded Property:— | | | |
| £2500 India 3 per cent. Stock | 2623 | 6 | 0 |
| £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference-Stock | 502 | 15 | 3 |
| £2250 London & North-Western Railway 4 per cent. Preference-Stock | 2898 | 10 | 6 |
| £2800 London & South-Western Railway 4 per cent. Preference-Stock | 3607 | 7 | 6 |
| £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference-Stock | 1850 | 19 | 6 |
| £267 6*s.* 7*d.* Natal 3 per cent. Stock | 250 | 0 | 0 |
| Arrears of Admission-Fees | 75 | 12 | 0 |
| Arrears of Annual Contributions | 178 | 10 | 0 |
| | £12,244 | 17 | 2 |

| | £ | s. | d. |
|---|---|---|---|
| Balance in favour of the Society | 12,244 | 17 | 2 |
| | £12,244 | 17 | 2 |

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

W. T. BLANFORD, *Treasurer.*

*January 28th, 1904.*

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

## Award of the Wollaston Medal.

In handing the Wollaston Medal, awarded to Prof. Albert Heim, of Zürich, to Mr. J. J. H. Teall, M.A., F.R.S., for transmission to the recipient, the Chairman addressed him as follows:—

Mr. Teall,—

The Council of the Geological Society of London have awarded to Prof. Heim the highest honour which they have to bestow—the Wollaston Medal, in recognition of the value of his researches concerning the mineral structure of the Earth, and more especially of his contributions towards the elucidation of the structure of mountain-masses, as illustrated in the chain of the Alps. In his great monograph, the 'Mechanismus der Gebirgsbildung,' he traced with remarkable skill the influence of plication in the terrestrial crust, following this influence step by step from the distortion and fracture of organic remains in hand-specimens up to the most gigantic foldings which have comprised a vast mountain-chain in their embrace. His researches, however, have not been confined to the internal structure of the Alps. He has devoted himself with not less enthusiasm and success to the study of their glaciers and their landslips. Gifted with no ordinary artistic power, he has been able to enrich geological science with a valuable series of landscape-drawings and sections, in which the intimate relations of geology and topography are admirably delineated. His latest achievement in this department is a large model of the massif of the Hohe Säntis, which was exhibited at the recent meeting of the International Geological Congress in Vienna. It was admitted by the assembled geologists to be probably the most accurate and beautiful model of a mountain-group that had ever been constructed. We may judge of the labour and enthusiasm spent on it from the fact that, besides climbing to every crest of that rugged tract, Prof. Heim made many ascents in a balloon, so as to obtain detailed and comprehensive bird's-eye views of the whole region which he wished to depict. In asking you to be so good as to transmit to him this Medal, I would request you to convey with it an expression of our warmest wishes for a long continuance of the mental and bodily activity which he has so unsparingly devoted to the interests of our science.

Mr. Teall, in reply, read the following translation of a letter which had been forwarded by the recipient:—

'I much regret that my duties here make it impossible for me to be present at your Annual Meeting, and that I am therefore unable in person to express my thanks for the honour which you are conferring upon me.

'It may perhaps interest you to know the circumstances which led me to turn my attention to Geology. When, at the age of nine years, I visited the Alps for the first time, in company with my father, the mountains appealed to my youthful imagination, and I then conceived the idea of representing them not only on paper but also in relief. I accordingly attempted to model them in clay, working at first directly from nature, and afterwards by the aid of the topographic maps which were then appearing. I soon found that one can only represent correctly that which one understands, and I was thus led to study the internal structure as well as the external form of the mountains.

'At the age of sixteen years I had prepared a model of the Tödi group on a scale of 1 : 25,000. Arnold Escher von der Linth heard of this model, and came to see it at my own home. This was the first time that I saw that illustrious man. He invited me to accompany him on a geological excursion, and from that time onward I looked up to him as my revered master. Thus the pleasure which I derived from my early visits to the mountains and my desire to represent them in relief led me naturally to the study of Geology.

'In receiving this high honour at your hands, I remember with heartfelt gratitude the instruction and encouragement that I have derived from a study of the literature and geology, and especially from personal intercourse with the fellow-workers, of the great nations which lie beyond my own small fatherland. Among these I reckon the British Empire as especially deserving of my gratitude. More than 35 years ago I derived inspiration as a student from a study of the works of Sir Charles Lyell, and since that time have continued to hold intercourse with British geologists—many of them Fellows of your Society—and to study their writings and collections.

'I am conscious that my work is very imperfect, and that in it error is mixed with truth. My life is unfortunately so overburdened with official and private duties that I have but little time for original research; yet I am filled with an earnest desire to do more, for I recognize that in such research is to be found the greatest happiness that human life can afford.

'It seems to me that the work which I have accomplished does not entitle me to this honour. I prefer rather to regard it as the recognition of a sincere effort to extend our knowledge, and I can assure you that, so far as in me lies, the remainder of my life shall be devoted to this object. You have given me a fresh stimulus—new encouragement. I thank you from the bottom of my heart.'

---

## Award of the Murchison Medal.

The Chairman then presented the Murchison Medal to Prof. George Alexander Louis Lebour, M.A., M.Sc., addressing him in the following words:—

Prof. Lebour,—

The Council have this year awarded to you the Murchison Medal, in recognition of the importance of your contributions to our knowledge of the Carboniferous and other rocks of the North of England. For thirty years you have been engaged in these researches, which have resulted in more accurate determinations of the stratigraphy of the Carboniferous System of Northumberland, and more satisfactory correlations of the various divisions of that system throughout the northern counties. In conjunction with Mr. Topley you brought forward convincing evidence that the famous Whin Sill is an intrusive sheet, and not, as some observers had supposed, an intercalated lava. Your papers on the salt-measures and on the Marl-Slate and Yellow Sands of your district have likewise added to our knowledge of these formations. This original work, however, has for many years been carried on in the intervals of a life primarily devoted to the teaching of geology, and we wish to mark our sense of the value of your educational labours as a Professor in the University of Durham. As one who in former days served under Murchison, you will doubtless value this medal as another link connecting you with that great master of our science. I may perhaps be permitted to add an expression of my own gratification that, looking back on my early association with you as a colleague in the Geological Survey, it has fallen to me to hand you to-day this mark of appreciation from the Council of the Geological Society.

Prof. Lebour replied as follows:—

Sir Archibald Geikie,—

My feelings on this occasion are divided between regret at the absence of my old friend, Prof. Lapworth, and gratification at receiving the Medal which commemorates my first Chief, Sir Roderick Murchison, from the hand of one who was his favourite colleague, his successor, and his biographer. An Award such as this is of the greatest value to a teacher: it confirms his pupils in the trust which they place in him, and at the same time gives him confidence in carrying on his own work. In my case, I will not be so presumptuous as to question the propriety of the Council's decision, however it may have surprised me. I am especially pleased that in the too kind words that you have uttered, the name of my dear friend and colleague of long ago, William Topley, has once more been coupled with mine. I am sure that no one would have rejoiced more than he at my good fortune this day.

I beg most heartily to thank the Council for the honour which they have done me.

---

## Award of the Lyell Medal.

In handing the Lyell Medal, awarded to Prof. Alfred Gabriel Nathorst, of Stockholm, to Baron C. de Bildt, Envoy Extraordinary and Minister Plenipotentiary of H.M. the King of Sweden & Norway, for transmission to the recipient, the Chairman addressed him as follows:—

Baron de Bildt,—

Your Excellency has been good enough to come here to-day to receive for your countryman, Prof. Nathorst, of Stockholm, the Lyell Medal, which has been awarded to him this year by the Geological Society in recognition of his long and distinguished labours to advance our knowledge of the vegetation which at successive periods in the history of the earth has flourished in Northern Europe and the Arctic regions. These labours range from the oldest to the youngest ages of geological time. Among the most ancient rocks various curious markings, which had generally been regarded as traces of marine plants, were shown many years ago by Prof. Nathorst, after an ingenious series of experiments, to be probably not of vegetable origin. But while he thus cut off what had been supposed to be an early marine flora, he has greatly extended our acquaintance with the terrestrial floras of Palæozoic time in the Arctic regions. His papers on the extension of the vegetation of the Upper Old Red Sandstone as far north as Bear Island, continuing the earlier work of Heer, are of special interest. He has thrown much light on the flora of the Triassic deposits that extend into the South of Sweden. From the far northern King Charles Land he has made known the existence of a Jurassic and a Cretaceous flora. His researches among Pleistocene and recent deposits, and the history which he has thence deduced of plant-migration and changes of climate in Europe, are singularly interesting and suggestive. Although it is as a student of fossil plants that Prof. Nathorst is most widely known, it was his keen eyes that detected for the first time casts of medusæ in the Lower Cambrian rocks of Scandinavia. In transmitting to him our Lyell Medal, your Excellency will, I hope, accompany it with an expression of our best wishes for his health and the long continuance of his scientific energy.

BARON de BILDT, in reply, read the following letter which he had received from Prof. NATHORST:—

'Allow me to express my heartiest thanks to the Council for the great and quite unexpected honour which they have conferred upon me by the award of the Lyell Medal. I regard this mark of approval of my geological and palæontological labours as a most gratifying distinction, and it encourages me to hope that, as the end of my life approaches, I may have the satisfaction of feeling that I have not lived altogether in vain.

'My gratification at receiving this honour is increased by the fact that it is associated with the name of Sir Charles Lyell. I vividly remember the enthusiasm with which, as a mere youth, I read the Swedish edition of his admirable and fascinating 'Principles of Geology'; and it is only right to add that it was this work which first excited my love for Geology; a branch of science which the Geological Society of London has vigorously promoted for almost a century.

'During my first visit to England in 1872, at the age of twenty-one, I was fortunate enough to be introduced to the great British geologist; and I still cherish a vivid remembrance of his kind and noble personality, and of his keen interest in my then recent discovery of the remains of *Salix polaris* and other Arctic plants in the Glacial deposits of the Norfolk coast. The meeting with Sir Charles forms one of the most highly-prized reminiscences of my youth.

'Let me also express my great satisfaction at receiving this Medal through so illustrious a geologist as Sir Archibald Geikie, whose writings have served as a source of information to the majority of geologists throughout the world.'

---

## AWARD OF THE WOLLASTON DONATION-FUND.

The CHAIRMAN then handed the Balance of the Proceeds of the Wollaston Donation Fund, awarded to Miss ETHEL MARY READER WOOD, M.Sc., to Dr. J. E. MARR, F.R.S., for transmission to the recipient, and addressed him in the following words:—

Dr. MARR,—

The Council have awarded to Miss Wood the Balance of the Proceeds of the Wollaston Donation-Fund as an acknowledgment of the value of her contributions to our knowledge of the Graptolites and of the rocks in which these organisms occur. Her papers furnish an excellent example of the application of zonal stratigraphy to groups of rocks which were thought to be already known with tolerable completeness. Much still remains to be done in this department of investigation. We had looked forward with pleasure to seeing her among us here to-day; but she has been unavoidably prevented from coming to London. In sending the Award to her, you will be so good as to express to her our hope that she will regard it as a token of the interest which we take in her work, and as an encouragement to her to continue to devote herself to the cause of science with the same skill and enthusiasm which have hitherto so eminently distinguished her career.

---

## Award of the Murchison Geological Fund.

In presenting the Balance of the Proceeds of the Murchison Geological Fund to Dr. Arthur Hutchinson, M.A., F.C.S., the Chairman addressed him as follows:—

Dr. Hutchinson,—

The Balance of the Proceeds of the Murchison Geological Fund has this year been awarded to you, in acknowledgment of the ability which the Council recognize in your published memoirs on mineralogical subjects, and to encourage you in further work. We especially desire to acknowledge the skill and industry displayed by you in two important memoirs. Your paper on the Diathermancy of Antimonite introduced and successfully applied a new method of crystallographic investigation, wherein an opaque mineral is examined between crossed nicols, by means of transmitted heat-rays, corresponding to the usual optical examination of transparent minerals. Your memoir on Stokesite records the discovery of a new mineral, of which you found only a single crystal upon a specimen of Cornish axinite. Your analysis proved it to be a compound of most unusual type—a silicate containing tin.

---

## Awards from the Lyell Geological Fund.

The Chairman then presented a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Prof. Sidney Hugh Reynolds, M.A., addressing him in the following words:—

Prof. Reynolds,—

This Award is made to you in special recognition of the value of your contributions to our knowledge of the Palæozoic rocks of Ireland and of the geology of the Bristol district, and to encourage you in further work. During the past eight years the Society has received from you a series of important papers which have appeared in its Quarterly Journal. In association with Mr. Lake you presented some interesting facts in regard to the *Lingula*-Flags of the Dolgelly district. In conjunction with Mr. Gardiner you have carried out a series of researches among the Silurian rocks of the South-East and of the West of Ireland, and have thrown fresh light on their associated volcanic rocks. Together with Prof. Lloyd Morgan, you have worked out the geology of the Tortworth district, and have cleared up the interesting history of its volcanic eruptions; while you have more recently studied the Carboniferous volcanic rocks of the neighbourhood of Weston-super-Mare. In addition to all these geological undertakings you are still further widening the range of your studies by continuing the Palæontographical Society's Memoir on the Pleistocene Mammalia. We cordially hope that many long years of active scientific work are in store for you, and that you will continue to enrich our Quarterly Journal with the results of your researches.

---

In handing the other moiety of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Dr. Charles Alfred Matley, to Prof. W. W. Watts, M.A., M.Sc., Sec.G.S., for transmission to the recipient, the Chairman addressed him as follows:—

Prof. Watts,—

The other moiety of the Lyell Fund has by the Council been assigned to Dr. Matley, as an acknowledgment of the value of his work in elucidating the geology of Anglesey, and to encourage him in further work. The complicated structure of that part of North Wales has long been recognized, but the nature and extent of the complication have only been realized in recent years, since more enlarged and accurate views of geological tectonics have been reached. It would be rash to assert that all the difficulties have been cleared away, but Dr. Matley has made a notable forward step in removing them. Besides his work in Anglesey he has devoted time and thought to the Cambrian formations of Pembrokeshire, and to the Keuper Marls and Sandstones of Warwickshire. We wish him many years of health and continued geological industry.

---

## Award of the Barlow-Jameson Fund.

The Chairman then handed the Proceeds of the Barlow-Jameson Fund, awarded to Mr. Hugh John Llewellyn Beadnell, to Major C. E. Beadnell, late R.A., for transmission to the recipient, addressing him in the following words:—

Major Beadnell,—

The Barlow-Jameson Fund is awarded to your son, Mr. Hugh John Llewellyn Beadnell, in recognition of the value of his Memoirs on the topography of the Oases and other districts of the Libyan Desert, and for his important collections of vertebrate fossils made in Egypt during the last three years. The enthusiasm with which he has prosecuted his researches in the Geological Survey of Egypt led some time ago to an attack of fever which nearly proved fatal. We hope that he will be able henceforth to ward off all such attacks, and to continue the career which he has so successfully begun. In transmitting to him this Award of the Council, you will not fail to convey to him an expression of our interest in his researches, and of our hope that he will be encouraged to continue to pursue them.

# THE ANNIVERSARY ADDRESS DELIVERED BY

Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S., Vice-President.

I propose, first of all, to refer to the most conspicuous losses which our ranks have sustained during the past year.

J. P. Lesley, one of the most distinguished and loveable men of science in the United States, was born at Philadelphia on September 17th, 1819. His grandfather was a cabinet-maker in Aberdeenshire, whence he had emigrated to America, carrying with him and transmitting to his descendants his Scottish strength of character, energy, industry, and uprightness. His father, who followed the same trade, taught his children to draw even before they learnt to write, and trained their observing faculties by requiring from them accurate descriptions of what they had seen or heard, illustrated with sketches which he criticized. In this way, and by practice in his father's workshop, Lesley acquired that accuracy of eye and deftness of hand which afterwards became such notable gifts in his qualifications as a geologist. He was christened Peter after his father and grandfather, and at first wrote his name 'Peter Lesley Jr.,' but disliking the Christian appellation that had been given to him, he eventually transformed his signature by putting the J of 'Junior' at the beginning, followed by only the first letter of 'Peter.' Hence arose the familiar signature of 'J. P. Lesley.'

His parents, recognizing the promise of his boyhood and youth, educated him for the ministry, and he took the degree of A.B. at the University of Pennsylvania in 1838. But his application to his studies, combined with his neglect of bodily exercise and training, so told upon his health that he was unable to go on immediately with the theological training which had been planned. Fortunately for him, and not less so for the science of geology in the United States, it happened that the infant Geological Survey of Pennsylvania was then attracting attention, under its able chief H. D. Rogers, and the place of sub-assistant on the staff was offered to young Lesley. Accepting this appointment, he began his geological career at the age of nineteen in the Pottsville anthracite-field, under Whelpley, who was in later years described by Lesley himself as 'the first perfect topographical geologist our science had.' Those who have travelled through the Carboniferous region of Pennsylvania, or have studied the excellent detailed maps of it which the State Surveys have published, will not wonder at the claim made by Lesley that 'topographical geology was born' in that State; nor will they fail to note how easily and irresistibly Lesley was led into that domain of geology where he became so pre-eminent a master. The contours of the surface depend so directly and clearly upon curvature and fracture of the terrestrial crust on the one hand, and upon the results of erosion on the other, that in few tracts of the earth's surface is this relationship so readily grasped, or appeals so powerfully to the imagination.

Before he was one-and-twenty Lesley had constructed his first topographical and geological sketch-map, which earned the commendation of Rogers 'for the faithful and laborious manner in which he had unfolded the geology of this occasionally complicated zone of country.' His scientific career, however, was soon arrested by the refusal of the State Legislature to grant any further appropriation for the continuance of the Survey, and by the consequent disbanding of the staff of assistants. Thus thrown back upon himself, the young geologist turned once more to the line of life which had been originally marked out for him. His geological rambles among the remote valleys of his native State had brought vividly before his eyes the benighted condition of their inhabitants; and now the idea was revived that he should proceed with his theological studies, in order to fit himself for the ministry and for eventually becoming a missionary to these neglected people. He accordingly entered the Theological Seminary at Princeton in 1841, and likewise proceeded to his degree of A.M. at the University of Pennsylvania. While working at Hebrew and theology, however, he found time, at Rogers's request, and with much patience and skill, to put together the mass of materials that had been gathered by the assistants for the construction of a coloured topographical and geological map of Pennsylvania. In this laborious task, as in all his subsequent labours, the value of his early training in drawing became strikingly conspicuous.

Having passed through the theological training, and having received his licence as a clergyman from the Presbytery of Philadelphia, he took a trip to Europe in 1844. Landing in Liverpool, he first made a walking pilgrimage through England, and thereafter another, with knapsack on back, through the west and south of

France and the west and north of Switzerland. His eyes being now opened to the perception of geological structure, he made good use of his opportunities in Dauphiné and in the Jura, where he could compare the plicated rocks of these classic regions with those which he had learnt to understand at home. He found in the Swiss ground proofs of 'the ancient action of similar forces under the same laws, but in less detail and with far less delicacy.' He remarks that he 'was fortunate in being the first geologist who had an opportunity to approach the dynamic phenomena of the Jura with an American eye, trained on the typical [Appalachian] ground.' Making his way through the Harz he came to Halle, for the purpose of remaining some months at its University, studying under the theologian Tholuck and others, where he found the theological atmosphere less close than that of his own home. He returned to Philadelphia in the early summer of 1845, and at once threw himself into the missionary work for which he had prepared. He distributed Presbyterian tracts for the American Tract Society of Philadelphia, through the northern and central parts of Pennsylvania, frequently preaching, and sometimes riding 40 miles in a day. He continued these labours for two seasons, until at last his health failed under the combined strain of mental excitement, bodily fatigue, and exposure to the weather.

At the end of the following year (1846) Rogers, who had never lost sight of him or of the possibility of winning him back to the geological camp, induced him to come to Boston and spend five months there in duplicating the State geological map and longitudinal sections which he had drawn while at Princeton, together with some hundreds of other drawings, besides preparing a large part of the text of the final Report. But the Legislature refused to grant money for their publication. Lesley, however, still clung to his ministerial calling, and towards the end of the year 1848 became the pastor of a Congregationalist church at Milton, a suburb of Boston. Early next spring he married Miss Lyman—an union which proved of the happiest kind, although it started with such prospects of feeble health and straightened means that one of their candid lady-friends remarked that 'it was enough for the pair to have the shelter of an umbrella, and if there should be children parasols might be given them.' Mrs. Lesley was his genial sympathetic companion and helper through the rest of his long life, the witness of and sharer in his successes, and now in her widowhood the recipient of many expressions of the esteem and affection with which her husband was regarded.

Lesley's theological views were slowly widening—a change which roused the anxiety of the rigidly-orthodox institutions with which he was connected. The Tract Society in Philadelphia began to move in the interests of the people of Boston, and ultimately his licence to preach was withdrawn. A portion of his congregation, however, adhered to him, and to them he continued to minister. But as he gradually became more completely Unitarian, he finally abandoned his pastorate in 1851. He was now thirty-two years of age—a time of life at which most men find it too late entirely to change their vocation. He, however, had never quite abandoned geological work, and he could revert to it with all the more eagerness, as, while it offered him the prospect of better health and sufficient maintenance, it opened out to him a career for which he felt himself to be well qualified, in which he had already made his mark, which promised him the most congenial occupation, and out of which no theological wolves could scare him. The Pennsylvanian Legislature in April 1851 at last made an appropriation for the renewal of the Geological Survey, and Rogers immediately secured Lesley as one of his chief assistants, his main object being to get the maps reduced and published, together with the Report. Owing to various causes, the publication was delayed for some years. But meanwhile Lesley's topographic power became generally known, and brought him private employment. In 1853 and 1854 he was engaged by the Pennsylvania Railroad Company to construct a large map, which was distinguished by the adoption of contour-lines instead of hachures. He undertook other surveys or geological reconnaissances, not only in Pennsylvania, but in South-Western Virginia and South-Eastern Tennessee.

In the midst of these avocations he found time, in the winter of 1855–56, to write his memorable little volume entitled 'Manual of Coal & its Topography, illustrated by original drawings, chiefly of facts in the Geology of the Appalachian region of the United States of North America, by J. P. Lesley, Topographical Geologist.' I well remember the pleasure with which, many long years ago, I first perused this original and suggestive treatise. It could only have been written by a man who, gifted with a keen eye and artistic power, had been enabled to cultivate his observing faculties in a region where the fundamental facts of geological structure were displayed with altogether exceptional clearness. It dealt with topography as no one had attempted to deal with it before, treating it both as a science that classified the various features of the land which are determined by geological structure, and likewise as an art deserving of the most scrupulous care in its cultivation on the part of the cartographer. 'The face of the earth,' he significantly wrote, 'is the face of a great angel, with infinite smiles and anguish-lines, and profound sympathies with peace and suffering stamped upon its features. Every lineament is a line of tragical history, full of pathos and sublimity.' If such was his conception of landscape, we can readily understand with how deep an artistic feeling he must have undertaken his work. 'The topographer,' he tells us, 'if a true artist, will put himself in true relations with this grand mute object of his study, and learn its own record of its wonderful experience, if he will picture the earth as it is. The draughtsman must first be a geologist.' Only a small edition of this remarkable book was published, and it was never reprinted. Hence it has been much less widely known than it well deserves to be.

About the time of the appearance of this volume, he was appointed Secretary of the American Iron Association of Philadelphia. In this situation it was one of his first duties to collect accurate statistics of the iron-industry of the United States. For this purpose he not only carried on a voluminous correspondence, but personally visited many of the ironworks himself, besides sending one or two assistants to others. The results thus accumulated were embodied by him in an important volume of nearly 800 pages, 'The Iron-Manufacturer's Guide,' which contained many maps and a large amount of original discussion supplied by himself.

At the beginning of 1858 he was elected Librarian of the American Philosophical Society, and thus began an intimate association with this distinguished institution which lasted to the end of his life. He subsequently became one of the Secretaries, and for many years was Vice-President, until he declined re-election in 1897. His devotion to this Society led him to work unweariedly on its behalf, and to stimulate others in the furtherance of its scientific reputation. In 1859 he became permanently Professor of Mining in the University of Pennsylvania.

For fifteen years from that date he was mainly occupied in making surveys and reports for public companies and private individuals. These labours involved much travelling and exposure, as well as much hard work indoors in the preparation of his maps and Reports. It is almost incredible that he could have turned out so vast an amount of material in the time. Some of this material was published and is of excellent quality, but a great deal of it never saw the light after the object was attained for which it was prepared. It is recorded that when he was sent by a Boston company to survey some lands in the Cape-Breton coal-field, he measured the strata, bed by bed, and in order to complete his section with accuracy, was let by a rope down the face of a high cliff. When at one time he seemed to be approaching dangerously near the verge of the precipice, one of his faithful and admiring attendants, fearing for his safety, took the precaution to knock him down, and then apologized for his apparent rudeness.

At length, in the middle of 1866, his health gave way so completely under the strain of this overwork, that he was compelled to seek rest and refreshment for two years in Europe, during which he spent some time in Egypt. By the spring of 1868 he was once more at his home in Philadelphia, but still unfit for much mental exertion. In 1872, the University gave him the professorship of Geology and Mining and made him Dean of the Scientific Department. Three years later he was chosen Dean of the Towne Scientific School. These University avocations kept his hands sufficiently full of work, when, in 1874, he received the chief appointment of his life, that of State Geologist of Pennsylvania. He had passed through thirty-five years of geological experience, and was now in his fifty-fifth year. Though the official emoluments of the post were small, compared with the income that he had been deriving from his private practice, he at once accepted the appointment and threw himself with all his wonted enthusiasm into the work of doing for his native State what he had long wished to see done. He would now have the opportunity of making a thorough survey of a region so full of geological interest and economic importance. How well he fulfilled the task which he set before himself, and to which he devoted the unceasing labour of some twenty strenuous years, those geologists can best appreciate who have made acquaintance with his voluminous Report. At last, worn out with his exertions, he had, in 1893, to lay down the pen, when the last coping-stone of the great work of his life had still to be placed.

The printed reports and map-atlases of the Second Geological Survey of Pennsylvania extend to no fewer than 120 volumes. Throughout these the hand of J. P. Lesley is everywhere apparent. He was the life and soul of the enterprise, firing his subordinates with some of his own ardour, training them in his methods of observation and topography, editing and sometimes necessarily re-writing their ill-expressed reports, but generously giving them full credit for all their work, even where much of it might have been his own. The volumes of the Final Reports, more than half of them from his pen, present a singularly impressive picture of the extent and value of a Survey which will be classic in geological literature, and will form the noblest monument to the genius of J. P. Lesley.

He remained in Philadelphia for three years longer, until the last volume of the Survey publications had been issued. Thereafter, in the summer of 1896, he removed to the village of Milton, where nearly fifty years before he had been pastor, and where he had recently spent his summer holidays. In that cherished retreat, so full of tender associations, he spent the remaining years of his life, slowly growing feebler, until on the evening of the 1st of last June he passed away.

Lesley was upwards of 6 feet high and, at least in his later years, broad in proportion. His face, with its large well-formed nose and mild eyes, was marked by a strong individuality in which firmness and kindliness were equally represented. He had great powers of conversation, and a remarkably winning manner which irresistibly attracted those who were thrown into personal contact with him. I shall retain as long as memory serves me the recollection of him in the midst of his Philadelphian home, with his charming wife, his two daughters, his piles of cases of maps and reports, and his geological assistants chivalrously on the alert to anticipate his wishes and to carry out his instructions.[1]

He had been elected a Foreign Correspondent of our Society in 1866, and was promoted to the rank of Foreign Member in 1887.

Within the last few weeks geological science has sustained a grievous loss by the death of one of its greatest masters—the illustrious Karl Alfred von Zittel. Although for several years past he had not been in robust health, yet his keen and kindly eyes retained still so much of their old brilliance, his interest in the progress of his favourite studies continued to be so lively, and the charm of his personal intercourse remained so delightfully unimpaired, that his wide circle of devoted friends could not but

[1] In preparing this notice of J. P. Lesley the fullest use has been made of the facts gathered together by Mr. B. S. Lyman in an excellent Biographical Notice (with an admirable portrait), published in the 'Transactions of the American Institute of Mining Engineers.'

hope that a career so full of distinction, of usefulness, and of sympathy might still be prolonged for much further achievement. But this was not to be. Full of honours and surrounded with universal esteem and affection, he has passed 'to where beyond these voices there is peace.'

Born at Bahlingen in Baden on September 25th, 1839, Zittel at the age of 18 proceeded to Heidelberg to study natural science. There, under the inspiration of Bronn and C. Leonhard, he was attracted more especially to geology and palæontology. After taking his degree of doctor, he spent a year in Paris, in order to profit by the instructions of the illustrious Hébert, to make himself practically acquainted with the rich fossil treasures of the Tertiary formations of that region, and to enlarge his knowledge by excursions into some of the most interesting and instructive parts of France. In 1861, having completed his student years, he became one of the volunteer assistants in the Geologische Reichsanstalt of Vienna; and two years later was formally attached to the University of that city as Privat-dozent. He was then appointed to the position of assistant in the Hofmineralien-Kabinett, which is now the great Natural History Museum. Having declined the offer of a professorship at Lemberg, he in 1863, when only 24 years of age, accepted the Ordinary professorship of Mineralogy, Geognosy, and Palæontology at the Polytechnikum of Carlsruhe. Two years thereafter he married the eldest daughter of J. W. Schirmer, landscape-painter and director of the art-school, and began that happy domestic union in which he rejoiced to the end of his life. In the autumn of 1866 he received a great mark of distinction in being invited to succeed Oppel in the chair of Palæontology in the University of Munich and in the keepership of the National Palæontological Collection. In 1880 geology was added to the curriculum taught by him; and in 1890, on the death of Schafhäutl, he succeeded also to the keepership of the National Geological Collection. In June 1899 his distinguished scientific position was fitly recognized by his being chosen to replace Pettenkofer, as President of the Bavarian Academy of Sciences and Keeper of the great scientific collections of the State. It was in Munich, amidst the wonderful collection of extinct animals which, largely by his own patient industry, tact, and skill, has been gathered together there, that his life-work was mainly accomplished. Under his enlightened guidance that city became one of the chief centres of palæontological research and progress.

The mere list of Zittel's published papers shows his unwearied energy and the wide range of his acquirements. This brief notice cannot be more than a necessarily-imperfect and inadequate account of his scientific achievements. Looking at them as a whole, we are struck with their breadth of view, their originality of treatment, and the complete command which they evince of the whole literature of every subject with which they deal.

His training having been so wide and so thorough, he was able throughout his career to take up the consideration of each branch of the geological sciences with full knowledge of its relations to all the other branches. His mental grasp, his scientific insight, and his faculty of luminous arrangement and clear exposition, are strikingly displayed in his great work, the 'Handbuch der Palæontologie.' The first part of this treatise appeared in 1876, and the last of its five massive volumes was issued in 1893. He thus spent upon it some seventeen of the best years of his life. It was no mere compilation. Almost incredible as the task may appear which he undertook, he entered in turn upon the detailed study of each great zoological group, and made himself so thoroughly master of it and of its connected literature, that he could write upon it with the ripe knowledge and full authority of an expert, competent to revise the work of his predecessors. He was thus in a position to present an ordered classification of the fossil groups, and to show their affinities more clearly than had been done before. Hence his volumes at once took their place as the great work of reference for modern palæontologists, who came to look up to him as their inspiring teacher, and to Munich as the Mecca towards which their pilgrim-steps should be directed.

The department of palæontology to which Zittel gave perhaps most exhaustive attention was that of the Fossil Sponges, his treatise on which probably embodies his most important original research. The group of Sponges had not been properly understood or arranged when he entered upon its study, but he worked out the true principle of classification of these organisms, applicable equally to the extinct and to the living forms.

He took much interest in the region of the Libyan Desert. The geological introduction to the first volume of that important work, 'Beiträge zur Geologie und Palæontologie der Libyschen Wüste' (1883), was written by him. In 1896 he renewed his interest in African geology by accompanying the excursion of the Geological Society of France to Algeria, which he greatly enjoyed.

Among Zittel's contributions to scientific literature a prominent place must unquestionably be given to one of the publications of his later years—his admirable 'Geschichte der Geologie und Palæontologie,' which appeared in the summer of 1899. Various attempts had previously been made to present a connected account of the progress of geology, but most of these dealt with the earlier periods of the science and were written before the extraordinary development, in the second half of last century, of our knowledge of the history of the earth. Zittel, while treating luminously of the older researches, set himself the formidable task of digesting the literature of geology and palæontology down to the end of last century, and presenting to the world an ordered narrative of the advances made in the several departments of these great domains of natural knowledge. While it is difficult to exaggerate the magnitude of this task, it is hardly less so to overpraise the success with which the task has been accomplished. Turning everywhere to the original sources of information, Zittel has been able to place in a new light the enquiries of the ancient observers and those who flourished in the heroic age of geology before the third decade of last century. He shows the relations of the work achieved by a host of labourers all over the world, and prepares the reader for the more detailed discussion of the striking amplification of geological effort in all directions during the rest of the century recently closed. In none of his writings does he manifest more impressively his breadth of view in natural science, his wide sympathy with every line of scientific advance, the calm logical attitude of his mind, the range of his knowledge, and the deftness of his literary skill in marshalling so vast a body of facts in clear and interesting order. His volume must form part of the library of every geologist; and to no book will the student of the future more frequently turn for information and guidance through the crowded literature of geology.[1]

On the 4th of October last Zittel was knocked over by a bicyclist in the street, and his right knee sustained such injury as to confine him to bed for several weeks. About two months later he accidentally further injured the wounded knee. This bodily affliction, coming after the deep mental distress into which he had been

[1] An excellent translation of this work, somewhat abridged, has been published, with Zittel's approval, by Mrs. Ogilvie-Gordon (a former pupil of his), under the title of 'History of Geology & Palæontology to the End of the Nineteenth Century' Contemporary Science Series, London, 1901.

plunged some time before by the tragic death of his son-in-law, proved too much for a frame now much enfeebled by cardiac complications, and he passed quietly away on the night of the 5th of January, 1904.

Few men in our time have been more widely known and esteemed among the geologists of Europe and America than Karl von Zittel. Though he stood in the front rank of science, the most universally accomplished palæontologist of his day, no one could be more modest and retiring. None could with more generous devotion, with more kindly guidance, or with wiser counsel encourage the younger men and women who looked up to him as their master. Great as was his scientific eminence, the beauty of his character was if possible greater still. He has left to the rising generation a noble example of a brilliant man of science, unwearied in activity, skilful and graceful as a writer, genial and stimulating as a teacher, sympathetic and helpful as a friend.

Zittel was elected a Foreign Correspondent of our Society in 1883, and became a Foreign Member in 1889. The highest distinction which it lies in the power of the Council to bestow, the Wollaston Medal, was awarded to him in 1894.

By the death of Alphonse François Renard geologists in our islands have been deprived, not only of one of the most eminent of their fellow-workers in the petrographical department of their science, but of the foreign geologist who (by reason of his frequent visits to this country) was probably personally known more widely amongst us than any of his contemporaries on the Continent. By a large number of the Fellows of this Society, his loss has been felt as that of a friend whose cheery, beaming face and interesting talk were always welcome. He was born of modest parentage at Renaix, in Eastern Flanders, on September 27th, 1842. He received his early education in his native town, and then became clerk to a manufacturer there; but a Catholic priest, having been struck with the lad's bright intelligence, persuaded him to continue his education and offered to defray his expenses. This generous recognition formed the turning-point in Renard's career. Beginning with the study of the humanities at the Episcopal College of Renaix, he continued it at the Jesuit College of Turnhout, until in 1863, at the age of 21, he entered upon the noviciate of the Society of Jesus at Tronchiennes. From 1866 to 1869 he acted as superintendent at the Collège de la Paix, Namur. In 1870, however, his scientific career was begun by his being sent to the Jesuit Training College at the old abbey of Maria Laach, by the side of the Laacher See in the Eifel, for the purpose of studying philosophy and the sciences. Up to that time he had paid no attention to geology. Placed in the midst of one of the old craters of that interesting volcanic region, this seminary was well fitted to kindle in any receptive youth a desire to know something of the history of the earth. When I visited it a few years before Renard came thither, I was astonished to find the equipment for teaching mineralogy, petrography, and geology so efficient. Herr Theodor Wolf, who has since become widely known from his researches in Ecuador, was one of the inspiring staff of teachers at the Abbey, until its suppression by the Prussian Government, and it was doubtless largely by his example and influence that Renard was drawn into geological investigation. The young student of philosophy became an active and eager member of the excursion-parties which were organized at the Abbey for the exploration of the volcanoes of the surrounding country. And there can be no doubt that it was these years at Maria Laach which finally determined his bent into the domain of petrography.

A brief interruption of his studies was caused by the Franco-German war, during which he retired to Belgium and became superintendent in the College at Tournai. But returning to the Laacher See, he continued his pursuits there, until in 1873 he took a third year of philosophy and science at Louvain. The following year, at the age of 30, he received the professorship of Chemistry and Geology in the College of the Belgian Jesuits at Louvain. Meanwhile his clerical training still continued. He studied theology as as well as lectured on science, and in September 1877 was ordained a priest. About the same time, his scientific abilities were recognized by his being appointed one of the Curators of the Royal Natural History Museum, Brussels; but though he came to reside in the capital, he continued to give his lectures at Louvain until 1882, when he relinquished them and devoted himself to his official work in the Museum. There he remained until, when the Chair of Geology at the University of Ghent became vacant in 1888, he received that appointment, and held it up to the time of his death.

It is now nearly thirty years since Renard began to publish the results of his scientific investigations. His first essay dealt with the plutonic rocks of his own Ardennes. In association with the late

Charles de la Vallée-Poussin, he wrote the important monograph on the mineralogical and stratigraphical characters of the rocks called 'plutonic' in Belgium and the French Ardennes, which was presented to the Belgian Academy in 1874, and appears among the 'Mémoires Couronnés' of that institution. From that time onward he continued to give to the world other papers on Belgian rocks, among them an interesting account of the minute structure and mineralogical composition of the whetslates, which he showed to abound in garnets. He described likewise the phthanites of the Carboniferous Limestone, and pointed out the distinctive characters of the calcite and dolomite in the same formation. But the most notable of these contributions to the geology and petrography of his native country were those in which he discussed the phenomena of regional metamorphism, as exhibited by the phyllades and the garnetiferous and amphibolitic rocks. Confirming the general accuracy of the previous observations of Dumont, he regarded the distinct metamorphism of that region as the result of intense mechanical disturbance, with accompanying chemical and mineralogical re-arrangements. In recent years, having widened his experience of the problems of metamorphism, he was inclined to question the validity of his earlier conclusions, and was rather disposed to think that the alteration of the rocks might be due really to contact-metamorphism, though the invading igneous material had not yet made its appearance at the surface during the prolonged denudation of the rocks. Prof. Gosselet, whose great work on the Ardennes marks him out as the chief authority on the geology of that region, strongly opposed this change of opinion, and contended for the essential accuracy of the earlier deduction.

Renard's published papers at once attracted attention, both among petrographers and stratigraphers. They showed him to be a capable chemist, and at the same time to have acquired a command of all the most modern resources of investigation with the microscope. But they further proved that he was no mere worker in a laboratory or museum, for they evinced that he had accustomed himself to study the rocks in the field, to examine their stratigraphical relations, and to take broad and enlightened views regarding their origin and history. His writings had gained so much approbation in this country, that when the various treasures brought home by the *Challenger*-Expedition were partitioned among recognized experts for determination and description, the petrographical specimens were entrusted without hesitation to Renard. He was likewise associated with Sir John Murray in the investigation of the voluminous series of deposits brought up from the bottoms of the various oceans traversed during the course of that vessel's voyage round the world. Numerous communications of singular novelty and importance continued to be published, as the outcome of this conjoint study, for some twelve years. At last, the results of the whole prolonged and laborious research were summed up in full detail in the great monograph on the 'Deep-Sea Deposits,' which forms to the geologist, perhaps the most valuable of all the massive quarto volumes of the *Challenger*-Reports. There can be no doubt that this work will become a classic in the literature of Oceanography, and will be looked on as practically the starting-point for all subsequent research on the subject of which it treats. Every geologist is now familiar with the more striking additions to our knowledge of the abysmal sediments, made by these researches of Murray and Renard—the detection and description of cosmic dust, which as a fine rain slowly accumulates on the ocean-floor; the development of zeolitic crystals on the sea-bottom at temperatures of 32° and under; and the distribution and mode of occurrence of manganiferous concretions and of phosphatic and glauconitic deposits on the bed of the ocean.

Renard was elected a Foreign Correspondent of this Society in 1880, immediately after the commencement of the publication of his contributions from the *Challenger*-stores. He became one of our Foreign Members in 1884, and in the following year he received our Bigsby Medal. His close connection with the *Challenger*-work and those who conducted it in Scotland was appropriately recorded by his election into the select number of the Honorary Fellows of the Royal Society of Edinburgh.

From the time of his entering the priesthood he was everywhere known as the Abbé Renard, and until not many years ago continued to wear the clerical dress even in his visits to this country. When he came to Scotland in the early years of his connection with the *Challenger*-work, I saw much of him, and he now and then joined me in a geological excursion, which one year we prolonged through the North-Western Highlands as far as Cape Wrath, where he passed the night at the lighthouse-keeper's, sitting on a wooden chair with his arms and head resting on the table. On that and on other occasions I had long talks with him on theological as well as geological and other matters, and could see even then that his views were much more liberal and advanced than might have been looked for in a Jesuit father. His hold on the orthodoxy of the Latin Church grew weaker as his scientific vision increased in strength and breadth.

The first overt act of renunciation of his ecclesiastical ties appears to have been taken by him in 1884, when he formally left the Society of the Jesuits. I had previously understood from him that he had never taken the final step that would have completed his attachment to that order, and that he was still at liberty to go no farther. In leaving the Jesuits he did not, nevertheless, leave the Church, but became thenceforth one of the secular clergy. In the end, however, the struggle between the influence of all the earlier associations of his life and the claims of what his reason now convinced him to be the truth, became too great to be longer endured, and he determined to sever his connection with Roman Catholicism. Had he gone no farther than a public announcement of this change of religious belief, the outcry against his apostasy would, in such a country as Belgium, have doubtless been loud and long. But, as if to leave no doubt of his secession, he, on March 21st, 1901, married Mlle. Henriette van Gobelschroy. That one who had been all his life a priest should take such a step could not but intensify the persecution that was gathering around him. Many bitter, unworthy, and baseless reproaches were heaped upon him, and many old and intimate friends now shunned him. A man of his kindly nature could not but feel deeply the insinuations and misrepresentations to which he was subjected. Perhaps I may be allowed to translate a few lines from the last letter that I received from him, which may show how he himself looked upon the step that he had taken. After thanking me for my good wishes on what he calls 'my act of moral emancipation and my marriage,' he proceeds thus :

> 'If I had had an opportunity of seeing you I should have been able to tell you in detail the struggles through which I have passed in order to gain this precious human liberty, which at last I enjoy. To-day a great calm reigns within me, such as one feels when one has done one's duty, and I have now, moreover, the consolation which only a family-hearth can give. I can enjoy my lot and throw back upon my past such a look as the traveller, arrived near the end of his journey, may cast on the rough and perilous paths which now lie behind him. Different roads lead to the truth, which must be the beacon light towards which we aim, and, how thick soever may be the night of falsehood and error, those who will can reach that goal. I have now the deep happiness of being one of these.'

A fatal disease, which had been insidiously making progress in his constitution for some years, and for which he had undergone more than one operation, at last carried him off on the 9th of last July, in the 61st year of his age.

Felix Karrer was born on March 11th, 1825, in Venice, which was then within the dominions of Austria. His father died when he was only four years old, and his mother thereupon removed with him, her only child, to Vienna, where he was educated and where he spent the rest of his long life. After a training in philosophical and legal studies, he received an appointment in the War Department and soon obtained promotion. But his duties there seem to have been little to his taste, and as his mother possessed means which, though not large, sufficed for the modest maintenance of her little household, he determined, when 32 years of age, to abandon an official career and to live an independent life. He had long been fond of stones, and often in his boyhood, to the vexation of his mother, would come home with his pockets full of them. He now gratified this propensity by attending the lectures of the illustrious Suess, who was then a young Docent in the University, teaching palæontology and geology. In Vienna, men of science who have incomes sufficient to enable them to gratify their scientific tastes, without being tied to a professorship or other official post, are much fewer than they are in this country. There can be little doubt that Karrer's unattached freedom not only enabled him to choose the pathways of research that best pleased him, but gave him a peculiar place among his contemporary geologists and palæontologists in Vienna.

He was soon attracted by the fossiliferous Tertiary deposits of the Vienna Basin, and was gradually led to study their minuter organisms, more especially their foraminifera. To enable him to pursue this line of investigation, he obtained the use of a window in one of the halls of the Hofmineralien-Kabinett. His friend Theodor Fuchs, with whom he was so intimately associated in that institution, relates that Karrer's equipment at his window consisted only of a broad board and a few boxes, yet that, with his practical habits and scrupulous orderliness, he was able there to gather together and stow away everything that was requisite for his work, coming day after day as punctually as any official. He sat at that window-board for more than five-and-twenty years, until the transference of the Collections to the new palatial Museum. Nearly the whole of the personal staff of the

Institution had changed during that time. Only Karrer remained steadily in his place, untouched by the passing years, the centre and living chronicle of the Kabinett.

His first paper, on the structure of the Eichkogel near Mödling, was published in 1859, in the 'Jahrbuch' of the Geologische Reichsanstalt. His attraction towards the investigation of the Foraminifera resulted in a long succession of memoirs, which formed his most important contribution to science. In association with Fuchs, he made many excursions to study the geology of the region around Vienna, and the two friends gathered together the results of their researches in a series of 'Geological Studies in the Tertiary Formations of the Vienna Basin,' which appeared in the 'Jahrbuch' from 1868 to 1875. The underground water-system of the same region in its geological relations likewise occupied much of his thought, and formed the theme of a number of papers by him. Chief among these is the elaborate monograph which forms the 9th volume of the 'Abhandlungen' of the Reichsanstalt, published in 1877. In this work, which is a study of the Tertiary formations on the western border of the Alpine part of the Vienna Basin, he discusses the geological relations of the various thermal and other springs in that basin, and gives sections illustrative of the structure of the ground traversed by the water-channels, together with copious lists of the organic remains obtained from the strata therein represented.

Karrer likewise devoted his energies to the development of some departments of industrial geology, particularly in regard to building-materials. He took an active part in the affairs of several Societies, more especially of the Scientific Club, of which he was for many years Secretary. He was enrolled among the Foreign Correspondents of our Society in 1890. Eminently courteous and ever ready to assist others, he was a great favourite with all who knew him. He was twice married. His first wife died without children, but by his second marriage he had a son and two daughters. All through his life he enjoyed remarkably-good health. He was never seriously ill, and at the end of sixty years he retained the bearing of a youth. In 1902 he began to suffer from dyspepsia, and an attack of influenza still further afflicted him. In the early spring of last year he was so far better as to be able once more to visit the Museum; but it was now as an enfeebled old man. He died calmly on the morning of April 19th, 1903.

The death of William Talbot Aveline severs one of the few remaining links connecting this generation with the heroic age of English geology. Born in 1822, he joined the staff of the Geological Survey under De la Beche in 1840, when he was only eighteen years old. At first he was stationed for a short period in Somerset, on the Mendip Hills, but soon afterwards was transferred to South Wales, the survey of which had now been begun. At Fishguard he had as one of his associates Andrew C. Ramsay, who had been appointed to the staff a year after him. In those days such detailed mapping as is now required had not been dreamt of. De la Beche, having made a masterly set of maps of the region south of the Bristol Channel, was anxious that the country on the north side of that estuary should be surveyed in the same broad, generalized, and rapid manner. Nor in the state of knowledge of the rocks at that time would any more detailed style of mapping have been practicable. Nothing was known of the subdivisions of the older Palæozoic rocks there, and the condition of English petrography did not admit of any detailed treatment of the igneous masses.

The surveyors were thus enabled to push on with comparative rapidity across Southern and Central Wales. The older Palæozoic rocks were represented on the maps by one colour, and no attempt was made to discriminate the varieties of the igneous rocks. But in the course of years the necessity for greater detail came to be strongly impressed on the minds of the more experienced members of the staff, particularly Ramsay, Aveline, Jukes, and Selwyn. The masterly researches of Sedgwick and McCoy had shown that what had been taken for Lower Silurian strata belonged really to the upper division of the system. Ramsay, realizing the great stratigraphical importance of the striking break between the two series at Builth, had joined with Aveline in reading before this Society, in 1848, a 'Sketch of the Structure of Parts of North & South Wales,' in which the nature and significance of this great unconformity and overlap were clearly stated. Aveline subsequently traced in North Wales the persistent group of the Tarannon Shales, and showed how distinct is the horizon that they occupy. The necessity for some revision of the early published maps was recognized by Ramsay, long before he could obtain the consent of De la Beche to undertake it. At length, as the last official act of his life, the illustrious Director-General, then near his death, agreed that the revision should be carried out. Aveline and J. W. Salter had been employed to trace the boundary-line between the Lower and Upper Silurian formations in Shropshire and the adjacent tracts of Wales; and Aveline was now commissioned, in 1855, to proceed to South Wales to correct the obvious inaccuracies of the maps of that region, to insert important stratigraphical boundary-lines, and to revise the igneous rocks, especially separating the basic from the acid series. At the end of the letter of instructions sent to him by Ramsay came this injunction: 'Finally, do not spare horse-flesh or car-hire to do it quickly.'

When Ramsay was making his preparations in 1854 for commencing the Survey in Scotland, he thought at first of taking Aveline as his chief assistant in the work, but the pressure of the revision in South Wales led to the abandonment of this intention and the substitution of Mr. H. H. Howell in his stead. When I first joined the Survey in 1855, the original intention of the Local Director had been to place me with Aveline in Pembrokeshire; but this idea was likewise abandoned, partly from the need for pushing on the Scottish Survey, and partly from the good progress already made in the South Welsh revision. But I well remember the account of Aveline given me at that time by Ramsay—a tall, dark, silent, big-booted man who strode with gigantic steps over the hills; whose eyes seemed always directed towards the front, but never let anything escape them; who wrote like a schoolboy, but was the ablest field-geologist on the staff. Ramsay's diary contains an entry in which, referring to a meeting that had been arranged with Aveline among the hills of North Wales, he draws the following picture of his colleague:—

> 'While loitering about, taking a final look, I spied Aveline coming down anxiously, with his hat pulled over his eyes, his coat-collar turned up, his gaiters hanging about his heels, taking long strides and looking out ahead, but never holloaing, as another man might have done.'

His silent demeanour passed into a proverb in the Survey. It probably reached its climax when, in company with one of his junior colleagues, he spent a whole day among the Welsh hills, and his conversation was said to have consisted only of two words. In the morning, as he passed a crag of rock, he tapped it with his hammer, and remarked 'Grits.' In the evening, on the way homewards, he had to chip another block, and again broke silence with 'more Grits.' And yet there were times when, in congenial company, his natural reserve and taciturnity would almost melt away, and when his eyes would glisten as he told some recollection of old

Survey days. His gentle, kindly, modest nature made him a great favourite among his colleagues and friends.

When in 1867 the organization of the staff of the Geological Survey was enlarged and re-arranged, Aveline became what was called 'District Surveyor,' and was entrusted with the charge of the mapping of the Lake District. For the next fifteen years he continued to reside in that region, until on reaching the age of 60 he claimed his retirement. Quitting the Survey in 1882, he retired to his paternal property at Wrington, in Somerset, and lived there as a country-squire, looking after his farm and attending to his family. As he always wrote with difficulty and hardly ever save under official compulsion, he made no contributions to science except his share in the Survey Memoirs, and now and then a letter to the 'Geological Magazine,' when some published statement stirred him into unwilling effort. Elected into this Society as far back as 1848, he seemed almost to have already passed away from us when the Council in 1894 awarded to him its Murchison Medal. This appropriate recognition of his long years of arduous toil in the service of geology gave him the keenest pleasure.

He had found his Somerset home increasingly inconvenient, on account of its distance from any centre of life, so that in the end he gave it up and settled finally in London, where he spent his last years and where he died on the 12th of May, 1903, at the age of 81.

The value of the geological work achieved by Aveline is not to be estimated from the number or importance of the memoirs and papers which he contributed to the literature of the science. As terse descriptions of the local facts which he had observed, these publications will always deserve attention. Most of them are to be found among the Sheet-Memoirs of the Geological Survey. He was an admirable field-geologist, with a keen eye for geological structure and a rare capacity for accurate mapping. It is by his maps that the nature and importance of his scientific work must be judged. No one who, with these maps in hand, has followed in his footsteps among the crags of North Wales, can fail to recognize his geological prowess. In the bede-roll of the Geological Survey few names will stand out more prominently than that of William Talbot Aveline.

Robert Etheridge was born at Ross, in Herefordshire, on December 3rd, 1819. Having come in his youth to Bristol, he was engaged in business there during his earlier years. But that he employed his leisure in natural-history pursuits is evident from the fact that at the age of 31 he was appointed Curator of the Museum of the Philosophical Society of Bristol. With the facilities for research which he then obtained, he made himself familiar with the Secondary rocks and their fossils, so well developed in the region around his home. His knowledge in this department of our science was recognized to be so exceptional, that in the year 1857 he was offered and accepted the post of one of the palæontologists in the Geological Survey at Jermyn Street, under the leadership of Murchison. At that time J. W. Salter, who was in the full vigour of his work as palæontologist, took charge more especially of the invertebrate palæontology of the Palæozoic formations; that of the Secondary and Tertiary groups was accordingly now put into the hands of Etheridge, who likewise gave demonstrations to the students at the Royal School of Mines under Huxley. He had previously had some experience in lecturing at the Bristol Mining School, and in 1859 he published the substance of his prelections there in the volume entitled 'Geology: its Relations & Bearing upon Mining.' In 1863 he succeeded Salter as Palæontologist to the Survey.

All through his life Etheridge was singularly industrious, busy at his various tasks, early and late; but the published papers and books which he has left furnish a wholly inadequate idea of the amount of work which he accomplished. He was constantly engaged in the details of a museum, determining, labelling, arranging, and cataloguing specimens. Much of this labour was severe and unceasing, but as it made little outward show it hardly, perhaps, received the recognition which it deserved. Yet, had it been pretermitted, the effects of the want of his skilled eyes and deft hands would soon have been apparent in the cases of the Museum. Further, during his connection with the Survey, he was charged with the preparation of lists of fossils for the various Memoirs—a task demanding care and accuracy, involving often much time and trouble, yet finally represented in print sometimes by but a few pages of text and a series of tabular statements, buried in the appendix to an official pamphlet composed of flimsy paper, badly printed perhaps with old broken type, and sold not infrequently at a prohibitive price.

Yet, notwithstanding the claims of the Museum and Survey, he contrived to find opportunity now and then to write a non-official paper on some of the subjects which came under his observation. The more important of these communications were read before this

Society. Among them was his elaborate account of the stratigraphy of Devon, which he was induced to undertake at the request of Murchison. Jukes had at that time promulgated certain views, which the Chief looked upon as heretical, regarding the Devonian system, and the Survey-Palæontologist was deputed to test their accuracy. He spent many weeks on the ground, and came back to support what had long been the orthodox faith. The world has not accepted the contention of Jukes. No one, however, who has attempted to understand on the ground the succession and tectonic relations of the Devonian rocks of Devon and Cornwall, can fail to be convinced that whether the accepted view as to the order of succession shall ultimately be established by detailed mapping or not, it was certainly founded in ignorance of the extremely-complicated structure of the region. Even yet, after all these years of patient investigation, reinforced more recently by the minute field-researches of the Geological Survey, the stratigraphy of that region of the country is far from having been unravelled and understood.

Other papers by Etheridge during his Survey-career, to which reference may be made here, are his account of the Dolomitic Conglomerate of the Bristol area, and more particularly his two Presidential Addresses to this Society, embracing as they did an enormous mass of detail which, though of temporary interest, has now little more than a historical value. His position at Jermyn Street made him an official referee, to whom specimens of fossils from all parts of the world were submitted for determination. A number of his reports on these were submitted to this Society, and are to be found in our Quarterly Journal. As a notable example of the laborious tasks which he undertook, allusion may be made here to his stratigraphical and zoological 'Catalogue of British Fossils,' wherein he attempted to give the position of each species in the geological formations, in systematic grade, and in scientific literature. Only the Palæozoic portion of this work has been published, the Mesozoic and Kainozoic portions remaining still in manuscript. These and all the other similar works of Etheridge bear witness to his remarkable neat-handedness. Page after page and table after table may be seen clearly written out, with few or no corrections, and now and then accompanied by a cleverly-drawn and coloured geological section in illustration of some question of stratigraphy.

In 1881 Etheridge quitted the Geological Survey to accept the post which was offered him of Assistant-Keeper of the Geological

Department of the British Museum, where he remained for ten years until he retired from the public service in 1891. While there he had a still ampler field for the exercise of his special gifts. After his retirement, his mental activity remaining unimpaired, he was employed in preparing and arranging in the Museum a stratigraphical collection of British rocks illustrative of the geological formations of our islands. This task afforded, again, full scope for his facility in drawing neat and effective sections, which, with coloured maps also constructed by him, make the specimens greatly more interesting and instructive.

In his later years he was often consulted as an expert in questions of water-supply, search for coal, and other cognate subjects. Among these employments the latest, on which he was engaged almost up to the time of his death, was the coal-boring at Dover, in relation to which he acted as geological adviser to the promoters, and where his knowledge of the Secondary rocks enabled him to recognize each stratigraphical horizon that was pierced before the boring-rods entered the Palæozoic formations.

Etheridge became a Fellow of this Society in 1854, while still Curator of the Museum at Bristol. After he settled in London he was a constant attendant at our meetings, and some of his phrases and mannerisms are pleasantly remembered by his surviving contemporaries. He was elected into the Royal Society in 1871. In 1880 he received the Murchison Medal, and in the same year was elected President of the Geological Society. He was the first recipient of the Bolitho Gold Medal of the Royal Geological Society of Cornwall. His gentle, kindly nature gained him troops of friends. He was ever ready to assist anyone who came to profit by his knowledge and experience. Up to the last he had enjoyed excellent health, and dined out with friends on the anniversary of his birthday, on December 3rd. Soon thereafter, however, he caught a chill, which rapidly developed into bronchitis, to which he succumbed on the 18th of the same month, in the 85th year of his age. A representative company of his friends, among whom were a number of Fellows of this Society, gathered round his grave in the Brompton Cemetery, and saw him laid not far from where his old chief Murchison rests.

In Maxwell Henry Close Ireland has lost her most distinguished glacialist, one of the pioneers to whose labours we are not a little indebted for the progress of glacial geology in the British Isles. He was born in Dublin in 1822, was educated partly at Weymouth, and took his degree of B.A. at Trinity College, Dublin, in 1846, and M.A. in 1867. At the age of six-and-twenty he was ordained as a clergyman of the Church of England, and from 1849 to 1857 was Rector of Shangton, in the south of Leicestershire. Having conscientious scruples as to retaining an office which he had obtained under the system of lay-patronage, he resigned the living, and then became Curate of Waltham-on-the-Wolds, a village on the Jurassic scarp between Melton Mowbray and Grantham—a position which he continued to hold until, in 1861, soon after the death of his father, he returned to Dublin, which capital thenceforth became his permanent home.

He had already begun to study the geology of his native country. As far back as the year 1863 he read to the Geological Society of Dublin a paper in which he discussed the nature and origin of slickensides. But it was the glaciation of the country that, from the beginning of his career, especially fascinated him. In pursuit of the trail of the old ice-sheets, he travelled far and wide over Ireland, and gained such a knowledge of the subject as enabled him to present, for the first time, a luminous account of the evidence that the island had once been cased in land-ice which moved off in all directions to the sea. In the year 1864 he began his series of glacial memoirs with one on the phenomena displayed in the district around Dublin, which was read before the Geological Society there. It will be remembered that, at that time, although a few British pioneers had come to the conclusion that the phenomena of the striated rock-surfaces all over these islands, and the origin and distribution of the Boulder-Clay, could only be accounted for by the action of sheets of land-ice, the great majority of the leaders as well as the rank and file of our geological army still stoutly held to the theory of submergence and floating ice. Maxwell Close, however, from the evidence which he obtained among the Wicklow Hills, soon became convinced that the facts could only be explained on the land-ice theory; and he stated clearly and cogently the grounds upon which this conviction rested. He inferred, from the striated surfaces around Bray, that the ice in that district must have been more than 1120 feet thick; while, from the occurrence of transported and striated stones, he concluded that it was probably much thicker, reaching at least to a depth of 1760 feet, if indeed it did not sweep over the summit of Lugnaquilla itself, which is 3039 feet above the sea. As a proof of his alertness and sagacity as an observer, it may be added that in this first of his glacial papers he noticed the occurrence of striated pavements in the Boulder-Drift, and adduced them to show that, although the ice had exerted enormous erosive power on solid rock, it had also sometimes flowed over its floor of detritus.

He must have spent a singularly-busy time during the next two years, scouring Ireland from one end to the other in search of the traces of the vanished ic e-sheets; for on March 14th, 1866, he read his admirable and classic paper, 'Notes on the General Glaciation of Ireland,' which for the first time gathered together and discussed the striking evidence which that country presents of having been the seat of a continuous mass of land-ice. He was now able to embody on a map the results of his journeys, combined with those already obtained by other observers, and to show the chief centres of dispersion and the directions in which the ice streamed outward to the sea. He was probably the first geologist in these islands to realize that, although the mountains undoubtedly helped to accumulate the ice, they were not indispensably necessary for the formation of a thick ice-covering for he showed that the great central plain of Ireland had undoubtedly been buried under such an icy mantle, which streamed outward in different directions. Reviewing the whole subject, and impartially balancing the arguments for the various explanations that had been proposed, he once more demonstrated the overwhelming evidence in favour of the action of land-ice as the origin of the glaciation and of the Boulder-Drift.

Yet Maxwell Close was no bigoted partizan. He admitted the submergence of the country and the action of floating ice during part of the Glacial Period. In 1874 he called attention to the high-level shell-gravels which had long been known to lie upon the hill-slopes near Dublin up to heights of 1000 and 1200 feet. He believed that these deposits, shells included, had been transported to their present positions by floating ice when the land was sunk to such depths beneath the sea. He thought that they had come from somewhere to the north-west, and from the character of the few and highly-fragmentary shells he inferred that they pointed to the former existence of rather more boreal conditions than those which now obtain in the region.

In association with Mr. G. H. Kinahan, Close published in 1872 a more detailed account of the glaciation of the district of Iar-Connaught, between Castlebar and Galway Bay. Mr. Kinahan had been engaged in the mapping of that region by the Geological

Survey, and embodied in a map the observations made by the Survey of the rock-striæ and drumlins of Boulder-Drift. The data thus supplied enabled Maxwell Close to discuss, in his clear logical manner, the phenomena of ice-action in a small localized centre of dispersion.

Geologists are further indebted to him for his able advocacy of the great extent of geological time, in opposition to the limitations sought to be imposed by the physicists. In 1878 he presented to the Dublin Meeting of the British Association a brief communication on this subject, wherein he contended that some of the physical arguments on which reliance had been placed were unsatisfactory and inconclusive, and left geology still in possession of 'her own strong and unrefuted arguments for the great extent of geological time.' He discussed the question at greater length in his address as President of the Royal Geological Society of Ireland, in February of the same year. In this suggestive essay he showed his marked qualifications for dealing with scientific problems that required mathematical and physical treatment.

In 1878 Mr. Close was elected Treasurer of the Royal Irish Academy, an office which he continued to fill with zeal and efficiency, until he resigned it in March last. He took an active interest in the Academy's business; likewise in that of the Royal Dublin Society. But it was the activity of a quiet retiring nature, careless of self, and only concerned for the welfare of the institutions themselves and of their individual members, as well as for the advance of true science. He was elected a Fellow of our own Society in 1874. He died on September 12th, 1903, respected by all who ever met him and beloved by those who were privileged with his friendship.

William Henry Corfield, who became a Fellow of this Society in 1866, was born on December 14th, 1843, and died on the 26th of August last, in the sixtieth year of his age. He was educated at the Cheltenham Grammar School and at Magdalen College, Oxford, where he obtained a Demyship in Natural Science at the early age of seventeen. In his youth he received a bent towards geological pursuits, inasmuch as in 1863 he was chosen by Daubeny to accompany him in an excursion to Auvergne. He obtained in open competition the Medical Fellowship at Pembroke College, Oxford, took first-class honours in the Natural-Science Schools with chemistry and geology as special subjects, gained the Burdett-Coutts

Scholarship in geology, and afterwards carried off the Radcliffe Travelling Fellowship in medicine. He took the degree of M.B. in 1868, and next year became Professor of Hygiene and Public Health at University College, London. It was in that department of applied science that he spent the remaining years of his strenuous life, attaining in it a high position. Though thus led away from the strictly-geological domain, he always retained his early interest in our science, and availed himself of his opportunities of showing the connection of geological structure with questions of sanitation.

Sir Charles Nicholson, who died on the 8th of November last, in his 94th year, became a Fellow of this Society as far back as 1841. After graduating in Medicine with high honours at the University of Edinburgh, he went at the age of twenty-five to Australia, where an uncle had acquired some property near Sydney, and where he wished to ascertain whether he could himself settle. Having decided to cast in his lot with the fortunes of the young colony, he at first devoted himself with ardour and success to the medical profession. Thereafter he acquired a partnership in a sheep-station, and was gradually drawn into active participation in all the social and political development of the community. He became a member of the first Legislative Assembly of New South Wales, and took such a leading part in its deliberations that he was thrice elected Speaker of the Chamber. His interest in educational progress was especially deep and enlightened. He had an active share in the foundation of the University of Sydney, and was for a number of years the Chancellor of that flourishing institution, endowing it with many valuable gifts, some of which—such as the collection of Egyptian antiquities, which he himself made in Egypt—had a high educational value. He eventually returned to this country, and spent the latter years of his life at the Grange, Totteridge, Hertfordshire. He was knighted in 1852, and in 1859 was made a Baronet. Those who were privileged with his friendship will cherish the memory of his kindly face, his keen appreciation of humour, and his interest in everything relating to scientific and educational progress.

John Allen Brown will be long remembered for the unwearied enthusiasm of his investigations of the Palæolithic gravels of Middlesex. Born in 1831, he succeeded his father as a diamond-merchant. At first, his tastes appear to have been rather geographical than geological, but eventually he was led to turn his attention to the superficial deposits around his home at Ealing which, as that suburb began to grow, were opened up in many places. From this branch of enquiry he hardly diverged up to the close of his life. He succeeded in amassing a valuable collection of stone-implements, which he arranged with much care and thought. The results of his investigations were from time to time embodied in communications to the Ealing Natural History Society and other societies. But these papers were subsequently incorporated and enlarged into his work on 'Palæolithic Man in North-West Middlesex,' by which he will be chiefly remembered. After a long and painful illness he died on September 24th last. He had been admitted into this Society in 1886.

William Vicary was born at Newton Abbot in 1811. When a young man he went to London to gain further acquaintance with the processes of tanning, his father being a tanner at Newton. He established himself in the same business at North Tawton, but retired from it many years ago, and thereafter lived at Exeter. Having thus leisure and a competency, he was able to indulge his tastes for scientific enquiry. A keen observer, he spent much of his time in travelling and collecting, and formed a fine assemblage of Devonian fossils which he bequeathed to the British Museum. He called attention to the fossiliferous character of some of the pebbles in the Budleigh-Salterton Pebble-Bed, and presented to this Society a paper on that subject which, with Salter's accompanying description of the fossils, appeared in 1864 in the twentieth volume of our Quarterly Journal (p. 283). In the same year he was elected a Fellow of this Society. He took interest also in the rocks and minerals of his native county, at one time fixing his attention on the igneous masses and at another on the murchisonite-pebbles and boulders in the Triassic conglomerates. For the purpose of aiding his examination of the fossil corals, he obtained a series of recent species. Vicary gave freely of his knowledge, and helped many geologists in other ways. Although he wrote little, he had wide scientific sympathies. Besides his geological work, he interested himself in meteorological observations and was one of the original contributors to 'British Rainfall,' in the first volume of which, published in 1860, he records a rainfall of 42·17 inches at Exeter. He died at his home in that city on October 22nd last, in his 92nd year.

Charles Henry Gatty, who became a Fellow of this Society in 1862, was born on March 6th, 1836, and was educated at Trinity College, Cambridge, where he took his B.A. degree in 1859 and became M.A. in 1862. From his college-days onward he took a lively interest in the natural-history sciences, especially zoology and geology. Having ample means at his disposal, he was able, not only to gratify his own tastes as a collector, but to assist the progress of the investigations of others. Thus he was early attracted to the Marine Laboratory at St. Andrews, established under the Fishery Board, which was the first institution of the kind founded in this country. Eventually he showed his appreciation of the value of the scientific work that was being accomplished there, by offering £1000 to build a new laboratory to replace the old wooden building which had originally been constructed as a fever-hospital. Subsequently he doubled his donation. He afterwards added still another £500 for furnishing and equipping the establishment, and in the end doubled this subscription also. His generous nature likewise led him to spend his money freely for philanthropic purposes. Thus he built and equipped a hospital for the sick near his home at East Grinstead.

He was himself a keen observer of marine life, and made considerable collections among the Channel Islands and along the southern coasts of England. Although he did not publish his observations, he continually communicated them to those who took interest in the same pursuits. With the Marine Laboratory at St. Andrews he was thus in frequent communication, sending notes of what he had himself noticed in Cornwall or elsewhere, and receiving with lively interest reports of the progress of the work at the northern station. He used to pay a visit to St. Andrews every year, spending most of his time there in the laboratory, until failing health prevented him from travelling so far.

His residence at Felbridge Place, near East Grinstead, was a charming house for a naturalist, surrounded with fine trees and shrubs, haunted by birds of many kinds which were left in undisturbed possession. Dr. Gatty was a Fellow of the Linnean and Zoological Societies and of the Royal Society of Edinburgh. St. Andrews showed its appreciation of his enlightened generosity by bestowing upon him the freedom of the city, while the University conferred upon him its degree of LL.D. He died on December 12th, 1903, unmarried, in the 68th year of his age.

Matthew Bell, one of the oldest Fellows of this Society, joined our ranks as far back as 1845. He was born in 1817, and after his education at Trinity College, Cambridge, passed his life quietly but usefully at his home, Broom Park, Bishopsbourne, near Canterbury. He filled the offices of Justice of the Peace and Deputy-Lieutenant of the County of Kent, and was High Sheriff in 1850. He was sometimes urged to enter Parliament and to contest the old East-Kent division, but he preferred the leisure and retirement of the life of a country squire. He took a share of the county-business, and acted as Director and Trustee of various societies and institutions. He was a liberal benefactor to all the good works that went on around him.

William Francis, although he never took an active participation in the work of our Society, was a familiar friend of many of our Fellows. Born in February 1817, he belonged to the heroic time of geology, and was an eye-witness of the career of many of the distinguished men by whom the success of our Society was early assured. He received a large part of his education in France and Germany, and acquired remarkable familiarity with the languages of those countries. He took the degree of Ph.D. in 1842. His scientific proclivities lay in the direction of chemistry and physics, and he was one of the original members of the Chemical Society In 1842 he founded the 'Chemical Gazette,' and nine years later became one of the editors of the 'Philosophical Magazine'—a charge which he continued to fill until the end of his long life. In 1859 he also became one of the editors of the 'Annals & Magazine of Natural History.' His wide range of scientific attainments and his sound judgment and great tact eminently fitted him for the editorial duties which he so ably discharged. His qualifications for this work were further augmented by his being during most of his life an active partner in the widely-known printing firm of Messrs. Taylor & Francis. He was elected into our Society in 1859. Some of us well remember the warm friendship which existed between him and our former Assistant-Secretary, Mr. Dallas, and the deep interest which he took in the welfare of Mr. Dallas's family.

Hugh Exton, M.D., was born at Huddersfield in January, 1833. At first he was apprenticed to a medical man there, but afterwards studied in London, and then at Leyden and Giessen. He went to the Cape of Good Hope in the 'fifties,' settling in practice at Cape Town;

there he married his first wife in 1861. He then established himself at Grahamstown, and about 1870 made a long trip northward in what is now Rhodesia, and there he gratified his taste for natural history; while shooting big game he had narrow escapes from danger, being cool and tactful. On his return he decided to settle at Bloemfontein. Here he had an extensive practice, and was highly respected by Boer and European alike. During his long stay at Bloemfontein he was a member of the Town Council, and was elected Burgomaster (Mayor) two years in succession. He was, moreover, the founder of the Museum there, and was its active Curator for some years. He came to England in 1883, with some of his family, and especially enjoyed the advantages of his stay in London. On his return to South Africa he took up his residence at Johannesburg, with a busy practice, becoming President of the Medical, Natural History, and Geological (South Africa) Societies. In 1883 he was elected a Fellow of the Geological Society of London, and contributed a note and plan, with specimens, of the gold-bearing rocks of the Witwatersrand.

On the outbreak of the War in 1899, Dr. Exton acted as Civil Surgeon with the British troops. He was stationed in the Hospital at Ladysmith from the time of its relief (1900) until a few months before the Declaration of Peace (June, 1902); these few months were spent in the military hospital at Harrismith, where he suffered much from the very cold winter. He finally went to King William's Town (British Kaffraria), where he died suddenly on January 7th, 1903.

Dr. Exton has left five sons, one of whom is in the medical profession; the others are interested in mining, engineering, and photography.

The Council of the South African Geological Society on December 7th, 1902, received his resignation of the Presidency, and gratefully acknowledged his services and help ever since the formation of the Society in 1895. In the funeral-sermon at St. Mary's, Johannesburg, his friend the Rector said of him that 'he spared neither time nor pains in doing good work.'

He was an enthusiastic Freemason (pastmaster) and an ardent geologist. The results of his researches at Ladysmith he contributed to the 'Geological Magazine' in 1891, in his Notes on the Neighbourhood of Ladysmith, in Northern Natal: (1) with reference to the local intrusive igneous rocks (chiefly andesite-diabase); and (2) on some travelled blocks, with peculiar structure, in the Ecca

Shales of the district. Lastly, at Harrismith he devoted much time to collecting specimens from and comparing the strata of the neighbouring hills; but his notes have not been published.[1]

Walter Drawbridge Crick was born at Hanslope on December 15th, 1857. Beginning life as a clerk in the Goods Department of the London & North-Western Railway Company, he afterwards became a traveller for a firm of shoe-manufacturers in Northampton —an occupation which brought him into intimate acquaintance with much of the North of England, and of Scotland and Ireland. At last, in 1880, while still a young man, he started in business with two partners as a firm of boot-and-shoe manufacturers in the same town, and continued to increase in prosperity until, in the end, the enlarged business passed entirely into his own hands. Early in life he had attended classes in chemistry and geology, and became an enthusiastic field-naturalist and collector of fossils. As his worldly means increased, he added other subjects of interest to his collecting-list—such as first editions of standard English literature, choice bindings, book-plates, coloured prints, stamps, coins, English porcelain and furniture. But geology and conchology continued to be his favourite recreations. He succeeded in gathering together a valuable collection of specimens, and gave particular attention to fossil gasteropoda and foraminifera. He took much interest in the local institutions of Northampton, especially the Natural History Society and the Free Library. He joined the Geologists' Association in 1886, and was elected into our Society in 1892. For the last four years he had been aware that his tenure of life was feeble; and at last, after only a few days' illness, he succumbed to syncope resulting from an attack of *angina pectoris*, on December 23rd, 1903, in the 47th year of his age.

---

## CONTINENTAL ELEVATION AND SUBSIDENCE.

As it is customary at this Anniversary that the occupant of the Presidential Chair should offer to the Society some observations on the progress of Geology during the preceding year, or on some special department of the science which seems to him worthy of

[1] This notice of Dr. Exton has been written by Prof. T. Rupert Jones, F.R.S.

attention, I have been unwilling that this time-honoured usage should be wholly omitted from our programme to-day. No one can more keenly regret than I do the enforced absence of our President, and the consequent loss of the brilliant and suggestive essay with which, had his health permitted, he would doubtless have favoured us. I will not pretend to undertake to fill the gap thus occasioned. All that I can attempt is to ask your attention for a little to an old and familiar problem which has, during recent years, once more come prominently forward in the copious literature of our science. I refer to the question of Changes in the relative Levels of Sea and Land, and I propose to offer a short summary of the present condition of the evidence which the British Islands afford for the discussion of this subject.

You are well aware that, among the later events in the geological history of Western Europe, few have attracted more notice or have given rise to more prolonged discussion than those which imply changes in the relative positions of sea and land. Without entering into the history of the controversy which began on this subject in the middle of the eighteenth century, I may remind you that Celsius in 1743 maintained that the proofs of apparent rise of land in Sweden were to be explained by a measurable sinking of the surface of the sea. This view was supported by Linnæus, but did not meet with universal acceptance, some observers holding that it was the land which was rising. An important contribution to the discussion was made in 1802 by Playfair, in his immortal 'Illustrations of the Huttonian Theory.' He conceived that

'in order to depress or elevate the absolute level of the sea, by a given quantity, in any one place, we must depress or elevate it by the same quantity over the whole surface of the earth.' (*Op. cit.* § 392, p. 446.)

He held that, although there is reason to believe that changes in the solid ocean-floor do take place, which may affect the level of the surface of the water, yet that such changes probably are comparatively slow and imperceptible. He concluded, therefore, that

'the simplest hypothesis for explaining those changes of level, is, that they proceed from the motion, upwards or downwards, of the land itself, and not from that of the sea.' (*Op. cit.* § 393, p. 447.)

This deduction was generally accepted by geologists during the greater part of last century, although it was disputed by a few writers who maintained that, from various causes, the level of the sea must be subject to considerable change.

Further consideration of the subject has shown that, while Playfair's conclusion may be accepted as a true explanation of local changes of relative level, yet that alterations of sea-level, wide in their geographical extent and serious in their vertical amount, may be brought about by movements of the hydrosphere, and without any movement, upward or downward, of the land. It is now recognized, for example, that the attraction of masses of high land must seriously raise the level of the adjacent seas, and that a similar effect will follow from the accumulation of a massive ice-cap at either pole. There can be little doubt, also, that during the secular cooling and contraction of the planet, the floor of the ocean-basins is progressively sinking, and that the consequence of this subsidence must be a proportionate emergence of land. But we are profoundly ignorant of the rate at which such subsidence takes place. Probably it is, on the whole, exceedingly slow, although it may be varied by occasional collapses, which, when they take place, doubtless give rise to gigantic seismic waves.

The objections which Robert Chambers and others made to the acceptance of Playfair's doctrine of the practical invariability of the sea-level have been augmented by various writers in more recent years, and most notably by my distinguished friend Prof. Suess. After a detailed investigation of the evidence adduced in favour of the elevation and subsidence of land, the great Austrian geologist has come to the conclusion that this evidence has been misinterpreted, that there are no vertical movements of the lithosphere (except such as may be connected with the secular contraction of the planet, as in the formation of mountain-chains), and that the doctrine of the slow uprise and sinking of countries is a mere phantasy, like the old 'Erhebungstheorie,' of which he regards it as a relic. This view he has interwoven in the magnificent and impressive picture which he has drawn of the grand march of the evolution of the earth's surface-features. Let me not be thought to be wanting in admiration of his great 'Antlitz der Erde,' if I venture to express my dissent from this particular doctrine, which is there expressed with all the fullness of knowledge and literary skill of which its author is so consummate a master.

Prof. Suess's opinions as to the secular elevation and depression of land have not escaped opposition and criticism, especially on the part of the geologists of those countries from which the classic examples of terrestrial upheaval have been drawn. But coming to us, as they do, from one gifted with such high powers of philosophic analysis, who has himself looked at some of the evidence on the ground, and has diligently perused the literature of the subject, they deserve the most serious consideration. It may serve some useful purpose, therefore, if we pass in brief review the state of the evidence presented in our islands for the discussion of this disputed problem.

No features in British geology are more familiar than the abundant proofs which have been brought forward of comparatively-recent changes of level, both in an upward and downward direction. A somewhat complex series of oscillations has been recognized, regarding the true amount and sequence of which opinions are still divided. It is no part of my present purpose, however, to review the whole length and breadth of this complicated piece of geological history. I will not enter upon the consideration of the sequence of the successive oscillations of which the records remain more or less clearly preserved. For the discussion which I propose it will be sufficient to consider the character of the evidence that will best furnish answers to the two questions: 1st. What reliable proofs can be adduced of Pleistocene and post-Pleistocene changes in the relative levels of land and sea?; and, 2ndly. How far do these proofs carry us in the endeavour to ascertain whether the changes have resulted from oscillation of the sea-level, or from movements of the solid land?

In all such discussions it is difficult to avoid the use of a long-established terminology, which has been generally accepted as correctly expressive of the facts to which it is applied. We have been accustomed to speak of the movements as inherent in the land rather than in the sea. But it may be desirable, in our examination of the facts, to avoid the use of such terms as Elevation or Upheaval, and Depression or Subsidence, as too obviously begging the question to be answered. Instead of using these phrases I will speak of the Emergence and Submergence of Land, the former being the negative and the latter the positive movements of Prof. Suess's nomenclature.

## I. Evidence for the Emergence and Submergence of Land.

### (i) Emergence.

Various kinds of evidence have long been cited by geologists, in proof that what is now dry land has once been under the sea. The favourite demonstration has been based on the presence of marine organisms upon *terra firma*; and this argument must be admitted to be in most cases sound. But it is now recognized that the mere occurrence of these organisms may not be itself a proof of former submergence, for they may by various means be transported to the land, without necessarily implying any change of level. We know, for example, that by a body of ice, moving out of a sea-basin upon the land, the shells of a sea-floor may be scraped up and carried above sea-level. Up to what heights this kind of transport is possible, or probable, we cannot at present say. But that it is a *vera causa* seems to be put beyond question by the broken condition of the shells, the mixture of species belonging to very different depths, and the manner in which they are dispersed through the various kinds of Drift in which they lie.

To keep the discussion within due bounds, I shall limit my remarks to the evidence of emergence supplied by what we call Raised Beaches. Geologists in the British Isles have long indulged the confident belief that these beaches afford demonstrative proof of changes in the relative levels of sea and land. The abundant and striking examples of them around our coasts have been universally accepted among us as marking former sea-margins, whether the sea be supposed to have risen upon the land or the land to have been upheaved above the sea. The recurrence of precisely-similar terraces along the western coast of Norway, but on a still more impressive scale, has been regarded as furnishing evidence of an extensive emergence of land, from the south of Britain to the northern end of the Scandinavian peninsula. Prof. Suess, however, seeks to show that, at least as regards the north-western coast of Norway, these opinions are based upon a misreading of the evidence. After his visit to that region, and his study of the literature of the strand-lines there so wonderfully developed, he has come to the conclusion that the Norwegian fjords furnish no argument against his doctrine that there has been no recent upheaval of the land. He asserts that

> 'we must interpret all the seter [rock-shelves] and the great majority of the terraces in the fjords of Western Norway as proofs of the retreat of the ice that once covered so much of the peninsula, and not as proofs of any oscillations of the surface of the sea, still less of any movement of the solid land.' [1]

It would widen the enquiry too much to enter upon an examination of the evidence, as it is presented in Scandinavia. But, having myself been all my life familiar with the strand-lines of this

[1] 'Das Antlitz der Erde' vol. ii (1888) p. 457.

country, and having traced those of the Norwegian coast from Bergen to Hammerfest, I may perhaps be permitted to point out, as deferentially as I possibly can, one or two of the insuperable difficulties with which, as I venture to think, Prof. Suess's theoretical explanation is beset. He has, as it seems to me, unwittingly confounded two sets of beach-lines, which differ a good deal from each other in general character, and are entirely distinct in origin. Availing himself of the remarkably full and interesting researches of Scandinavian geologists regarding the glaciation of their country, he dwells upon the importance of the terraces left by the freshwater lakes that were dammed back by the great ice-sheet as it retired. He believes that these phenomena extended even to the Norwegian coast, and that the strand-lines of the fjords, whether in the form of platforms eroded out of the solid rock (seter) or terraces of sediment, mark former levels of lakes that filled these valleys when their mouths were blocked up with the ice-sheet. As the lowest of these strand-lines includes sands and gravels crowded with marine shells, he is compelled to admit that it marks a former sea-beach. But he endeavours to discriminate between it and the other horizontal shelves, which follow it in parallel lines at higher levels. He affirms that the latter present a series of 'characters absolutely irreconcilable with what we know of the action of the sea along a shore'—such as the series of fragmentary terraces found at increasing heights inland, their absence from the parts near the general coast-line, and the breadth of the seter. He passes lightly over the fact that some of these higher terraces have yielded marine organisms which are progressively of more Arctic character, according to their altitude, and according, consequently, to the antiquity of the sediments in which they lie.

Now, according to the experience of those northern geologists who have specially studied Scandinavian glaciation, the lakes that were formed by the ponding-back of the drainage against the flanks of the ice-sheet lie to the east of the watershed of the peninsula. These observers have ascertained that when this ice-sheet was waning, it retreated eastward from the backbone of the country and lay on the eastern or Swedish slope, leaving a gradually-increasing breadth of ground clear of ice. The streams flowing eastward over this liberated area had their drainage arrested against the margin of the ice; and hence arose a vast series of lakes which lasted for longer or shorter periods, until, by the continued creeping-backward of the ice, their contents were drained off to lower levels. A multitude of records of old water-levels or 'strand-lines' was thus left over the surface of the country. It is the opinion of Scandinavian geologists that all the terraces not of marine origin lie within that area.[1]

As one of the distinctive characters of the shore-lines left by the glacier-lakes, the author of the 'Antlitz der Erde' cites the occurrence of the rock-shelves or platforms (seter) eroded out of the solid rock, and he refers the origin of these common features of the fjords to the daily oscillations of temperature at the surface of the lakes.[2] I shall try to show, by a reference to the abundant examples of such rock-shelves in our own islands, that this explanation is at least inadequate. If, however, for a moment, we grant that the strand-lines, including the seter of the Norwegian fjords, do mark levels of former freshwater lakes, it is obvious that, in order to pond the drainage back and produce these lakes, the mouths of the fjords must have been in some way blocked up by a barrier which has disappeared. If this barrier were land-ice, as Prof. Suess appears to assume, the water would rise behind it, until, if the overflow found no escape into the Atlantic, it would pass over the watershed, and joining the various bodies of water that were there intercepted by the great Swedish ice-sheet, would eventually find its way into the Gulf of Bothnia. There would thus be two huge bodies of ice, between which the drainage was accumulated.[3] We must remember, however, that the strand-lines are not confined to the fjords, but sweep round the coast on either

[1] See two important papers by A. M. Hansen in the Christiania 'Archiv for Mathematik og Naturvidenskaberne.' The first of these, vol. x (1886) pp. 329–52, deals with the occurrence of seter or strand-lines in connection with ice-dammed lakes at great heights above the sea, ranging from 652 to 1090 metres. The second, vol. xiv (1890) pp. 254–343, & vol. xv (1892) pp. 1–96, contains a full discussion of the character, distribution, and origin of the strand-lines of Norway. See also G. de Geer, Sveriges Geol. Undersökn. Ser. C, No. 161, 1896; & G. Andersson, *ibid.* No. 166, 1897, p. 5. Although the largest and most abundant lakes, formed during the retreat of the ice-sheet, undoubtedly lie on the eastern or Swedish side of the watershed, it is not improbable that others were produced also on the western side by the irregular way in which the ice disappeared. Dr. C. Sandler has suggested that the mouths of the Norwegian fjords may have been blocked up by a succession of vast moraines, which kept back the sea and turned these sea-lochs into inland lakes. But the difficulties in the way of the acceptance of this explanation are insuperable. See Petermann's Mittheil. vol. xxxvi (1890) pp. 209, 235.

[2] 'Das Antlitz der Erde' vol. ii (1888) p. 431.

[3] Dr. Sandler, in the paper already quoted, has considered the possibility of such a flanking ice-dam, but has dismissed the idea as untenable.

side, and even appear on the islands that flank the mainland of Norway, some of them actually looking out to the open sea. The supposed ice-sheet must therefore have lain mainly outside these islands. But there is absolutely no evidence of any such detached western ice-body, and every reason to believe that it never existed.

At the period of maximum glaciation the ice-sheet probably advanced westward beyond the present limits of the land. But, when it began to retreat, it would naturally creep backward up the fjords, which would be still the main lines of ice-drainage. We can conceive, indeed, that at an early stage of this retreat, a glacier or ice-lobe may here and there have blocked up a large valley and produced a lake, as in the instances cited by Prof. Suess from Greenland. But the strand-lines of Western Norway are not exceptional phenomena. They continue as characteristic features of the coast-line and of the fjords for several hundred miles, and must owe their origin to some general and widely-extending cause. That they are true sea-beaches, as has been generally believed, I have not the smallest doubt.

Fortunately, we possess in our own islands a body of evidence bearing on this question, not certainly as voluminous and impressive as that of Scandinavia, but having the compensating advantage of great simplicity and clearness. On the one hand, the famous Parallel Roads of Glen Spean and Glen Roy, and those of other less-known valleys, stand out as acknowledged relics of glacier-lakes; while round our coasts, on both sides of the country, raised beaches, which have been hitherto regarded as old sea-margins, run for hundreds of miles. These two series of terraces are found close together, yet there is, I think, no difficulty in drawing a satisfactory distinction between them. Indeed, their proximity enables us all the more clearly to perceive their contrasts.

There must, of course, be certain general resemblances between the littoral formations of lakes and of the sea.[1] The erosion produced by the waves or wavelets of a body of fresh water is similar in kind to that performed by the sea, although different in degree. In like manner, the beaches of deposit formed in lakes possess, on a minor scale, many of the characters of those accumulated along the sea-shore. And it may readily be granted that, in isolated exposures of some old beach, it may be difficult or impossible to decide, in default of evidence from elsewhere, whether

[1] This subject has been instructively treated by Prof. G. K. Gilbert in his monograph on Lake Bonneville, U.S. Geol. Surv. Monogr. no. i, 1890.

the phenomena observable are to be assigned to the work of the sea or of a lake. Nevertheless, on a review of the whole evidence, at least as it is presented in this country, I feel very confident that there is no risk of confusion in this matter. The marine terraces maintain their distinctive features up to the very foot of the slopes where the lake-terraces begin, while these in turn are marked by other special peculiarities.

Let any observer who has followed the great 50-foot raised beach along the western coast of Scotland and up the Linnhe Loch to the mouth of the Great Glen, look away to the right hand where the wide Strath of Spean leads into the interior. While yet standing on the platform of the raised beach, if the air be clear his eye may detect the beginning of a line, drawn as with a ruler, at the same height along the slopes on either side of the valley. This is the lowest of the three great Parallel Roads of Glen Roy, and runs at a height of 850 feet above the level of the sea. If he will now ascend into Glen Roy, where the three terraces are best seen, he will soon be struck by the distinctive differences between these old lake-margins and the raised beaches with which he has already made himself familiar. In the first place, he will remark their faintness, as compared with the marine platforms of the coast. Though readily traceable from a distance in their horizontal continuity, they are in many places hardly discernible when one is actually standing upon them. A little examination soon reveals that each of them has been produced mainly by the arrest of sediment washed from the slopes above into the water of the vanished lake. Instructive illustrations of this process may often be observed along the sides of reservoirs which have been constructed in steep-sided valleys: there each prolonged halt of the water at a particular level is marked by a shelf of detritus which, blown by wind and washed down the declivities by rain, is stopped when it enters the water, where it accumulates as a miniature beach.

Here and there, especially on more exposed projections of the hillsides, there has been a little cutting-back by the shore-waves or drifting ice-floes of the old lake in Glen Roy. Occasionally also, where a streamlet has entered the water, its arrested detritus has accumulated as a broad, flat delta or terrace. But it is manifest that, in such limited expanses of water, wind-waves could have had comparatively little erosive power. Nor can we imagine that, even if the water froze, its floe-ice could have had any potent influence in sawing into the rocks of the declivities and producing s e t e r or rock-shelves. Certainly throughout this wonderful assemblage of lake-shores, there is nothing for a moment to be compared to the incised platforms of rock so abundant as part of the raised beaches of the western coast of Scotland. We must remember also that the production of such ice-dammed lakes took place as a mere episode in the retreat of the ice. No means are available to determine what may have been the length of time during which the water stood at the level of any one of these Parallel Roads. We may probably infer, from the absence of well-marked and continuous intervening shore-lines, that the shrinkage of the ice and the consequent lowering of the level of the water were somewhat rapid.

The Parallel Roads of Lochaber, although the most imposing, are not the only examples of the shore-lines of ancient glacier-lakes in this country. Another striking case is that of Strath Bran in Ross-shire, where the glaciers descending from the mountains on each side ponded back the drainage of the valley, and sent it across the present watershed of the country at a height of about 600 feet above the sea. The conspicuous gravel-terraces at Achnashean are a memorial of this vanished sheet of water.[1]

Now, with these undoubted records of ancient lakes, let us compare the structure and distribution of our Raised Beaches. These shore-lines are found, on both sides of Scotland, at approximately the same heights above the level of the sea. They are partly terraces of deposit, and partly true seter or platforms cut out of the solid rock, the same beach presenting frequent alternations of both structures. In general, it may be said that the detrital terraces are found chiefly in bays, sea-lochs, or other sheltered places; while the rock-terraces are conspicuous in more open sounds and exposed parts of the coast, where the tidal currents and wind-waves are most powerful.

As the highest terraces are the oldest, they have been longest exposed to the influences of denudation, and are thus the faintest and most fragmentary. But the dimensions and perfection of a raised beach do not depend merely on age, but in large measure on the length of time that the water stood at that level, and the varying local conditions that favoured or retarded the planing-down of solid rock or the deposition of littoral sediment.

That these beaches unquestionably mark shore-lines of the sea may be inferred on three grounds:—(1) Their position on both

[1] 'Summary of Progress of the Geological Survey for 1898' pp. 175, 176.

sides of the island at corresponding heights. No possible arrangement of ice-dams in the Atlantic and in the basin of the North Sea can be conceived that would have everywhere ponded back the land-drainage to similar levels. (2) Their independence of local conditions. The same terrace may be traced down both sides of a sea-loch and round the coast into the next loch, retaining all the while its horizontal continuity. Not only on the mainland, but on the chain of islands outside, the same parallel bar has been incised, both on the inner or sheltered side and also on the outer flank looking to the open Atlantic. (3) Their organic remains. From the youngest of the beaches up to the highest, the terraces of deposit contain marine organisms which have not been scooped out of some earlier formation, but lie in the positions in which the animals died, or into which they were washed by shore-waves and currents. The fossils of the latest beaches are entirely identical, or almost so, with forms still living in the adjacent seas, while those of the higher beaches are boreal or Arctic.

In some sheltered places, such as the Dornoch Firth, especially near Tain, and some inlets on the west side of the island of Jura, a number of successive bars or terraces of deposit may be observed, up to heights of 100 feet or more above the sea. But there are in Scotland three strand-lines so conspicuous and so persistent that attention may be confined to them. From what has been taken to be their average height above mean sea-level or Ordnance-datum, they are known respectively as the 100-foot, the 50-foot, and the 25-foot beaches.

Here I should like to point out what I have long regarded as a reproach to the geologists of this country. No systematic effort has ever yet been made to determine accurately, by a series of careful levellings, the precise heights of these old shore-lines. We only know that, roughly speaking, a raised beach retains its level for long distances, and appears to lie at the same height on both sides of the country. But we are still ignorant whether or not an appreciable difference of level might not be detected between the western and the eastern development of the same beach, nor do we know whether it would not betray some variation in its height between its northern and southern limits. There seems to be a tendency for the levels of the beaches to rise slightly towards the head of an estuary or sea-loch. But whether this difference is more than can be accounted for by the ordinary elevation of the tidal wave as it ascends a narrowing inlet, remains to be determined.

Obviously, until accurate information is obtained on all ascertainable differences of level in the system of our raised beaches, we must remain unprovided with some of the most important material for a discussion of the history of these beaches. It is surely not too much to hope that one or more observers, endowed with the requisite geological knowledge and geodetic skill, may before long be found who will undertake the investigation of this interesting subject, and thus aid in the solution of a problem which does not merely concern the evolution of our own islands, but is of high importance as a question in geological theory.

The 100-foot terrace carries us back into the Glacial Period. Bones of Arctic species of seals have been obtained from its deposits, and its fine clays and sands point to the settling-down of glacier-mud in sheltered firths. Here and there, especially where it has accumulated in front of a glacier that bore down coarse detritus, it is marked by a thick terrace of unfossiliferous gravel and sand, as in the remarkable green platforms which form so conspicuous a feature on either side of the narrows of Loch Carron. Its absence from the upper part of this and other sea-lochs has been accounted for, on the supposition that these fjords continued to be filled with ice which barred back the sea and broke off there in icebergs. The deeper-water deposits of the period of this beach are probably represented by the Clyde Beds and their equivalents, with their abundant and well-preserved boreal and Arctic shells.

The 50-foot beach is much more perfect than the last-named. It must mark a prolonged halt of the land at that particular level. It is in some places a terrace of deposit, in others a platform (or s e t e) levelled out of the rock. This strand-line also belongs to the Glacial Period. After it was formed, some of the glaciers of Ross-shire and Sutherland came down to the edge of the sea, and shed their moraines upon the terrace.[1] Its organisms are still somewhat Arctic in facies.

The 25-foot beach is remarkably perfect in some firths, such as those of the Clyde and Forth, as well as along many parts of the eastern and western coasts, and it extends into the North-West of England and the North-East of Ireland. It combines both terraces of deposit with rock-platforms or s e t e r, and its abundant fossils are still common in the neighbouring sea. Though it sometimes presents a striking feature in the topography, it probably marks a

[1] L. W. Hinxman, Trans. Edin. Geol. Soc. vol. vi (1892) p. 249.

less prolonged interval of rest than the 50-foot beach. It is not only post-Glacial, but in some places contains traces of Neolithic man.

In the structure of these old sea-margins a feature of special interest is presented by the platforms which have been eroded out of the solid rock, and which afford not a little light as to the origin of the Norwegian *seter*. On the east side of Scotland these platforms have been to a great extent cut in Boulder-Clay—a material that would offer comparatively feeble resistance to erosion. On the western coast, however, the rock-platforms, both of the 50-foot and the 25-foot beaches, have been in large measure cut out of much more enduring materials. The rock-shelves of the east side of Jura have been levelled in hard schists and quartzites; those so conspicuous around the island of Lismore in the Linnhe Loch, out of massive pre-Cambrian limestone. In Mull and the other members of the Inner Hebrides, they have been eroded in various rocks of the Tertiary volcanic series. In the Firth of Clyde, they have been planed down among the sandstones and igneous rocks of the Carboniferous and Triassic formations, as well as here and there in Boulder-Clay.

The surface of these rock-terraces is flat, and usually covered with a thin coating of grass-grown soil through which harder knobs and stacks of the underlying rock here and there protrude. At the inner margin of the terrace, the rocks rise into a cliff or steep bank, the base of which is frequently pierced with caves. That these caves were mainly due to erosion by moving water is abundantly evident in the rounded and smoothed surfaces of their sides. Their floors are often rough with round shingle, which has undoubtedly been the material employed by Nature in their excavation. No one who has made himself familiar with the rock-platforms which at the present day are in course of erosion by the sea along these same coasts, can for a moment doubt that the rock-platforms of the raised beaches which, down to the minutest point, resemble them, have likewise been eroded by the waves of the sea. Nowhere have I seen this lesson more instructively taught than at Kincraig Hill on the coast of Fife, an old volcanic vent which, from a height of 200 feet above the sea, descends in vertical precipices to the edge of the present beach. Round the west side of the hill the three terraces (100-foot, 50-foot, and 25-foot) have been cut out of the volcanic agglomerate as parallel shelves or *seter*. At the foot of the cliffs when the tide is out, one can walk for half a mile upon a broad flat platform, which is now in course of erosion out of the same material by the flux and reflux of the tides in the open estuary of the Forth. Were the land to emerge above its present level, a fourth platform would be exposed along this coast, broader and more perfect than its older predecessors above, but showing all the same family characteristics.

That the daily oscillations of temperature invoked by Prof. Suess in explanation of the Norwegian seter have had their share in the erosion of these Scottish examples, cannot be doubted. But this share is evidently feeble in amount now, although it may have been more considerable during the Glacial Period. More potent as a contributory influence in the erosion of the older terraces, was probably the action of floating ice, driven along the shores by winds and tidal currents. Down to the time of the 50-foot beach, when glaciers in the North of Scotland descended to the edge of the sea, there may have been a good deal of such ice in the more enclosed sea-lochs, where the water, freshened by the discharge of melting snow-fields and glaciers, might itself be covered with a cake of ice. And there was not improbably a good deal more ice in the fjords of Norway. The grinding and rasping action of such ice, driven by gales ashore, has long been remarked. But, in any case, we are justified in regarding the Scottish seter as examples of truly marine erosion, and I can see no reason why those of Norway should not have had the same origin. It is at least clear that the statement that the characters of seter 'are absolutely irreconcilable with what we know of the action of the sea near its surface,' cannot be sustained.[1]

Certain features of the extension of the raised beaches throughout Britain appear to be of fundamental importance in relation to the discussion of the problem of the emergence of land. Though so persistent along both the western and eastern coasts of Scotland, these beaches, as is now well known, do not stretch northward into the Orkney and Shetland Isles. Along precipitous sea-fronts we could not expect to meet with them, but among these islands there are endless sheltered inlets and bays which, had they indented the

[1] As far back as 1874 S. A. Sexe expressed the opinion that the sea does not now incise any strand-lines like the old seter (Universitetsprogram, Christiania, 1874, p. 38). Eight years previously, after a visit to the Norwegian seter, I was convinced of their marine origin, and suggested that their erosion 'may have been due in large measure to the effects of the freezings and thawings along the old ice-foot, and to the rasping and grating of coast-ice. Such, too, may have been the origin of the higher horizontal rock-terraces of Scotland' Proc. Roy. Soc. Edin. vol. v (1866) p. 548.

shores of the mainland of Scotland, would undoubtedly have had their fringe of terraces. The conditions for the development and preservation of the beaches were so entirely favourable, that their absence can only be legitimately accounted for on the supposition that they can never have existed here. Still farther north, among the Færöe Isles, no trace of any raised beaches is to be found among the numerous natural harbours and creeks that break the monotony of the vast ranges of basalt-precipice. Here, again, we cannot suppose that any such beaches were ever formed.

If, now, we turn to the southward extension of the Scottish raised beaches, we find these features beginning to lose their distinctness as they are traced into England. The 100-foot beach, which has not been recognized along the northern coast of Sutherland or in Caithness, appears also to fail before it reaches the English coast. It is well-marked in the estuaries of the Clyde and Forth, whence in a fragmentary condition it has been traced into Wigtonshire on the one side, and to the north of Berwickshire on the other. But no remnants of it appear to have been detected in the North of England.

It is much to be wished that a series of detailed investigations, similar to those desiderated for Scotland, should be undertaken for the far fainter and more fragmentary raised beaches of England and Wales. At present no one has attempted to correlate these shore-lines in the two kingdoms. South of the Tweed the evidence is confessedly imperfect, but although a passing observer may be struck by the absence of the terraces which are so distinctive a feature in Scotland, a more sedulous search might yet detect them in places where they have not hitherto been recognized.

A raised beach standing at a maximum height of about 40 feet above high-water mark has almost entirely disappeared from the eastern coast of England, the only surviving portions being apparently that at Saltburn, and perhaps that at Hunstanton.[1] The presence of Glacial Drift above the raised beach of East Yorkshire would seem to place that old shore-line back in the Glacial Period. It may possibly be coæval with the 50-foot beach of Scotland, perhaps even older. On the opposite side of the island a raised beach at St. Bees stands between 20 and 30 feet above the sea. It might be surmised to be of post-Glacial age, and to belong to the same interval as that which is marked by the 25-foot beach of Scotland and the North-

[1] C. Reid, 'Geology of Holderness' Mem. Geol. Surv. (1885) p. 72.

East of Ireland. But if Mr. Holmes's suggestion be well-founded, this beach may really represent the 50-foot terrace. He is of opinion that the adjacent sunk forest indicates a later submergence, whereby the beach has been brought into its present relative position.[1]

In England and Wales the most continuous and best-preserved examples of raised beaches are to be seen on the coasts of the southern counties. Mr. Clement Reid has traced one of these shore-lines through West Sussex and Hampshire into Dorset, at a height of about 130 feet (or rather more) above the mean sea-level. This terrace is best developed at Goodwood Park, where its sandy layers have yielded numerous foraminifera, together with *Balanus*, *Mytilus edulis*, *Tellina balthica*, *Trophon*, and a *Pholas*-bored boulder of chalk weighing about 2 hundredweight. This raised beach is overlain by 17 feet of Coombe Rock, which, as Mr. Reid has shown, points to Arctic conditions of deposit, and thus throws the terrace back into the Glacial Period. The same observer has noted in many places along the southern coast a succession of shingle-terraces which may mark stages in the emergence of the land.[2]

The lower raised beaches along the coasts of Dorset, Devon, and Cornwall have long been known, although their geological age, their history, and their relation to the later phases of Pleistocene time, have not yet been satisfactorily cleared up. William Pengelly, who devoted so much time to this subject, clearly proved that these beaches do not stand now at their original level, but that after their formation the region was upraised to the amount, as estimated by him, of not less than 70 feet, when the lowest sunk forests flourished as land-surfaces, and that thereafter came a submergence of certainly 40 and perhaps many more feet.[3]

Mr. Tiddeman has shown that, in Gower, on the coast of Glamorgan, a raised beach which lies from 10 to 30 feet above the level of the modern beach, and contains littoral shells of common species, is yet older than at least some part of the Glacial Period, for it is overlain by Glacial Drift. In this case also, its present is probably not its original level. There is evidence of considerable submergence, at a comparatively-late period, farther east in the same

[1] Trans. Cumberland Assoc. pt. ii (1876–77) p. 70.

[2] 'Geology of the Country near Chichester' Mem. Geol. Surv. (1903) p. 40; Geology of the Country around Ringwood' *ibid.* (1902) chapt. ix; & Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 344.

[3] Trans. Devon. Assoc. vol. i (1865) pt. iv, p. 34, & vol. ii (1867) pp. 25, 134.

county and along the southern coast of England, as will be more specially remarked in a later part of this Address; and the inter-Glacial or pre-Glacial raised beaches of the whole of this region doubtless stood at one time higher above the sea-level than they do now.

The raised beaches of Ireland call for no special remark, beyond an expression of regret that they are so few and so fragmentary. The so-called '25-foot terrace' of the Clyde Basin is prolonged into the north-eastern counties of the sister-island, where it lies from 10 to 20 feet above the present sea-level, and has yielded so many worked flints and flint-flakes that it is regarded as not older than Neolithic. The same beach has been recognized at intervals on the northern shores and also down the eastern coast, at least as far south as Dublin Bay. But both along the east and west sides of the island, the general absence of well-marked raised beaches in sheltered bays and inlets, where, had they ever existed, they might have been confidently expected to have been preserved, cannot but strike the eye of the geologist. Recently Messrs. Muff & Wright, of the Geological Survey, have detected an ancient shore-line at Cork Harbour which they have traced, not only within the Harbour, but for a long distance on the shore to the east and west of that inlet. Though only a few feet above the present high-water mark, this beach has been ascertained to be older than the oldest Irish Boulder-Clay, for it is overlain by the so-called 'shelly marl' which was brought in upon the land from the sea-basin. The similarity of position and antiquity between this beach and that underlying the Drift in Gower, is obviously as important as it is interesting. A shore-line, which must be of pre-Glacial or inter-Glacial age, is traceable in the South of Ireland and in South Wales. It has not only survived the erosive processes of the Glacial Period, but it appears to have outlived some serious alterations in the relative levels of sea and land which have taken place since its formation. Moreover, we have to note the fact that neither at Cork nor in Gower does any younger post-Glacial terrace appear to be recognizable. If we might judge from the analogy of other parts of these islands where the succession of raised beaches is tolerably complete, we should infer that if ever any later terrace existed here, it must now be submerged—an inference which, it will be observed, is supported by the evidence of considerable submergence in South Wales, and on the southern coast of Hampshire.

## (ii) Submergence.

Of the various kinds of proof of the submersion of terrestrial surfaces furnished in these islands, I will refer only to two: first, the extension of land-valleys beneath the sea; and, secondly, the existence of what are known as Sunk Forests.

1. That the fjords of Norway, the sea-lochs of the West of Scotland, and the harbours or inlets of the West of Ireland were originally valleys on the dry land, although now deeply submerged, has long been an accepted belief among those geologists who have specially considered the subject. The interval of time which has elapsed since this submergence has not sufficed to fill up with sediment these submarine depressions. By a study of the sea-charts, we can still trace the winding curves of the ancient valleys, and can even here and there detect among them the basins which, when the present sea-bottom was a land-surface, were filled with freshwater lakes. On the sea-floor to the east of our own country and of Scandinavia, such relics of subaërial denudation are less imposingly preserved, yet evidence of the submergence of land-valleys has been noted there also. It must of course be remembered that the land on that side is of much lower altitude than on the western coasts, that the ground slopes gently under the sea, and that the valleys are comparatively insignificant depressions on its general surface. Moreover, the more abundant drainage on the longer slope east of the watershed, and the much greater development of Drift on that side, leads to a far more copious discharge of sediment into the shallow North Sea and the Gulf of Bothnia, and the submarine prolongations of the old land-valleys are thus apt to be buried under recent accumulations of detritus. There may, however, perhaps be another cause for the contrast between the profoundly indented and precipitous western coast and the comparatively low and monotonous trend of the eastern coast. I have long been disposed to believe that the submergence has been greater towards the west than towards the east. In the prolongation of the West-Highland sea-lochs on the floor of the Atlantic outside, the original land-surface sometimes lies 600 feet or more below the present sea-level. The same fact presents itself in Norway, as in the striking case of the sinuous submerged valley which continues the line of the Stor Fjord, south of Molde, for some 50 kilometres (or 31 English miles) seaward, and descends to a depth of 1000 feet below the surface. If the submerged land-surface of North-Western

Europe could be upraised some 600 feet, the submarine prolongations of the sea-lochs would once more become glens and straths, and their rock-basins would again be turned into freshwater lakes.

There is no similar series of well-marked submerged valleys on the floor of the North Sea from which to estimate the amount of submergence of that tract, at least half of which, at no very distant date, formed a land-surface that connected Britain with the rest of the Continent. The charts show this sea-floor to consist of two distinct portions. The northern half forms a plain, which appears to slope gradually towards the north. The southern half, however, rises somewhat rapidly from the edge of that plain into an escarpment that runs in a north-easterly direction for a distance of 500 miles, from off Flamborough Head to the Skagerrak. From the top of this escarpment the surface undulates southward as a higher submarine plain, traversed by the still feebly-traceable submerged valleys of the Elbe, the Rhine, and the Thames, and covering an area of more than 50,000 square miles.[1] An uprise of not more than 300 feet would turn this tract into a rolling plateau of dry land, like the Downs and Wolds of Yorkshire, which are its emerged continuation. Such an amount of uplift would probably be amply sufficient for the transaction of all the later geological history of the region. The conversion of the area into a sea-bottom may not have been a continuous process. It was probably in operation during the early stages of the Glacial Period, and its latest phases come down at least into Neolithic time.

2. The sheets of peat with stools and trunks of trees, known as Sunk or Submerged Forests, and of such frequent occurrence around the coasts of the British Isles, have long been confidently regarded as proofs of recent subsidence of the land. That they generally mark former land-surfaces cannot be doubted, for the tree-stumps are seen to send their roots down into the soil underneath, and manifestly stand in the places where they originally grew. The presence of hazel-nuts, elytra of beetles, land-snails, and other terrestrial organisms, affords further confirmation of this conclusion. The great majority of these vegetable accumulations are found between tide-marks in bays and estuaries, and in many

[1] See the excellent chart accompanying the paper by Mr. John Murray, Proc. Inst. C. E. vol. xx (1861) p. 314. The submerged land-valleys off the coasts of South Wales, Devon, and Cornwall have been described by Mr. T Codrington, Quart. Journ. Geol. Soc. vol. liv (1898) p. 251.

cases they can be seen to pass below the limits of the lowest tides, and thus to be constantly in part submerged. The trees and the freshwater plants must have lived above the reach of the sea, so that they now lie 20 feet or more below the level at which they originally grew: and the conclusion has been drawn that they mark a general subsidence of these islands, to the amount of at least 20 feet, at a comparatively recent date.

I am inclined to believe that this conclusion has been rather too sweepingly drawn. That some of the submerged forests may be satisfactorily accounted for without any change in the level of the land or of the sea, was urgently enforced more than eighty years ago by John Fleming, in reference to the examples first brought to notice by him in the estuaries of the Tay and the Forth.[1] It will be readily understood that, in the later stages of the Glacial Period, when much detritus was swept off the land into the sea, the conditions would probably be especially favourable for the formation of alluvial bars along our coasts, such as are now in course of accumulation for hundreds of miles on the southern coast of Iceland, where some of the features of that period may still be said to linger. Behind these barriers lagoons would be formed, which in course of time might become marshes, and eventually peaty flats, supporting a growth of trees. But when the supply of sediment failed, and the sea, instead of heaping up the bars, began to breach them, the level of the bogs would sink by the escape of their water to the beach, and the tide at high-water would overflow and kill off the forests. Occasionally, owing to the action of underground drainage, the seaward margins of forest-covered peaty flats may have been detached from the main body and launched downward on the beach, even beneath low-water mark.

Prof. Suess invokes changes of this nature to account for the phenomena of the sunk forests around the borders of the North Sea, which he thinks do not indicate any change of level of the land. He believes these changes to be of local origin, due sometimes to downward slipping of the peat-mosses, sometimes to invasion of the sea during violent storms, or where natural or artificial barriers have been broken down, sometimes, as in the Baltic, to variations of sea-level due to meteorological causes.

[1] His account of the submerged forest on the south side of the Firth of Tay is contained in the 9th volume (1822) of the Trans. Roy. Soc. Edin., p. 419; and that of the similar accumulation in Largo Bay, on the northern shore of the Firth of Forth, in the Quarterly Journal of Science, Literature, & Art, n. s. vol. vii (1830) p. 21.

Had our littoral sunk forests been confined to a few places where the topographical conditions were specially favourable for their production, we may concede that they would not in themselves furnish sufficient proof of a shift of level, either on the part of the land or of the sea. But when we consider their widespread distribution all round the margin of these islands, even on those shores where it is difficult to believe that there has been any subsidence or slipping downward of a land-surface owing to the draining-off of underground water, we may well doubt whether the old belief should be disturbed, that the facts, taken as a whole, prove a general submergence.

Fortunately, the evidence available on this subject allows us to go a step farther. We need not be content with such debateable proofs as are furnished by the sunk forests between tide-marks, for land-surfaces can be adduced, which are buried beneath marine accumulations under circumstances that leave no doubt as to the facts of submergence.

In the North-East of Ireland, excavations at Belfast have shown the existence of a bed of peat lying almost immediately upon the Glacial deposits, at a depth of 27 feet below high-water mark. It has a maximum thickness of 18 inches, and consists of the matted remains of marsh-plants, and of hazel, alder, oak, willow, and Scottish pine, together with elytra of beetles and mammalian bones. It is overlain by estuarine clays, the upper portion of which, containing abundant *Thracia convexa*, *Scrobicularia alba*, etc., is believed to have been deposited in at least 5 fathoms of water, and to be contemporaneous with the raised beaches of the same region.[1] In this instance, mere local settlement from removal of subsoil water, or from the slipping forward of the thin seam of peat, is excluded, and we are presented with evidence of an actual shift of relative level, amounting probably to more than 30 feet. If this land-surface was really coæval with the neighbouring post-Glacial raised beach, the original amount of submergence must have been still greater, and by a subsequent emergence of the land, to the extent of from 10 to 20 feet, the peat has been brought up so much nearer to sea-level.

On the east side of England, besides the sunk forests on the foreshore, important evidence of submergence has been furnished by old land-surfaces lying considerably below the level of the lowest tides. At the dock-excavations of Hull a sunk forest, abounding in remains

[1] G. W. Lamplugh, &c. 'The Geology of the Country around Belfast' Mem. Geol. Surv. Irel. (1904) p. 54.

of oak and other trees, is found at a depth of 40 to 50 feet below high-water mark, beneath a deposit of marine warp. A higher land-surface is marked by a second sunk forest, seen on the foreshore above the warp, and indicating a submergence of about 4 or 5 feet. At Grimsby, also, a former land-surface, probably continuous with the older one at Hull, has been reached at a depth of 35 feet and more below high-water mark. It may point to a submergence of perhaps as much as 52 feet.[1] In the Fenland district, at least five buried forests have been observed, each characterized by its own vegetation.[2]

On the coast of South Wales, interesting sections have been laid open in the excavation for the Barry Docks, in Glamorgan. These furnish conclusive proof of a succession of at least four layers of peat overlain by estuarine deposits, and in a situation which precludes any recourse to local settlement by drainage of underground water or downward slipping. The strata are manifestly undisturbed, and the lowest is an unmistakable land-surface. It consists of peat full of remains of oak, hazel, cornel, hawthorn, and willow, together with crushed shells of *Hyalinia* and, apparently, *Pisidium* and *Planorbis*. The soil underneath this forest-growth has yielded specimens of *Helix*, *Hyalinia*, *Succinea*, *Limnæa*, *Pupa*, and *Valvata*. This buried forest-growth lies at a depth of 35 feet beneath Ordnance-datum, or 55 feet beneath the line of high-water of ordinary spring tides. It proves a submergence of at least 55 feet, and the peat-bands at higher levels mark successive pauses in this submergence. That the movement was in progress in Neolithic time may be concluded from the occurrence of a portion of a polished celt in the uppermost layer of peat, from which also two bone-needles are reported to have been obtained.[3] Mr. Strahan informs me that, wherever excavations have been made at the mouths of the valleys on the coast of South Wales, similar layers of peat have been cut through at depths below low-water mark. It would thus appear that the submergence has been general all along the coast-line.

On the Southern English coast similar evidence of a considerable

[1] See S. V. Wood, Jun., & J. L. Rome, Quart. Journ. Geol. Soc. vol. xxiv (1868) p. 157; also Clement Reid, 'Geology of Holderness' Mem. Geol. Surv. (1885) p. 77.

[2] S. B. J. Skertchly, 'Geology of the Fenland' Mem. Geol. Surv. (1877) p. 169.

[3] A. Strahan, Quart. Journ. Geol. Soc. vol. lii (1896) p. 474, and the 'Geology of Newport' (1899) and 'Geology of Cardiff' (1902) in the Memoirs of the Geological Survey. Further evidence of the submergence of the rock-valleys of South Wales, Devon, and Cornwall, will be found in Mr. Codrington's paper, already cited on p. xcviii.

change of level has long been known. The evidence was collected and discussed by William Pengelly in the papers above cited (p. xcv). He inferred, from the position of the sunk forests along the Cornish coast, that this region had been submerged to the extent of at least 67 feet since the time when these forests existed as land-surfaces.

Further proofs of the eastward extension of this submergence have more recently been revealed, during the extensive excavations for new dock-accommodation at Southampton. A bed of peat, 10 feet thick, has there been found, descending to a depth of 43 feet below Ordnance-datum. This vegetable accumulation has yielded many land- and freshwater-shells; abundant trunks of oak with roots, sometimes 2 feet long, passing down into the loam beneath; plentiful remains of beech and hazel, together with some birch and pine. The plants also included bulrush, sedge, bog-myrtle, heaths, and bracken. From this bed, bones, horn-cores, and part of the skull of *Bos primigenius* were obtained; likewise horns and bones of red deer, tusk of boar, bones of hare, and horn of reindeer. Traces of man were found in the same deposit, as shown by the occurrence of dark flint-flakes, a round perforated hammer-stone, and a fine bone-needle polished by use.[1]

There is thus evidence of a comparatively-recent submergence of the South-West of England, to the extent of at least 50 or 60 feet. We are probably justified in considering the present position of the Glacial raised beach in Gower as a further indication of the same movement, and there seems no reason why we should not connect the evidence of this beach with that of the terrace lately detected in Cork. If these tracts are included in our survey, we see that the submergence probably stretched across South Wales and St. George's Channel to the South of Ireland. The evidence from Hull and Grimsby, which shows that a similar marked submergence has taken place along part of the East Coast, not improbably indicates that the change of level extended across Wales and the centre of England. This submergence appears to be the latest in the long series of oscillations which have affected the southern portions of our islands. No proof has yet been obtained that so serious an amount of recent submergence has extended farther north. In the northern tracts the latest recorded change of level has been an emergence of the land in Neolithic time.

[1] T. W. Shore & J. W. Elwes, Papers & Proceedings of the Hampshire Field-Club, no. iii (1889) p. 43. The history of recent submergences along this coast-line is sketched by Mr. Shore, in a paper on 'Hampshire Mudlands & other Alluviums' *ibid.* vol. ii (1894) p. 181.

## II. Bearing of the Evidence on the Causes of Emergence and Submergence.

Let me now endeavour to set forth the conclusions to which the evidence obtainable in the British Isles points, in regard to the causes which, in this region, have determined the emergence and submergence of land. The vertical range of the changes of level to which I have restricted myself in this Address amounts at least to as much as 700 feet, that is some 600 feet below and 100 feet above the surface of the sea. But it will be remembered that, if we include all the deposits that contain recent marine shells *in situ*, the range of movement will be found considerably to exceed 1000 feet. The problem to be solved is whether this wide amplitude of shift in the relative levels of sea and land should be attributed to variations in the height of the surface of the oceanic envelope, or to secular movements of the terrestrial crust.

Any change of sea-level might be expected to be general and fairly uniform over long distances. The area of the British Isles is too restricted to permit us to believe that there could ever have been any serious difference in that level between the eastern and western coasts, or between the northern and southern limits of the country. Whether, therefore, the surface of the sea rose upon the land or sank away from it, we should find the records of these changes to extend over the entire region and to be marked on the whole by a persistent uniformity of level. But an examination of the evidence fails to furnish proofs of any such extension and uniformity.

In the first place, the raised beaches, although so perfectly developed over nearly the whole of Scotland, disappear towards the north among the Orkney and Shetland Islands where, had they ever existed, they had every chance of being as well preserved as anywhere on the mainland. These islands obviously lay outside of the area affected by the movement that led to the formation of the beaches. But they could not have escaped from the effects of any rise in the level of the sea. Again, it is incredible that if the great 100-foot terrace, so prominent a feature in Scotland, had been formed by an uprise of the surface of the sea, the same terrace should not have been visible in thousands of favourable positions in England, Wales, and Ireland. Its entire absence cannot be accounted for by the presence of former ice-sheets in these regions, or by subsequent denudation. This absence may surely be taken as proof that the terrace never extended over these parts of our islands.

In the second place, had the position of the sunk forests in the southern half of England and Wales been due to a rise in the sea-level, similar evidence of submerged land-surfaces at corresponding depths should have been met with generally round our coast-line. Neolithic man was an inhabitant of the country before this submergence was complete, and has dropped his handiwork in the beds of peat. In the North of Ireland and in Central Scotland, however, during Neolithic time the land was emerging from the sea, and man has left his flint-flakes and weapons in the youngest raised beaches. Thus in the same period of geological time the sea-level must be supposed to have risen 50 or 60 feet in the south, and to have sunk 25 or 30 feet in the north. But we cannot suppose that within a distance of 300 or 400 miles there could have been a difference of 75 feet or more in the level of the water.

In the third place, I have very little doubt that when accurate levellings are taken of the raised beaches, it will be found that their apparent horizontality is not absolute, but that they rise slowly in certain directions, more particularly towards the axis of the country. I think it not improbable also that a difference of level will be detected between the same beach on the eastern and on the western coast, and between its most northerly and most southerly parts. Such evidence of a deformation of the land can only be determined by the careful geodetic measurements which I long to see carried out.

In the meantime, on a review of the whole evidence, I feel confident that the balance of proof is largely in favour of the old belief that the changes of level, of which our islands furnish such signal illustrations, have been primarily due, not to any oscillations of the surface of the ocean, but to movements of the terrestrial crust connected with the slow cooling and contraction of our globe. If this belief is to be overthrown, better evidence must be brought against it than has been hitherto adduced.

February 24th, 1904.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Arthur Hutchinson, M.A., Ph.D., F.C.S., Demonstrator in Mineralogy in the University of Cambridge, Fellow & Tutor of Pembroke College, Cambridge, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The President read the following resolution of the Council, which had been forwarded to Mrs. McMahon :—

'That the Council desire to place on record their regret at the death of General C. A. McMahon, F.R.S., who for so many years was one of their colleagues, and took so active an interest in the affairs of the Society; and the Council further wish to express their sincere sympathy with Mrs. McMahon and the family in their bereavement.'

The President also announced that Prof. T. G. Bonney, Sc.D., F.R.S., and Mr. H. W. Monckton, F.L.S., would represent the Society at General McMahon's funeral on the following day.

The President stated that Prof. Lapworth had written, thanking the Fellows for their kind expression of sympathy with him in his illness, and for the telegram despatched to him in the course of the Annual General Meeting.

The following communications were read :—

1. 'Eocene and Later Formations surrounding the Dardanelles.' By Lieut.-Col. Thomas English, late R.E., F.G.S.

2. 'The Derby Earthquakes of March 24th and May 3rd, 1903.' By Dr. Charles Davison, F.G.S.

The following specimens, etc. were exhibited :—

Rocks and Fossils from the Dardanelles, and a Model of the surrounding Country, exhibited by Lieut.-Col. T. English, F.G.S., in illustration of his paper.

At 7.30 p.m., before the Ordinary Meeting, a Special General Meeting was held, for the purpose of taking into consideration the following alterations in the Bye-Laws proposed on behalf of the Council :—

A. That Bye-Laws Sect. XIV, Art. 4, and Sect. XXI, Art. 6 be repealed.

B. (1) That Bye-Laws, Sect. XII, Art. 3, and Sect. XII, Art. 4, 1° be repealed.
(2) That the following new Bye-Law be enacted, to be called Sect. IX, Art. 12 *a*, to come between Arts. 12 & 13 of Sect. IX : 'Persons not

belonging to the Society, if introduced by Fellows or Foreign Members, may be present at General Meetings, subject to such regulations as the Council may make from time to time.'

(3) That the following alteration be made in Bye-Laws, Sect. XIX, Art. 1: That the words 'subject to such regulations as the Council may make from time to time' be added after the words 'General Meetings of the Society' at the end of line 4.

These resolutions were ballotted on by the Fellows present, and agreed to.

---

March 9th, 1904.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

Mr. G. Barrow exhibited and commented on a small striated boulder, which was found a little above high-water on White Island, one of the northern projections of the Scilly Isles. It was firmly embedded in the ground, and therefore the striations which occur on both faces could not have been produced *in situ* by the grinding action of boulders or stones moved by powerful waves.

The following communications were read:—

1. 'On the probable Occurrence of an Eocene Outlier off the Cornish Coast.' By Clement Reid, Esq., F.R.S., F.L.S., F.G.S.[1]

2. 'The Valley of the Teign.' By Alfred John Jukes-Browne, Esq., B.A., F.G.S.

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

Specimens exhibited by Clement Reid, Esq., F.R.S., F.L.S., F.G.S., in illustration of his paper.

The following Regulations, as to the Admission of Visitors to General Meetings of the Society, have been made by the Council, in accordance with the Bye-Laws, Sect. IX, Art. 12 *a* and Sect. XIX, Art. 1, as amended at the Special General Meeting held on February 24th, 1904:—

(I) Annual General Meetings.

1. Except by permission of the President, or one of the Secretaries, or of the Council, no Visitor shall be permitted to be present at an Annual General Meeting until after the report of the Council has been read, and the discussion (if any) under Bye-Laws, Sect. X, Art. 20, has taken place.

---

[1] Communicated by permission of the Director of H.M. Geological Survey.

2. As soon as the above-mentioned discussion has concluded, and the motion that the report be printed has been voted on, Visitors will be admitted, on the introduction of Fellows or Foreign Members.

(II) Special General Meetings.

3. No Visitors will be permitted to be present at Special General Meetings, except by express permission of the Council, or, if there is no meeting of the Council between the time of an application to be present at a Special General Meeting being received and the time fixed for such meeting, by express permission of the President or one of the Secretaries, who shall report to the Council the granting of such permission and the reason for so doing.

(III) Ordinary General Meetings.

4. Visitors will be permitted to be present at Ordinary General Meetings, on the introduction of Fellows or Foreign Members.

(IV) General.

5. The name of every Visitor present at any General Meeting shall be inserted in a book to be kept for the purpose, with the name of the Fellow or Foreign Member introducing such Visitor.

6. No newspaper-reporters, as such, shall be admitted as Visitors at General Meetings, except by express permission of the Council.

7. If necessary, from considerations of space or otherwise, the Council, the President, or one of the Secretaries may regulate the number of Visitors that may be introduced by any one Fellow or Foreign Member at any particular meeting.

March 9th, 1904.

---

March 23rd, 1904.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Gladstone Anthony Allen, Esq., B.Sc.(Lond.), 56 Trinity Street, Old Hill (Staffordshire); and Francis Edward Middleton, Esq., Elm Villa, St. John's, Wakefield, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'On the Moine Gneisses of the East-Central Highlands and their Position in the Highland Sequence.'[1] By George Barrow, Esq., F.G.S.

The following specimens, etc. were exhibited:—

Rock-specimens, Microscope-Sections, and Lantern-Slides, exhibited by George Barrow, Esq., F.G.S., in illustration of his paper.

---

[1] Communicated by permission of the Director of H.M. Geological Survey.

April 13th, 1904.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Prof. Henry Fairfield Osborn, of New York (U.S.A.), was elected a Foreign Member; and Dr. Erich Dagobert von Drygalski, of the University of Berlin, and Dr. Henry S. Washington, of Locust, New Jersey (U.S.A.), were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Discovery of Human Remains under the Stalagmite-Floor of Gough's Cavern, near Cheddar.' By Henry Nathaniel Davies, Esq., F.G.S.

2. 'The History of Volcanic Action in the Phlegræan Fields.' By Prof. Giuseppe De Lorenzo, of the Royal University of Naples. (Communicated by Sir Archibald Geikie, Sc.D., Sec.R.S., V.P.G.S.)

The following specimens and maps were exhibited:—

Specimens and Flint-Implements from Gough's Cavern, near Cheddar, exhibited by H. N. Davies, Esq., F.G.S., in illustration of his paper.

Sheets 120 & 133 of the Geological Survey-Map of Saxony, presented by the Director of that Survey.

---

April 27th, 1904.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

Prof. W. W. Watts, in exhibiting the platinotype-prints issued by the Geological Photographs Committee of the British Association, said that these constituted the third issue of the first series. These photographs would be in the hands of subscribers within the next few days.

The following communications were read:—

1. 'On a New Species of *Eoscorpius* from the Upper Carboniferous Rocks of Lancashire.' By Walter Baldwin, Esq., F.G.S., and William Henry Sutcliffe, Esq., F.G.S.

2. 'The Genesis of the Gold-Deposits of Barkerville (British Columbia) and the Vicinity.' By Austin J. R. Atkin, Esq. (Communicated by the Secretary.)

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

Specimens and Lantern-Slides exhibited by W. Baldwin, Esq., F.G.S., and W. H. Sutcliffe, Esq., F.G.S., in illustration of their paper.

Sheets 1 to 4 of the new colour-printed Drift-Map of the London District, presented by the Director of H.M. Geological Survey.

Eight sheets of the $\frac{1}{100,000}$ Map of the Royal Geological Survey of Italy, presented by the Director of that Survey.

Revised edition of the Geological Map of the Southern Transvaal, by Dr. F. H. Hatch, M.Inst.C.E., F.G.S., presented by the Author.

---

May 11th, 1904.

Horace B. Woodward, Esq., F.R.S., Vice-President, in the Chair.

Leonard J. Bates, Esq., Mining Engineer, Oakdene, Claughton, Birkenhead; Charles Joseph Gray, Esq., Pietermaritzburg (Natal); Ivan Ascanio Stigand, Esq., B.A., Balek Pappan, Koetei (Dutch Borneo); and Robert B. Young, Esq., M.A., B.Sc., P.O. Box 3572, Johannesburg (Transvaal), were elected Fellows of the Society.

The List of Donations to the Library was read.

The Chairman referred in feeling terms to the grievous loss sustained by the Society in the death of Sir Clement Le Neve Foster, F.R.S., Professor of Mining at the Royal College of Science. He was elected a Fellow in 1863, and as early as 1865 he communicated to this Society, conjointly with William Topley, the now classic paper on the Medway Gravels & the Denudation of the Weald—a paper which had largely influenced the views of geologists on the physiography of the South-East of England.

The Chairman announced that the Council had resolved to award the proceeds of the Daniel-Pidgeon Fund for 1904 to Mr. Linsdall Richardson, F.G.S., of Cheltenham.

The following communications were read:—

1. 'On some Quartzite-Dykes in Mountain-Limestone near Snelston (Derbyshire).' By Henry Howe Arnold-Bemrose, Esq., M.A., F.G.S.

2. 'Phenomena bearing upon the Age of the Lake of Geneva.' By Dr. C. S. Du Riche Preller, M.A., Ph.D., A.M.I.C.E., M.I.E.E., F.R.S.E., F.G.S.

The following specimens were exhibited :—

Rock-Specimens, Microscope-Sections, and Lantern-Slides, exhibited by H. H. Arnold-Bemrose, Esq., M.A., F.G.S., in illustration of his paper.

Palæolithic Implements from Drift-Deposits at Knowle Gravel-Pits, Marlborough, obtained by Mr. J. W. Brooke, and exhibited by George Clinch, Esq., F.G.S.

Volcanic rocks from, and Photographic Views of, the Island of Ascension, obtained by Mr. W. Hebdon, and exhibited by Dr. A. E. Salter, F.G.S.

---

May 25th, 1904.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On the Occurrence of a Limestone with Upper Gault Fossils at Barnwell, near Cambridge.' By William George Fearnsides, Esq., M.A., F.G.S.

2. 'On the Age of the Llyn-Padarn Dykes.' By James Vincent Elsden, Esq., B.Sc., F.G.S.

The following specimens were exhibited :—

Rock-Specimens and Microscope-Slide of the Hard Band associated with the zone of *Schlœnbachia varicosa*, from Barnwell, near Cambridge, and Fossils representative of the fauna of these beds, exhibited by W. G. Fearnsides, Esq., M.A., F.G.S., in illustration of his paper.

Rock-Specimens, Microscope-Sections, and Lantern-Slides of Llyn-Padarn Dykes, exhibited by J. V. Elsden, Esq., B.Sc., F.G.S., in illustration of his paper.

---

June 8th, 1904.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Fritz Joseph Ernst, Esq., F.R.G.S., Lorraine, Jordan-Hill Road, Hobart (Tasmania); Isaac Vaughan Evans, Esq., 149 Richmond Road, Cardiff; and Henry Marks Kruszinski, Esq., 62 Highbury New Park, N., were elected Fellows; Prof. Joseph Paxson Iddings, University of Chicago, Illinois (U.S.A.), was elected a Foreign Member; and Dr. William Bullock Clark, Baltimore, Maryland

(U.S.A.), and the Hon. Frank Springer, East Las Vegas, New Mexico (U.S.A.), were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the 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 President announced that the Council had made the following Regulations as to Exhibits at Meetings :—

1. That at Ordinary General Meetings when geological communications are read, the Chairman, when drawing attention to any specimen or drawing exhibited, may invite the Fellow who makes the exhibit to make a brief statement concerning it, at such time during the Meeting as the Chairman shall determine; but no discussion shall be allowed, except at the request of the Chairman.

2. Attention will not be called to any exhibit not illustrating a paper, unless it has been shown to the Chairman or to one of the Secretaries before the beginning of the Meeting.

The following communications were read :—

1. 'The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area.' By Arthur Vaughan, Esq., B.A., B.Sc., F.G.S.

2. 'On a small *Plesiosaurus*-Skeleton from the White Lias of Westbury-on-Severn.' By Wintour Frederick Gwinnell, Esq., F.G.S.

3. 'The Evidence for a Non-Sequence between the Keuper and Rhætic Series in North-West Gloucestershire and Worcestershire.' By Linsdall Richardson, Esq., F.G.S.

The following specimens, etc., were exhibited :—

Specimens, Photographs, and Lantern-Slides, exhibited by Arthur Vaughan, Esq., B.A., B.Sc., F.G.S., in illustration of his paper.

Specimens of *Spirifer tornacensis*, from the Carboniferous Limestone of Tournay (Belgium), and of *Sp. mosquensis*, exhibited by John Francis Walker, Esq., M.A., F.L.S., F.G.S., in illustration of Mr. Vaughan's paper.

*Plesiosaurus*-Skeleton from the White Lias of Westbury-on-Severn, exhibited by Wintour Frederick Gwinnell, Esq., F.G.S., in illustration of his paper.

Geological Survey of Ireland: 1-inch colour-printed map of the Belfast District, presented by the Director of H.M. Geological Survey.

June 22nd, 1904.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Edmund John Spargo, Esq., Consulting Mining Engineer, 56 Ferndale Road, Sefton Park, Liverpool, was elected a Fellow of the Society.

The List of Donations to the Library was read.

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

The following communications were read:—

1. 'The Igneous Rocks of Pontesford Hill (Shropshire).' By Prof. William S. Boulton, B.Sc., Assoc.R.C.S., F.G.S.

2. 'The Tertiary Fossils of Somaliland, as represented in the British Museum (Natural History).' By Richard Bullen Newton, Esq., F.G.S.

3. 'The Caernarvon Earthquake of June 19th, 1903, and its Accessory Shocks.' By Charles Davison, Sc.D., F.G.S.

The following specimens, etc. were exhibited:—

Specimens, Microscope-Sections, and Lantern-Slides, exhibited by Prof. W. S. Boulton, B.Sc., A.R.C.S., F.G.S., in illustration of his paper.

Tertiary Fossils from Somaliland, exhibited by R. Bullen Newton, Esq., F.G.S., in illustration of his paper.

Five new Sheets of the Geological-Survey Map of Japan, presented by the Director of that Survey.

THE

# QUARTERLY JOURNAL

OF

# THE GEOLOGICAL SOCIETY OF LONDON.

VOL. LX.

---

## 1. *On the* OCCURRENCE *of* EDESTUS *in the* COAL-MEASURES *of* BRITAIN. By EDWIN TULLEY NEWTON, Esq., F.R.S., V.P.G.S.[1] (Read November 18th, 1903.)

[PLATE I.]

THE presence of marine beds in the Coal-Measures of North Staffordshire was first made known by Mr. J. Ward [1],[2] of Longton, in 1865; but their occurrence in other districts had already been observed by the officers of the Geological Survey [2 & 3].

These marine bands are chiefly met with during the sinking of shafts; and Mr. J. T. Stobbs, F.G.S., of Stoke-on-Trent, has for some time past been studying those that occur in North Staffordshire. It is due to the vigilant observations of that gentleman, and to the assistance of the pupils of his mining class, that these beds are found to occur with much greater frequency than has hitherto been supposed.

Mr. Stobbs very courteously called the attention of the Geological Survey to one of these marine bands, found at about 18 yards below the 'Twist Coal,' in the Smallthorne sinking of Messrs. Robert Heath & Son's pits at Nettlebank (North Staffordshire).

An interesting series of fossils has been found in the shales and impure limestones brought to bank from this particular band; and with the permission of the colliery-owners, the fossil-collector of the Geological Survey, Mr. J. Pringle, went to Smallthorne to secure a series of these fossils. Among the specimens thus obtained, there is one which calls for special notice, as it establishes for the first time the occurrence in Britain of the remarkable genus of fishes known as *Edestus*. This genus was originally described

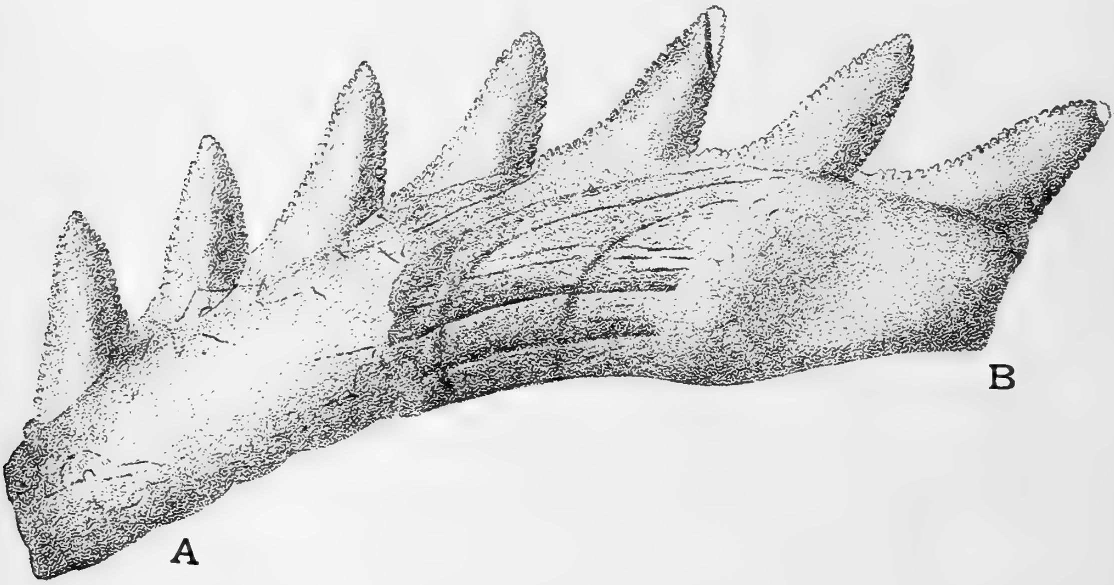
[1] Communicated by permission of the Director of H.M. Geological Survey.
[2] These numbers in square brackets throughout the paper refer to the bibliographical list on p. 7.

from the Coal-Measures of the United States, but was afterwards recognized in beds of similar age in Russia and Australia. The accompanying figure (fig. 1, below) of the first-described specimen (*Edestus minor*) will call to mind the form of this ichthyodorulite, which has been thought to be a dorsal defence. To it have also been assigned various other functions in the economy of the fish to which it belonged; its true nature, however, remains uncertain.

The segmented character of *Edestus minor* is shown in this figure; and separate segments of this and other species have been met with in North America, showing that each tooth was attached to a firm base, elongated in one direction and grooved above for the reception of the under part of a similar segment. Several such segments were united in the original specimen.

Fig. 1.—*Side view of* Edestus minor. (½ *nat. size.*)

[From Geol. Surv. Illinois, vol. iv (1870) pl. i, fig. 2.]




A = Anterior, oldest segment. B = Posterior, newest segment.

It is now more than 48 years (August 1855) since Hitchcock [4] first made known the remains of the remarkable fish from the 'Coal-formation' of Park County (Indiana), to which Newberry [8] afterwards gave the name of *Edestus minor*. It was Leidy [5], however, who proposed the generic name of *Edestus* for a large and closely-allied form from the Coal-Measures of Arkansas, which he described under the name of *Edestus vorax*.

In the year 1870, Newberry and Worthen [9] made known another species, *Edestus Heinrichsii*, from the Coal-Measures of Illinois. Up to that time the genus had only been known in North America; but in 1878 Dr. H. Trautschold [10] recognized, among the fossils described by him from Miachkova, near Moscow, a single denticle, referable to this genus, which he named *Edestus protopirata*; and subsequently, in 1884 [12], the same writer obtained, also from near Moscow, a more perfect specimen with a large part of its grooved basal segment: thus more firmly establishing the occurrence of the genus in Europe.

In was in 1886 that Dr. Henry Woodward [14] described the remarkable ichthyodorulite from the Carboniferous rocks of Western Australia, to which he gave the name of *Edestus Davisii*. The specimen differed in several points from the forms hitherto referred to *Edestus*, more especially in its deeper curvature and in the larger number of its denticles; but Dr. Woodward was correct in regarding it as nearly related to *Edestus*, although it is now placed in a distinct genus.

Another species which, on account of its large size, received the name of *Edestus giganteus*, was described by Newberry [17] in 1889, from the Coal-Measures of Decatur, Macon County (Illinois); and in 1898 Dr. Bashford Dean [20] gave an account of another much-curved form, under the title of *Edestus Lecontei*, from the west of the Rocky Mountains, in Nevada.

In 1899, Dr. Karpinski [21] published his detailed memoir on the Edestidæ and on a new genus, *Helicoprion*. Several examples of these 'spiral saws' had been found in the 'Artinskian stage' (Permo-Carboniferous) near the town of Krasnoi Ufimsk, in Eastern European Russia, a little west of the Urals. These extraordinary tooth-bearing spirals still remain an unsolved problem, notwithstanding the lively discussion to which Dr. Karpinski's memoir has given rise, and which continues to the present time, several eminent workers abroad and at home having expressed their views on the subject [see 27–31]. Not the least important of these contributions were the papers published by Dr. Eastman in 1901 and 1902 [22–26]. In one of these [24] a new genus, *Campyloprion*, is established for certain fossils closely allied to *Helicoprion*. In this, and the subsequent memoir, Dr. Eastman describes the *Orodus*-like jaw of *Campodus*, with its somewhat compressed and enrolled symphysial series of teeth, which are regarded as of Cestraciont type, and are thought to indicate the principle of enrolling of the teeth on or near the symphysis, which culminated in the 'spiral saw' of *Helicoprion*; *Edestus* and *Campyloprion* showing intermediate stages, in which the teeth were broken off or worn away, instead of being retained and rolled into a spiral.

The presence of *Helicoprion* in the Carboniferous rocks of Japan has been made known by M. H. Yabe [32], and I am indebted to Dr. A. Smith Woodward for this reference.

The specimen, found by Mr. Pringle at Nettlebank, was, when it first came into my hands, in several pieces, and much of it was still hidden in the hackly, dark limestone.[1] The fossil itself being very brittle, the greatest care was necessary for its development; it is now, however, in a condition to show its complete form, with the exception of the point of the tooth, which was not found.

[1] Dr. W. Pollard, F.G.S., who has kindly examined the rock, says that it is an impure limestone, containing some magnesia and ferrous carbonate.

The specimen is evidently a single segment of a fossil very closely resembling *Edestus minor*, and consists of an elongated basal portion bearing at one extremity a smooth, enamelled, and serrated crown. The inferior border of the base is concave from end to end, and the superior border is convex in the same direction. Below the crown the base is flattened on each side and angular at the inferior border. This angularity becomes less marked towards the middle, and the lower border is then more and more rounded to the opposite end, this portion of the base being thicker and deeper than the part which carries the crown. Two or three vascular grooves are seen upon the side, extending from apertures which penetrate to the deeper parts of the base. The whole of the base has an open spongy texture, the interstices being filled with the dark matrix.

The line of demarcation between the crown and the base is clearly defined by the edge of the enamel, the roughness of the base increasing as it approaches this dividing-line, which is not quite parallel with the lower margin, but approaches it somewhat as it nears the extremity, and then, curving downward, the enamel completely embraces the end of the base, while beyond it extends the distal part of the crown.

The free cutting-edges of the crown, so far as preserved, are strongly denticulated, there being on the upper margin twelve denticles in 14 millimetres. A closer examination with a lens shows that each of these denticles is again divided into three serrations, the median one being about twice as large as the outer two. So much of the lower margin as is preserved shows six denticles in 5 millimetres, but there is no evidence of these being serrated.

The outer edge of the enamelled crown forms a narrow pointed spur, extending in the direction of the elongated base as far as the end of the upper denticulated cutting-edge, but separated from it by a tongue of the roughened base, which passes in between them for about a third of the length of the crown. Probably there is a similar spur of enamel on the opposite side of the tooth, but this is hidden in the matrix. The end of the crown being absent, its form cannot be known, but, judging from what remains, it seems to have resembled that of *Edestus minor*; the dotted line in Pl. I, fig. 1 gives a restoration on this basis.

Seen from the end, the crown is much compressed, and the section exposed by the broken surface is lenticular (Pl. I, fig. 6). Below the broken end the denticles extend quite to the lower margin, and on each side, just above the lowest denticle, is a little rounded cusp.

When the specimen is viewed from above, a deep trough is seen to extend throughout its length, excepting the portion occupied by the crown, close to which the trough descends about halfway into the thickness of the base, and becomes deeper as it passes away from the crown, occupying the whole depth at the opposite extremity. This end of the specimen has the two sides very unlike (see Pl. I, fig. 1), for, while the side next to the matrix ends in a rounded point, the side freed from matrix is deeply notched. A part of this side has been accidentally cut away, but the notch is not due to this cause, for the fragment cut off is similarly, though not so deeply, notched. Some splinters of bone near by may, however, indicate that fracture took place before fossilization.

The upper view shows the specimen to be nearly equilateral, so nearly so indeed that the inequalities may be, and probably are, due to distortion, or imperfection, in fossilization. But this want of equality must not be lost sight of, for if such specimens be not practically equilateral, we lose the chief evidence for the median position of these ichthyodorulites in the fish to which they belonged.

MEASUREMENTS OF *EDESTUS* FROM SMALLTHORNE, IN MILLIMETRES.

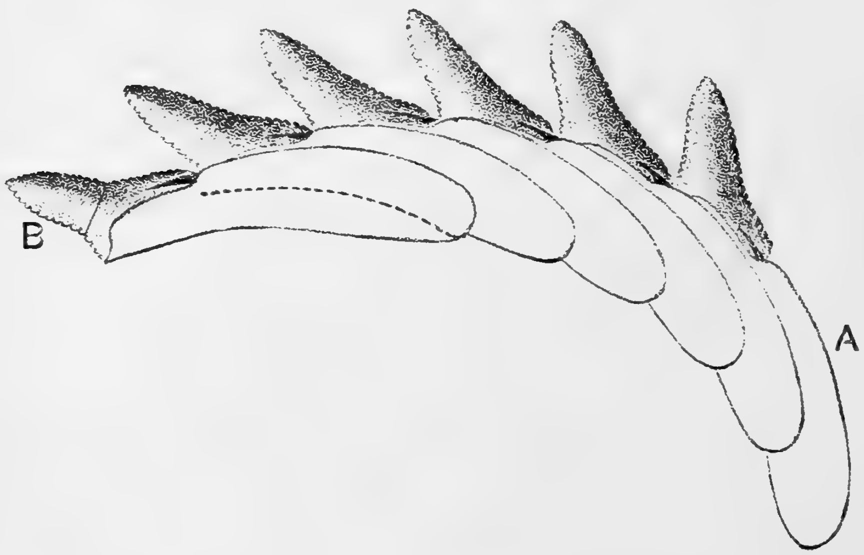
| | |
|---|---|
| Length of lower margin *a–b*, Pl. I, fig. 1...... | 59·0 |
| Height of base at *f–g*.............................. | 12·0 |
| Thickness of base at *f–g* ........................ | 10·5 |
| Height at *h*, Pl. I, fig. 3 ........................ | 11·0 |
| Depth of groove at *h*.............................. | 5·5 |
| Lower edge of crown, *a–c*........................ | 18·0 |
| Upper margin preserved, *c–d* ................. | 14·0 |
| Lower margin preserved, *a–e* .................. | 5·0 |
| Broken end of crown, *d–e*........................ | 8·0 |
| Broken end of crown, thickness ............... | 2·3 |
| Length of spur ...................................... | 7·0 |

The shape of the base below the crown and the form of the trough of the upper surface show clearly that this specimen is one segment of a series, fitting one into the upper groove of another, as in *Edestus*. And the close resemblance between this fossil and *Edestus minor* leaves no room for doubting their generic identity; but the question of species is more troublesome.

That our fossil is more nearly allied to *Edestus minor* than to any other known species of the genus is evident; but the want of a perfect crown prevents a completely-satisfactory comparison. The type-specimen of *Edestus minor*, described by Newberry, had a very little of the lower part of the crown or base preserved; but the upper part is lanceolate, and is described as having double denticles; this is unlike the Smallthorne fossil, which has the denticles in triple form. Hitchcock's original specimen (see text-fig. 1, p. 2), which was subsequently referred to *E. minor* by Newberry, has the crowns of the teeth rather more obtusely lanceolate than in the type, and each crown is said to have a lateral spur of enamel similar to that seen in the Smallthorne specimen, but the denticles are double. So far as one can judge of the form of a segment in *E. minor*, it is unlike this British fossil. The much smaller specimen from Moscow, referred by Dr. Karpinski to *E. minor*, has a narrower and more acuminate crown than either of the American specimens, but shows the same slender spur of enamel, and the denticles are said to be as in *E. minor*. The base below the crown is very like the same part in the Smallthorne fossil; but, on close comparison, it will be seen that the lower edge of the enamel forms nearly a straight line in the Russian tooth, while a few of the lower denticles are at right angles with the rest of the crown. In the British specimen, on the other hand, the lower edge of the enamel is strongly bent, while the lower denticulated margin is only slightly curved at its lower end. There is likewise a difference in the denticles; the Russian specimen having them, as in *Edestus minor*, double and not triple.

Dr. Karpinski was evidently in some doubt as to his specimen being really an example of *E. minor*, for he says that it is either this or a closely-allied species, and I am inclined to think that the latter suggestion is the more justifiable. But, however that may be, the Smallthorne specimen can scarcely be referred to *Edestus minor*, the differences mentioned above preventing such a reference. Bearing in mind, therefore, the most striking peculiarity of our fossil, I propose to name it *Edestus triserratus*.

Fig. 2.—*Segments of* Edestus triserratus *restored.* ($\frac{3}{5}$ *nat. size.*)




A = Anterior, oldest segment. B = Posterior, newest segment.

Fortunately the basal portion of our specimen and its trough are so well shown, that the manner in which the segments fitted together is obvious; and, taking advantage of this, the appearance of half a dozen such segments combined is shown in text-fig. 2.

The crowns of all the teeth in Newberry's figure of *E. minor* are so nearly of the same size, that one is justified in assuming that the teeth and segments of our British specimens did not vary greatly in this respect, and consequently the combined series would have had much the appearance of my restoration; but probably the basal portions of the older segments of *Edestus* changed somewhat in shape by continued deposition or absorption of bony material. At first sight it is not clear which is the growing end of such a series. Among a large number of segments of *E. Heinrichsii* that Newberry had for examination was one which possessed no groove; and he concluded that this was the first of a series, that a new segment was formed with its base under the toothed end of the older one, and that this by growth gradually ensheathed the one above. This seems most likely to be the correct interpretation, although doubt has been thrown upon the supposed non-grooved segment, which was thought to be the first formed.

That the curved and toothed ichthyodorulites, to which the name of *Edestus* is properly restricted, belonged to a fish closely allied to that which carried the 'spiral saw,' *Helicoprion*, is generally agreed, but it is by no means proved that the two forms had a similar function.

Dr. Eastman has shown good reason for thinking that the enrolling of the symphysial teeth of *Campodus* is an indication of the nature of the spiral of *Helicoprion*, although he was not the first to suggest this interpretation. There is, however, but a distant relationship between these two genera, even if his idea that they are both Cestracionts should prove correct. That *Campyloprion* is nearly related to *Helicoprion* will be readily admitted; indeed, there seems no obvious reason why the fossils referred to this genus may not have been parts of spirals similar to that of *Helicoprion*, and if so they might conveniently have remained in that genus.

With regard to *Edestus*, the form of each tooth-crown and base is so unlike those in *Helicoprion* that its generic distinction will not be disputed; but, at the same time, its near relationship to *Helicoprion* has not been questioned.

However anomalous the 'spiral saw' of *Helicoprion* may be, it seems most in accordance with our present knowledge to regard it as the enrolled dentition at or near the symphysis of an elasmobranch, possibly allied to Cestracionts. That the forms referred to *Edestus* are of the same nature seems less probable; and, while admitting that this interpretation may prove correct for them also, it still seems to me that these straighter forms, with large anteriorly-projecting bases, are more likely to be dorsal defences.

## Bibliographical List.


1. J. Ward. [On Marine Bands in the Coal-Measures of North Staffordshire.] Geol. Mag. vol. ii (1865) pp. 234 & 286.
2. E. Hull & A. H. Green. Trans. Manch. Geol. Soc. vol. iii (1862) p. 348.
3. E. Hull & J. W. Salter. Mem. Geol. Surv. 'Geology of the Country around Oldham' 1864, p. 64.
4. E. Hitchcock. 'Account of the Discovery of the Fossil Jaw of an Extinct Family of Sharks from the Coal-Formation' Proc. Amer. Assoc. Adv. Sci. (Ninth Meeting, Providence, 1855) Cambr. 1856, p. 229.
5. Joseph Leidy. 'Indications of Five Species, with Two New Genera, of Extinct Fishes' Proc. Acad. Nat. Sci. Philad. vol. vii, 1854–55 (1856) p. 414. Also Journ. Acad. Nat. Sci. Philad. ser. 2, vol. iii, 1856 (1858) p. 159 & pl. xv.
6. ——. 'Remarks on certain Extinct Species of Fishes' Proc. Acad. Nat. Sci. Philad. vol. viii, 1856 (1857) p. 301.
7. R. Owen. 'Palæontology' 2nd ed. Edinburgh, 8vo (1861) pp. 123–24 & fig. 38.
8. J. S. Newberry. Geol. Surv. Illinois, vol. ii (1866) p. 84 & pl. iv.
9. J. S. Newberry & A. H. Worthen. *Ibid.* vol. iv (1870) p. 350 & pl. i, fig. 2.
10. H. Trautschold. 'Die Kalkbrüche von Mjatschkowa' Nouv. Mém. Soc. Imp. Nat. Moscou, vol. xiv (1879) p. 49 & pl. vi, fig. 8.
11. M. Lohest. 'Recherches sur les Poissons des Terrains paléozoïques de Belgique' Ann. Soc. Géol. Belg. vol. xi (1883) p. 314.

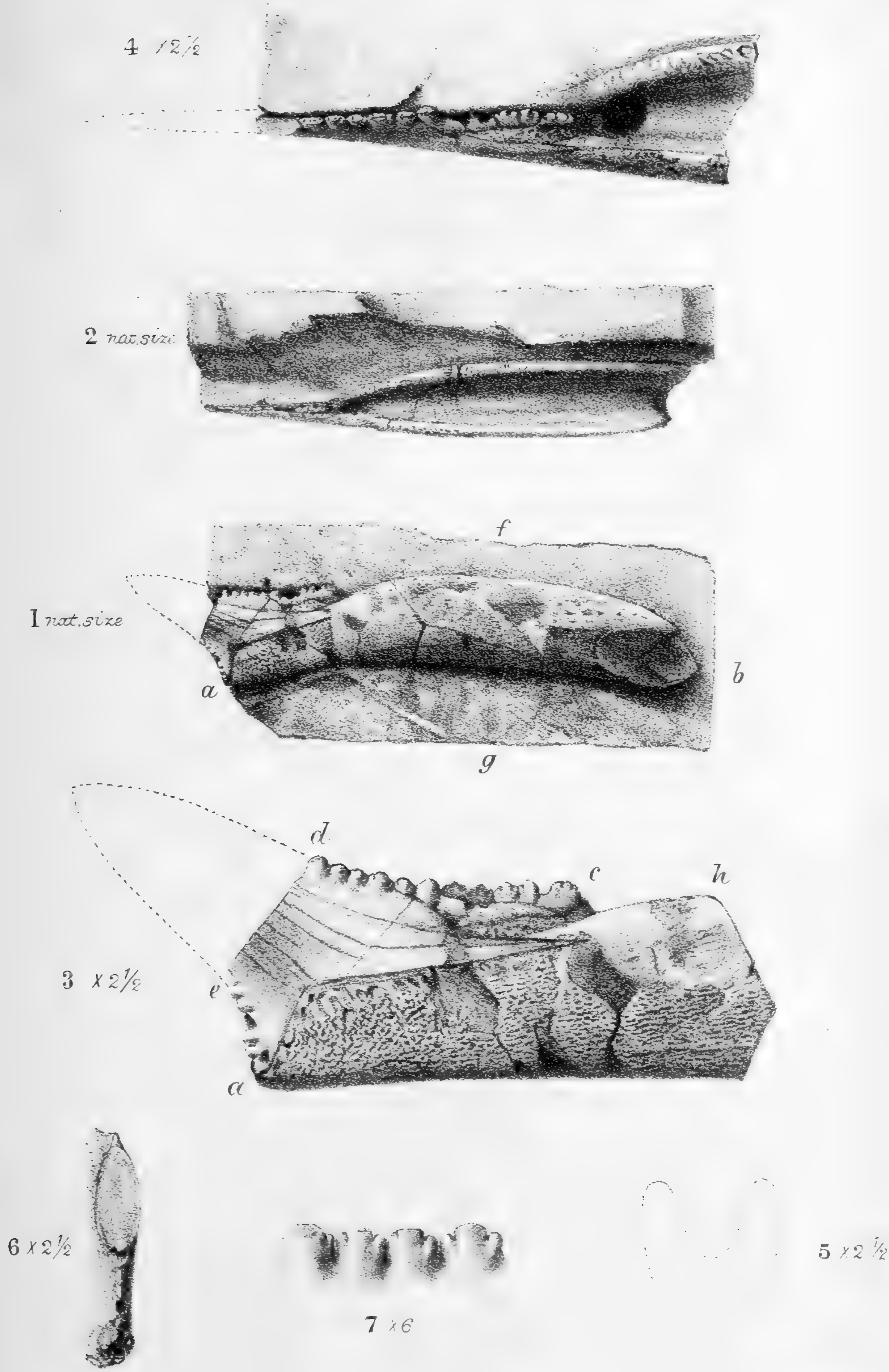
12. H. Trautschold. 'Ueber *Edestus* und einige andere Fischreste des Moskauer Bergkalks' Bull. Soc. Imp. Nat. Moscou, vol. lviii, pt. ii, 1883 (1884) p. 160 & pl. v, figs. 1 & 2.
13. ——. 'Ueber das Genus *Edestus*' *Ibid.* vol. lxi, pt. ii, 1885 (1886) p. 94.
14. H. Woodward. 'On a Remarkable Ichthyodorulite from the Carboniferous Series, Gascoyne (Western Australia)' Geol. Mag. 1886, p. 1 & pl. i.
15. Fanny R. M. Hitchcock. 'On the Homologies of *Edestus*' Proc. Am. Assoc. Adv. Sci. (Thirty-sixth Meeting, New York, August 1887) Salem, 1888, p. 260. Also Amer. Nat. vol. xxi (1887) p. 847.
16. H. Trautschold. 'Ueber *Edestus protopirata,* Trd.' Zeitschr. Deutsch. Geol. Gesellsch. vol. xl (1888) p. 750.
17. J. S. Newberry. 'On the Structure & Relations of *Edestus,* with a Description of a Gigantic New Species' Ann. N.Y. Acad. Sci. vol. iv, no. 4, 1888 (1889) p. 113 & pls. iv–vi. See also 'The Palæozoic Fishes of North America' Monogr. U.S. Geol. Surv. vol. xvi (1889) p. 217 & pls. xxxix–xl.
18. H. Trautschold. 'Ueber *Protopirata centrodon,* Trd.' Bull. Soc. Imp. Nat. Moscou, n. s. vol. iv, 1890 (1891) p. 317.
19. A. Smith Woodward. Catal. Foss. Fishes Brit. Mus. pt. ii (1891) p. 151.
20. Bashford Dean. 'On a New Species of *Edestus* (*E. Lecontei*) from Nevada' Trans. N.Y. Acad. Sci. vol. xvi (1898) p. 61 & pls. iv–v.
21. A. Karpinski. 'Ueber die Reste von Edestiden und die Neue Gattung *Helicoprion*' Verh. K.-Russ. Mineralog. Gesellsch. ser. 2, vol. xxxvi (1899) p. 361 & pls. i–iv; also Mém. Acad. Imp. Sci. St. Pétersb. ser. 8, vol. viii, no. 7 (1899) pp. 1–76 & pls. i–iv.
22. C. R. Eastman. [Review of Karpinski's Memoir.] Amer. Nat. vol. xxxiv (1900) p. 579.
23. ——. 'On *Campodus variabilis,* N. & W.' Denver Meeting Amer. Assoc. Adv. Sci. n. s. vol. xiv (1901) p. 795.
24. ——. 'On *Campyloprion,* a New Form of *Edestus*-like Dentition' Geol. Mag. 1902, p. 148 & pl. viii.
25. ——. 'Some Carboniferous Cestraciont & Acanthodian Sharks' Bull. Mus. Comp. Zool. Harvard Coll. vol. xxxix, no. 3 (1902) p. 55 & pls. i–vii.
26. ——. 'Carboniferous Fishes from the Central Western States' *Ibid.* vol. xxxix, no. 7 (1903) p. 184 & pl. i.
27. [Review of Karpinski's Memoir.] Bull. Soc. belge de Géol. vol. xiii (1903) for 1899, p. 205.
28. E. Van den Broeck. [On the same.] *Ibid.* p. 215.
29. A. Smith Woodward. 'Note sur l'*Helicoprion* et les Édestidés' *Ibid.* p. 230.
30. G. Simoens. 'Note sur *Helicoprion Bessonowi* (Karpinsky)' *Ibid.* p. 235.
31. C. Van de Wiele. 'Aperçu sur les Vestiges fossiles d'Édestidés, & le nouveau Genre *Helicoprion*' *Ibid.* p. 244.
32. H. Yabe. 'On *Fusulina*-Limestone with *Helicoprion* in Japan' Journ. Geol. Soc. Tokyo, vol. x, no. 113, Jan. 20th (2563) 1903, p. 8.

## EXPLANATION OF PLATE I.

*Edestus triserratus,* sp. nov.

From the Coal-Measures of Nettlebank (Staffordshire), preserved in the Museum of Practical Geology, Jermyn Street, London.

Fig. 1. Side view. Natural size.
2. Seen from above. Natural size.
3. Side view of crown and part of base. Two and a half times the natural size.
4. Crown and part of base seen from above. Two and a half times the natural size.
5. Section of base at *h*. Two and a half times the natural size.
6. View of broken end (*a, e, d*). Two and a half times the natural size.
7. Denticles showing triserration. Six times the natural size.




A. T. Hollick del. et lith.

Mintern Bros. imp.

EDESTUS TRISERRATUS, nov. sp.

## Discussion.

Dr. A. Smith Woodward confirmed the Author's interpretation of the fossil exhibited, and remarked on the imperfection of our knowledge of the marine Upper Carboniferous fishes. The fragmentary character of the known remains of Edestidæ prevented the formation of any definite judgment as to their true nature. He regarded the fossils named *Edestus* and *Helicoprion* as the fused teeth of sharks, and alluded to the discovery of analogous whorls of teeth in the mouth of a Lower Devonian shark described by Dr. Traquair. He did not think that the more flattened rows of teeth needed a different interpretation from that of the more spiral whorls.

The Author, in reply, called attention to the use which the living 'sawfish' (*Pristis*) makes of its toothed rostrum, as indicating a possible function of the *Helicoprion*-spiral, if (as has been supposed) this was placed in front of the head.

## 2. METAMORPHISM *in the* LOCH-LOMOND DISTRICT. By E. HUBERT CUNNINGHAM-CRAIG, Esq., B.A., F.G.S.[1] (Read November 4th, 1903.)

[PLATES II–V: MICROSCOPE-SECTIONS.]

CONTENTS.



### I. INTRODUCTION.

THIS communication has been written, not so much with the idea of describing any phase of metamorphism specially interesting in itself, as of contributing to our knowledge of what metamorphism is, and of distinguishing between different kinds of metamorphism.

The term 'metamorphism,' or even 'progressive metamorphism,' has so often been used in a somewhat vague sense, without any distinct specification as to whether dynamic, thermal, hydrothermal, or contact-metamorphism, or a combination of two or more of these, is meant, that a study of an area where each of these types can be readily distinguished by its effects and considered separately, may prove of interest, as indicating the nature of those problems which workers among the Highland rocks have to investigate.

In the 'Loch-Lomond District' I include all the Highland rocks on both sides of the loch, as well as the area lying to the eastward, including the Trossachs—in fact that part of the Highlands which is embraced by Sheet 38 of the Ordnance-Survey map. The material for this paper was collected two years ago, after four years of work in the district, and the main conclusions will appear in the 'Explanation of Sheet 38' by the Geological Survey of Scotland.

It is well-known that, in passing north-westward from the Highland Boundary-Fault, the metamorphism is seen to increase in degree. The progressive metamorphism in the Loch-Lomond district can be considered under two heads—dynamic, and what, for want of a better word, I call 'constructive' metamorphism. These processes

[1] Communicated by permission of the Director of H.M. Geological Survey.

have in all likelihood taken place contemporaneously to some extent, or at least the duration of the latter process has overlapped that of the former: but it is convenient, in dealing with the progressive alteration, to consider each process separately, as they can be distinguished by their effects.

The dynamic metamorphism is, in effect, chiefly a destructive process as regards the allothigenic mineral-constituents and their arrangement in a rock: it is an almost purely-mechanical action, which sets up new structures, but may not have had the slightest effect in the development of authigenic minerals.

The constructive metamorphism, which may be thermal or hydrothermal, is constructive in the sense of developing authigenic minerals; but in its effect upon structures, whether original or produced by dynamic metamorphism, it may tend either to emphasize or to obliterate them.

The foregoing explanation is necessary, as giving the precise meanings of these terms as I shall use them in this communication, meanings which do not necessarily coincide with those applied to the same terms by other observers.

## II. Dynamic Metamorphism.

The effects of dynamic metamorphism upon any bed depend on (1) its lithological character, and (2) the nature and position of the folding at the particular place where the bed is observed. If the bed be massive, coarse, and gritty, it will be able to resist the deforming forces more successfully than if fine-grained, less homogeneous, or of naturally softer material.

The effect of the nature of the folding is not so apparent, but can be explained readily by a consideration of the physical conditions in each case, on the assumption that the motive force is a pressure tangential to the earth's surface. It is evident that a certain amount of shearing-movement must accompany the folding, compression, or stretching affecting the different parts of the fold; but so long as a bed is free to move as a whole (as in folding), differential movement between the particles cannot take place to any very great extent. The great shearing-movements which have proved so effective in destroying original structures, may be considered quite apart from the folding. They may have, and in many cases certainly have, taken place after all folding-movement in the immediate neighbourhood has ceased. The effect of the nature of the folding is expressed simply in the angle at which the original divisional planes of the rock are presented to the direction of movement, which we assume to be a tangential pressure. The original divisional planes in a sedimentary rock, planes of stratification, are in fact surfaces between materials differing more or less in physical properties, such as the coefficient of elasticity; and a force applied from opposite sides of these surfaces must be resolved into two components—one normal to the surface, tending to produce compression, and one parallel to the surface, producing what in geological parlance is called a shear. The angle at which the surface lies to the force determines the magnitude of each component. Thus, if a bed presents surfaces exactly normal to the force, the shear-component is *nil*, and the only effect that can take place is a compression of the bed which may cause a cleavage; while, if the bed lies at a lower angle to the force, the shear-component is proportionately greater. Theoretically, I believe, the shear-component should be greatest when the surface is inclined at an angle of 45° to the force, but in actual fact we find that the shearing is greatest in horizontal or almost horizontal folds. The reason for this is not far to seek, as the flat-lying folds are farthest from the main axis of folding, that is, they occur where the greatest movement is possible. The effect of the folding now becomes apparent: in tightly-packed vertical folding shear-movements may be impossible, a cleavage of the finer bands of a rock may be the only appreciable effect, and original structures may be to a great extent preserved; while, in a gently-inclined set of folds, the shearing may be very great, original structures may be completely destroyed, and a high degree of schistosity induced parallel to the original bedding. The greatest shearing-movements naturally take place along those surfaces where there is the greatest difference in physical properties between the beds on opposite sides of the surface; and thus the shearing is concentrated, so to speak, in the finer and softer beds against harder and more massive beds which may not be greatly affected, thus causing what Mr. Lamplugh has described in the Geological Survey Memoir upon the Isle of Man (1903) as 'grit-band metamorphism.' The shearing may have taken place during the folding and the bending-over of the crests of the folds away from the central axis of folding, but much of the shearing has probably taken place at a slightly-later stage, while any subsequent crust-movement may intensify the same effects. Should a later movement, however, be checked by the presence of any massive barrier, and should the 'load' or weight of superincumbent material be sufficient to prevent the development of a series of large folds, puckering of the finer beds would be the result, and would be shown by puckered folding, wrinkling of the finer and more elastic bands, and finally by strain-slip cleavage in the laminæ.

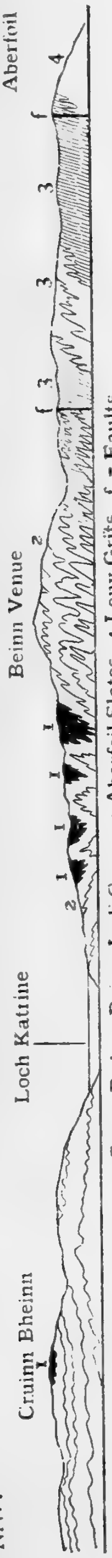
## III. Constructive Metamorphism.

The effects of constructive metamorphism upon a rock depend on (1) its chemical composition, which determines the possibility of the formation of new minerals; and (2) the extent to which the rock has been, or is being, affected by dynamic metamorphism. It seems that the shearing and crushing processes, by mingling more intimately the material from which the rock is built, afford more favourable conditions for the segregation necessary in building up a highly-crystalline rock under constructive metamorphism. Thus, where original structures have been most completely broken down, the constructive metamorphism can exert greater effect upon the crushed material, and the resulting rock may be much more highly-crystalline than a rock of similar composition which has escaped the shearing and crushing to some extent.

As the present state of any mass of rock depends on the extent to which each of these processes took effect, it is evident that the type and nature of the folding become very important factors in regional metamorphism. With these preliminary observations, which sum up the conclusions arrived at by other workers among metamorphic rocks, as well as my own observations during seven years of study of folded rocks, I may now proceed to a description of the folding in the area in question.

Fig. 1.

Section from Aberfoil to Allt a'choinn. Length 10 Miles.




1. Green Beds. 2. Beinn-Ledi Group. 3. Aberfoil Slates. 4. Leny Grits. f. = Faults.

## IV. Nature of the Folding, and Stratigraphical Relations. (Fig. 1.)

The folding of the Leny Grits and Aberfoil Slates, the groups lying nearest to the Highland Border, is not very well seen, as a well-marked cleavage has been produced in all the finer beds, and has even affected the coarser grits to some extent, with the result that the bedding is often obscured. Where actual dips can be observed, however, they are nearly always at high angles, while the mapping out in detail of certain grit-bands shows that the folding, though never very deep, is somewhat tightly 'packed.' The magnificent sections afforded by the slate-quarries at Aberfoil and Luss confirm this observation. The cleavage is usually approximately vertical, and often coincides with the bedding.

Passing north-westward and ascending in the series, the cleavage gradually disappears, the finer beds showing traces of it long after the more massive beds have ceased to give any clear evidence of such a deformation. A shear-structure becomes more noticeable as the cleavage declines, and the folding is easily recognizable. The rocks belong to the Beinn-Ledi Group, and are chiefly fine quartzose grits, becoming coarser in the higher members. A compound syncline and anticline are disclosed, formed of folds which are practically isoclinal, with nearly vertical axial planes. This flexuring of the massive Beinn-Ledi Grits is a very important factor in the metamorphism of the district, as the coarse upper beds thrown into great vertical folds in the anticline seem to have formed a relatively rigid barrier, against which the strata on either side have been strongly compressed. The anticline is well-marked by the occurrence of many of the highest hills in the district, as, for example, Beinn Ledi, Beinn Aan, Beinn Venue, and Beinn Bhreac, which demonstrate the great resistance to denudation that these beds present when vertically folded. A point to be noted in the belt of country containing the anticline is that, although the folding is isoclinal in the low ground, upon the hilltops the folds become shallower and open out, thus showing a vertical gradation from simple flexure to highly-compressed folding.

North-west of the anticline of Beinn-Ledi Grits comes one of the most important structures in the area, a complex syncline of considerable depth which brings down the overlying Green Beds. This structure is traceable from Loch Lomond at Rowardennan, where the trough is shallow, to the Trossachs, where the trough is most clearly marked and deepest. The whole trough, which attains a breadth of $1\frac{1}{2}$ miles in places, is marked by the outcrops of the Green Beds, repeated several times—each outcrop being essentially a minor synclinal fold. It was the mapping of these beds, which form an easily recognizable horizon, that first made clear the structure of the district. The folding is still distinctly isoclinal in the lower ground, but less highly compressed towards the hilltops; while, as we proceed north-westward, the axes of the folds are seen to incline at successively lower angles to the south-east. Thus, as regards the folding, but not the bedding, there is a fairly well-marked fan-structure, which embraces the anticline of the Beinn-Ledi Grits and the syncline of the Green Beds.

To the north of Loch Katrine this complicated syncline opens out rapidly into a wide shallow basin, somewhat complicated by faulting and overfolding at the south-western edge, where one lip of the basin, as represented by the outcrop of the Green Beds, is repeated four times in Glen Finglas. On the south-eastern margin of this basin the folds of Green Beds 'pitch out' towards the hilltops, and the folding, though still sharp, becomes shallow: so that the outcrop is represented by a few corrugated outliers, in which the folding, though acute, is not of sufficient depth to affect the shape of the outlier. Farther to the north-east, where the basin-shape becomes less complicated, the folds open out still more, the strata being flexured into large gentle domes and troughs, while each bed is folded into small corrugated and right-angled folds; overfolds are infrequent, and when present their axes incline to the north-west.

South-west of the Green-Bed outcrop in the great syncline the folding is less well-marked and regular, but traces of the trough can be made out on the western side of Loch Lomond.

The area, amounting to nearly one-third of the whole sheet, to the north-west of the great syncline, does not afford good evidence of folding on a large scale. This is no doubt partly due to the fact that recognizable horizons cannot be followed throughout the area, but it is also certain that through the greater part of this area there is little or none of the regular compressed folding characteristic of the belt of country nearer to the Highland Boundary.

The north-western margin of the trough gives evidence of low-lying folds which are gradually losing their sharpness, and the rocks emerging from beneath the trough exhibit this to an even greater extent, so that very rapidly all trace of regular folding is lost. Rolling and puckered folding of no great depth is the rule, and continues north-westward to the neighbourhood of Ardlui at the head of Loch Lomond, where evidence of more regular folding, the margin of the great Highland fan-structure to the north, begins to appear.

The structure, then, from the great trough to the north-western corner of the sheet, is practically horizontal, the minor flexuring and crumpling of the beds being of little account, and the surface is occupied by rocks of the Beinn-Ledi Group. This fact was only arrived at by careful examination of a great part of the area, and the identification of outliers of the coarsest bed of Beinn-Ledi Grit at various points: as, for example, An Garadh north of Loch Katrine, Beinn Lomond, and Beinn Bhreac and Tullich Hill in Dumbartonshire. Still more important were the recognition of an outlier of the Green Beds on Cruinn Bheinn, north of Loch Katrine, at a distance of 2 miles from the margin of the great trough, and the identification of the Green Beds again at Ardlui, in a very highly-altered state.

These points having established the stratigraphy and the general structure by actual mapping, we are now enabled to consider the bearing of the structure upon the general and progressive metamorphism of the area.

## V. Petrographical Descriptions.

A large number of microscope-slides from the area have been examined, and in the following descriptions selected slides and specimens from different parts of the area form the basis of the account of the various phases of metamorphism to be considered; a series collected from the western shore of Loch Lomond to illustrate the progressive metamorphism, for the Explanation of Sheet 38 of the 1-inch Geological Survey Map of Scotland, is included.[1]

### (a) The Leny-Grit Group.

The Leny Grits appear to differ very little in character, from whatever part of the area they are collected. They consist essentially of pebbles of quartz and felspar (mostly oligoclase) in a fine matrix which is usually more or less chloritic, and partakes more of the nature of an ordinary clastic than a crystalline rock. The matrix exhibits a distinct schistosity; but the pebbles, especially where the grit is coarse, are little affected: strain-shadows in the quartz and peripheral granulation are often the only signs of dynamic metamorphism. The smaller pebbles, however, may be completely granulitized, or may show 'tails'

[1] I am indebted to Mr. J. D. Falconer, of the University of Edinburgh, for very kindly preparing the microphotographs which have been used to illustrate this paper.

of granulitic material drawn out in the direction of schistosity. The felspar-pebbles are either fractured or apparently unaffected, but are often much decomposed. The matrix is also cloudy and decomposed; it consists of granulitic quartz, a little chlorite and sericitic mica, and iron-ores, and it has never attacked the pebbles, even where they are somewhat ragged in outline. A slide of coarse grit[1] (8983, Pl. II, fig. 1) from Craignahuillie, south of Luss, is a fair instance of the state of metamorphism attained in this group. A finer grit from Creachan Hill, south of Luss, shows the pebbles with ragged ends, and the complete granulitization of some of them. An alkali-felspar (much decomposed) is present in this rock, and a small patch of microcline has been preserved in a quartz-pebble. The matrix is chloritic and sericitic. The preservation of the microcline by being included in a fragment of quartz is significant, as suggesting that alkali-felspar may have been present in greater quantity in the original rock but has been destroyed in the dynamic metamorphism, giving rise to the sericitic mica of the matrix. Clastic micas may be occasionally detected in the finer grits. These beds occur, as has been stated, in highly-compressed vertical folds, and it is evident that the phase of dynamic metamorphism is not very high, while constructive metamorphism can hardly be said to have commenced, its only effects being the meagre development of sericitic mica and chlorite, which may also be partly of clastic origin.

### (*b*) The Aberfoil-Slate Group.

Passing north-westward, and ascending in the series, we come to the Aberfoil Slates and slaty grits, a series of fine sediments which are much more liable to dynamic alteration from their comparative softness, and also to constructive metamorphism from their more complex composition. A section of slate (2567), from the head of Glen Fruin, shows a considerable development of more or less indeterminable micaceous minerals, chiefly sericitic mica and chlorite, along the cleavage-planes, which cross the bedding at a high angle. The bedding is marked by the presence of minute aggregates of quartz, and one distinct pebble is noticeable. How much of the micaceous constituents can be said to be due to constructive metamorphism it is impossible to say, but there has evidently been no crystallization on more than a very minute scale; the rock has been deformed, and the constituents rearranged by dynamic metamorphism, but the constructive metamorphism is still at a minimum.

Another section (2568) from Rowmore, Garelochhead, shows an originally fine gritty rock assuming the character of a phyllite. Much drawn-out phacoids of quartz and a little plagioclase-felspar show that the rock was originally gritty, but a good deal of the felspar has probably been destroyed, and the development of micaceous

[1] The numbers are those of the slides in the collection of the Geological Survey of Scotland.

minerals serves to class the rock as a phyllite. The developing schistosity is along the planes of cleavage. Reconstruction of the matrix under constructive metamorphism is at a very low phase.

### (*c*) The Beinn-Ledi Group.

Still proceeding north-westward, we reach the Beinn-Ledi Group of grits, schists, and greywackés. These rocks, where folded into a vertical isocline, have as a rule suffered little from shearing-stresses, especially where coarse and gritty in texture and highly siliceous in composition; the finer and more felspathic bands, on the other hand, present a more favourable field for the action of metamorphic processes, and are accordingly more greatly affected.

A specimen (3679) taken from the Trossachs, a quarter of a mile east of Loch Katrine, shows the state of a fairly fine grit in a vertically-folded area. The matrix is mainly composed of granulitic quartz, with some cloudy indeterminate material and sericitic mica. The pebbles are chiefly of quartz, though a number of small striated felspars are visible. The felspar-pebbles appear to have been fractured or crushed more than the quartz, and there is a little calcite present—an important point, which will be referred to later. There is very little sign of shearing or orientation of the pebbles; they lie at all angles to the planes of schistosity, but show peripheral granulitization and a tendency to merge into the matrix. There is no recrystallization of the matrix to obscure the original planes of bedding, which coincide with the schistosity; but much of the granulitization may possibly be due to incipient thermometamorphism. On the whole, the rock shows fewer signs of dynamic metamorphism than the last, and very little constructive metamorphism.

To examine the effects of metamorphism upon the rocks at about this horizon—high up in the Beinn-Ledi Group,—a series of specimens was collected from the western shore of Loch Lomond, all being taken at approximately the same level, and being (as nearly as it was possible to ascertain) from the same horizon. It has been mentioned before that in this area, west of Loch Lomond, rocks of the Beinn-Ledi Group occupy the surface from Luss to Ardlui. The next specimen taken comes from Rudha Mor, beyond the belt of vertical folding and where the folds are rapidly becoming flatter and of small amplitude. This specimen (8984, Pl. III, figs. 1 & 2) shows, as might be expected, a much advanced stage in the metamorphism. It has been a coarse siliceous grit, but now, although the larger pebbles are still distinct, the development of planes of schistosity has cut up the rock into elongated phacoids, with micaceous folia separating them. Under the microscope the matrix is seen to consist of granulitic quartz, sericitic mica, biotite, and a few grains of sphene; the pebbles are of quartz and decomposed felspar. The quartz-pebbles are sometimes completely granulitized and merging into the matrix; others are only peripherally granulitized, but show strain-shadows and drawn-out 'tails' of granulitic quartz. The felspar-pebbles are almost completely destroyed and decomposed, and are associated with the micaceous films. The biotite is in well-developed flakes, lying at all angles to the schistosity, but it seldom pierces the quartz-granules of the matrix, showing that the quartz has not been recrystallized to any great extent. The biotite is the first clearly authigenic mineral to be observed in these rocks, and has evidently been developed by constructive metamorphism after the shearing-movements which produced the schistosity had ceased.

From this point onward, as we recede from the Highland Border, allothigenic minerals decrease in number, while there is a corresponding increase in authigenic constituents. I am inclined to regard the constructive metamorphism which has affected the last-described specimen as probably a normal thermometamorphism. In the specimens that follow we find effects, increasing to the northward, of a different type of constructive metamorphism, the nature of which will be discussed later.

The next specimen (8985) was collected at Rudha Dubh, 1½ miles to the north-north-west. It has probably been a finer-grained rock originally, and occurring in a locality where the beds are lying at a low angle, schistosity has reached a much higher stage. The rock consists of irregular grains of quartz and plagioclase, with folia of sericitic mica, chlorite, and green or chloritized biotite, some calcite (probably from decomposed plagioclase), and a few grians of sphene and magnetite. Pebbles have disappeared, but the arrangement of lenticular aggregates of granulitic quartz suggests that pebbles may once have been present: they may be called the 'ghosts' of clastic grains. The quartz and felspar do not appear to have been recrystallized to any extent; but the micas, chlorite, and possibly sphene, are authigenic. The presence of calcite, the development of chlorite, and the chloritization of biotite might be attributed to weathering. I am inclined to regard them, however, as the first stages in the special type of constructive metamorphism, which, from this point to the head of the loch, becomes increasingly conspicuous.

A rock (8986) from the shore opposite Tarbet Isle, where the strata and folding are practically horizontal, carries the metamorphism a stage further. This is a siliceous but conspicuously-schistose rock, with a considerable development of white mica, which gives it a flaser-structure. Only the 'ghosts' or suggestions of original pebbles are to be seen, but their shape and size point to the rock having been originally coarser in grain than the last. Fragments of both oligoclase and alkali-felspar are present, although they may be in part recrystallized. The quartz is certainly becoming authigenic by recrystallization into a larger mosaic, the grains of which not infrequently include flakes of biotite. Some calcite and magnetite are also present.

At this stage, it may be as well to glance at the evidence from the area to the eastward of the loch, and approximately on the same line of strike, both the flexuring and the strata striking from north-east to south-west. The rocks which emerge from below the great syncline differ very greatly, as has already been stated, from the same rocks to the south-eastward of the syncline. The area south of Loch Katrine illustrates this admirably. In the rolling and crumpled folds north-west of the trough grit-beds are frequently noticed, but they can never be traced far; the normal type is a glistening mica-schist, which apparently becomes more micaceous, and certainly more fissile, to the north-westward, as gritty bands become less and less frequent. The rocks invariably split along the planes of foliation, and thus present micaceous surfaces giving all the appearance of a phyllite; but a careful examination shows that to call them 'phyllites' would misrepresent their composition. If a good cross-fracture (a difficult thing to obtain) is examined, it is seen that these schists are made up of folia or elongated phacoids composed chiefly of quartz, separated by mere films of micaceous minerals along which the rock naturally fractures. Thus the quantity of the micas present is apt to be overestimated at first. In the phacoids remains of allothigenic structures may often be observed, long after all traces of a regular bed of grit have been lost. A specimen (3681) from the shore of Loch Katrine, three-quarters of a mile south-south-east of Stronachlachar Hotel, is a characteristic example of this type of mica-schist. No grits have been recognized in the locality. The specimen consists of alternating folia of granulitic quartz and micaceous minerals, chlorite, white mica, and a little biotite; the quartz has partly recrystallized, and contains the micas. A few large allothigenic quartzes, however, are still present, but they are almost entirely granulitized; and there are also several much-fractured and decomposed remnants of plagioclase-pebbles. Thus it is seen that, even in a locality where the rocks are typically mica-schists, evidence of their having been grits may be obtained, and that the grits were fairly coarse in grain may be deduced from the size of the remnants of pebbles.

Returning to the shore-section on Loch Lomond, we find at Inveruglas a rock (8987: Pl. II, fig. 2) in which all allothigenic minerals have disappeared, while distinct evidence of a new and remarkable type of constructive metamorphism, to which allusion has been made above, is obtained. The rock consists of quartz, recrystallized, and often leached out into veinlets following the foliation-planes, felspar in a few small decomposed fragments, and well-developed micas, muscovite and a little biotite, which are both included in the recrystallized quartz. Veins of calcite point to the removal of lime from crushed and decomposed plagioclase. But the most important point is the development of a few small clear blebs of albite, which are chiefly associated with the micaceous folia. The rock shows the first stage in the building-up of an albite-gneiss. From this point onward it is impossible to note increase in the dynamic metamorphism, as there are no clastic structures by the destruction of which such metamorphism can be measured; it is evident, however, that in the area north-west of Inveruglas the dynamic metamorphism does not diminish, and it may have increased. The constructive metamorphism increases rapidly.

Three specimens from the eastern side of the loch at Inversnaid supply the next link in the chain.

The first of these (8999, fig. 2, below) is a very siliceous rock, consisting chiefly of folia of granulitic quartz with biotite, chloritized biotite, albite, and magnetite. The quartz is all recrystallized into a coarse mosaic, and the albites are larger and more distinct than in the last specimen; there is also a tendency for the albite-grains to

Fig. 2.—*Slide No. 8999.* [*Seen under a 1-inch objective.*]

[A highly-crystalline gneiss from Inversnaid, showing the first appearance of small authigenic albites and the leaching-out of quartz into lenticles. Muscovite and biotite are also present.]

be concentrated in folia. In a more micaceous specimen (9000), chlorite and muscovite are very abundant, being associated both with folia of quartz and with the authigenic albites; but the albites are hardly, if at all, more abundant than in the more siliceous specimen. The third specimen (3680) is composed chiefly of flakes of chlorite and muscovite lying at all angles to the bedding, with interstitial quartz and a few large albites. Thus, in a rock which most closely resembles a phyllite or slate in composition, the development of albite is little greater than in a highly-quartzose gneiss evidently formed from a grit. The albites in these specimens show little or no trace of idiomorphic outlines: they appear as rounded or elongated grains. Polysynthetic twinning is never observed:

but the albites contain numerous inclusions, chiefly of magnetite, which are sometimes so abundant as to show the direction of original foliation or bedding, as in the last specimen. The micaceous minerals, however, are never included in the albites.

The next specimen, from Creag an Ardain (8988), shows a still further advance: the albites are larger and more conspicuous, and are aggregated more distinctly into folia or lenticles, while the quartz is also to a great extent segregated out into lenticles. The albites are associated with a large quantity of chlorite and some white mica, while biotite is no longer present.

In the next slide (8989), from Ardvoirlich, the albites are even more conspicuous, and the rock may be described as a typical albite-gneiss. The association of the albite with chlorite is again to be noted, and the inclusion of quartz, magnetite, and epidote in the albites. The epidote is important, its occurrence pointing to the presence of lime, derived probably from destroyed plagioclase.

Rudha Ban, from which the next specimen (8990, Pl. IV, figs. 1 & 2) is taken, has long been a famous locality for albite-gneisses. All the rocks in this neighbourhood contain a large percentage of albite, and when the grains of this mineral are large they weather-out like the pebbles in a grit, giving almost a clastic appearance to highly-crystalline rocks. The slide shows very clearly the segregation of the materials into folia, quartzose lenticles alternating with those rich in albite. The quartzose lenticles often attain a large size, and appear as discontinuous veinlets in the matrix; but it is quite evident that these veinlets belong essentially to the rocks in which they occur, and the silica has not been introduced from elsewhere.

Another slide from farther north, at Stuckindroin (8991), presents the same characteristics in a rock of more siliceous composition: albite and chlorite, though present in considerable quantity, being less conspicuous than quartz and muscovite. A few small garnets are occasionally present in these rocks, but they are comparatively rare, and never attain a sufficient size to be conspicuous in hand-specimens. Calcite-veins are often fairly numerous, biotite is almost, if not entirely, absent, while chlorite is abundant.

On the whole, the rocks in this belt of country, from Inveruglas to Stuckindroin, are remarkably constant in character; they are all albite-gneisses produced by a constructive metamorphism, which reaches its maximum about the neighbourhood of Ardvoirlich and Rudha Ban, and does not appear to decrease to the northward. Two points are worthy of attention: (1) that the albites show a tendency to include all the other minerals, with the exception of micas and chlorite; and (2) that the albites give no indications of having been affected by movement of any kind—in fact, the lines of inclusions not infrequently show the minute puckering and folding which was the latest movement to affect the rocks: thus proving that the albites have developed since the movement ceased.

### (*d*) The Green Beds.

The progressive metamorphism of the Green Beds cannot be traced in this area in detail, as there are no exposures of these strata between Beinn Lomond and Ardlui. It is not necessary to describe now the alteration that they have undergone, a description which I hope to give in a future communication. It will be sufficient to state here that the metamorphism of these well-known rocks bears out the conclusions as to progressive metamorphism arrived at after examination of the rocks of the Beinn-Ledi Group. On the southern slopes of Beinn Lomond they are epidotic and chloritic grits; at Ardlui they are hornblende-schists, not easy to distinguish from hornblende-schists of igneous origin.

## VI. Chemical Analyses.

The stratigraphical relations of the albite-gneisses having been proved by a study of the structure of the district, and by the identification of the Green Beds at Ardlui, we are impelled to the conclusion that they have been formed by the action of dynamic and constructive metamorphism from the Beinn-Ledi Grits, unless we are to assume a change in lithological character and chemical composition in the rocks of the Beinn-Ledi Group when traced north-westward. Chemical analysis was necessary to prove whether or not such a change existed. I was inclined to disbelieve in such a change, but I found, after arriving at the conclusion stated above, that Continental geologists favoured the view that albite-gneisses of similar character had been formed by the metamorphism of phyllites rather than grits.

Mr. Teall, in the Appendix to the Survey Memoir on the 'Geology of Cowal' (1897) p. 297, refers to the occurrence of rocks containing authigenic albite in the northern border of the central zone of the Eastern Alps. These rocks were described by A. Bœhm,[1] who defined the type as transitional between the old crystalline schists and the true phyllites. Mr. Teall also refers to the albite-phyllites of Saxony,[2] and of the Green Mountains of Massachusetts.[3] In all these instances the association of minerals appears to be similar: white mica, chlorite, and folia of quartz accompanying the albite.

The suggestion is made in some, if not all, of these cases that the albite-gneisses have been formed from phyllites, but the descriptions, especially in the case of the Green Mountains, hardly seem to uphold this idea. Prof. Wolff, in his description of these schists or gneisses

[1] 'Ueber die Gesteine des Wechsels' Tschermak's Min. u. Petr. Mitth. n. s. vol. v (1883) p. 197.

[2] K. Dalmer, 'Erlaüterungen zur geologischen Specialkarte des Königreichs Sachsen—Section Lössnitz' 1881.

[3] Monogr. U.S. Geol. Surv. vol. xxiii (1894).

in Hoosac Mountain,[1] calls attention to the strings and lenticles of quartz developed along the bedding-planes of the albite-schist, as evidence of a higher percentage of silica in the rock than would be met with in a true phyllite.

In the Survey Memoir on the 'Geology of Cowal,' also. Mr. C. T. Clough suggests the possibility of the development of albite-gneisses from phyllites; and two analyses (*op. cit.* p. 39) were made from selected specimens—one of phyllite, the other of albite-gneiss, to see whether these rocks were similar in chemical composition. These analyses are tabulated below.

| | I. Per cent. | II. Per cent. | III. Per cent. | IV. Per cent. |
|---|---|---|---|---|
| $SiO_2$ | 43·3 | 63·4 | 65·11 | 77·22 |
| $TiO_2$ | 1·2 | trace | 0·83 | 0·59 |
| $Al_2O_3$ | 26·2 | 18·1 | 15·78 | 10·07 |
| $Fe_2O_3$ / FeO | 13·6 | 6·7 | 6·49 | 4·02 |
| MnO | not estimated | not est. | 0·24 | 0·30 |
| CaO | 0·5 | 0·9 | 1·34 | 1·10 |
| MgO | 3·8 | 1·9 | 1·95 | 1·17 |
| $K_2O$ | 4·6 | 3·2 | 3·97 | 2·65 |
| $Na_2O$ | 1·8 | 3·2 | 2·49 | 2·65 |
| $H_2O$ / $CO_2$ | 4·5 | 2·8 | 1·41 | 0·36 |
| $CO_2$ | | | 0·39 | 0·32 |
| $P_2O_5$ | not estimated | not est. | 0·25 | 0·14 |
| S | not estimated | not est. | 0·14 | ... |
| Totals | 99·5 | 100·2 | 100·39 | 100·59 |

As the iron in I & II was estimated as $Fe_2O_3$, and FeO was not estimated, the total iron in III & IV is given as $Fe_2O_3$ for the sake of comparison.

The percentages 4·5 & 2·8 in I & II respectively were 'loss on ignition,' and are given as $H_2O$ & $CO_2$ bracketted; this loss may also include a percentage of sulphur.

I. Green phyllite from Blairmore (Cowal),<br>
II. Albite-schist from Stuck Burn (Cowal), } analysed by Mr. J. J. H. Teall.

III. Albite-gneiss from Rudha Ban,<br>
IV. Schistose grit from Rudha Dubh, } analysed by Dr. W. Pollard.

For the 'Explanation of Sheet 38' by the Geological Survey, two analyses have also been made by Dr. W. Pollard: one of a typical albite-gneiss from Rudha Ban; the other of the coarsest and most siliceous grit that could be obtained in the section on the western shore of Loch Lomond, at Rudha Dubh. It must be mentioned here that a finer-grained, less siliceous, and more micaceous specimen of schistose grit could easily have been selected; but in order that there should be no forcing of the evidence to agree with the conclusions to which I had come previously, I determined to select the very coarsest and most siliceous grit that I could find—in fact, what I may call an extreme case of siliceous grit, as compared with an average specimen of albite-gneiss.

[1] Monogr. U.S. Geol. Surv. vol. xxiii (1894) pp. 59 *et seqq.*

In the foregoing table (p. 23) these analyses are set forth. It will be seen at a glance that there is a very close resemblance between the albite-gneiss from Cowal (II) and the albite-gneiss from Loch Lomond (III), not only in the actual percentages, but in the ratios of one base to another. I may here remark that the discrepancy between the ratios of potash to soda in the two rocks may be more apparent than real, as Dr. Pollard made three separate estimations of the alkalis in III from different samples of the same specimen, checking his results by an estimation of the silica, and so proving that the analyses were absolutely correct. These analyses gave somewhat different results, as follows:—

| | *a.* | *b.* | |
|---|---|---|---|
| $K_2O$ ............... | 3·88 | 3·97 | 3·27 |
| $Na_2O$ ............ | 2·38 | 2·49 | 3·15 |

Result *b* was obtained from the largest amount of material, and is accordingly given in the table, but it will be seen that *c* gives a ratio practically the same as the ratio of potash to soda in II. If the mean of the three analyses be taken, we get 3·70 per cent. of potash to 3 of soda, a ratio not differing very greatly from that in II.

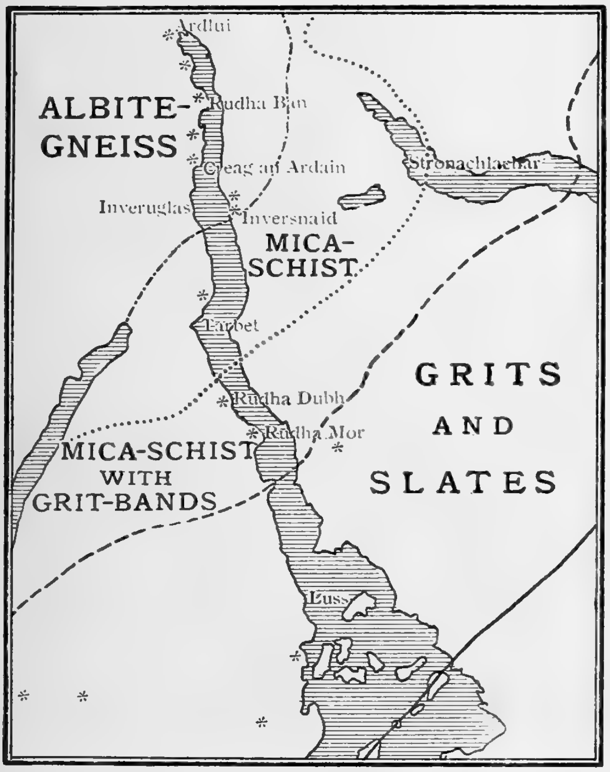
The next point brought out by these analyses is the great dissimilarity between the phyllite (I) and either of the albite-gneisses (II & III). The low percentage of silica, lime, and soda, and the high percentage of alumina, iron, magnesia, and potash make this clear at once; while if the ratios, for example, of potash to soda, be taken, the difference becomes even more conspicuous. It is evident that a phyllite of such composition could not possibly form an albite-gneiss.

When we turn to the analysis of the schistose grit (IV), it does not seem at first to resemble those of the albite-gneisses very closely, but it must be remembered that this rock was selected as being the most siliceous that could be obtained. Consequently, we find a very high percentage of silica, and the other constituents are reduced in proportion. Taking the ratios of one constituent to another, the resemblance between the grit and the albite-gneiss becomes very striking: thus the ratio of alumina to lime or magnesia in the grit approximates fairly well to the ratio of the same constituents in the albite-gneisses, while the ratio of potash to soda is exactly the same as in the albite-gneiss specimen from Cowal. From these facts it is evident that an albite-gneiss could be formed even from a highly-siliceous grit.

## VII. The Zones of Progressive Metamorphism.

The sketch-map (fig. 3, p. 25) shows approximately the different zones in the metamorphism of the Beinn-Ledi Group: first that in which grits predominate, almost every rock being a fine or a coarse grit; then the zone of mica-schists, in which a few of the coarser grit-bands still survive owing to their resistance to dynamic metamorphism; then the zone of mica-schists, composed entirely of authigenic minerals; and finally the zone of albite-gneiss. To the south-west, in Cowal, the boundaries of these zones cross, a circumstance which makes the study of the metamorphism much more difficult, as schistose grits may be found stratified with albite-gneisses: the former representing beds which have resisted successfully the dynamic metamorphism, and consequently to a great extent the constructive metamorphism; while the latter are the beds which have succumbed to the dynamic, and so fallen an easy prey to the constructive, metamorphism. The crossing of the boundaries of these metamorphic zones probably takes place also north of Glen Gyle: it is demonstrative proof that the albite-gneisses are not a stratigraphical group. The Loch-Lomond district is remarkable in being practically free from such confusing complications.

Fig. 3.—*Sketch-map of the Loch-Lomond district, to illustrate the zones of metamorphism. (Approximate scale: 6 miles = 1 inch.)*




[The asterisks indicate localities where specimens of the rocks described in this paper were obtained.]

## VIII. Contact-Metamorphism.

One other phase of metamorphism in the district must be recorded briefly, and that is contact-metamorphism. In the albite-gneiss area are numerous intrusions of what are called the 'newer granites and diorites'; that is to say, a series of intrusions well-known in the Highlands, and probably in the main of Old-Red-Sandstone age, which have been intruded after the regional metamorphism. The effect of these intrusions on the albite-gneisses is remarkable. On approaching such an intrusion as the Beinn-Vane (Mheadhoin) diorite or the Inversnaid hyperite, the albites are seen to assume a red coloration, due to the oxidation of the magnetite-inclusions, while chlorite begins to give place to biotite. Under the microscope the albite soon appears cloudy and decomposed, and finally, as the junction is approached, vanishes altogether, while biotite and contact-minerals make their appearance, and may become very conspicuous, in the 'hornfelsed' zone near the contact. Dr. Flett has identified cordierite in the hornfels surrounding the Inversnaid hyperite.

A specimen (8992, Pl. V, figs. 1 & 2), which shows very clearly what happens to the albite-gneiss within an aureole of contact-metamorphism, is taken from the railway-cutting north of Ardlui, at a distance of about $1\frac{1}{4}$ miles from the great Meall-Garabal complex described by Messrs. Teall & Dakyns.[1] The hand-specimen resembles very closely the normal albite-gneiss with quartz-veinlets, but the colour is darker and the rock generally less fissile. Under the microscope it is seen that albite and chlorite have almost entirely disappeared, the former being replaced chiefly by aggregates of white mica, in which a soda-mica is probably present, while sporadically-developed flakes of biotite replace the sheaves of chlorite. In the siliceous folia the development of biotite is more regular. A few rather decomposed blebs of albite can still be recognized in some parts of the slide, and in these cases a little chlorite is generally present also. More significant of the contact-action are groups of andalusite-granules which occur among the feathery masses of white mica.[2]

## IX. Nature of the Albite-Gneiss Metamorphism.

It is not my intention to go more fully into the contact-action of these igneous masses. Mr. Clough, in the Survey Memoir on the 'Geology of Cowal,' has described the contact-metamorphism on the other side of the same petrographical complex. For my purpose, sufficient has been said to show the effects of a thermal contact on the rocks which have been previously altered to albite-gneisses. This leads naturally to the question as to what is the kind of metamorphism to which the production of these albite-gneisses is to be attributed. On this question I have to offer a suggestion, which must for the present remain more theoretical than the other conclusions set forward in this paper. I have had the experience of tracing the same rocks of the Beinn-Ledi Group through a progressive metamorphism in other districts, and more especially in the district of Aberfeldy, where they may be traced from not very greatly-altered schistose grits into highly-crystalline muscovite-biotite-schists or gneisses with a considerable number of large and well-developed garnets. The dynamic metamorphism is much the same as in the Loch-

[1] Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 104.

[2] In the andalusite-biotite hornfels near the contact with the Glen-Fine granite, described by Mr. Clough, in the Survey Memoir on the 'Geology of Cowal' (1897) p. 98, a quantity of albite is still present, but it has probably been recrystallized: idiomorphic outlines are not uncommon, and twinning is frequent.

Lomond district, but the constructive metamorphism is very different, for nothing like the albite-gneisses has been observed in the Aberfeldy district. If albite be present at all, it is in small water-clear granules mixed with the granulitic quartz-folia. Chlorite is absent, and in its place occur folia of intergrown muscovite and biotite with a considerable development of garnet. We have been accustomed to consider this type of alteration as due to an essentially-thermal metamorphism. I venture to suggest that the albite-gneisses are due to a hydrothermal type of metamorphism. The absence, or presence only in very small number, of garnets: the leaching-out of the siliceous and felspathic materials into separate folia; the fact that the albites only begin to develop after the plagioclase has been destroyed, and after the removal of lime as carbonate (of which there is evidence); and the association of the albites with a hydrated mineral, chlorite, all point to this conclusion. The fact that a thermal contact at once destroys the development of albite adds confirmatory evidence. The view that we are dealing with a hydrothermal type of constructive metamorphism is not inconsistent with the observations of Tschermak and other Continental geologists, who found that albite-gneisses formed a transitional stage between slightly and highly-altered sediments.

## X. Recapitulation.

To recapitulate, we are dealing in the Loch-Lomond district with a progressive metamorphism, each stage of which can be accurately determined, and each process of which can be studied, as a rule, without confusing its effects with those due to another process. In the first place, we saw rocks from the Leny-Grit Group and Aberfoil-Slate Group yielding evidence of dynamic metamorphism not in a high degree, and of practically no constructive metamorphism whatever. Then, entering a higher stratigraphical horizon, the Beinn-Ledi Group, we saw the dynamic metamorphism increasing, and at Rudha Mor the beginning of a constructive metamorphism of the thermal type, which was quickly superseded by a constructive metamorphism probably of hydrothermal type, under which, combined with, or preceded by, the increasing dynamic metamorphism, the rocks rapidly became more highly crystalline until all clastic structures had been obliterated. The segregation of like materials into folia, the total recrystallization, and the genesis of new mineral-groupings, resulted finally in the production of coarsely-crystalline albite-gneisses from a series of fine and coarse siliceous and felspathic grits. Finally, we have seen the effects of contact with plutonic igneous masses, in the obliteration of many of the results produced by the hydrothermal constructive metamorphism.

## EXPLANATION OF PLATES II–V.

[With the exception of fig. 2 in Pl. V, photographed under a $\frac{2}{3}$-inch objective, all the slides are represented as viewed under a 1-inch objective.]

### Plate II.

Fig. 1 (8983). Schistose grit from Craignahuillie, which shows the breaking-down of a large quartz-pebble in a schistose but non-crystalline matrix. (See p. 16.)

2 (8987). A highly-quartzose schist from Inveruglas, in which allothigenic structures have been completely destroyed. It shows recrystallized quartz and authigenic muscovite. A vein of calcite, derived from crushed felspar, is seen on the right. (See p. 19.)

### Plate III.

Fig. 1 (8984). Schistose grit from Rudha Mor, showing a large quartz-pebble, partly granulitized, in a matrix rich in authigenic biotite.

2. The same under crossed nicols. (See p. 17.)

### Plate IV.

Fig. 1 (8990). A typical albite-gneiss from Rudha Ban, very highly crystalline. It contains albite, quartz (recrystallized in lenticles), chlorite (abundant), muscovite, and pyrites. (See p. 21.)

2. The same under crossed nicols.

### Plate V.

Fig. 1 (8992). This shows the effects of contact-metamorphism on an albite-gneiss from Ardlui. There is a finely-crystalline development of biotite and white mica, with quartz recrystallized in lenticles, but albite and chlorite are absent. (See p. 26.)

2. The same, more highly magnified: showing the granular development of andalusite.

## Discussion.

Mr. H. M. Cadell said that the completion of this map interested him greatly, as it had been some 25 years in progress and was happily out at last, to the great advantage of Scottish geologists, who had awaited it for nearly a generation. He had worked on the western part some 18 or 19 years ago, and the Author had worked out the structure in much greater detail and with the aid of the microscope, which was not so much in vogue when he was there, the consequence being that the Author had greatly modified part of his (the speaker's) results. He was glad of this, as geology was, and should be, a progressive science. He would like the Author to say what became of the limestones that occurred among the slates south of Luss, as these passed northward into the more highly-metamorphosed area; also what, if any, was the nature of the contact-metamorphism round the granite and diorite-intrusions north of Arrochar; and further, whether the Author knew the source of the ilmenite which occurred in considerable quantities in that locality.

The Chairman (Sir Archibald Geikie) spoke of the early work of the Geological Survey in the Loch-Lomond district, and the difficulty that was experienced there in making out the order of succession of

FIG. 1.

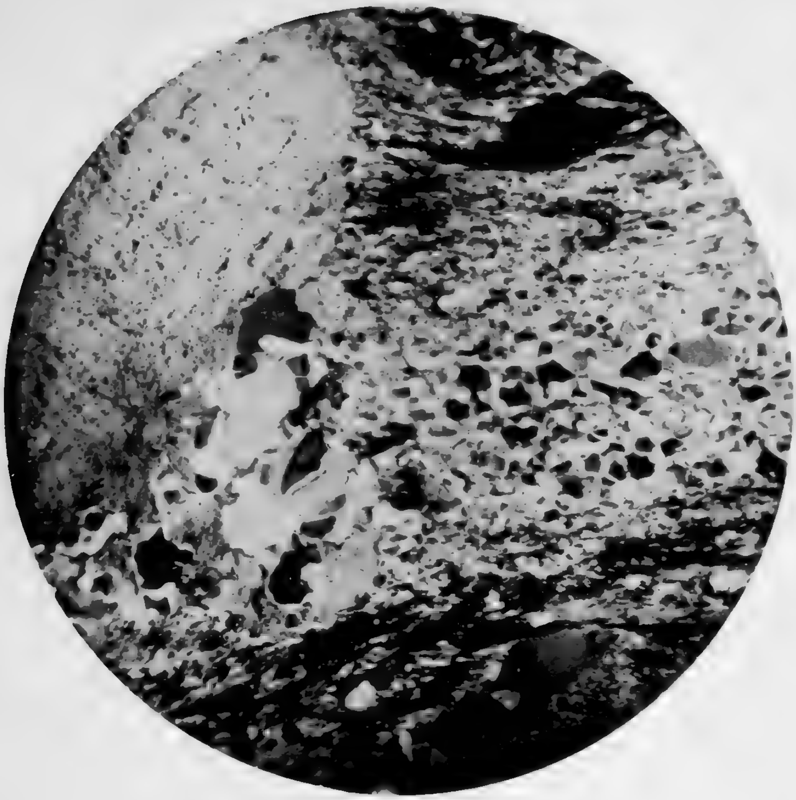


FIG. 2.

J. D. F., Photomicr. Bemrose Ltd., Collo.

SCHISTOSE GRIT AND QUARTZOSE SCHIST.

FIG 1.

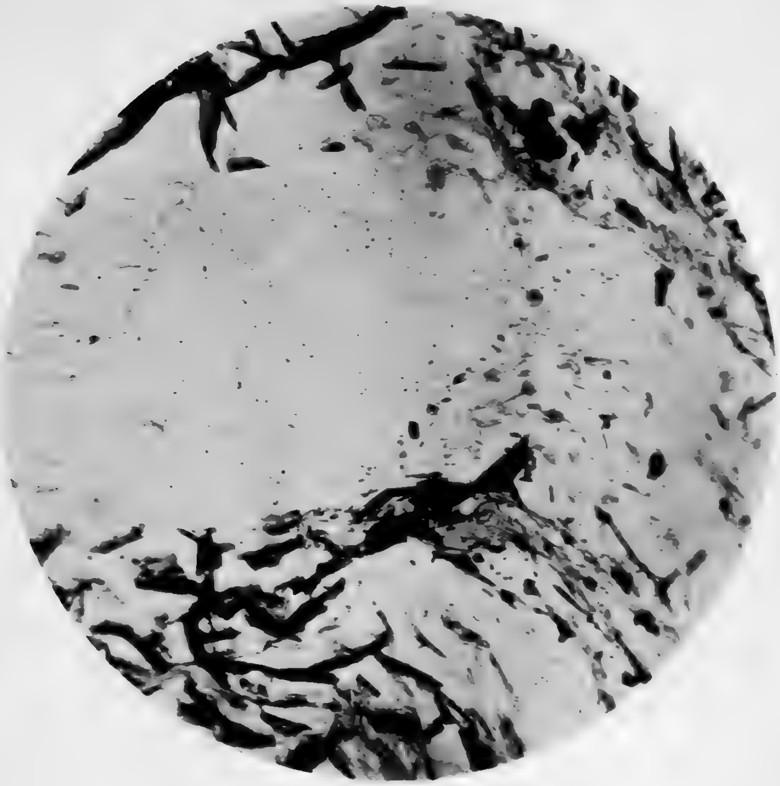


FIG. 2.

*J. D. F., Photomicr.*

*Bemrose Ltd., Collo.*

SCHISTOSE GRIT FROM RUDHA MOR.

Fig. 1.

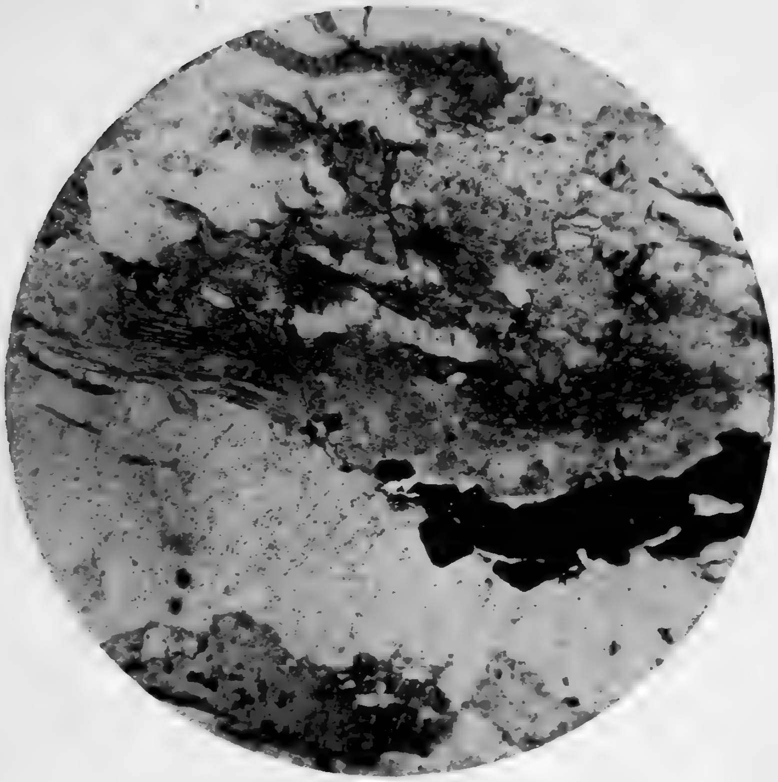
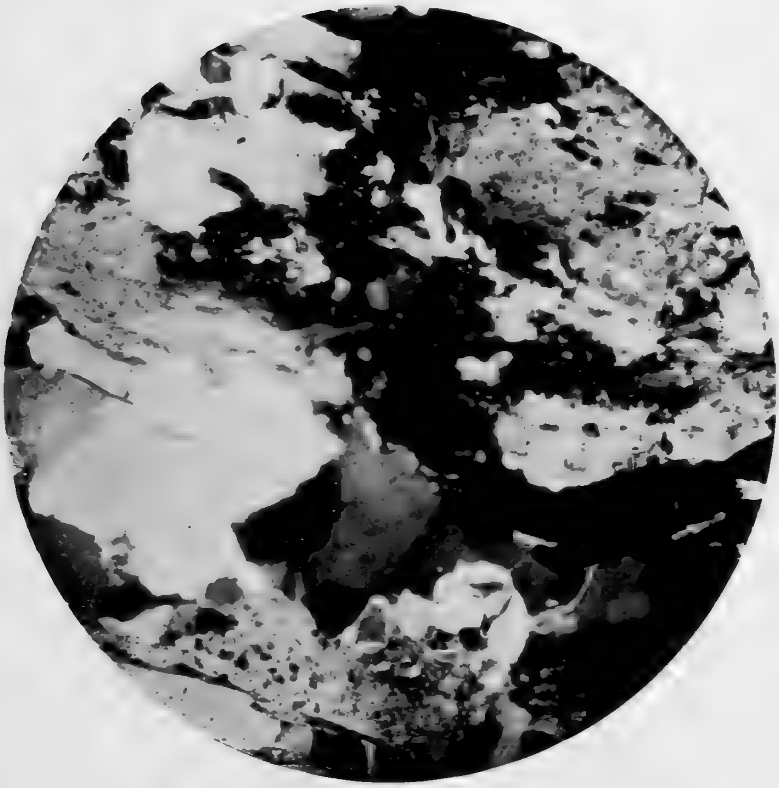


Fig. 2.

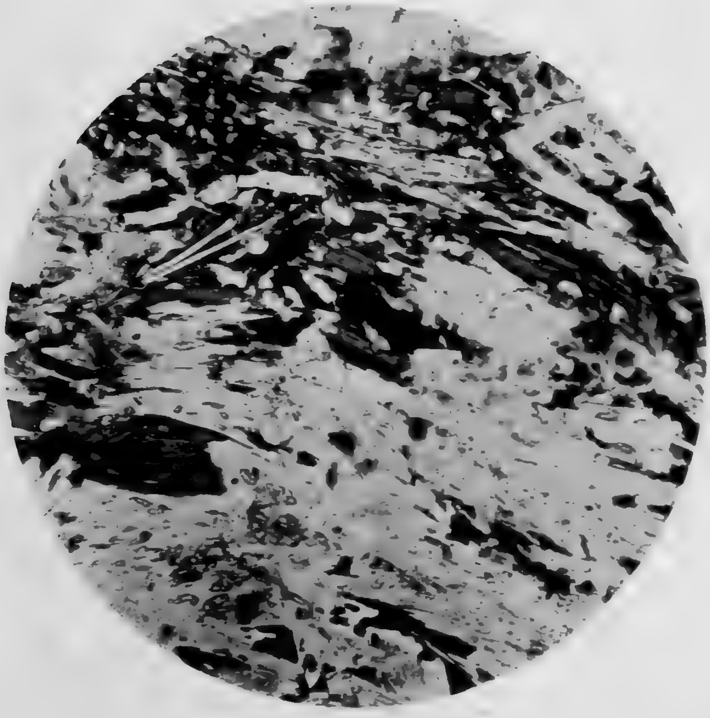


*J. D. F., Photomicr.* *Bemrose Ltd., Collo.*

Albite-Gneiss from Rudha Ban.

Fig. 1.

Fig. 2.



*J. D. F., Photomicr.* *Bemrose Ltd., Collo.*

Contact-Metamorphosed Albite-Gneiss from Ardlui.

the crystalline schists and less-altered sedimentary rocks. It was felt that, until a much larger area of the Highlands had been mapped and some more distinctive stratigraphical horizons had been traced, no definite conclusions on the subject could be drawn. The fresh information required had been now supplied by the work of the Author. Using the horizon of the 'Green Beds' as the key to the structure of the ground, he had shown that the apparently-enormous thickness of the rocks could be satisfactorily reduced to much more reasonable proportions, and that folding on a great scale had affected the whole region. With the microscope as an adjunct to his field-work, the Author had been able to trace an interesting series of metamorphic changes, from the coarse grits of the Highland Border into highly-crystalline albite-gneisses. He was about to proceed to the West Indies to undertake some important duties there, and the speaker was sure that the Society would heartily wish him all success in that distant region, and would hope to welcome him on his return with a fresh harvest of geological results.

The Author, in answer to Mr. Cadell, said that the limestone in the Aberfoil Slates was not the same as the limestone occurring to the north, which was the Loch-Tay Limestone, at a much higher horizon. The contact-metamorphism had not been examined in detail, nor had the source of the ilmenite in these schists been ascertained. As the Chairman had said, it was the mapping of the 'Green Beds' which had explained the structure of the district and indicated the thickness of the rocks. He thanked the Chairman for his remarks, and the Fellows for the manner in which the paper had been received.

### 3. *On a* New Cave *on the* Eastern Side *of* Gibraltar. By Henry Dyke Acland, Esq., F.G.S. (Read November 4th, 1903.)

[Plate VI—Plan & Sections.]

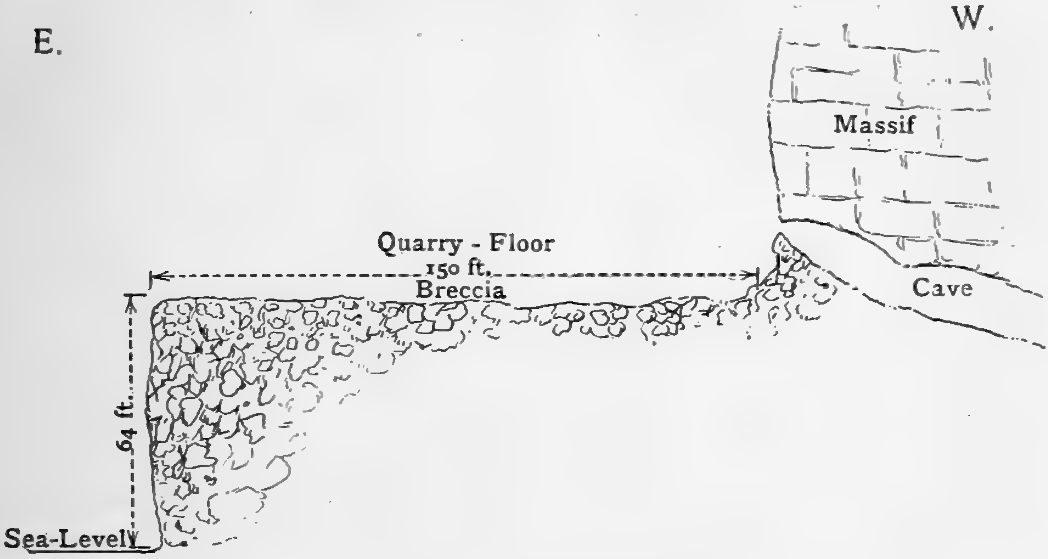
A new cave was discovered on the eastern side of Gibraltar on August 15th, 1902. It is situated a short distance south of the eastern end of the tunnel which pierces the Rock, from the Dockyard on the western side to 'Monkey's Quarry' on the eastern. Blasting and quarrying operations are being carried on in the quarry, to procure material for the new dockyard. An explosion is said to have blown in the face of the limestone-cliff, and a small hole was discovered; when this was entered, it was found that it led into a cave of considerable dimensions. I have not been able to determine whether the hole was made in the 'massif,' or whether the explosion merely blew away the rubble and breccia that forms the talus of the cliff, thereby uncovering an old entrance. Further quarrying operations have so enlarged the opening that none of the original cliff-face remains very near it. I am told by Mr. A. K. Peaty, Assistant Civil Engineer, that he saw the opening two hours after it had been made, and that, in his opinion, the hole had been pierced through the massif, and was not a re-opening of the old entrance. In any case, it must have been very near an old entrance, as a glance at Pl. VI, fig. 1 shows that the stalagmite-floor slopes up to within a few feet of the present opening, and the sides of the cave, so far as they can be seen through the accumulation of fallen rock, clearly indicate that an old entrance was very close at hand. Moreover, this stalagmitic floor does not rest upon the solid rock, but upon a mass of breccia of unknown thickness; and it seems probable that, if this were removed, the original floor of the cave would be found at a much lower level.

It may be desirable to describe, first of all, the situation of the cave and its general features, and then to point out some of the interesting problems which it presents.

Fig. 1 (p. 31) shows that the cliff comes down at this place to a platform formed by the quarrying away of the talus, 64 feet above sea-level. The cliff consists of massive limestone, in which no bedding can be detected. There is a small fault to the south of the entrance to the cave, and this probably forms one side of the cave itself. The talus consists of coarse rubble, resting upon similar material of more ancient date which is now consolidated into a breccia. This platform was covered, before the quarrying began, to a large extent with roughly-stratified fine and coarse rubble, similar to that which still remains *in situ* immediately south of the tunnel.

The present entrance to the cave is 24 feet above the platform, and 88 feet above sea-level. On entering the cave, a fine view is obtained of the 'main hall,' and of the stalactites and stalagmites with which it is decorated. Some of these are of considerable size, and measure from 3 to 5 feet in circumference, 3 feet from the ground. The hall has a width of 45 feet, and an estimated height of 70 at its greatest. It will be at once observed that the floor slopes westward at a considerable angle, about 20°. This slope, as will be seen in Pl. VI, fig. 1, continues for a distance of about 140 feet to a point 19 feet above sea-level. The floor is very smooth with stalagmite, and some of the fallen stalactites are firmly recemented to it. The southern side of the main hall is for some distance striated, as if from the action of blown sand.

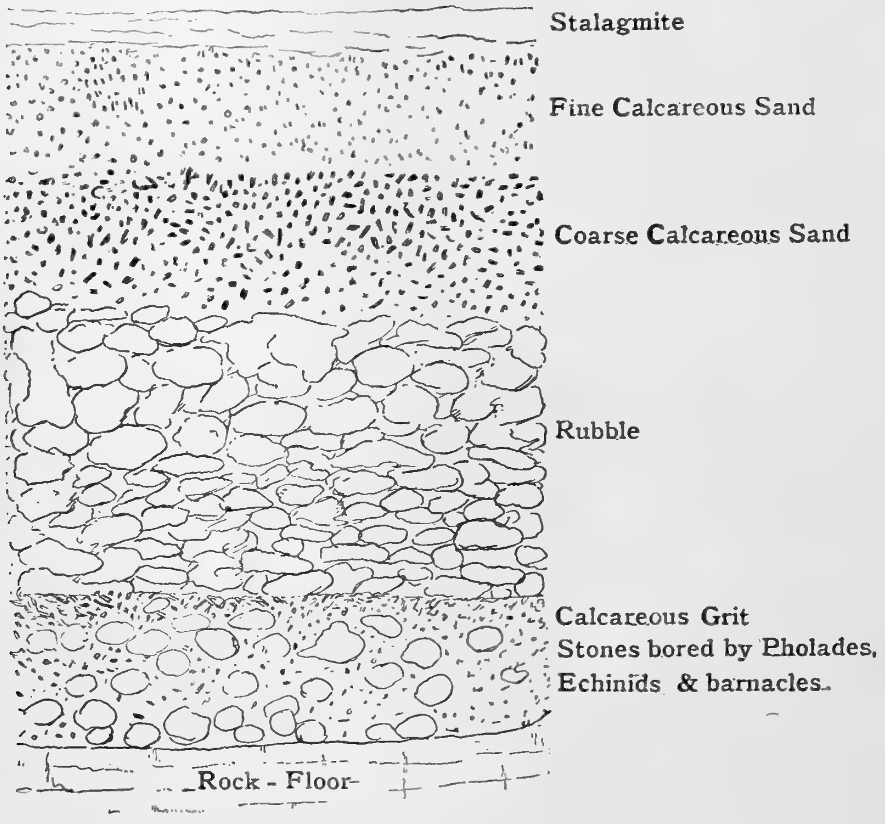
Fig. 1.—*Section at Monkey's Quarry, Gibraltar.*




At this point (1 in the section, Pl. VI, fig. 1), the lower gallery begins. This runs almost horizontally for a distance of 180 feet, turning to the south-west at 120 feet; then there is a sharp dip downward, and the passage becomes so narrow that it is impossible to proceed very far. Fig. 1 in Pl. VI shows that, as a matter of fact, the end of the horizontal part of the gallery is a few inches higher than the entrance, and that there is a slight rise about halfway along, but this is probably due to the unequal filling-up of the floor, and also to the unequal deposit of stalagmite. The mean height of the floor above sea-level is about 16½ feet, and the lowest point reached in the descending fissure is very little, if anything, above the level of the sea. There is no standing water here or elsewhere in the cave, except one or two small puddles. The sides of this fissure are honeycombed in a very marked manner, to the height of about 10 feet from the floor. The pittings are from 3 to 5 inches in diameter, and about 1½ inches deep. The sides and roof of the fissure, at the point where it begins to turn down, are smooth and waterworn, but the descending part, as far as could be seen, is not so, except the floor, which is smooth because it is covered with stalagmite. The floor has been opened at a point marked 2 on the section (Pl. VI, fig. 1), to the depth of 15 feet. Below is a rough drawing of a section of it (fig. 2).

Beneath the stalagmite-floor, which varied in thickness from a few inches to a foot or more, was a layer of fine calcareous sand. Then came coarser sand, and then rubble down to the depth of 11 feet. Embedded in the coarse sand and rubble were angular and subangular boulders of limestone, some of large size. A complete change then took place, and there came a bed of hard calcareous grit, the coarse grains of sand, small pebbles, fragments of shells, and small stalactites being cemented together by some material closely resembling stalagmite. This bed was several inches thick

Fig. 2.—*Section of the floor in the cave at Monkey's Quarry, Gibraltar.*




where it lay between the boulders. In it and below it were numerous well-rounded stones, some of them pierced by *Pholas*. There were also a few scattered chips of angular limestone. At 13 feet I found echinids and barnacles.

The shaft was sunk down the side of the cave, which was smooth and waterworn, and in places there were holes apparently bored by *Pholas*. At 15 feet the side sloped inward rapidly towards the centre of the gallery, and the bottom of the shaft was solid rock. I have no doubt that this is the original floor of the cave. At this point, therefore, it is about 2 feet above sea-level. There were a few inches of fresh water at the bottom, and although the rise and fall of the tide is 3 feet, the level of the water did not seem to be affected by it.

At point 1, a small vertical cliff, some 30 feet high, is seen. This is the termination of the floor of the upper gallery. It is much undercut on its southern face, which forms the side of the lower gallery, and is evidently the massif of the Rock. This cliff has to be ascended by a ladder. The gallery has some fine stalagmites and stalactites in it, and is 127 feet long, 20 to 25 feet wide, and 30 to 35 feet high. There is a narrow and irregular opening, about 55 feet long, from this upper gallery to the lower, on the south side of the former. The western end is waterworn, and has no fissure visible; it is now quite dry, there being no drip from the roof. I opened the floor in the bay at the side, and in the centre. I found a thin coating of stalagmite, and at the side some red soil 2 or 3 inches deep, and then reached the solid rock. In the centre, below about 6 inches of moist and clayey earth, probably derived from the decomposition of the limestone, there was a layer of coarse and fine calcareous sand and pebbles, 3 to 4 inches deep over the solid rock. There was very little residuum from the sand when I dissolved some of it in hydrochloric acid. The sides of this gallery are not honeycombed in the same way as those of the lower gallery are. The pittings are not so numerous, and have no regularity.

From point 1, another gallery (if it can be so called) extends eastward. At first the roof is a thin sheet of stalagmite, which gradually curves over, so that in time the entrance would be completely hidden. A few feet inside the entrance the roof is seen to be composed of breccia, the fragments being very firmly cemented together. Some of these fragments are of large size, measuring 6 feet by 4 by 2. The floor is of the same formation, and in places the breccia is being covered with stalagmite. It is a rough scramble to get up the slope. Some 90 feet from the entrance the breccia ceases to be visible, and its place is taken by rubble, large and small. This I attribute to constant falls from the roof, which have perhaps been assisted by the blasting operations outside. It was not possible during my several visits to get more than about 135 feet to the eastward. This is, however, manifestly beyond the present eastern face of the Rock, and therefore outside what must have been at one time the main entrance to the cave, which is now blocked by a large accumulation of breccia and rubble. By scrambling down a steep slope to the north, at a point some 30 feet from the entrance of this gallery, the original side of the cave can be reached, and on it honeycombing is visible for a distance of 30 feet or so, and is then again buried under the breccia. The highest point of the pitting is about 28 feet above sea-level. This corresponds with the honeycombing that is visible in the lower gallery, and is to be attributed to the same cause. At no place could I find any evidence of the position of the solid rock in the floor, and it would evidently require the removal of a large amount of rubble and breccia to reach it.

Such is a brief description of the general character of the cave. It remains to point out one or two of its more interesting features from a geological point of view.

Gibraltar, as is well known, has many examples of both fissure and marine caves at very various heights above sea-level, St. Michael's Cave on the western side being perhaps the most famous of the first kind, and the caves on the eastern coast-line of the second. There can be no doubt that the upper gallery in the cave just described is wholly or partly of marine origin, from the character of the concave and unfissured end, the sand and pebbles formed beneath the stalagmite-floor, and the fact that the floor is horizontal. It is equally evident that the main hall and lower gallery originated in a fissure, and were subsequently exposed to the action of the sea. The presence of echinids of the same species as those which still exist in the Mediterranean makes it probable that the upper gallery is the older, and that the Rock has been elevated since the upper gallery received in a great measure its present form.

The band of honeycombing is evidence that the water must have remained at the same level in the cave for some considerable time. The edges of the pittings are so sharp that they cannot have been exposed to the action of moving water for any lengthy period. They are not seen in the shaft in the lower gallery below the level of the present floor, and the side of the cave at that point has the appearance of having been planed down by the sea. It is not likely to have been fresh water, as it is difficult to see whence any considerable stream of the latter could have come, or whither it could have gone.

The striations on the south side of the main hall may be due to the action of blown sand. Very similar markings of recent origin are to be now seen on the sides of the entrance to the well-known Monkey's Cave, which lies a short distance to the south, and there a heap of sand lies in the cave. If the striations in the main hall are due to this cause, it shows that there must have been a large opening to the cave on a much lower level than the present one.

By the kindness of Dr. A. Smith Woodward, F.R.S., and Dr. F. A. Bather, M.A., the echinids have been identified. They are *Strongylocentrotus lividus*, a species still common in the Mediterranean. The cave must therefore have been open to the sea at a comparatively-recent geological period. The bed of sand and *Pholas*-bored stones in which they were found was about 4 feet thick, above which are 11 feet of rubble, sand, and stalagmite. The rubble may be attributed to falls from the roof.

The breccia brings us to the last page in the history of the cave until its recent discovery. I believe its origin to be twofold. It will be observed that the floor of the main hall slopes considerably inward from the entrance. The middle gallery enables us to see that the old entrance is blocked up by breccia. That its position is not due to the force of the waves is evident from its being breccia, and not conglomerate. Sir Andrew Ramsay & Prof. James Geikie in their paper[1] discuss at considerable length the origin of the breccias of Gibraltar, and they consider that 'they belong to two distinct stages,' although in the map which accompanies their paper the same sign is used for both. The discovery of the echinids in the lower gallery tends to disprove that the later breccias, at any rate, owe their origin to 'cold climatic conditions.'[2] When the tunnel was made through the Rock, from the west near the Moorish castle, to the catchment-area above Catalan Bay, a narrow fissure was discovered that extended vertically from the outer air to an unknown depth. If this went so far down as to reach the sea-level and was then undermined, it would cause an enormous fall of rock, and if that happened at the mouth of a cave, no doubt some of it would fall inside and form a sloping floor such as there is in this cave. In course of time the rubble would be consolidated into breccia.

The conclusions, therefore, that may be arrived at from the evidence furnished by this cave are:—

1. That it existed as a fissure-cave before it was subjected to the action of the sea.
2. That it had a large entrance open to the sea for a long period.
3. That during that time the Rock was elevated some 42 feet.
4. That it was closed to the sea at a recent geological period.
5. That the breccia and sand-slopes at this point on the eastern side of the Rock, which are 150 feet wide and reach to a height of 200 or 300 feet above sea-level, date from a still more recent epoch.

In conclusion, I wish to express my obligations to the Admiral Superintendent for allowing me the opportunity of examining the cave; to Mr. A. Scott, Chief Civil Engineer, Messrs. L. T. Stoddard & A. K. Peaty, Assistant Civil Engineers, and Mr. R. Taylor, contractor's agent; to Mr. R. I. Ingles, one of his superintendents; and to the Hon. F. W. D. Smith, M.P., for much courtesy and assistance in the way of plans, photographs, etc.

## EXPLANATION OF PLATE VI.

Fig. 1. Longitudinal section of the cave at Monkey's Quarry, Gibraltar, on the scale of 40 feet to the inch.
2. Plan of the cave at Monkey's Quarry, Gibraltar, on the scale of 40 feet to the inch.
3. Transverse section of the same at XY.

## Discussion.

Dr. A. Smith Woodward expressed satisfaction that renewed

[1] Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 515.
[2] *Ibid.* p. 530.

attention was being paid to the caverns of Gibraltar; and congratulated the Author on his work. Although the result was different from what might have been anticipated, he hoped that the Author would continue his search for ossiferous deposits in that cave. Many interesting species of mammals had been obtained by Brome, Busk, and Falconer, but the known remains were so fragmentary that more satisfactory specimens were much needed.

Dr. Henry Woodward said that great interest attached to the exploration of the caves of Gibraltar, as in the earlier ones explored by Brome, Busk, and Falconer some very interesting deposits of bone-breccia had been met with. At the time when Busk examined them but little interest was felt in the small rodentia, as they were believed only to be common well-known forms; but Dr. Forsyth Major, who had lately examined some specimens, had detected *Lagomys* and other interesting remains, and earnestly desired to obtain more material for study, to which the Author's communication promised possibly to lead up.

The Author replied that the bone-breccia on the western side of the Rock was probably of a different date from the breccia on the eastern side.

Fig. 1.–LONRALTAR.

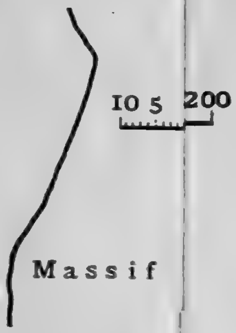


Fig. 1.—LONGITUDINAL SECTION OF CAVE AT MONKEY'S QUARRY, GIBRALTAR.

Section on line A. B. C. D. E. F. [lower gallery] Fig. 2.

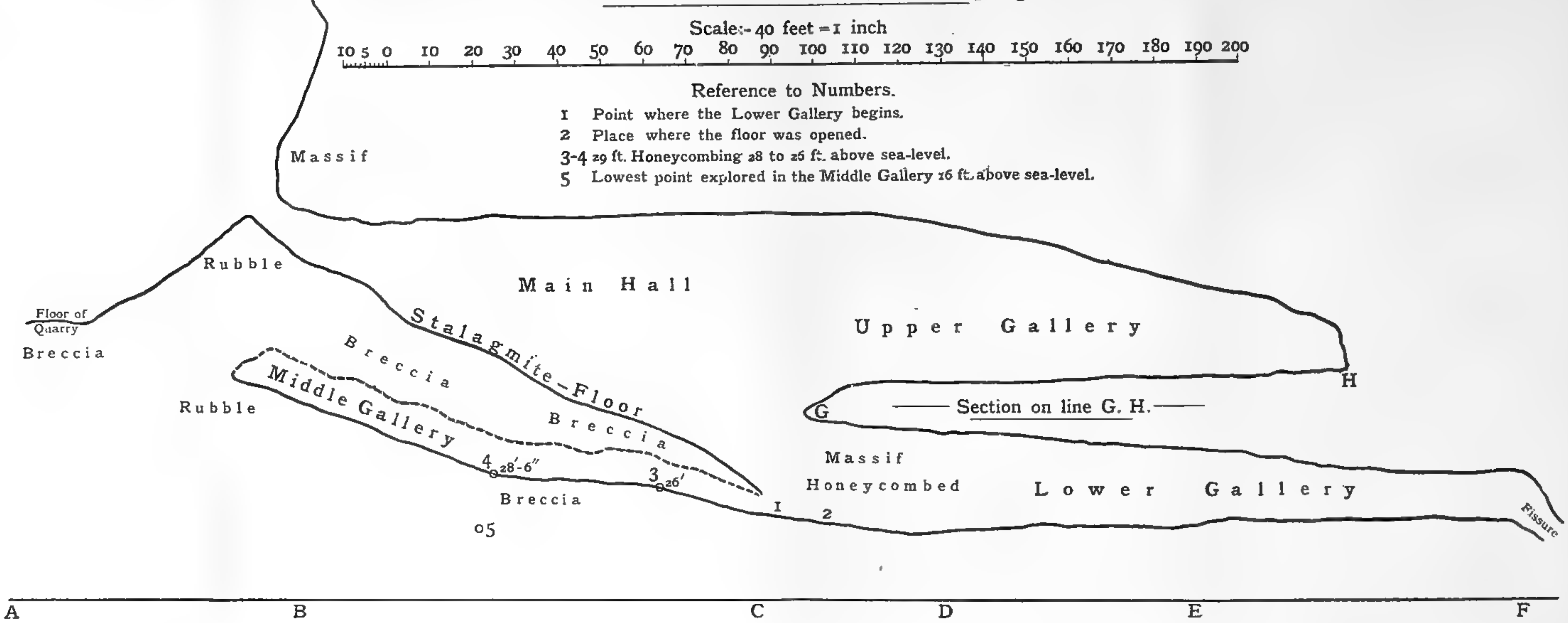



Fig. 2.—PLAN OF CAVE AT MONKEY'S QUARRY, GIBRALTAR.

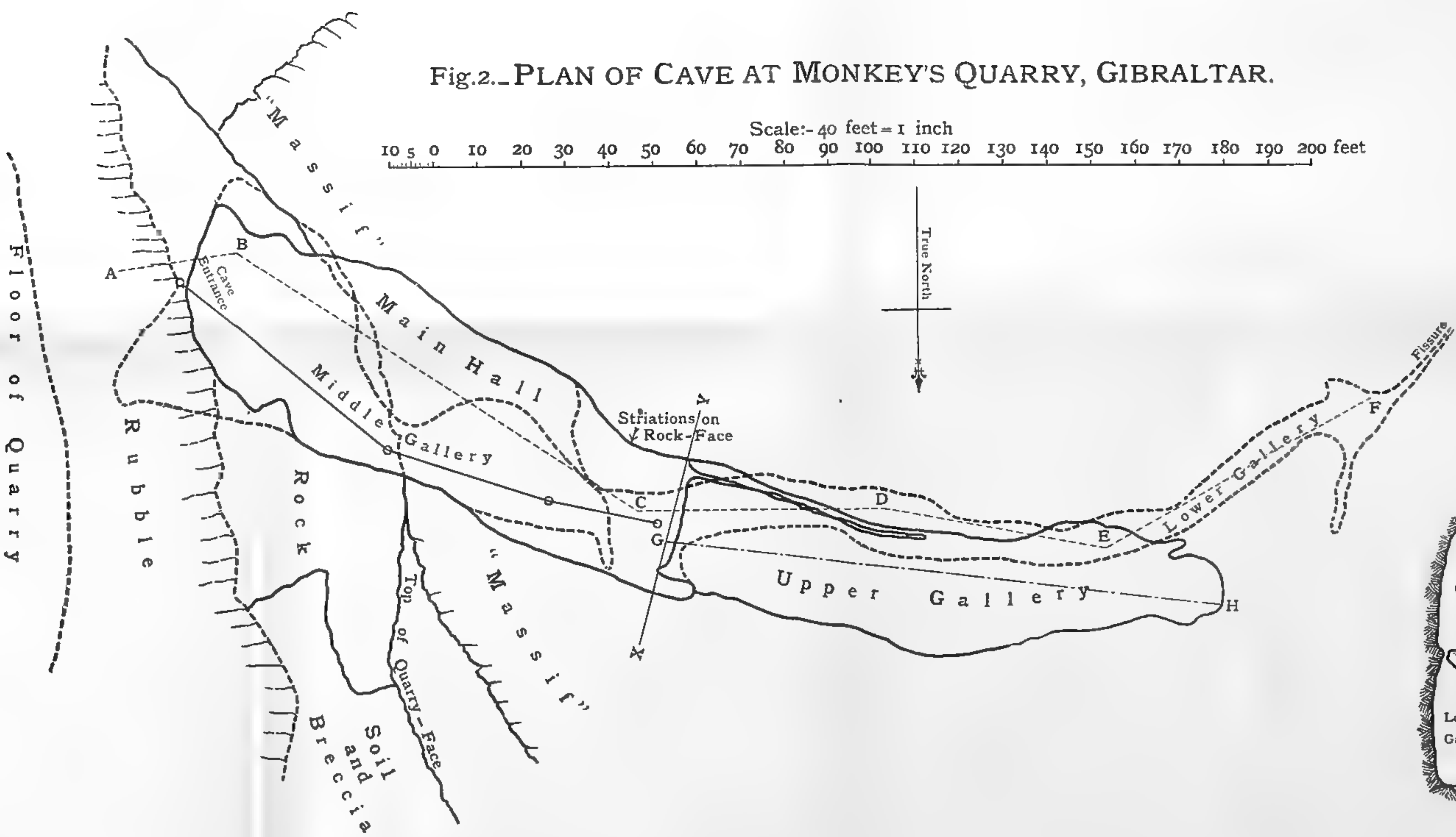



Fig. 3.

# 4. *A* Contribution *to the* Glacial Geology *of* Tasmania. By J. Walter Gregory, D.Sc., F.R.S., F.G.S., Professor of Geology in Melbourne University, Victoria. (Read December 2nd, 1903.)

[Plates VII & VIII.]

Contents.



## I. Introduction.

The existence of Pleistocene glaciation in Southern Australia has been so often affirmed on unsatisfactory evidence, that the assertion of a recent glaciation in Tasmania has been received with doubt. Two years ago I read through the literature on the glaciation of Tasmania, and came to the conclusion that, except for such traces of high-level glacial action as those at Mount Sedgwick, recorded by E. J. Dunn and T. B. Moore, and those near the summit of Mount Ida, recorded by Officer, Balfour, and Hogg, the evidence consisted of material that was either not of glacial origin, or was due to glacial action at some Upper Palæozoic date. The advocates of a low-level, recent glaciation in Tasmania were men who had apparently received no special geological training, and who had not written other papers by which the value of their geological observations could be tested. The professional and the trained geologists were almost unanimous in denying the existence of signs of recent ice-action in the lower valleys of Tasmania.

## II. The Geology and Topography of the Area.

It may be advisable here to introduce a short statement of the geological structure and physical geography of that part of Tasmania in which the deposits described as glacial occur. Most of them have been recorded from the country beside the West-Coast Range, and the western part of the Central Plateau of Tasmania. The West-Coast Range runs north and south, at a distance of 20 to 25 miles from the western coast of Northern Tasmania. It consists of a series of isolated masses of coarse conglomerates and quartzites, of Devonian age. These masses are parts of a formerly-continuous sheet, which has now been reduced to a series of disconnected outliers, resting upon Ordovician rocks and upon a series of schists which are probably Archæan.

The chief peaks of the West-Coast Range, taken in order from south to north, are Mount Sorell, Mount Darwin, Mount Jukes, Mount Huxley, Mount Owen, Mount Lyell, Mount Sedgwick, Mount Tyndall, Mount Geikie, Mount Read, and Mount Murchison. West of this line is a broad peneplain composed of contorted slates and sandstones, with some limestones, of Lower Palæozoic age. The surface slopes westward towards an old coast-line, several hundred feet above the present sea-level. East of the West-Coast Range, and separated from it by the valley of the King and Murchison Rivers, is the great Central Plateau of Tasmania. This plateau is composed, in the main, of Silurian and Carboniferous rocks, which are covered unconformably by a broad sheet of Mesozoic diabase, represented on Mr. R. M. Johnston's map of the Geology of Tasmania as forming the surface of the main part of the tableland. The southern part of the West-Coast Range is drained by the King River and its tributaries. This river flows past the eastern base of Mounts Sedgwick, Lyell, and Owen, and then cuts across the Range in a cañon between Mounts Huxley and Jukes. It bends northward and is joined by the Queen River, which drains the western slopes of the range from Mount Sedgwick to Mount Owen. The Linda River, also a tributary of the King, occupies a broad valley eroded along a fault-line ; it breaks through the West-Coast Range, between Mount Owen on the south and Mount Lyell on the north.

A high ridge capped by diabase, and known as the Eldon Range, runs out westward from the main Central Plateau ; an outlier of this ridge forms the peak of Mount Sedgwick. Farther north is Cradle Mountain, a bold bluff forming the north-western corner of the Central Plateau. The streams from this mountain flow either directly into the Pieman River, or northward, past Mounts Romulus and Remus, into the Mackintosh River, the upper part of the Pieman. The country around the Mackintosh is a broad plateau, through which the rivers flow in deep and narrow gorges of recent age. The Pieman River flows directly into the Southern Ocean, while the King River flows into Macquarie Harbour, near the town of Strahan.

## III. Previous Records.

A brief summary of previous work on this subject will, I think, be useful, as the literature is scattered and its interpretation in Europe may be somewhat difficult.

The first recognition of glacial action in Tasmania was apparently in the 'fifties,' by Charles Gould, formerly the Government Geologist of Tasmania. His observations were never published ; but his conclusions were verbally handed down, and have been referred to by Mr. R. M. Johnston,[1] who, in 1888, on the strength of this evidence,

[1] 'The Glacier-Epoch of Australasia' Proc. Roy. Soc. Tasm. vol. iv, 1893 (1894) p. 92.

accepted the former occurrence of local ice-sheets in the Mackintosh Valley.

The earliest-published suggestion of the recent glaciation of Tasmania known to me is in a report by Mr. T. B. Moore, issued in 1883.[1] In this report the author refers to a boulder-deposit on 'Painter's Plain' in Central Tasmania, at the junction of the Franklin River and its tributary, the Loddon; these plains are at the height of 1220 feet above the sea. Moore describes the bed as an

'accumulation composed of every variety of rock, with large boulders of greenstone strewn over the plains. These boulders are also met with cropping out on the tops of the surrounding quartzite-hills. It is quite possible that these masses of greenstone, occurring as they do in solitary blocks or groups, have been brought, in the Glacial Period, from the higher lands of Mount Lyell, or the Eldon Range, and deposited by that agency in their present resting-place.'

Further evidence was advanced two years later in a paper by C. P. Sprent,[2] who claimed a glacial origin for some erratic boulders in the Mackintosh Valley. The Mackintosh or Upper Pieman River flows through a gorge which is said to be 1400 feet deep, and cut through a plateau about 2000 feet above sea-level. Sprent crossed the Mackintosh, between its tributaries the Bingham River and the Cradle River, which flows from Cradle Mountain; hence his locality can be closely determined, and it is clearly in the high plateau of North-Western Tasmania.

Sprent's most striking evidence was the discovery in the Mackintosh gorge of some granite-boulders, 5 tons in weight. The adjacent rocks were of sandstone; he could find no granite *in situ*; and thought it impossible to account for the occurrence of these granite-masses 'except on the glacial supposition.' This evidence was not convincing, for the erratics might have come either from Upper Palæozoic glacial deposits, or even from local granite, which might have occurred in the district. Sprent asserted (*op. cit.* p. 58) that

'traces of glacial action are common all over the West Coast in localities close to the high mountains':

he gave, however, no evidence in support of this view, and stated that

'it is probable that these glaciers did not extend to the low lands.'

Mr. Johnston, in his voluminous work, 'The Geology of Tasmania' 1888 (p. 164), admitted glacial action as

'an important agent in the denudation of the immense cañons or gorges which trend away from the elevated plateau [of North-Western Tasmania] westward.'

But he agreed with Sprent that the glaciers were local in their

[1] 'Exploration.—Mr. T. B. Moore's Report upon the Country between Lake St. Clair & Macquarie Harbour' Parl. Pap. Tasm. vol. xlv (1883) no. 56, p. 6.

[2] 'Recent Explorations on the West Coast of Tasmania' Trans. & Proc. Roy. Geogr. Soc. Austral. Vict. Branch, vol. iii (1887) p. 58.

range, and limited to the highlands of the Central Plateau. Johnston considered [1] Sprent's erratics

'as due to small glaciers in alpine situations, of which there is some evidence in the deep sub-alpine valleys of the Western Highlands of Tasmania.'

The author was emphatic [2] that

'there is no similar evidence [to that in the Northern Hemisphere] of a severe Glacial Period in the Southern Hemisphere.'

He repeats that

'in Tasmania a greater elevation of the land, dating from the close of the Palæogene Epoch, result[ed] in a limited amount of glaciation in alpine regions only.'

Further arguments in support of the view that Tasmania had suffered no severe glaciation in Kainozoic times were advanced, in 1886, by Prof. F. W. Hutton,[3] on the evidence of the distribution of *Siphonalia maxima*. He maintained that

'Tasmania has not undergone a glacial epoch since *S. maxima* lived on its shores.'[4]

The first conclusive evidence of Pleistocene glacial action in Tasmania was published by Mr. E. J. Dunn in 1894.[5] In this paper he showed the occurrence of an extensive glaciation in the country around Lake Dora, to the north-east of Mount Tyndall. Mr. Dunn's experience as a glacial observer left no room for doubt as to the accuracy of his observations; but they were confined to the evidence of glacial action on the summit of the Western Highlands, and gave no proof of any extension of the glacial action to low levels. Mr. Dunn also recorded the occurrence near Mount Read, north-west of Mount Tyndall, of some glacial deposits belonging rather to the close of the Palæozoic or beginning of the Mesozoic Era. Their altitude is apparently about 1100 feet above sea-level.

A further account of the glaciation near Mount Tyndall was given by Mr. T. B. Moore in a short, but important, contribution issued in 1894.[6] He described abundant traces of glacial action around Mount Tyndall (3875 feet) and Mount Sedgwick (4000 feet); and stated that the rocks were glaciated to within 20 feet of the summit of Mount Tyndall, and to near the summit of Mount Sedgwick. The eastern slopes of those mountains he described as swept bare by glacial action. On the north-eastern side of Mount Geikie (3950 feet) he found a well-marked roche moutonnée, which he named after Montgomery. He gave further information as to a glaciated rock, found by Mr. Dunn, which he called 'Dunn's Boss,'

[1] 'The Geology of Tasmania' 1888, p. 215. [2] *Op. cit.* p. 296.

[3] 'On the supposed Glacial Epoch in Australia' Proc. Linn. Soc. N.S.W. vol. x, 1885 (1886) pp. 334–41.

[4] *Op. cit.* p. 337.

[5] 'Glaciation of the Western Highlands (Tasmania)' Proc. Roy. Soc. Vict. n. s. vol. vi (1894) pp. 133–38 & pl. viii.

[6] 'Discovery of Glaciation in the Vicinity of Mount Tyndall in Tasmania' Proc. Roy. Soc. Tasm. vol. iv, 1893 (1894) pp. 147–49.

'after the discoverer of glacial action in Tasmania.'[1] Moore also found, on the western slope of the West-Coast Range, a series of well-preserved moraines; some of them lay beside the western ends of the small lakes, which lie scattered in the valleys between the chief peaks. Beside Basin Lake he found one which he called the Hamilton Moraine; another he described as occurring on the northern side of Lake Margaret; and a third to the north of Mount Tyndall. The ice that formed these moraines Moore estimated as being 1000 feet in thickness. That the deposits were post-Carboniferous in age was proved by his discovery of boulders of Carboniferous rocks in the moraines.

As Dunn had previously recognized recent glacial action in this district, there seemed no reason to distrust Moore's evidence, in so far as it related to the summit of the higher plateau of Tasmania; but his arguments in favour of an extension of the former glaciers to a lower level were less convincing. In a note, published at the same time as his paper on Mount Tyndall, Mr. Moore reported the existence of morainic material at low levels in the broad valley of the King, and its tributary the Linda. He stated, for instance, that a moraine connects the eastern flank of Mount Owen to some hills in the King Valley, known as the Thureau Hills. These localities range from 900 feet down to only 400 feet above the level of the sea.

Mr. Moore was emphatic as to the origin of these deposits, and he had excellent sections on which to found his opinion. For he claimed that the material worked at the old King Lyell Mine was glacial. He wrote

> 'it will be interesting for the Linda gold-mining shareholders to know that the deep ground hydraulically sluiced on their sections is nothing but a huge mass of morainal matter; many of the large boulders and smaller accumulations of stones of a soft nature are beautifully scored.'

This evidence would have appeared conclusive, had not Moore's views been opposed by geologists whose opinion carried greater weight. Thus Mr. A. Montgomery,[2] the Government Geologist of Tasmania, in a paper published later in the same volume, treated the occurrence of the Carboniferous fossils of Mount Sedgwick, which Moore regarded as ice-borne erratics, merely as proof[3]

> 'that the sedimentary strata [the Carboniferous] there too underlie the green-stone-capping'

of that mountain. He objects that the fossiliferous conglomerate was not due to the action of floating ice, but

> 'that it is a moraine-drift derived from the lower beds of the Carboniferous formation, which, farther north, near Barn Bluff and Cradle Mountain, consist mainly of conglomerates. These would supply the stones of granite, slate, porphyry, etc., which Mr. Moore has noticed, and also the fossils'

---

[1] Proc. Roy. Soc. Tasm. vol. iv, 1893 (1894) p. 148.
[2] 'Glacial Action in Tasmania' Proc. Roy. Soc. Tasm. vol. iv, 1893 (1894) pp. 159–69.
[3] *Ibid.* p. 161.

Montgomery adduced further evidence of glacial deposits in the same district of Tasmania, but he adopted somewhat extreme views as to the powers of ice. He remarked that[1]

'the great lakes on the Central Plateau are almost *prima-facie* evidence of glaciation,'

and attributed to ice-erosion the formation of the deep river-gorges in the north-western plateau of Tasmania. He argued that

'if we allow that the deep valleys at the head of the Pieman were once occupied by glaciers, we must admit that the ice came down to within 500 or 600 feet of the present sea-level.'[2]

Further, he remarked that the lower limit was possibly at places which are now 500 or 600 feet above sea-level, and he considered that the country then stood at a lower level than at the present time. Finally, he quotes Johnston's view

'that there is no evidence of glacial action in the lower lying lands, and regards the glaciers as having been of small extent. While inclined to believe that the ice-covering has been more extensive than he is disposed to allow, in the main I agree with his view, and do not think that the whole country could have been ice-bound.'[3]

While Montgomery disputed part of Moore's interpretation of the deposits on Mount Sedgwick, Messrs. Graham Officer, L. Balfour, and E. G. Hogg denied the glacial origin of his low-level deposits in the Linda Valley. They themselves reported the evidence of a boulder-clay, with scratched boulders, only 1 mile from Strahan on Macquarie Harbour.[4] They described this deposit as very hard, and as possessing that peculiar pinkish-purple colour characteristic of some of the ancient glacial beds of Victoria. They apparently regarded these low-level glacial deposits near Strahan as of the same age as those of Bacchus Marsh. They carefully examined the moraines described by Moore in the Linda and King Valleys, and disputed their glacial origin. They described the moraine at Gormanston, in the Linda Valley, regarding which Moore gave most details, as

'a great accumulation of angular débris which has gravitated from the adjoining heights. We are inclined to think that much of the morainal matter referred to by Mr. Moore is simply this gravitated débris.' (*Loc. cit.*)

They regarded it rather as a talus-heap than a glacial deposit. The moraines reported at a still lower level in the King Valley they also doubted, and they suggested that the greenstone-boulders found there might have been derived from local dykes. They supported their explanation by the remark

'we may add that other evidence of glaciation in the form of roches moutonnées and ground-moraines seemed to be quite absent.'[5]

---

[1] Proc. Roy. Soc. Tasm. vol. iv, 1893 (1894) p. 165.
[2] *Ibid.* p. 164. [3] *Ibid.* pp. 168–69.
[4] 'Geological Notes on the Country between Strahan & Lake St. Clair (Tasmania)' Proc. Roy. Soc. Vict. n. s. vol. vii, 1894 (1895) pp. 123–24.
[5] *Ibid.* p. 125.

The authors of this paper were well acquainted with the Palæozoic glacial deposits of Victoria, so that their opinions naturally carried much weight; and they were soon supported by Mr. R. M. Johnston, in his paper on 'The Glacier-Epoch of Australasia.'[1] He wrote that

'the absence in lower levels of any evidence of ice-action confirms my opinion as to the absence of intense glacial action during our Glacial and Pluvial Epochs.'

He accepted glacial deposits 'on the 2182-to-2400 ft. Plateau between Mount Sedgwick and Mount Tyndall; but he suggested that even some of these high-level glacial beds may be of Upper Palæozoic age. He said[2]:

The occurrence of what appears to be the older conglomerates, so closely associated with newer drifts . . . . suggests doubt as to whether some of the moraine-stuff, found on the flanks of [the] western mountains, upon whose crests this older conglomerate rests, may not be confounded at times with the true moraine-stuff of the more recent glacier-epoch.'

Further proof of the existence of the Upper Palæozoic glacial beds in Tasmania has been recently advanced by Mr. A. E. Kitson.[3] He has described their occurrence at Wynyard, in a section which is important, because it demonstrates that these deposits underlie Middle Coal-Measures.

The previously-cited literature proves the occurrence in North-Western Tasmania

(1) of Carboniferous glacial beds;
(2) of high-level, recent glacial deposits—proved by Messrs. E. J. Dunn, T. B. Moore, Graham Officer, etc.; further deposits probably of glacial origin but of doubtful age, have been remarked by Sprent, etc.;
and (3) its general conclusion—denied, however, by Mr. Moore, and to some extent by Mr. Montgomery—is, that the recent glaciation was confined to high levels.

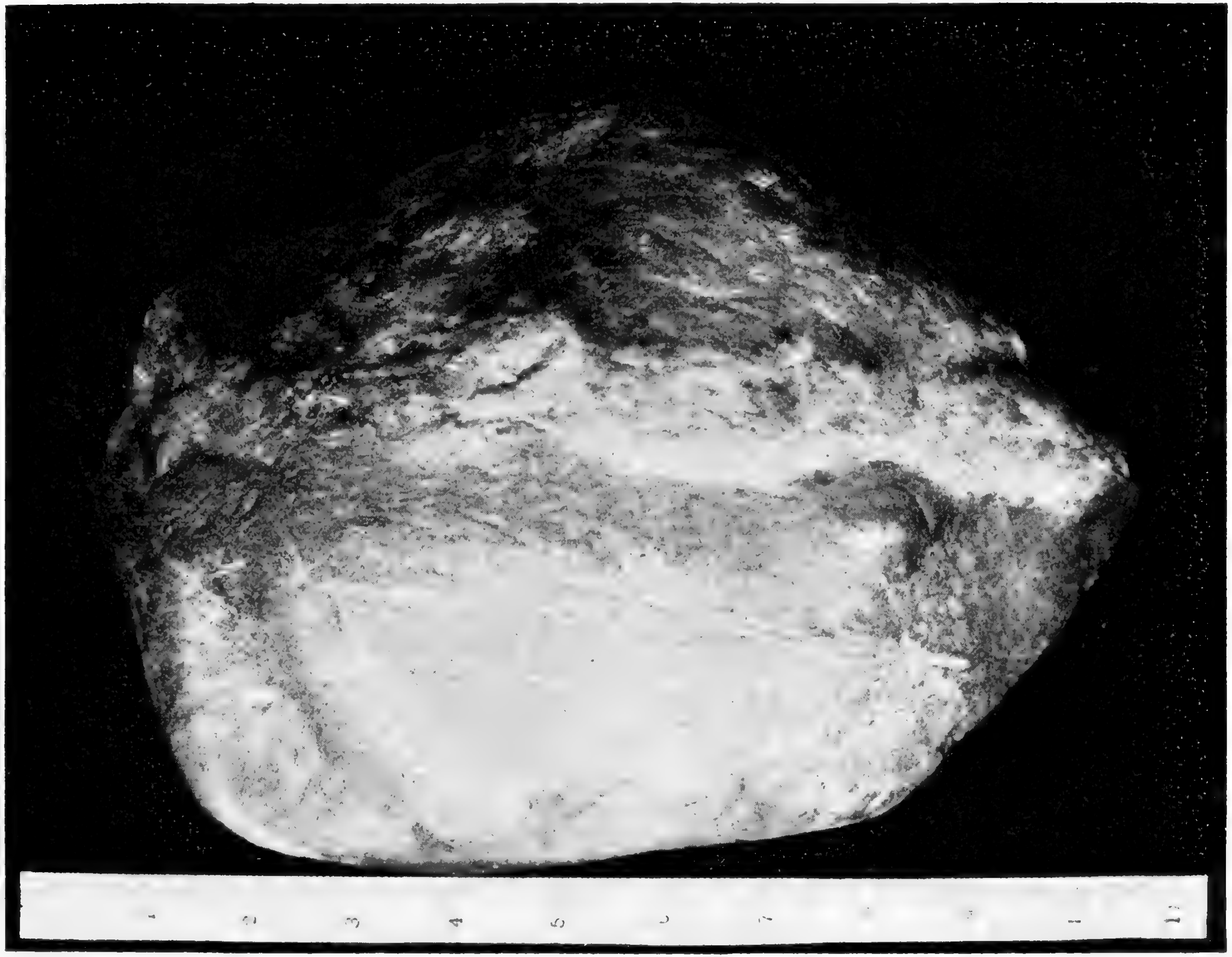
## IV. The Glacial Deposits of the King and Linda Valleys.

Despite, therefore, the clearness of Moore's description, the literature on the glacial geology of Tasmania led me, in 1900, to accept Johnston's conclusion that the last Tasmanian glaciation was limited to high levels, and that the reported low-level glacial deposits were either Upper Palæozoic in age, or not glacial.

In the railway-journey across North-Western Tasmania, from Emu Bay to Macquarie Harbour, I saw two conglomerates, which struck me as resembling glacial deposits; but I had no opportunity of examining them, and, as the train climbed slowly up to Queenstown, I saw many coarse gravels containing quartz-boulders, so

[1] Proc. Roy. Soc. Tasm. vol. iv, 1893 (1894) p. 126. [2] *Ibid.* p. 99.
[3] 'On the Occurrence of Glacial Beds at Wynyard, near Table Cape (Tasmania)' Proc. Roy. Soc. Vict. n. s. vol. xv (1902) pp. 28–35.

Fig. 1.—*A glaciated boulder from the Gormanston Moraine.*



[Scale of inches.]

large that I could understand their being regarded as of glacial origin. Absorbed in the interesting problems of the Mount-Lyell mining-field, I had dismissed glacial questions from my mind, especially as I found only talus-boulders at the old mine-workings, where Moore had described a moraine. I was therefore led to accept the view of Officer, Balfour, and Hogg, that Moore had mistaken coarse talus for glacial deposits. I was according surprised, when having occasion to cross the hill on which Gormanston is situated, to find on its western face some beds of tough, fine, well-bedded glacial clays, with ice-scratched boulders. Above this deposit were beds of typical boulder-clay. One of the boulders in the bedded clay was a foot long, and was standing on its edge; it had compressed the layers below it, and had evidently fallen through water from floating ice; near it were a few scratched stones. The boulder-clays, moreover, were clearly of recent origin, and formed later than the excavation of the Linda Valley; they occurred as a bank projecting from the southern side of the valley, and nearly damming it across, like a delta. A short examination showed that Moore was right in his view that the town of Gormanston stands on a glacial moraine of recent geological age.

This moraine occurs now in a fan-shaped hill, a mile long by half a mile wide; it rests against the southern bank of the Linda Valley at the Gormanston Gap. The top of the moraine is. in places, fairly level, and at the height of 320 feet above the Linda Creek. For it has been planed down by the southern tributaries of the Linda, which flows round its northern edge. The moraine must once have extended right across the valley to the southern foot of the ridge of Mount Lyell, where patches of it still occur. But the moraine has been cut through by the Linda. Excellent sections of the glacial beds are exposed in the banks of the creeks which run from the Gormanston Gap to the Linda township, and along the eastern side of the deposit; and also in the railway-cuttings of the North Mount-Lyell Railway, on the northern face of the moraine. The moraine is composed mainly of typical boulder-clays. The bedded clays are best exposed on the western side of the deposit, as if they had accumulated in a glacier-lake that occupied the upper part of the Linda Valley, above the moraine-dam.

The bulk of the moraine is formed of unstratified clay, crowded with boulders and pebbles. The majority of the included fragments are quartzites, derived from the conglomerates that form the summits of Mount Lyell and Mount Owen. These hard materials frequently retain their original form, but some of them show signs of facetting, suggesting ice-action. Some of the boulders are rocks not found in the immediate neighbourhood. There are coarse blocks of hard blue stone, exactly similar to the Mesozoic diabase which caps the central plateau of Tasmania, and forms the crests of the Eldon Range and the peak of Mount Sedgwick. There are also boulders of quartzite and sandstones, probably derived from the Silurian rocks to the east of the King River, and some blocks of hard slate which I found exquisitely glaciated. In the railway-cutting by Gormanston Station is an erratic of fossiliferous limestone, measuring $4\frac{1}{2}$ feet in length by $3\frac{1}{2}$ in width and $2\frac{1}{2}$ in height; it is scratched all over, and partly polished.

The Linda moraine rises to the height of about 1200 feet above the sea, and on the floor by the Linda Valley, near the slaughter-yards, it is at the level of only 900 feet. A bore of the King Lyell Mine is said to have pierced the same deposits to a depth of 280 feet, and would thus show that they occur at an altitude of not more than 700 feet above sea-level.

That the moraine formerly extended right across the Linda Valley is shown by the occurrence of a strip of glacial deposits on the northern bank of that valley, immediately above the river. But the northern side of the valley is so steep, and the Linda is there so near to the southern foot of Mount Lyell, that but little of the glacial deposits remain *in situ*. There can, however, be no doubt that the moraine once formed a dam across the Linda Valley from north to south, that it was cut through by the Linda River, and that its summit has been planed down to the level of the Gormanston Gap.

East of the moraine the floor of the Linda Valley is a level, alluvial plain, in places half a mile wide; the glacial deposits can be found rising from the alluvium, on both sides, until, a little over a mile to the east of the moraine, the valley narrows, owing to the projection of the steep north-eastern spur of Mount Owen. Patches of the glacial deposits can be found at intervals along the edge of the alluvial flats on the southern side of the river. More of the material occurs on the northern side of the valley, which is rough and densely timbered; a railway-line for mining purposes has recently been made round the eastern end of Mount Lyell, from the Linda township to the valley between Mount Lyell and Mount Sedgwick. This railway crosses the eastern spur of Mount Lyell at the height of about 1500 feet. The glacial deposits are exposed at intervals in the railway-cutting, and they are especially well developed in the King Valley, and along the northern foot of Mount Lyell, at the eastern end of the Sedgwick Valley.

The North Lyell Railway shows a good section of the glacial deposits, in the bluff above the junction of the King River and the Linda. The railway-line has cut through an enormous boulder of black, fossiliferous, Carboniferous Limestone. The two ends of the boulder are exposed on the banks on each side of the line, and it must have been at least 16 feet long.

The King River flows through a broad valley, and its floor is an alluvial, forest-covered plain, over a mile in width. The eastern end of Mount Lyell overhangs the valley. Mount Lyell itself is a long east-and-west ridge, which separates the Linda Valley from a much larger and broader valley to the north, between it and Mount Sedgwick. The railway-cutting round the eastern end of Mount

Lyell exhibits unstratified boulder-clays, with many of the white quartzite-pebbles and boulders from the conglomerates of the West-Coast Range; but the clays also contain a larger number of the diabase-boulders than occur in the Linda Valley, as well as some sedimentary rocks, which I did not find *in situ* on the eastern side of the King River. Following the King River to the south, glacial deposits can be traced for miles down the valley. Ill-health prevented me from examining these deposits, except from the railway-train; but their features are so distinct, that I have no doubt that Moore was correct in his statement that the Thureau Hills are joined to Mount Owen by a moraine (see p. 41). The glacial deposits in this part of the King Valley descend to the level of less than 800 feet above the sea.

The glacial evidence, at high levels, is in places remarkably distinct. Mount Sedgwick consists of a peak of diabase, resting on a ridge of the West-Coast Range conglomerates. This ridge runs east-and-west. Well-marked roches moutonnées occur at many points over the ridge near the highest peak, and the diabase is glaciated in broad surfaces close to the summit. The lakes to the north, in the valley between Mount Sedgwick and Mount Tyndall, are bordered by small, but well-preserved moraines; one of them lies round the western side of Lake Margaret. These occurrences, however, are of less interest, as they are at a higher level than that at which the existence of glacial action in Tasmania has been called in dispute.

With such abundant glacial evidence in the valleys, glacial contours might be expected upon the hills; but this part of Tasmania has a rainfall of over 100 inches in the year. The rainfall at Lake Margaret, according to Mr. Huntly Clarke, the Engineer of Supplies to the Mount-Lyell Mine, exceeds 140 inches a year. Accordingly, rock-weathering takes place at a very rapid rate, while the sheltered slopes of the hills are covered with dense forest. I had, however, been impressed with the strikingly-glaciated aspect of the northern face of Mount Owen, before I had seen the definite moraine-deposits of the Linda Valley. The northern face is smooth and rounded, and it has been swept bare of all drift-deposits. Hence, though I had not time to search this face for glacial striæ, I think that it may be fairly assumed that the northern face of Mount Owen was ice-worn to the height of about 1900 feet. In the King Valley, close by the confluence of the King and the Linda, there is a hillock of conglomerate, the shape of which has been rounded by the passage of ice across it. The ends of the conglomerate-spurs immediately south of the Linda township also owe their rounded surface to glacial erosion; and a still better case of glacial contours is shown by the eastern end of the spur, south of the road from Linda to the Lyell Blocks Mine.

Moreover, looking down on the ridge of schists that separates the Linda Valley from the Queen Valley, I noted that it appears to have been glaciated. The schists weather so rapidly that no glaciated or striated surfaces remain; but the aspect of the ridge, from the crags of conglomerate above North Lyell, shows in places the vestiges of glaciated contours. The southern slopes of Mount Sedgwick, and the valley between that mountain and Mount Tyndall, also exhibit well-developed glacial contours.

## V. The Origin of the King-River Glacier.

The origin of the glaciers and the direction of their movement is clearly indicated by the nature of the erratic blocks. The King Valley, east of Mounts Lyell and Owen, practically separates two distinct types of country. On the east is a district made up of Silurian and Carboniferous rocks and Mesozoic diabases. West of the King River the rocks consist of some ancient schists, probably Archæan in age, some 'Middle Silurian' slates, limestones, and quartzites, and the Devonian conglomerates and sandstones of the West-Coast Range. The only occurrence that I found of Carboniferous rocks to the west of the King Valley is near Linda, where there are a few narrow outcrops of black *Fenestella*-shales, on the floor of the Linda Valley. This bed has been preserved there by having been faulted down among the conglomerates. The only near occurrence of diabase west of the King River, with which I am acquainted, is on the summit of Mount Sedgwick. As the glacial deposits include abundant boulders of Carboniferous Limestone and shales, of sandstones (which are probably from the Silurian rocks), and of diabase, the glaciers probably came from the east and north-east. In that direction lies the great Central Plateau of Tasmania, of which the Eldon Range is an outlier.

The upper portion of the King-River Valley consists of two parts at right angles to each other. The uppermost part trends east and west along the southern face of the Eldon Range: this valley is continued westward by the broad valley, between Mounts Sedgwick and Lyell,[1] until it opens out onto the peneplain of North-Western Tasmania. At the western end of the Eldon Range the King River bends abruptly southward, while a small tributary comes in from the north, between the end of the Eldon Range and Mount Sedgwick.

The general evidence suggests that, during the time of this glaciation, the Eldon Range and the Central Plateau formed the collecting-ground of the glaciers. From this area the glaciers flowed westward and south-westward. One glacier flowed down the valley between Mount Tyndall and Mount Sedgwick: doubtless it received tributary glaciers from those two peaks. A well-marked terminal moraine round the western end of Lake Margaret marks either the farthest westerly extension of the glacier, or one of the stages in its retreat.

[1] The Upper King River probably flowed originally through the Sedgwick Valley; see my paper on 'Some Features in the Geography of North-Western Tasmania' Proc. Roy. Soc. Vict. n. s. vol. xvi (1903) pp. 180-81.

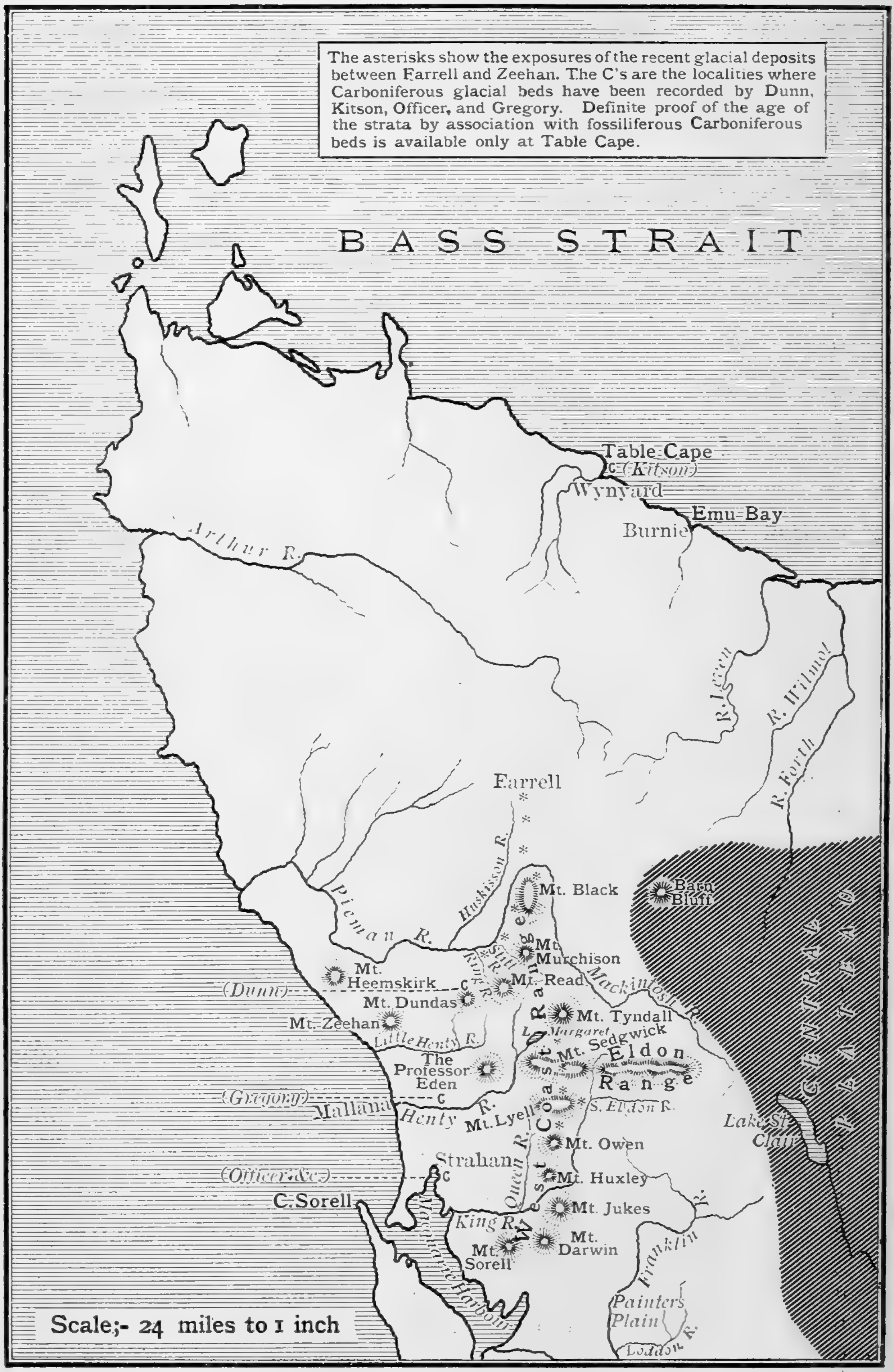
A second glacier flowed along the King Valley, south of the Eldon Range, and was continued westward along the Sedgwick Valley to the north of Mount Lyell. It deposited a moraine, imperfectly preserved, north of the Comstock Mine. I saw no evidence that this glacier extended farther westward. Another branch of the main glacier flowed southward along the present course of the King Valley, and abutted against the eastern face of Mount Lyell. On the melting of the glacier, the slopes of the valley were covered with a thick deposit of boulder-clay. This glacier continued farther southward, and deposited a terminal moraine between the eastern base of Mount Owen and the Thureau Hills. A lobe from the glacier flowed westward up the valley of the Linda—a valley due to fault-action. The ice of this lobe flowed over the schist-ridge that separates the Linda and Queen Valleys. It wore the conglomerate-spurs from this ridge near the Linda township into roches moutonnées, and deposited some boulder-clay with diabase-boulders at Queenstown, where some of the material is still preserved opposite the Mount-Lyell Company's pumping-station (altitude 464 feet). During the retreat of this Linda-Valley glacier, a glacial lake formed between the glaciers and the Mount-Lyell ridge; the drainage from this lake escaped southward into the valley of Conglomerate Creek, cutting the Gormanston Gap (altitude 1356 feet). One important stage in the retreat of this glacier is marked by the deposition of the great Gormanston Moraine.

## VI. The Range of the Pleistocene Glaciation.

The extent of the Pleistocene glaciation is shown on the accompanying sketch-map (fig. 2, p. 50). The localities marked by asterisks are those where glacial deposits, which I regard as Pleistocene, have been recorded. The small letters (*c*) indicate localities of glacial deposition probably dating from the Carboniferous. The correlation of the deposits to the north and west of Mount Lyell rests, in part, on the lithological nature of the deposits, and partly on other indications of ice-action in their localities.

During a first visit to Tasmania I had been struck by the morainic aspect of some beds near Farrell, on the Emu-Bay and Zeehan Railway. The locality is about 60 miles from Burnie, at an altitude of 1300 feet. For an opportunity of examining these beds I am indebted to Mr. J. Stirling, the manager of the railway, who kindly stopped the train for this purpose. The evidence available clearly shows that the beds are of glacial origin. They include some gigantic erratics of conglomerate: one measures 25 by 18 by 12 feet, and numerous smaller erratics occur beside it. They are not fragments, left *in situ* by the denudation of a band of the West-Coast conglomerates, for they rest on a bed of clay. Mr. Stirling tells me that, during the construction of the railway, a hole was dug into this clay, at a culvert a few hundred yards south of the biggest

Fig. 2.—*Sketch-map of North-Western Tasmania, illustrating the range of the Pleistocene glaciation.*



erratic; and although the hole was 20 feet deep, it did not reach the bottom of the clay.

Associated with the conglomerate-boulders are others of various igneous rocks, belonging to the series of felsites. I pulled three small boulders out of the clay exposed on the cutting for a culvert, close to the biggest erratic; two of the three boulders had glacial scratches. The glacial clay was soft, though tough; it had the lithological characters of a recent, and not of a Carboniferous glacial deposit. Moreover, the northern face of Mount Black (altitude about 3500 feet), the nearest conspicuous mountain, appears conspicuously moutonnée, affording further proof of recent glacial action in this part of Tasmania.

Mr. Stirling kindly invited me to ride on the locomotive from Farrell to Zeehan, and thus I had a better view of the cuttings than I could have got from the railway-carriage. I was thus able to notice that the glacial deposits occurred at intervals along the line from Farrell to near Zeehan. As the train sometimes went slowly up the steep grades, I had a fair view of the sections exposed. The sections along the ascent from the bridge over the Pieman River, up its left bank, show a typical boulder-clay, with boulders 2 feet or more in length, embedded in a fine clay. The shape of the boulders suggested ice-wearing, and they rest in places upon the worn surface of the schists. Farther along the line there are some finely-bedded clays, covered by a layer of boulder-clay. Between Bobadill Creek and Chasm Creek are some more bedded clays resting upon clay and slate, and overlain by boulder-clay. The bridge over the Pieman is 400 feet above sea-level, while the railway-bridge over its tributary the Ring River is at a slightly lower level; and in both cases the glacial beds occur almost at the level of the bridges. About Rosebery, at the level of 510 feet above the sea, there are also some good exposures of boulder-clay; the last of the boulder-clays, however, were left some time before reaching Zeehan. The boulder-clays in this area seem to occur in an irregular sheet, descending in the deepest pre-glacial valleys to but little over 400 feet above the level of the sea.

The glacial deposits of Farrell, Rosebery, and Dundas may be assigned to the action of a Pleistocene glacier, which flowed northwestward from the ice-sheet of the Central Plateau. Moreover, the erratics found by Sprent in the Mackintosh Valley, at a locality only some 6 miles from Farrell, may be safely attributed to the Pleistocene, and not to the Carboniferous glaciation.

The railway-line from Zeehan to Strahan, on Macquarie Harbour, passes through a series of cuttings in coarse boulder-deposits; they extend along the line for 2 or 3 miles, on the northern side of the Henty River, between Mallana and Eden. They range in altitude from about 50 to 350 feet above sea-level.

For an opportunity of examining one of these sections I am indebted to the courtesy of Mr. Parry, the station-master at Zeehan, who kindly stopped the train for me. A four-minutes' examination of one section showed that the beds are true boulder-clays: the clay is tough, hard, and fine; the boulders range up to 2 feet in longest diameter, and lie at all angles in the fine clay. The shape of the boulders is characteristic of ice-action, most of them having one or more flattened surfaces. The boulders, however, are so decomposed that I could not find any indubitable glacial scratches; and they are so soft, that I could dig into them with the hammer. They include boulders of Devonian conglomerates and diabase, indicating a mixture of materials. There is no outcrop of diabase in the immediate neighbourhood.

The boulder-clay at this locality consists of a series of patches; remnants, no doubt, of a formerly-extensive sheet. This fact, coupled with the extreme decomposition of the boulders, indicates a great age for this material. Moreover, there is no indication of recent glacial action in this locality. Therefore, although the evidence is inconclusive, these boulder-clays may be provisionally correlated with the Carboniferous Series; and the boulder-clays of the Pieman Valley give the lowest level (400 feet above the sea) yet proved for the Tasmanian Pleistocene glaciers. It must be remembered, however, that there is certain evidence of a recent uplift of this part of Tasmania to the height of several hundred feet, so that some of the glaciers may have actually reached sea-level.

## VII. The Age of the Glaciation.

The only direct evidence as to the latest date at which the glacial deposits of North-Western Tasmania were formed is derived from their condition of preservation. Mr. Dunn has remarked on the very recent aspect of some of the rock-scorings, and many of the glacial deposits are but slightly worn and weathered. The moraine in the Linda Valley has been simply rounded off and cut through by the Linda River; the moraines around Lake Margaret are still in excellent preservation. The deposits of the main King Valley have been more denuded, for the river has widened that valley and removed much of the old morainic material, except where it is preserved on the flanks of Mount Lyell and Mount Owen. Some of the glacial deposits, however, are little more altered than those of the North of England, despite the heavy rainfall by which they are attacked. And, so far as it is safe to judge the age of glacial deposits by their condition of preservation, they may be as recent as some of the later moraines of the North of England.

The maximum age of the deposits is given by their stratigraphical relations. They are not only later than the formation of a great peneplain, which is one of the most conspicuous features in North-Western Tasmania, but they were formed after the dissection of this peneplain had begun; for some of the glacial deposits in the valley of the Queen River at Queenstown are but little above the present floor of the valley.

Dimensions:—

Diameter = 72 millimetres.
Height of the last whorl = 0·302 of the diameter.
Thickness = 0·347 of the diameter.
Width of the umbilicus = 0·487 of the diameter.

Locality and Stratigraphical Position.—The specimen described came from the Kimeridge Clay at Chippinghurst, near Chiselhampton, 6½ miles south of Oxford, and is in the Buckland Collection, in the University Museum, Oxford. The species is the zone-fossil of the Upper Kimeridge Clay.

Affinities and Differences.—The points of difference between this specimen and d'Orbigny's type have already been referred to. A specimen from Hartwell, in the British Museum (Natural History), forms a link between the two, approaching the former in having three simple ribs, and the latter in having whorls which are not depressed, and only twenty-five ribs at a diameter of 69 millimetres. As the shell is preserved, the constrictions behind each simple rib are well marked.

*Perisphinctes bipliciformis*, Nikítin[1] is very closely related to it, and so is *Ammonites annulosus*, Quenstedt.[2] It may be identical with *Am. rotundus*, Sow., and if it is so, that name has the priority: I have not adopted it because the 'type' of *rotundus* is only a worn fragment, upon which it is quite impossible to found a species.

In conclusion I have much pleasure in expressing my thanks to Mr. S. S. Buckman and Dr. Henry Woodward for suggestions; to Dr. A. Smith Woodward for facilities for examining specimens in the Natural History Museum; and especially to Prof. Sollas for help in every way.

## EXPLANATION OF PLATES IX–XII.

[All the figures are of the natural size.]

### Plate IX.

*Perisphinctes plicatilis* (Sow.).

Fig. 1. Side view.
2. Front view.

This is Sowerby's 'type'-specimen, and is preserved in the Buckland Collection, at the University Museum, Oxford.

### Plate X.

*Perisphinctes biplex* (Sow.).

Fig. 1. Side view.
2. Natural cross-section.

This is Sowerby's 'type'-specimen, and is preserved at the British Museum (Natural History).

---

[1] 'Die Jura-Ablagerungen zwischen Rybinsk, Mologa und Myschkin, an der oberen Wolga' Mem. Acad. Imp. Sci. St. Petersb. ser. 7, vol. xxviii (1881) no. 5, pl. vi, fig. 52.

[2] 'Die Ammoniten des schwäbischen Jura' vol. ii (1886–87) pl. lxxxviii, fig. 22.

PLATE XI.

*Perisphinctes variocostatus* (Buckland).

This is Buckland's 'type'-specimen, and is preserved in the Buckland Collection, at the University Museum, Oxford.

PLATE XII.

*Olcostephanus Pallasianus* (d'Orb.), var. nov.

Fig. 1. Side view.
2. Front view.

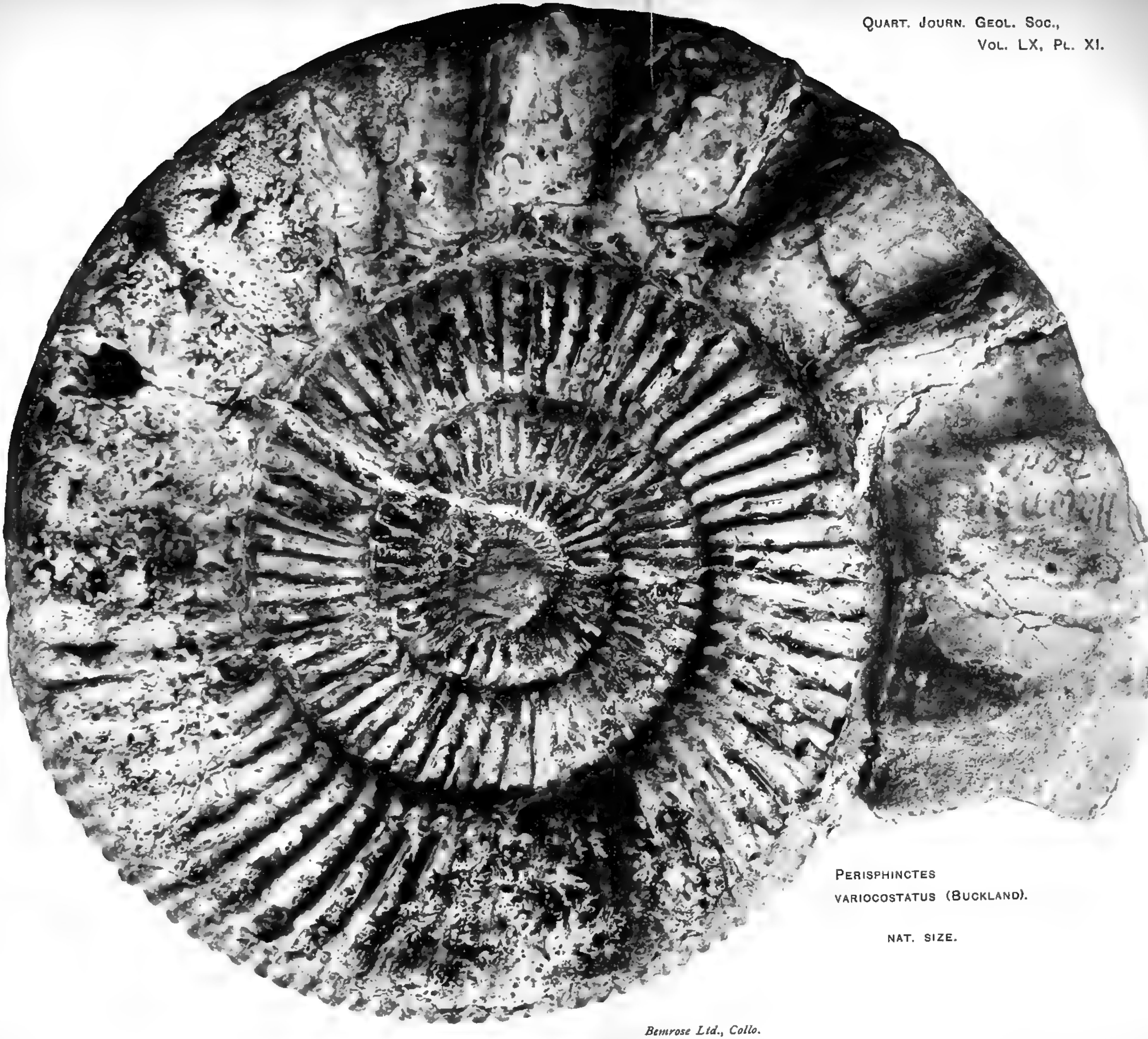
This specimen is preserved in the Buckland Collection, at the University Museum, Oxford. It is figured as an example of the ammonite which has so long been known as *Ammonites biplex*.

DISCUSSION.

The Rev. J. F. BLAKE congratulated the Authoress on having come independently, by the study of the type-specimens, to the same conclusions as those foreigners who had studied our Upper Jurassic ammonites. Nikítin and Pavlow had pointed out, after their visit to England in 1888 for the International Geological Congress, that the shell that we had been in the habit of calling *Ammonites plicatilis* was what they had understood by *Am. biplex*, and that what we called *Am. biplex* was what they knew as *Am. Pallasianus*. M. P. de Loriol also had figured the latter species under the name of *Am. biplex*.

The speaker thought that he was in a position to show that the trouble had arisen from Sowerby himself, who, to illustrate his description of *Am. plicatilis*, had figured the one specimen intended to illustrate his description of *Am. biplex*: while, to illustrate his description of *Am. biplex*, he had figured the two specimens intended to illustrate his description of *Am. plicatilis*. This (said the speaker) was shown not only by a comparison of details, but by the mere fact that *Am. plicatilis* was spoken of in the plural, and as occurring abundantly and in company with *Am. excavatus* in places where the easily-recognizable specimens figured as *Am. biplex* do occur in such company; while *Am. biplex* was spoken of as one specimen occurring in Drift, which could not therefore be represented by two examples, though it might well be by the figure of *Am. plicatilis*, which cannot be recognized as an Upper Jurassic fossil, but whose home might perhaps be now determined, since the Authoress had rediscovered the specimen. The use of the term '*biplex*' for the very distinct Upper-Kimeridge form appears to have been introduced by Fitton, who has been followed by others until corrected by the Russians.

A curious question arises out of the mistake thus indicated. If an author describes under the same name one specimen in the text and illustrates another specimen in the plates, which is the type? In the view of the speaker, if they be of different species, the name



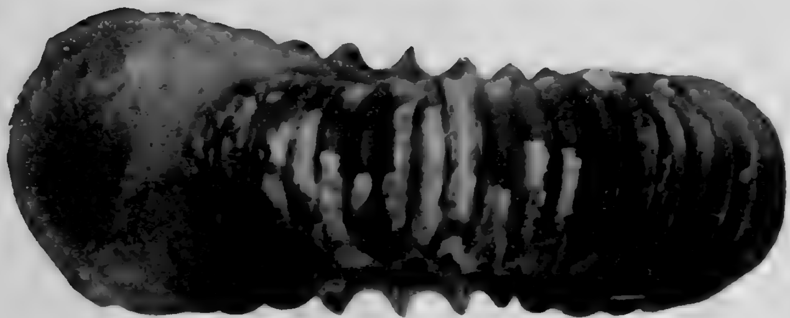
PERISPHINCTES
VARIOCOSTATUS (BUCKLAND).

NAT. SIZE.

Bemrose Ltd., Collo.

Fig. 1. Nat. size.

Fig. 2. Nat. size.



*Bemrose Ltd., Collo.*

Olcostephanus Pallasianus (d'Orb).

var. nov.

belongs to the description. On this principle British geologists have acted; but foreigners have been led by the figures.

The reference of the type of *Ammonites variocostatus* to the Ampthill Clay, which represents a Corallian horizon, seems to be correct. It appears in fragments on that horizon at Shotover, and a fine specimen from Osmington was exhibited by the speaker. It is the adult form of *Am. plicatilis* (Sowerby's description).

Mr. H. B. WOODWARD remarked on the importance of finding these type-specimens and of figuring them by the aid of photography. He observed that the complexities of modern nomenclature were a great trouble to the student, as in some lately-published manuals different generic (or subgeneric) names were used for the same species. With field-experience, however, one might become familiar with the many forms of each leading species and with the horizons which they characterized; and the safest plan seemed to be to identify the fossils without naming them.

Mr. E. T. NEWTON thought that the Rev. J. F. Blake's explanations showed the desirability of publishing good figures and descriptions of the obscure and little-known type-specimens which formed the subject of the Authoress's paper. The plicatiloid ammonites were avowedly a difficult group to deal with; and a full knowledge of the type-specimens was a necessary foundation to work upon.

Prof. SOLLAS remarked that he had listened with great pleasure to the complimentary remarks on the work of the Authoress, and regretted that she was not present to defend before the Society her own position in the disputed matter of nomenclature. The Rev. J. F. Blake's suggestion was certainly ingenious, and required careful examination; but, whether well-founded or not, it had always been customary to accept the evidence of so-called 'type'-specimens as conclusive. The type in the Natural History Museum was named and figured as '*biplex*,' that in the Oxford University Museum was named and figured as '*plicatilis*'; so that, unless we abandoned our usual methods, these must be accepted as the correct designations of their respective forms.

## POSTSCRIPT TO THE DISCUSSION.

[I am sure that Mr. Blake will be the first to abandon his ingenious suggestion when he has seen both of the 'types' in question. No one familiar with the Corallian Beds of Dry Sandford and Marcham can doubt which of the two came from there, and which from the Drift. But, apart from this, it is impossible to transpose Sowerby's descriptions, for a careful perusal of them shows that he does not speak of *Ammonites plicatilis* in the plural. The only suggestions of plurality are found in the mention of two localities in this sentence:—

'A sandy stratum, containing beds of sandy limestone, at Dry Sandford and Marcham, N.W. of Abingdon, produces this shell';

and in a reference to 'several other ammonites' in the following :—

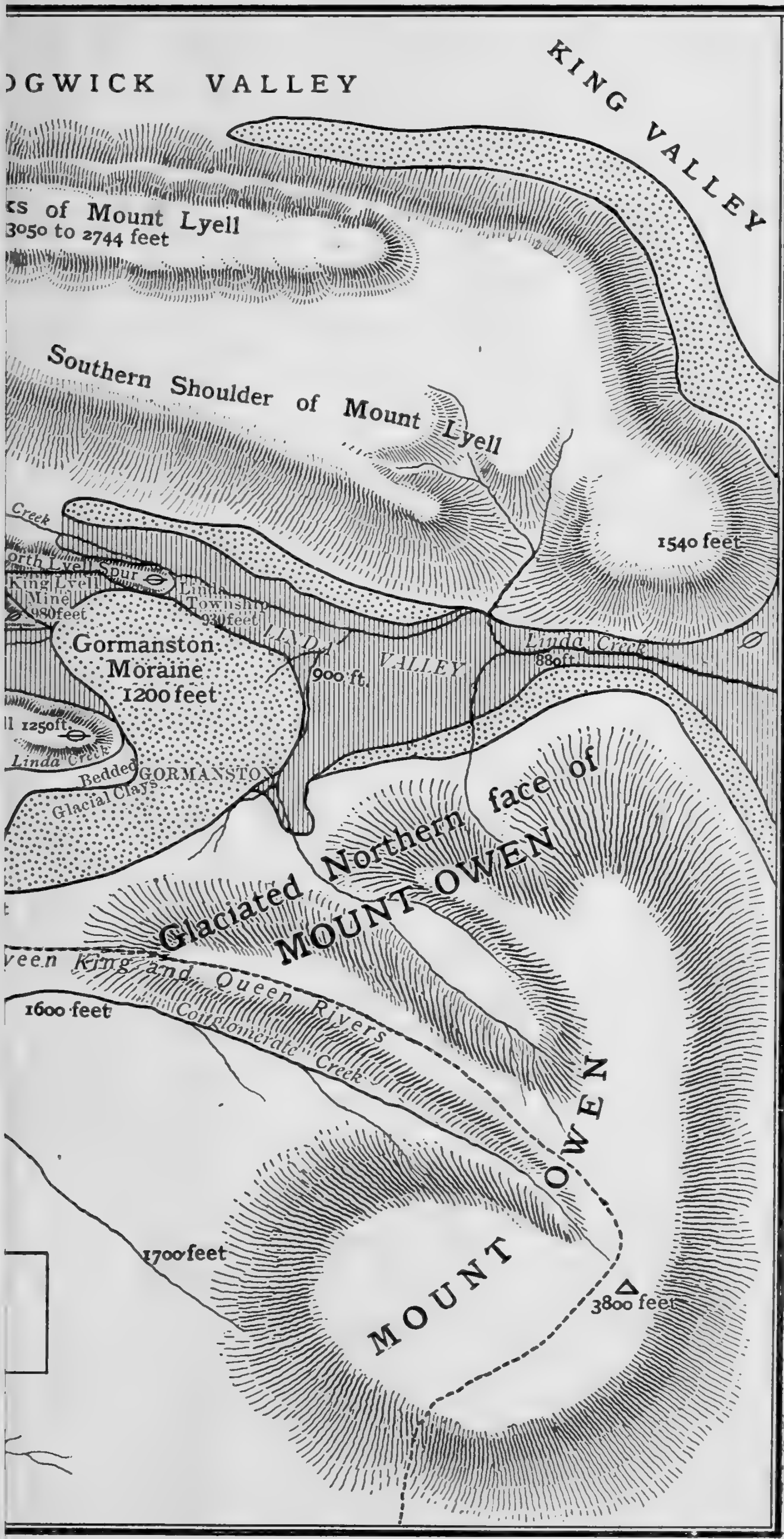
'Several other ammonites occur in the same stratum, among them is *Am. concavus* of tab. 105; most of them have lost the shell; the present is only a cast of the inside....';[1]

and again in a footnote referring to the said tab. 105. Further, in the description of *Am. biplex* Sowerby distinctly refers to two figures; he does not, it is true, actually mention fig. 1, but he describes it, and says that it came from Suffolk, adding 'Fig. 2 is from Barrow.'[2] Additional evidence can be found in the suture-line, which is very complicated and very clearly shown in *Am. plicatilis*, while it is only indicated here and there in *Am. biplex*; Sowerby states that 'the septa are acutely sinuated' in the case of the former, and does not mention them in the case of the latter.

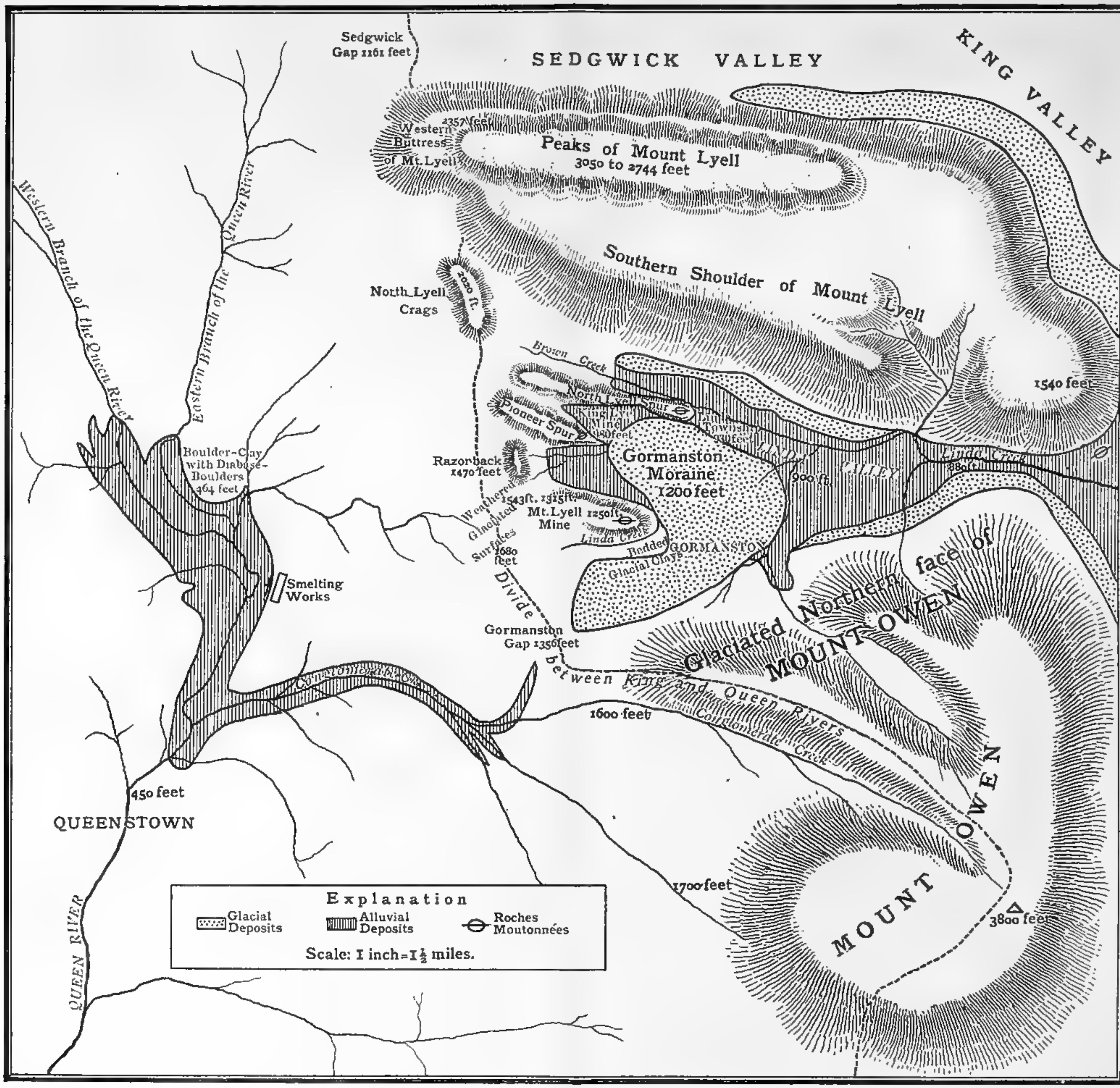
I hope to deal fully with *Am. excavatus* at no very distant date. It is, however, necessary to mention it now, as its occurrence with *Am. biplex* has been adduced by Mr. Blake in support of his suggestion. In one of the quotations given above, Sowerby says that *Am. concavus* of tab. 105 is found with *Am. plicatilis*. Unfortunately, tab. 105 is described as *Am. excavatus*,[3] and here it must be allowed that Sowerby has made a slip. Still, there is no doubt that he meant *Am. excavatus*, as *Am. concavus* is an Inferior Oolite form, and could not therefore occur in the neighbourhood of Dry Sandford and Marcham. Now the type of *Am. excavatus* came from Shotover, and we have specimens in the University Museum, Oxford, from the Corallian, which I have identified with it; there is, therefore, every probability of its occurring along with *Am. plicatilis* in the neighbourhood of Dry Sandford and Marcham. Before accepting its recorded occurrence with *Am. biplex*, I should like to see the specimens which were found together, because I am of opinion that *Am. excavatus* is confined to the Upper Oxford Clay and the Corallian Beds, while the true *Am. biplex* is a Kimeridgian form, although several species of *Perisphinctes*, which are related to it, do occur in the Corallian.

There is yet another point on which I must beg to differ from Mr. Blake, and that is in regarding *Am. variocostatus* as the adult form of *Am. plicatilis*. The ribs of the inner whorls of the former are much coarser and less numerous than those of the latter, and the suture-line is different. At the same time, I think it highly probable that the ribs of the adult *Am. plicatilis* suffered a change similar to that which the ribs of *Am. variocostatus* undergo.—M. H., *December 5th, 1903.*]

[1] 'Mineral Conchology' vol. ii (1818) p. 149.
[2] *Ibid.* vol. iii (1821) p. 168.
[3] *Ibid.* vol. ii (1818) p. 5.




AREA AROUND MOUNT LYELL.




SKETCH-MAP OF THE GLACIATED AREA AROUND MOUNT LYELL.

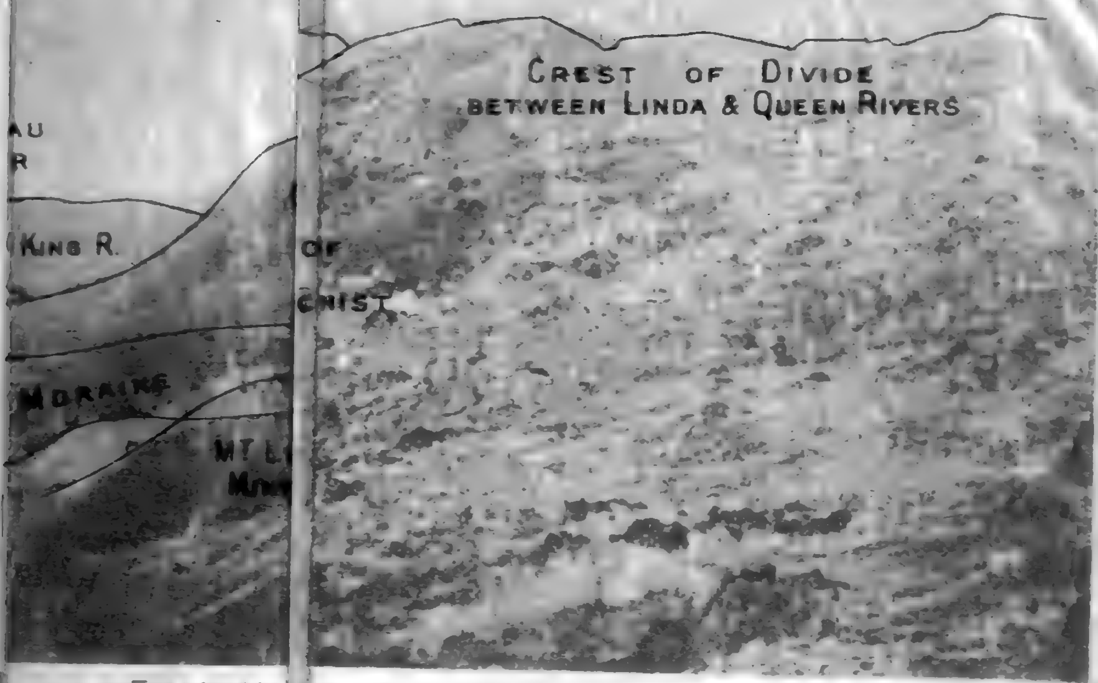
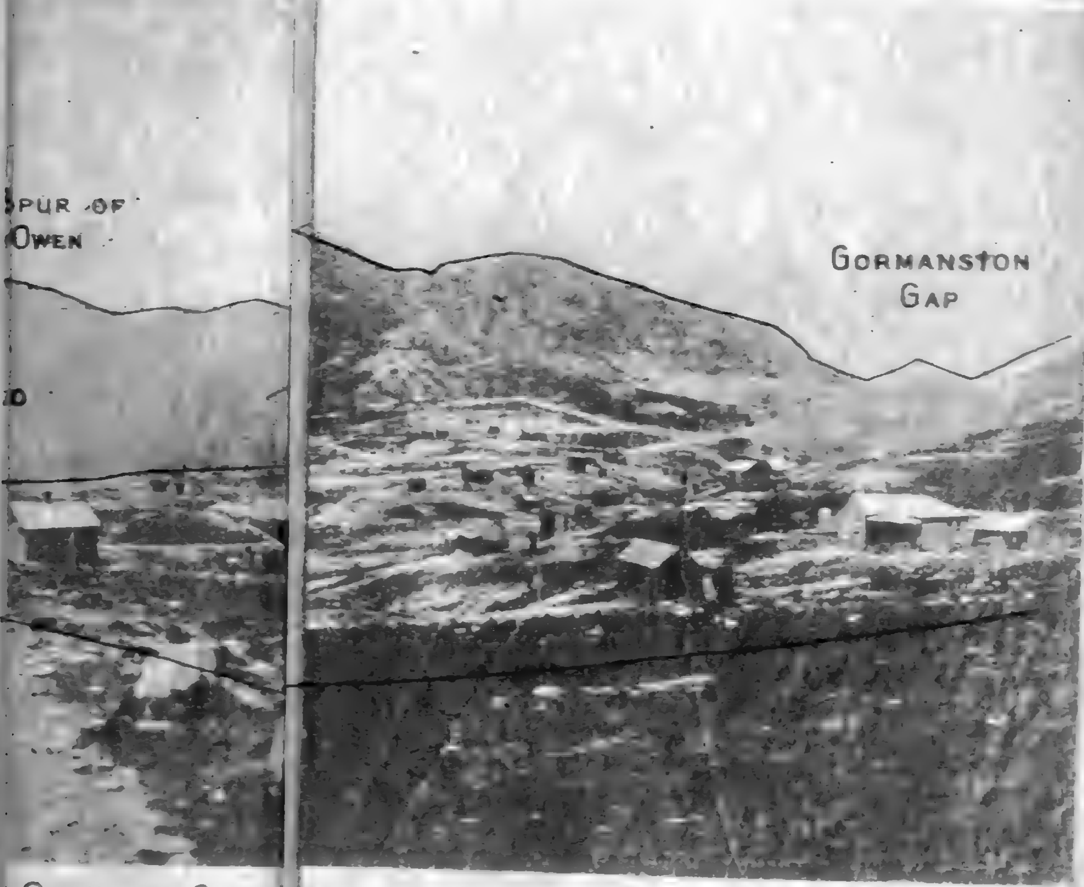



FIG. 1.—VIE




OWEN, THE GORMA MOUNT-LYELL MINE OFFICES.

Bemrose & Sons. Ltd., Printers, Derby, London and Watford.

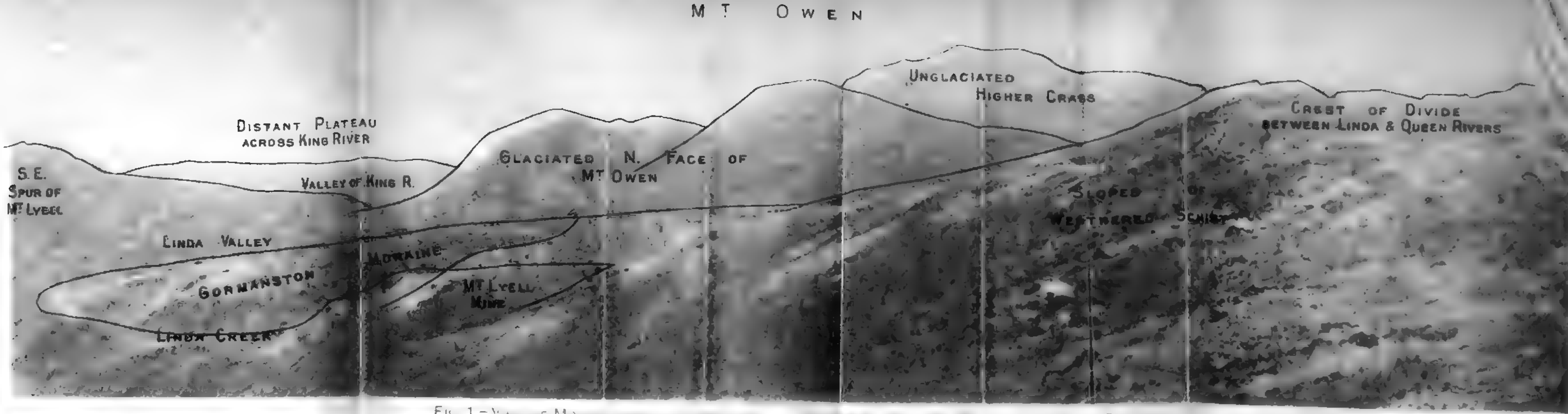



Fig. 1.—View of M ... ine, from the R...

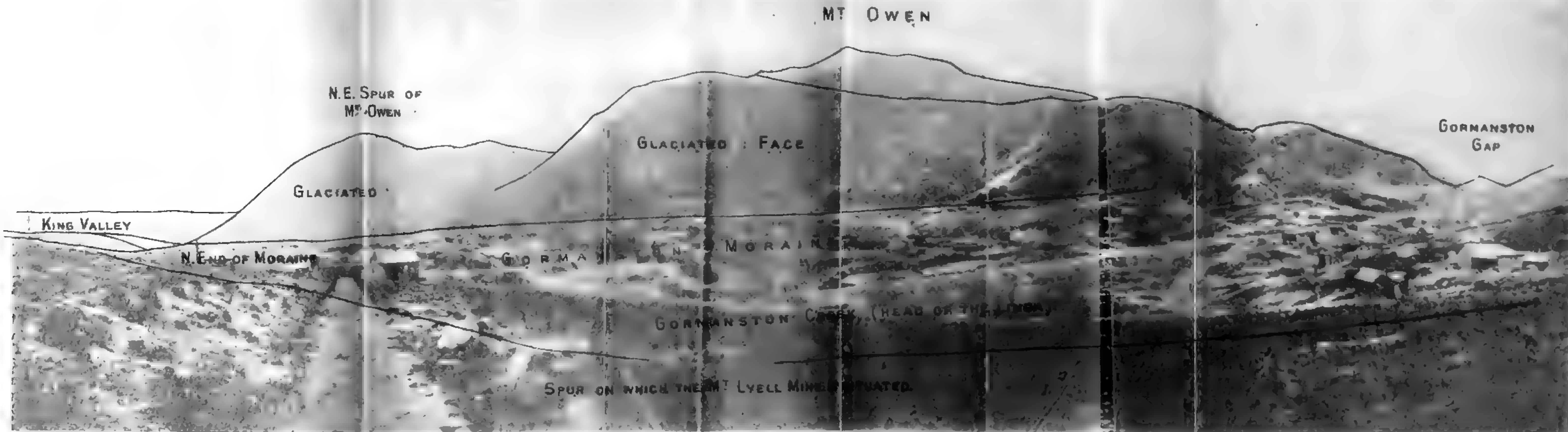



Fig. 2.—View of Mount Owen, the Gor... ...ll beside the Mount-Lyell Mine Office

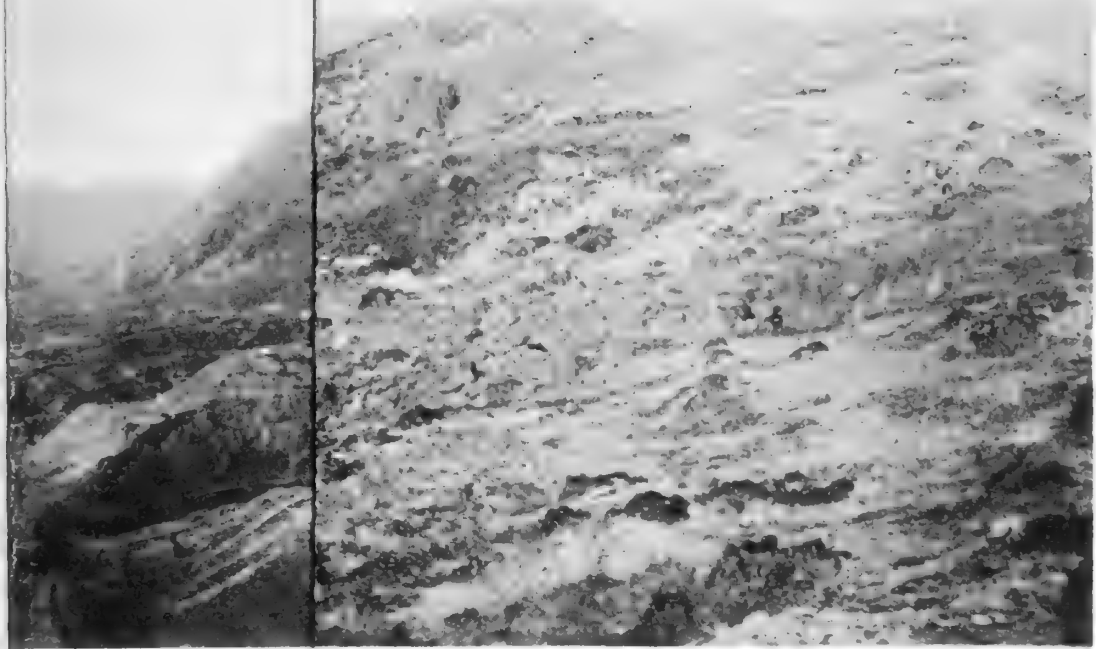


FIG. 1.—VIEW

OWEN, THE GORMAN MOUNT-LYELL MINE OFFICES.

*Bemrose & Sons. Ltd., Printers, Derby, London and Watford.*

FIG. 1.—VIEW OF MOUNT OWEN, THE LINDA VALLEY, AND THE GORMANSTON MORAINE, FROM THE RAZORBACK.

FIG. 2.—VIEW OF MOUNT OWEN, THE GORMANSTON GAP, AND THE PLANED SURFACE OF THE GORMANSTON MORAINE, FROM THE HILL BESIDE THE MOUNT-LYELL MINE OFFICES.

Bemrose & Sons, Ltd., Printers, Derby, London and Watford.

## EXPLANATION OF PLATES VII & VIII.

### Plate VII.

Sketch-map of the glaciated area around Mount Lyell, including the Gormanston Moraine in the Linda Valley, on the scale of 1½ miles to the inch.

### Plate VIII.

Fig. 1. View of Mount Owen, the Linda Valley, and the Gormanston Moraine, from the Razorback: showing the glaciated aspect of the lower northern slopes of Mount Owen.

2. View of Mount Owen, the Gormanston Gap, and the planed surface of the Gormanston Moraine, from the hill beside the Mount-Lyell Mine Offices.

### Discussion.

Dr. W. T. Blanford called attention to the fact that the Author's clear account of the Pleistocene glacial evidence in the Tasmanian lowlands was an important addition to our knowledge of the records left by the Glacial Period in the Southern Hemisphere; for instance, in New Zealand, in Tierra del Fuego and the neighbourhood, and on the mountains of South-Eastern Australia. Everywhere in the Southern lands the marks of ice-action resembled those found in the Northern Hemisphere, and appeared to be of about the same antiquity.

Mr. C. F. Heathcote said that he had been acquainted with the district described for more than 8 years. He quite agreed with the Author that the previous evidence as to glaciation was unreliable: he had studied the evidence himself, and was dissatisfied with it. The continuous rains and the extremely-close growth of the Tasmanian 'bush' made geological work on the western coast of that island a matter of considerable difficulty, and he congratulated those interested in the Colony on their being now able to avail themselves of the careful record of observations which the Author had placed before the Society.

Mr. P. F. Kendall remarked that it was fortunate that these disputed points of Tasmanian geology had been studied by one so well able to determine their merits as the Author. The phenomena presented one peculiar feature: they indicated glaciation by ice-sheets, not by valley-glaciers. The boulders had been brought from great distances across a country of low relief; nor was that characteristic product of glaciation, boulder-clay, wanting. Glaciation extending down to a few hundred feet from sea-level, in a latitude corresponding to that of Madrid in the Northern Hemisphere, was a very remarkable occurrence. Perhaps the very high rainfall of Tasmania had something to do with it.

## 5. NOTES *on* UPPER JURASSIC AMMONITES, *with* SPECIAL REFERENCE *to* SPECIMENS *in the* UNIVERSITY MUSEUM, OXFORD: No. I. By Miss MAUD HEALEY. (Communicated by Prof. W. J. SOLLAS, D.Sc., LL.D., F.R.S. Read November 18th, 1903.)

[PLATES IX–XII.]

IN the course of rearranging the Upper Jurassic fossils in the University Museum, Oxford, my attention has been called to the large amount of misconception which exists with regard to Sowerby's species *Ammonites plicatilis* and *Am. biplex*. The former is rightly recognized in England as the zone-fossil of the Upper Corallian, but Dr. J. von Siemiradzki[1] gives the name to a specimen from the *ornatus*-zone. He makes the following surprising remark with reference to it:—

'Da Sowerby's Originale nicht erhalten sind, bleibt uns nichts anderes übrig, als die nächst älteste Figur von Phillips als Typus der Art anzusehen.'

The original specimen is in the Buckland Collection in the University Museum, Oxford; but even if it had been lost, Sowerby's figure would have had a better right to be taken as the type than that of Phillips, for it has the priority and there is no ambiguity about it, while the history of the latter is very involved and the original, so far as I can ascertain, is not preserved. The reference which Dr. Siemiradzki gives for it is 'Geology of Yorkshire' (1829) pl. iv, fig. 29, that is, the first edition, in which the figure in question is that of a keeled ammonite and is named *Ammonites solaris*; while the figure[2] which he gives as an example of *Perisphinctes plicatilis* makes it quite clear that he is really referring to the third edition (1874), in which fig. 29 on pl. iv is that of a species of *Perisphinctes* and is described in the explanation of the plates[3] as '*Am. solaris* (erased 1874), *Am. plicatis* (replacing *Am. solaris*),' but referred to on p. 265 as *Am. plicatilis*, Sow. It is therefore most probable that '*plicatis*' was intended for '*plicatilis*' on p. 325; but, granted that this is so, it in no way affects the validity of Sowerby's 'type.' The second edition (1835) of the 'Geology of Yorkshire' is the same as the first.

*Perisphinctes biplex* is, in England, generally considered to be the zone-fossil of the Upper Kimeridge Clay, Damon's figure[4] having apparently been taken as the type instead of Sowerby's.[5] Dr. Siemiradzki devotes two pages of his monograph[6] to it, and gives a figure of the original *biplex*, which is preserved in the British Museum (Natural History). Unfortunately, he had only a plaster-cast on

[1] 'Monographische Beschreibung der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv (1898) p. 249.
[2] *Ibid.* pl. xxv, fig. 45.
[3] 'Illustrations of the Geology of Yorkshire' 3rd ed. vol. i (1874) p. 325.
[4] 'Geology of Weymouth' Suppl. 2nd ed. (1880) pl. ix, fig. 9.
[5] 'Mineral Conchology' vol. iii (1821) pl. ccxciii, figs. 1 & 2.
[6] Palæontographica, vol. xlv (1898) pp. 265–67.

which to base his conclusions, and a cast of so extraordinary a specimen could hardly fail to be misleading. He ignores *Perisphinctes variocostatus* (Buckland), but this I believe to be the species which he means by *P. biplex*, or at least a variety of it. The real *biplex*, I venture to suggest, should be set aside as a freak.

Under these circumstances, it seems desirable to refigure and redescribe Sowerby's 'types' *P. plicatilis* and *P. biplex*, also Buckland's *P. variocostatus*, and a specimen of the ammonite which has so long been known in England (but not on the Continent[1]) as *Ammonites biplex*, namely, *Olcostephanus Pallasianus* (d'Orb.).

The synonymy given here does not profess to be complete.

PERISPHINCTES PLICATILIS (Sow.). (Pl. IX, figs. 1 & 2 & text-fig. 1.)
[The 'type'-specimen.]

1818. *Ammonites plicatilis*, Sow. 'Mineral Conchology' vol. ii, pl. clxvi.
1880. Do. do. do. Damon, 'Geology of Weymouth' Suppl. 2nd ed. pl. xvii, fig. 3.

Description.—The cast only is preserved. It is discoidal and compressed. The sides of the whorls are flattened; the back rounded; the cross-section is really oblong, but it has a squarish appearance (Pl. IX, fig. 2) owing to the weathering having followed the backward slope of the suspensive lobe. There are seventy fine ribs on the last whorl; they are directed slightly forward, and fork as they pass over on to the back; occasionally they trifurcate, and still more rarely they remain simple. The back of the specimen is so much worn that the ribs appear to have been interrupted, and in places the siphuncle even is exposed. There are very faint indications of about twelve constrictions, but they are so faint that I should scarcely have noticed them had they not been more distinct in another specimen, which differs from the 'type' in having (1) one auxiliary lobe less, (2) fifty-four ribs at a diameter of 96 millimetres instead of sixty-eight, and (3) the body-chamber preserved. The last-named occupies nearly four-fifths of the last whorl.

Fig. 1.—*Suture-line of* Perisphinctes plicatilis, *nat. size.*

The suture-line (fig. 1, above) is very complex, the suspensive lobe running back farther than either the first lateral or the siphonal.

Dimensions:—

| | |
|---|---|
| Diameter = 107·2 millimetres; 84 millimetres. | Thickness of the last whorl = 0·268 of the diameter. |
| Height of the last whorl = 0·321 of the diameter; 0·359 of the diameter. | Width of the umbilicus = 0·431 of the diameter; 0·396 of the diameter. |

[1] See A. Pavlow, Bull. Soc. Imp. des Nat. Moscou, ser. 2, vol. iii (1889) p. 96; also J. von Siemiradzki, Palæontographica, vol. xlv (1898) p. 267.

Many figures and descriptions of the changes which *P. plicatilis* undergoes as it grows bigger have been published; but as I have not yet seen the form which I should feel justified in calling the adult of this species, I must for the present content myself with a description of the 'type'-specimen.

Locality and Stratigraphical Position.—Unfortunately, no precise record of the locality whence this 'type' came has been preserved. Sowerby contented himself with the indefinite statement that it is found in a

'sandy stratum containing beds of sandy limestone at Dry Sandford and Marcham, N.W. of Abingdon.'[1]

It is, however, undoubtedly an Upper Corallian form, and is usually taken as the zone-fossil of that horizon.

Affinities and Differences.—*Ammonites plicatilis*, as figured by Alcide d'Orbigny,[2] is more evolute and more compressed than the type, while his figures on pl. cxci are *Perisphinctes biplex* according to Dr. Siemiradzki, that is, *P. variocostatus* (Buckl.). Dr. Siemiradzki regards *Am. biplex* as figured by d'Orbigny,[3] and *P. plicatilis* as represented by Waagen,[4] as synonymous with *P. orientalis*, Siem. They differ from Sowerby's 'type' *plicatilis* in being more evolute and more compressed, but they are much nearer to it than the figures in 'Paléontologie Française.' A. de Riaz[5] takes d'Orbigny's fig. 1, pl. cxcii, as the type, and consequently the specimen that he regards as typical[6] is more evolute and slightly more compressed than the real *plicatilis*: it is also distinguished by fewer and more pronounced constrictions. De Riaz further states that he agrees with Favre in his interpretation of this species; but the latter's figures[7] appear to me to be quite different, inasmuch as they have rounder whorls, and their ribs are stronger, fewer in number, and bifurcate sooner. De Riaz does note the last point.

*Perisphinctes Martelli*, Oppel, approaches our 'type' very closely. I am accepting Dr. Siemiradzki's[8] views on *P. Martelli,* as he is acquainted with Oppel's original specimens. He takes fig. 3, pl. lv, of Waagen (*op. cit.*), as representing it, and puts pl. cxci, d'Orb. Pal. Franç., Ter. Jur. vol. i (which Oppel[9] quotes as the 'type' of his species), with *P. biplex* (Sow.). The suture-line which he delineates differs from that of *P. plicatilis* (Sow.) in the character of the terminal branches of the siphonal lobe, and in having one auxiliary

[1] 'Mineral Conchology' vol. ii (1818) p. 149.

[2] Pal. Franç. 'Terrains Jurassiques' vol. i (1849) pl. cxcii, figs. 1 & 2.

[3] Murchison, De Verneuil, & Keyserling, 'Géologie de la Russie d'Europe & des Montagnes d'Oural' vol. ii (1845) pl. xxxvii, figs. 3 & 4.

[4] Mem. Geol. Surv. India, Palæontologia Indica, ser. ix, 'Jurassic Cephalopoda of Kutch' vol. i (1875) pl. li, figs. 2 *a* & 2 *b*.

[5] 'Description des Ammonites des Couches à *Peltoceras transversarium* (Oxfordien supérieur) de Trept (Isère)' Lyons–Paris, folio, 1898, p. 10.

[6] *Ibid.* pl. iii, fig. 1.

[7] Mém. Soc. Pal. Suisse, vol. ii (1875) 'Description des Fossiles du Terrain jurassique de la Montagne des Voirons' pl. iii, figs. 1–3.

[8] Palæontographica, vol. xlv (1898) p. 267.

[9] Palæontologische Mittheilungen aus dem Museum des kgl.-bayerischen Staates: 'Ueber jurassische Ammoniten' 1862, p. 247.

lobe less. Waagen's *Martelli*[1] is only distinguished from *plicatilis* by having fewer ribs. I very much doubt the specific value of this distinction. *P. Dunikowskii*, Siem.[2] includes *P. chloroolithicus*, Gümb., as figured by Waagen.[3] Its whorls are slightly more compressed than those of *plicatilis*, which is therefore intermediate between it and *Martelli*, having the ribs of the former and the cross-section of the latter. *Am. Schilli*, Oppel,[4] is distinguished by the slope of its sides towards the back being much greater. It is also slightly too involute and the second lateral saddle is different.

I do not propose to enter into the question as to how many of these are good species, but some of them, I think, might with great advantage be reduced to the rank of varieties.

Remarks.—This specimen is in the Buckland Collection, in the University Museum, Oxford. It bore no label, but no one who has compared it with Sowerby's original figure can doubt its identity. Sowerby's figure is reversed, and somewhat restored: hence the slight differences between it and a photograph of the specimen.

PERISPHINCTES BIPLEX (Sow.). (Pl. X, figs. 1 & 2.) [The 'type'-specimen.]

1821. *Ammonites biplex*, Sowerby, 'Mineral Conchology' vol. iii, pl. ccxciii, figs. 1 & 2.

Description.—In the first place, it is necessary to remark that Sowerby's two figures do not represent parts of the same specimen, as Dr. Siemiradzki believed them to do. The smaller (*loc. cit.* fig. 2) is a fragment of a cast in dark, bluish clay, with traces of a nacreous shell still adhering to it, and may be dismissed from our consideration at once. The larger (*loc. cit.* fig. 1) looks as though it had come out of a septarian nodule, probably from the Kimeridge Clay. Sowerby obtained it from the Drift of Suffolk.[5] It is preserved in calcite and pyrites, except the body-chamber, which is filled with a somewhat hard, yellowish, compact matrix, and occupies about three-quarters of the last whorl. The whole shell is somewhat distorted. The cross-section of the inner whorls is broader than high, but as the shell grows older this is reversed. There are fifty ribs at a diameter of 100 millimetres. They run slightly forward, and bifurcate just as they pass over on to the back; one trifurcates, and one remains simple until it reaches the middle of the back, where it unites with both branches of the opposite rib. The suture-line is but partly visible here and there.

The shell is broken across along the line QR (Pl. X, fig. 1) which does not pass through the centre, and when the two parts are put together they form what appears to be an ordinary ammonite; but the cross-section (Pl. X, fig. 2) shows that this is far

[1] 'Jurassic Cephalopoda of Kutch' vol. i (1875) pl. lv, figs. 3 *a* & 3 *b*.
[2] Palæontographica, vol. xlv (1898) p. 269.
[3] 'Jurassic Cephalopoda of Kutch' vol. i (1875) pl. l, figs. 3 *a* & 3 *b*.
[4] 'Jurassische Ammoniten' [atlas] 1862, pl. lxv, figs. 7 *a* & 7 *b*.
[5] 'Mineral Conchology' vol. iii (1821) p. 168.

from being the case. For convenience of description, I have called one surface A, the other B. Fig. 1 represents the B surface. On surface A all the inner whorls are perfect; on B also they are perfect, down to an umbilical diameter of 16 millimetres, that is to the point O in fig. 2. On side A of the cross-section there is revealed a small, perfect ammonite, which can be traced to a diameter of 46 millimetres, after which it is lost in a whorl the sides of which are those of both the A and B surfaces, the shell having here attained a diameter of 50 millimetres. The centres of the two surfaces correspond, and so do the inner whorls. The back of the little ammonite shows bifurcating ribs. It does not seem possible that it could have been forced into its present position by extraneous means, for neither the A nor the B surface shows signs of disturbance in the inner whorls. On the other hand, it is very difficult to imagine it growing in its present position.

Remarks.—I have already indicated the probability of *Perisphinctes biplex* being a Kimeridgian form, but the horizon whence it came must remain doubtful. In cases like this, it is perhaps wisest to abandon the name altogether, or at least to restrict it to the abnormal specimen to which it was first attached.

I have not given dimensions, because no reliance can be placed on them in such cases.

The specimen is in the British Museum (Natural History).

PERISPHINCTES VARIOCOSTATUS (Buckland). (Pl. XI, & text-fig. 2.)
[The 'type'-specimen.]

1836. *Ammonites variocostatus*, Buckland, 'Bridgewater Treatise' (no. 6) pl. xlii, fig. 7.

1898. *Perisphinctes biplex*, Siemiradzki, Palæontographica, vol. xlv, 'Monographische Beschreibung der Ammonitengattung *Perisphinctes*' p. 265.

Description.—The shell is large and discoidal. The whorls are about as high as thick, and are ornamented with strong ribs, directed slightly forward and bifurcating with perfect regularity as they pass over on to the back. At a diameter of some 180 millimetres the whorls become depressed, and at the same time the ribs become farther apart, cease to bifurcate, and begin to develop wedge-shaped swellings. At a diameter of 183 millimetres there are fifty-five ribs, and at 100 or thereabouts (for the outer whorls prevent accurate measurements) fifty-three.

Fig. 2.—*Suture-line of* Perisphinctes variocostatus, *restored. Nat. size.*

The suture-line delineated in fig. 2 (above) is restored. This was necessary, because the suture-line, where fully exposed, is too much simplified by weathering to be reliable.

A small portion of the body-chamber is preserved.

Dimensions:—

Diameter = 183 millimetres; 215 millimetres.
Height of the last whorl = 0·262 of the diameter; 0·274 of the diameter.
Thickness of the last whorl = 0·289 of the diameter; 0·294 of the diameter.
Width of the umbilicus = 0·502 of the diameter; 0·504 of the diameter.

The measurements of the height and thickness of the last whorl are not very accurate, as the shell is absent in places and the cast is worn.

Locality and Stratigraphical Position.—Buckland states that this specimen came from the Oxford Clay at Hawnes, 4 miles south of Bedford, but I am of opinion that it came from the Ampthill Clay, and for the following reasons:—

1. It is distinctively Corallian in appearance.

2. Hawnes is only 3 miles north-east of Ampthill, and is near the edge of the band of colour indicating Lower Greensand on the Geological-Survey maps. Further, the Geological Surveyors[1] say that

'traced beyond Ampthill the boundary of the Oxford and Kimeridge Clays is largely concealed for some distance by the Cretaceous rocks.'

3. It is not pyritized, and T. Roberts[2] remarks that in the Ampthill Clay

'[fossils] are never pyritized, and on this account the clay is easily distinguished from the underlying Oxford Clay.'

Affinities and Differences.—*Perisphinctes variocostatus* differs from Siemiradzki's interpretation of *P. biplex* (Sow.) in the following details:—

1. It has never more than fifty-five to fifty-seven ribs to a whorl, while *P. biplex* has seventy in middle-sized whorls,[3] but at a diameter of 100 millimetres it has fifty-three as against fifty.

2. Its innermost whorls are slightly more evolute.

The dimensions are practically the same, and the change in the character of the ribs occurs in both at a diameter of about 200 millimetres. As to the suture-line, Dr. Siemiradzki speaks doubtfully of that given by A. d'Orbigny[4] as belonging to his *biplex*. It has a shorter auxiliary lobe than *variocostatus*.

The dimensions of *P. torquatus*, Sow., as tabulated by Dr. Siemiradzki,[5] for a diameter of 157 millimetres, are exactly those of *P. variocostatus* at 183 mm.; but in other respects the two are quite

[1] H. B. Woodward, Mem. Geol. Surv. 'The Jurassic Rocks of Britain' vol. v (1895) p. 138.

[2] 'The Jurassic Rocks of the Neighbourhood of Cambridge' 1892, p. 36. [Sedgwick Prize Essay for 1886.]

[3] Siemiradzki, Palæontographica, vol. xlv (1898) p. 266.

[4] Paléontologie Française 'Terrains Jurassiques' vol. i (1849) pl. cxci.

[5] Palæontographica, vol. xlv (1898) p. 264.

distinct. Sowerby's 'type' is a small specimen from Cutch[1]; but Waagen[2] figures one 210 millimetres in diameter, and this shows that the ribs do not change nearly so soon as in *variocostatus*, that the back remains rounder, and that the ribs frequently trifurcate.

*P. variocostatus* has fewer and thicker ribs than *P. Martelli* or *plicatilis*, and the suspensive lobe runs back at a greater angle.

*P. chloroolithicus* and *P. Vaydelota* are more compressed and more evolute.

Remarks.—This specimen is in the Buckland Collection, in the University Museum, Oxford. 'Hawnes, Bedford,' is written in ink on it, and it bears fragments of an old label on which 'Hawnes.. va' .. is still legible, in the same handwriting as that found on most of Buckland's labels. It corresponds exactly with Buckland's detailed description[3] and with his figure,[4] although the latter is too much reduced to be of great value.

OLCOSTEPHANUS PALLASIANUS (d'Orb.), var. nov. (Pl. XII, figs. 1 & 2, & text-fig. 3.)

1845. *Ammonites Pallasianus*, d'Orb., Murchison, De Verneuil, & Keyserling, 'Géologie de la Russie d'Europe & des Montagnes d'Oural' vol. ii, pl. xxxii, figs 1–3.
1864. *A. kimmeridiensis*, K. von Seebach, 'Der Hannoversche Jura' Berlin, p. 157.
1873. *A. biplex* (Sow.), P. de Loriol et Pellat, 'Monographie paléontologique & géologique des Etages supérieurs de la Formation jurassique des Environs de Boulogne-sur-Mer' Mém. Soc. Phys. Hist. Nat. Genève, vol. xxiii, p. 269 & pl. ii, figs. 1*a*–1*b*.
1880. *A. biplex* (Sow.), Damon, 'Geology of Weymouth' Suppl. 2nd ed. pl. ix, fig. 9.
1871. *A. biplex* (Sow.), Phillips, 'Geology of Oxford & the Valley of the Thames' p. 333 & pl. xv, fig. 17.
1895. *A. biplex* (Sow.), Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. v, fig. 72, p. 156.

Description.—Only minute fragments of the actual shell are preserved. The cast is discoidal; the whorls rounded and somewhat depressed; the ribs sharp and prominent, about 31 in number; all but three bifurcate as they pass over on to the back; these three remain simple, and, judging from analogy with other specimens, would each be preceded by a constriction if the shell were preserved. The body-chamber occupies nine-tenths of the last whorl.

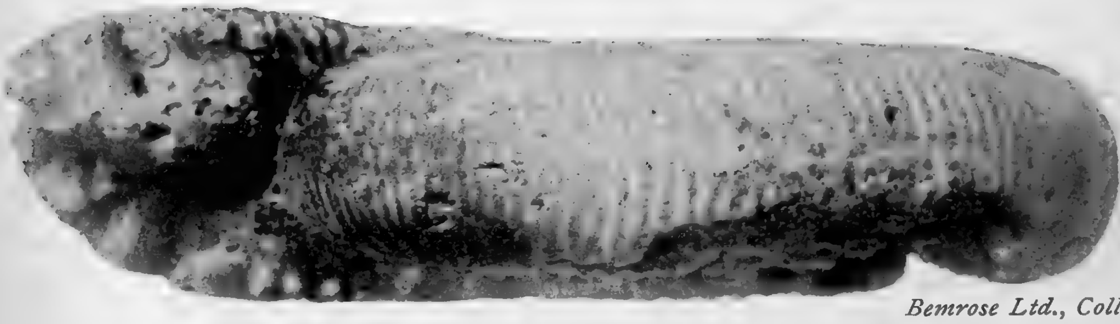
Fig. 3.—*Suture-line of* Olcostephanus Pallasianus, *var. nov. Nat. size.*

Remarks.—I have identified this specimen with d'Orbigny's figure (*loc. supra cit.*) with some hesitation, caused chiefly by the cross-section of the whorls, which is more depressed, and by the number of the ribs, d'Orbigny's figure showing only twenty-six, of which six are simple. The suture-line also is slightly different.

[1] Trans. Geol. Soc. ser. 2, vol. v (1840) pl. lxi, fig. 12.
[2] 'Jurassic Cephalopoda of Kutch' vol. i (1875) pl. liv.
[3] 'Bridgewater Treatise' No. 6, vol. ii (1836) p. 62. [4] *Ibid.* pl. xlii, fig. 7.

Fig 1. nat. size.

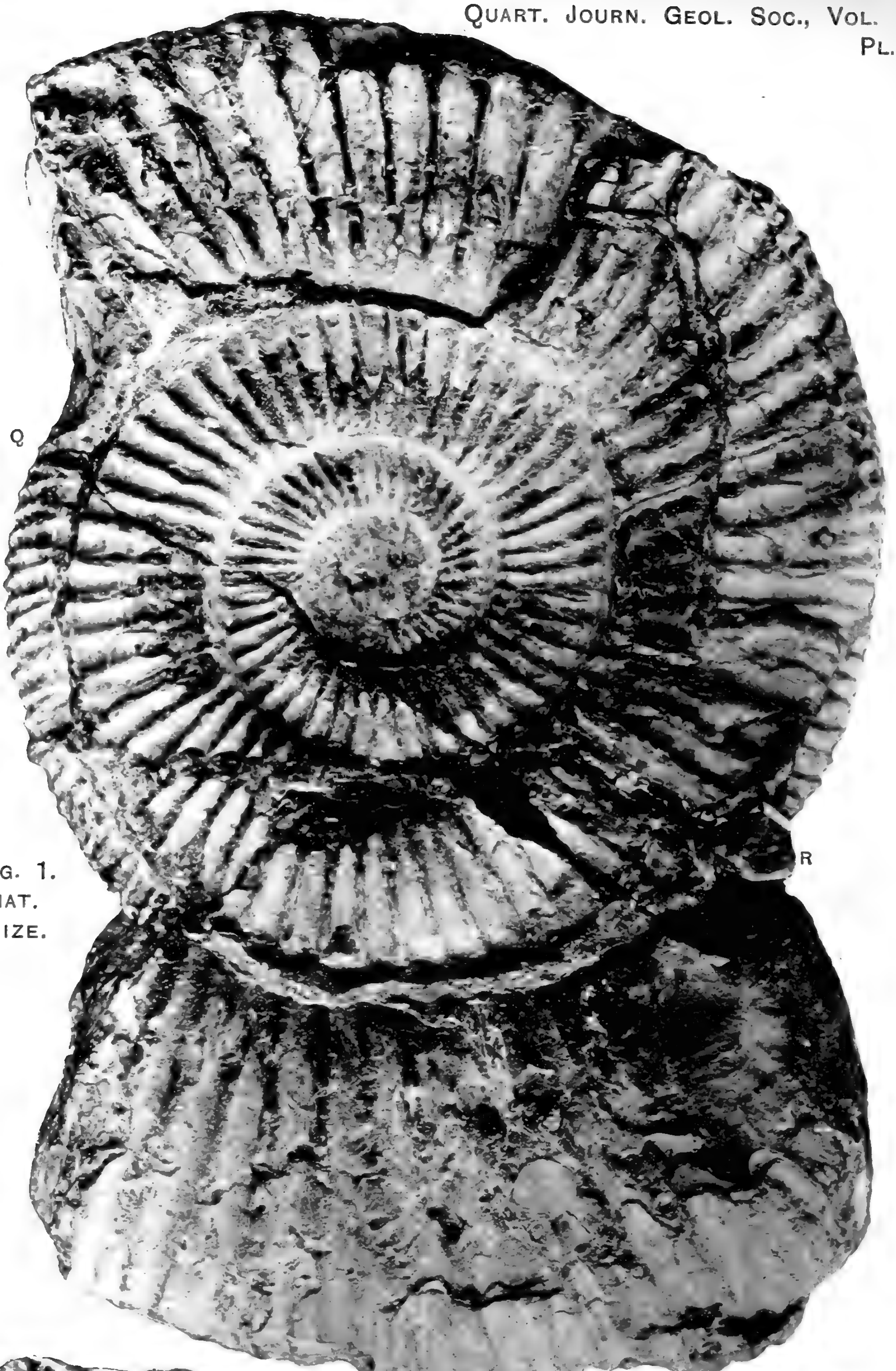
Fig. 2. nat. size.



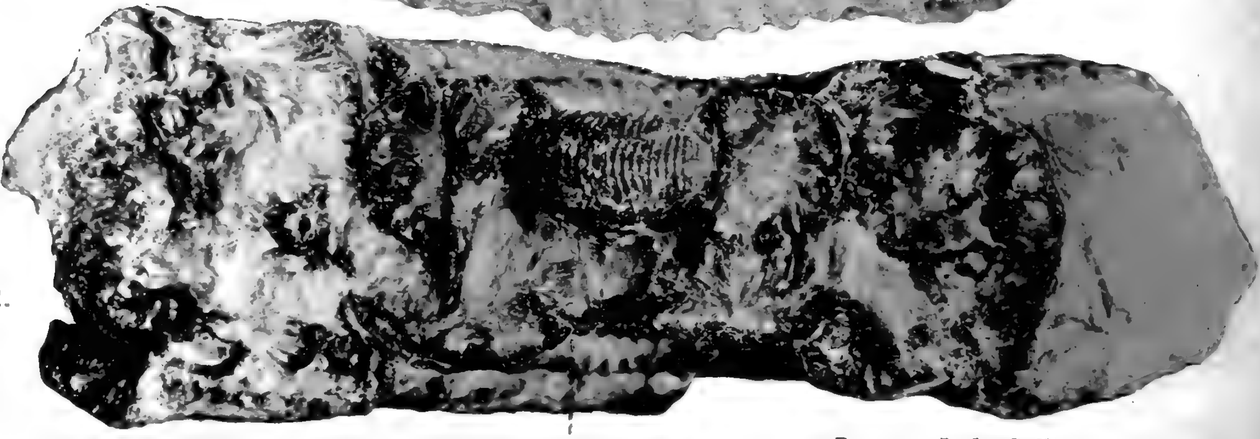
*Bemrose Ltd., Collo.*

Perisphinctes plicatilis (Sow.).

FIG. 1.
NAT.
SIZE.




2.
.
E.




*Bemrose Ltd., Collo.*

PERISPHINCTES BIPLEX (SOW.).

## 6. *The* Age *of the* principal Lake-Basins *between the* Jura *and the* Alps. By C. 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 April 29th, 1903.)

[Abstract.]

1. In a paper read before the Society in 1902,[1] the Author showed, on the evidence of extensive high-level deposits of Deckenschotter in Subalpine France and Switzerland, that the principal Swiss lake-basins could not have existed at the time when those deposits were formed, during and after the first or Pliocene glaciation of the Alps. In the present paper he deals with the question reserved in the preceding one, that is, to which subsequent period the formation of those lake-basins should be assigned. By the light of further recent investigations in the different localities, he first considers the conditions of the Zurich lake-valley, where the successive glacial and fluviatile deposits are clearly defined, and then applies his conclusions to the other principal lake-basins lying in the same zone along the edge of the Alps.

2. The hitherto generally-accepted view that the lake-basins are pre-Glacial in the old sense, or were formed during the first inter-Glacial period, rests, in the main, on two arguments: (1) that the alluvia at the lower ends of the lakes are all Glacial, not only from their appearance, but because the materials composing them could only have been transported thence by glaciers, which either passed over the lakes by bridging them, or through them by completely filling them with ice; and (2) that the zonal bending of the Molasse along the edge of the Alps, to which the lake-basins owe their existence, occurred before the second or maximum glaciation, because on the hills flanking the Lake of Zurich the younger moraine-banks are undisturbed: and, further, because at a point in the Lorze ravine (near the Lake of Zug) the Deckenschotter conglomerate dips reversely, that is, up the valley, while the overlying, younger, loose gravel dips in the opposite direction.

3. The Author adduces evidence to show that the deep-level gravel-beds in the Limmat Valley near and below Zurich are essentially fluviatile, composed of the characteristic Alpine material of the Rhine and Linth drainage-areas, and in all other respects similar to the gravel carried by the River Sihl at the present day. These gravel-beds rest upon Glacial clay of the second glaciation, which fills the Molasse-bed of the valley to a great depth, and are overlain by the moraine-bars and secondary products of the third glaciation, the latter being overlain by, and mixed with, the post-Glacial alluvia of the Sihl.

4. He further argues that it is, on mechanical grounds, difficult

[1] Quart. Journ. Geol. Soc. vol. lviii (1902) p. 450.

to conceive how glaciers could either bridge, or completely fill with ice, basins so extensive as those of the principal Alpine lakes, from 2 to 8 miles in width and from 470 to 1020 feet in depth, the quantity of water to be displaced and expelled in the individual cases ranging from 3500 million to 90,000 million cubic metres or tons.

5. As regards the more recently-advanced argument of the younger moraine-banks flanking the Lake of Zurich and of the Deckenschotter in the Lorze Valley near Zug, the Author points out that it is not borne out by the evidence on the ground, and that, apart from the difficulty of differentiating the second and third glaciation-materials in both localities, it is obviously hazardous to deduce from purely-local phenomena of this kind the date of the zonal bending affecting six valley-systems, and extending over more than 200 miles along the edge of the Alps.

6. The Author's investigations point to the conclusion that the deep-level Limmat gravel-beds, overlain by the moraine-bars of the third glaciation, were deposited by a river during the second inter-Glacial period; that the lowering of the valley-floor was initiated in the course of the third glaciation, probably when the glacier had already reached its maximum extension, about 10 miles below Zurich; that the zonal subsidence continued throughout the retreat of the ice; and that the simultaneous formation of the lake-basin should, therefore, be assigned to the end of the Glacial Period, after which the original basin was, notably at its upper end, restricted to its present dimensions by post-Glacial alluvia.

7. In conclusion, the Author shows that the same arguments apply, in the main, also to the origin and age of the other principal zonal lake-basins, which he illustrates by longitudinal sections. In his view, the position and depth of these basins, as well as the intervening ground, point to the probability that the bending took place not only along one line, but along several, more or less parallel, not always continuous lines within the zone between the Alps and the Jura; that the bending was by no means of uniform depth; and that, therefore, the Alps did not subside as a rigid mass, but that the zonal bending along their edge merely extended locally for some distance from the deepest points of the lake-basins along the floors of the principal Alpine river-valleys.

## Discussion.

Prof. Bonney said that he had always felt great difficulty in understanding how the glaciers made their way through the lake-basins, supposing these to have been in existence at the time of the great glaciation. But what had most impressed him was the fact that the Zurich gravels were true river-gravels, and quite different from deposits formed in proximity to a glacier. Of this difference he gave details, pointing out that a stone must travel not a few miles (much longer than the distance determined experimentally by Daubrée) in order to become well rounded. So that neither the

Deckenschotter nor the Zurich gravels (and the same was true elsewhere) could have been formed in the neighbourhood of a glacier. He had always attributed the Alpine lakes to zonal bending, and had long thought that there were at least two lines on the north side; but he was inclined to believe that there might have been slight subsidence along the watershed of the Alps, as the higher parts of the Alpine Rhine and Rhône valleys seemed now to be filling up.

Prof. Garwood, in reply to a question asked by the Author, stated that he did not think that the Fairhaven glaciers in Spitsbergen, quoted by Martins, affected the point at issue: the observation probably referred to an overhanging advance of the upper layers of the ice, so common in that district; and he could hardly believe that any of the Swiss geologists seriously suggested that a glacier could traverse a large lake-basin in the manner indicated by the Author, by clinging merely by its borders, and pass through unsupported in the middle. He was interested to hear that the Author attributed the formation of these large Swiss lakes to a time posterior to the maximum glaciation of the Alps, on the strength of the fluviatile character of the deposits described from their lower end; but, what he would specially like to know, was the age of the valleys in which the lakes occurred. A similar problem of the origin of the Italian lakes had occupied his attention for some years, and he did not think that a local subsidence could alone account for these lakes on the south side of the Alps. The Lake of Como was an especially difficult problem, as it not only ran at right angles both to the axis of the Alps and the strike of the limestones, but also exhibited a reversed drainage of a very peculiar character. Why did the drainage flow from Como to Lecco? What river or glacier-system could be pointed to at the present day, which, after flowing as a trunk-stream, divided into two deep branches, as must have been the case if the present drainage of the Lake of Como represented the original direction of flow of the valleys? It had often occurred to him that the rivers might once have flowed northward, and not southward. It was a curious fact that so many of the lake-branches came in from the south; and Lugano, which is 100 feet higher than Como, might very easily have entered as a tributary of the latter lake at Menaggio. The difficulty in the way was the range of the Splügen Alps. Mr. Marr had once suggested that this uplift might have taken place since the formation of the old valley-systems now occupied by the lakes: this would throw back the date of these valleys to Miocene times. He had collected for some time from the deposits of the Righi district with this idea in his mind, but without any definite result. The more, however, that he saw of the district, the more was he convinced of the great age of the valleys, and the probability of the reversal of the original direction of their drainage. He thought that the many areas of special subsidence required by the Author for all the Swiss lakes would require some definite proof in each case. He was glad to find that the Author did not include direct glacial erosion among the possible modes of origin for the lakes; although it must be remembered that quite recently an eminent American geologist had stated his conviction that the Lago Maggiore was entirely due to excavation by the Ticino Glacier during the Glacial Period.

The Rev. E. Hill said that he could not follow the Author's argument against ice-filled basins, but agreed with his conclusions. The gravels below the lakes were the proofs. A lake was a barrier to gravel-transport more effectual than a strait to quadrupeds; and in a time of ice-filled basins the precipitation, chiefly in snow, would be unfavourable to pebble-manufacture. He asked whether there were traces of submerged channels in the lakes. Such would be almost conclusive in favour of the Author's views.

Dr. J. W. Evans asked whether the Author considered that the sites of the lakes were still actually covered with ice when the depression occurred which caused their formation; and suggested that the cessation of river-action—as a result of great cold or deficiency in rainfall—was a necessary condition of the origination of lakes by earth-movements, except when such movements were unusually rapid.

Mr. Whitaker enquired whether any further proofs were available, beyond those adduced by the Author, in regard to the fluviatile origin of the gravels. He pointed out that, in many British river-gravels, remains of terrestrial or freshwater organisms were occasionally found; and, if such could be obtained from the Swiss gravels, the discovery would strengthen the Author's argument.

Dr. Jack asked whether the gravels in the lower portions of the lakes, which had been referred to as fluviatile, might not be re-arranged gravel from cones of dejection brought down by lateral streams, subsequently to the erosion of the lakes. He confessed that he was much surprised to hear the Author (as he understood him) deny the former greater extension of the lakes. Every lake that he had ever seen was obviously and visibly shrinking, and it was only a question of time when every lake on earth would be silted up. He admitted that lakes formed 'cataclysmically' are comparatively rare, but not unknown, even in modern times: for example, he had seen a good many lakes which were formed in the Tarawera district of New Zealand, during the eruption of a few years ago. One occupied the site of the famous 'pink and white terraces.'

The Author, in thanking the Fellows for the kind reception accorded to his paper, observed, in reply, that Prof. Bonney had examined the Limmat gravel-beds with him in 1896, and had ever since taken a kind and keen interest in the subject, and that consequently his concurrence in the conclusions arrived at in the paper was of great value, both as to the age of the lakes and the system of flexures which produced them. Prof. Garwood's interesting and welcome explanation of a Spitsbergen glacier bridging the sea (quoted by Martins in 1845) reduced that phenomenon to its true proportions, namely to a probable simple overhang of the upper layers of the glacier. With regard to the Italian lakes, he (the Author), although knowing them well, had not yet examined them in detail, and therefore could not as yet express an opinion as to their age and origin, although there was a *prima-facie* presumption of these, too, being the result of a lowering of their former river-floors by flexures. In reply to Mr. Hill, he said that there were channels of considerable length and depth at the upper ends of the Lakes of Constance and Geneva. With regard to Dr. Evans's remarks, the lakes being formed during the retreat of the ice, it followed that the glaciers were probably still melting in the basins as these were forming by a lowering of the floors. In reply to Dr. Jack, he said that the only lateral torrent to which the deep-level Limmat gravel-beds could be due (if not to the main river) was the river Sihl, the alluvium of which was, however, entirely post-Glacial and superficial. He by no means denied the possibility of a former, greater extension, and, consequently, of higher levels of the lakes; but averred that direct evidence was necessary to prove it in individual cases, for an alluvial plain might also be formed by a meandering river. In answer to Mr. Whitaker's question, he said that the only fluviatile deposits of the Glacial Period in which, to his (the Author's) knowledge, fossils had been found, were those of the Upper Pliocene Deckenschotter, or alluvion ancienne, near Lyons; while the younger inter-Glacial gravel-alluvia contained few, if any; but that he had reason to believe that confirmatory evidence—if such were wanted—of the age of the deep-level Limmat gravel-beds (second inter-Glacial period) near Zurich would be found in a similar sequence of deposits in the Rhône Valley near Geneva, with which he proposed to deal on a future occasion.

# 7. Notes *on the* Garnet-bearing *and* Associated Rocks *of the* Borrowdale Volcanic Series.

By the late Edward Eaton Walker, B.A., B.Sc., Scholar of Trinity College, Cambridge, Geologist to the British East-Africa Protectorate. (Communicated by J. E. Marr, Esq., M.A., F.R.S., F.G.S. Read December 2nd, 1903.)[1]

[Plates XIII & XIV—Microscope-Sections.]

Table of Contents.



## I. The Intrusive Complex of Blea Crag, Langstrath.

During the past year I have spent the greater part of my vacations in the study of the garnet-bearing rocks associated with the Borrowdale Volcanic Series. Being unable to proceed further with this work, I venture to put forward the results of my observations, in the hope that they may be of use to those who continue the study of these rocks. I should like, at the outset, to say how greatly indebted I am to Mr. Marr for all the help that he has given me; he has not only placed at my disposal his own maps of the area and the details of his own observations, but has always been ready with encouragement and advice. My thanks are also due to Mr. Harker for the kind help and advice that he has given me during the progress of the work.

[1] [The manuscript of this paper was placed in my hands by Mr. Walker when he left for Africa early in 1902, the work having been largely done in 1901. I was requested to keep the MS. and not to communicate it to the Society, unless it was certain that the Author could not continue the work, for he had hoped, on his return to England, to prosecute his researches among these rocks, especially by completing the chemical analyses, which were only partially carried out. His sad death, occurring but a year after he went out, has deprived our science of a most promising student, of whom his friends expected great things, and I feel that the paper, which I now have the honour of communicating to the Society, furnishes no mean evidence of Walker's powers. Although the work is incomplete, it will certainly be of great value to those interested in Lake-District geology, and also to students of the remarkable and exceptional type of rock which is therein described.— J. E. M., *October 1903.*]

The Volcanic Series runs in a broad belt, 12 or 13 miles wide, across Cumberland and Westmorland. In order to become acquainted with the various features of the garnetiferous rocks, I have attempted to cover some 130 square miles of ground; and as the greater part of this area has only been visited once, I feel some diffidence in drawing any conclusions from so hurried a survey.

Perhaps the most interesting of these garnet-bearing rocks are those which occur as dykes and sills intrusive in the Volcanic Series. They are chiefly to be found in the central part of the district, in connection with the large intrusive masses of the Eskdale Granite and the Ennerdale Granophyre.

The most typical of these minor intrusions is to be seen in the Langstrath Valley (75° N.W.) at and around Blea Crag. Clifton Ward mapped this as a small laccolite: if such be the case, it is of very irregular form, for on the west side of the valley the branches often run at right angles to the strike of the surrounding rocks. Ward described the rock as a diabase with felsite-veins; there seems, however, to be an almost infinite variety of rock, from a very fine-grained black, through a coarse porphyritic dark-green rock, to one containing quartz and pink felspar.

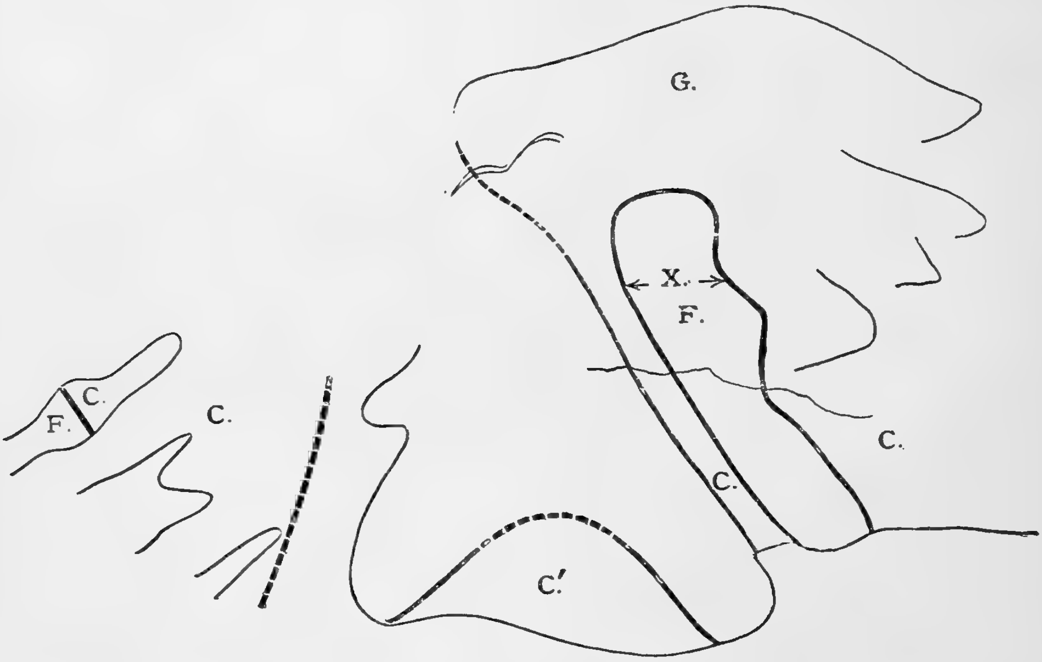
I made an attempt to put in the dividing-lines between these various types, but found that, except for small areas, this was impossible—the rocks varying in composition and texture every few yards, and shading gradually one into the other.

Some very good junctions are, however, seen in a small exposure north-north-west of Blea Crag, and separated from it by two small streams. This little section was visited by the members of the Geologists' Association in August 1900. The lines of the junction are here seen to be very sharp—the fine-grained black rock weathering with a smooth, and the coarse rock with a pitted surface. Where the broken lines occur in fig. 1 (p. 72) no distinct junction is seen, but the two types shade one into the other and give rise to a dark-green porphyritic rock. Near the junction of the two the coarse pink rock is found with greenish aggregates, representing, no doubt, portions of the fine-grained rock which have been absorbed and have become more crystalline in the process. It is possible to obtain a perfectly-gradual transition from the fine-grained black rock, through a dark-green to the coarse pink rock, in a single hand-specimen.

Good junctions are also seen below Blea Crag itself, where the fine-grained rock is plastered against the coarse, and is penetrated by veins of the latter. The junction may be followed up the southern face of the Crag, but it is lost above.

From these sections it is evident that the fine-grained rock was first intruded, followed by the more acid rock. The interval between the two periods of intrusion must have been short, for the two types have intermixed to form an intermediate one. We have here, then, a case of the intrusion of the basic and acid portions of an already-differentiated magma, and by the intermixture of the two extremes intermediate types have been produced. In the face of Blea Crag an intermediate rock is cut by a more acid rock—the junctions being well defined; so it is probable that there were successive periods of intrusion and intermixture. That differentiation went on almost simultaneously with intrusion, is well shown by a specimen obtained from the summit of Blea Crag, in which the black fine-grained rock encloses completely a portion of coarse pink rock, the latter being an acid segregation. Naturally, under these circumstances, xenoliths are exceedingly abundant and of great variety. Usually the xenolith is more basic than the enclosing mass, but the reverse also occurs.

Fig. 1.—*Diagrammatic sketch of an exposure north-north-west of Blea Crag, Langstrath.*




F = Fine-grained black rock.
C = Coarse pink rock.
C′= The same, with pink felspars.

G = Dark-green porphyritic rock, with greenish-white porphyritic felspars.
←X→ = $1\frac{1}{2}$ yards.

The dark fine-grained rock bears a very great resemblance to the dark-green fine ash into which these rocks are intruded; and, so far as it is possible to judge, Ward mapped this rock as an ash.

A section (3750)[1] across the specimen mentioned above shows that the pink rock is a granophyre. The structure is entirely a micropegmatitic intergrowth of quartz and orthoclase. Oblong sections of turbid felspar are seen to be continuous with the felspar of the intergrowth, but it is only these idiomorphic felspars that are altered to white mica. Sometimes they show signs of corrosion by the granophyric material. Garnet occurs in rounded sections, ilmenite and chlorite occurring at the border as products of its decomposition. Chlorite-scales are abundant throughout the

[1] The numbers in parentheses throughout this paper refer to the numbers on the slides which are in the Sedgwick Museum, Cambridge.

rock, frequently associated with a twinned muscovite. Pyrites is common, in square sections giving a reddish transmitted light, and is almost invariably surrounded by chlorite. Zircon occurs in minute crystals, with the pyramid-planes developed.

Very little can be made out of the fine-grained rock. Chlorite-flakes are scattered throughout; quartz, a few minute felspars entirely altered to white mica, and aggregates of iron-ore also occur in it. When this rock is taken up by the coarse rock of the small exposure, it becomes dark-green and much more crystalline. A section across the two (3795) shows that the coarse rock is a basic granophyre, containing turbid phenocrysts of plagioclase in a micropegmatitic groundmass. Colourless fragments of augite-crystals occur, surrounded by a mixture of chlorite and calcite produced from their decomposition. Apatite is fairly abundant. The dark-green rock might be described as a quartz-diabase. The same turbid felspar occurs sparingly as phenocrysts in a matrix of plagioclase, quartz, and chlorite. Sometimes the chlorite-patches enclose the felspar in ophitic relation. Iron-ore is more abundant than in the coarser rock, but apatite less so.

Turning to the intermediate porphyritic types, we find that the most basic (3752) contains quartz and felspar-phenocrysts, with garnet and pyrites. The last-named mineral is very abundant, and occurs in small cubes, surrounded by a zone of quartz which may consist of radial flakes or of little grains. Garnet occurs in rounded sections, much corroded and surrounded by a ring of plagioclase. Pseudomorphs of chlorite and epidote after original biotite are common. The epidote is usually developed in grains along the cleavage. The groundmass consists of felspar-laths, quartz, and pyrites.

The next type (3751: Pl. XIII, fig. 1) contains phenocrysts of a felspar, probably an acid labradorite, enclosed by flakes of biotite. Xenoliths consisting of altered felspar, hornblende, and ilmenite occur, closely resembling the hornblende-porphyrite to be described later. Large blebs of quartz are seen, much corroded, and consequently surrounded by an aureole of a lighter colour than the rest of the groundmass. A slide of this rock shows beautifully the felspar-ring developed round a garnet. The garnet is much corroded, and biotite occurs in the embayments; the whole garnet is surrounded by plagioclase, with many prisms of apatite. Biotite is often entirely decomposed to chlorite and iron-ore, lenticles of calcite being developed occasionally along the cleavage.

Slide 3776 differs from the last-described in the greater proportion of felspar-phenocrysts, of quartz in the groundmass, and the smaller quantity of iron-ore. The felspars show albite and pericline-twinning, with occasional well-marked zonary banding. Extinction-angles point to andesine or oligoclase-andesine. Paragonite-mica and possibly free quartz result from them; and in many cases the crystals are completely transformed into these products, acquiring at the same time a reddish tinge, which gives them the appearance of a pink orthoclase when the rock is viewed in bulk. Biotite embraces, or has a parallel arrangement with, the felspars, and decomposes to chlorite and epidote. Apatite is most abundant in this rock.

In the last three types the groundmass becomes gradually coarser, and a gradual passage is traced from a quartz-garnet-porphyrite with pyrites into a true granophyre. The felspar, becoming more and more abundant, finally develops into irregular masses and takes part in the micropegmatitic intergrowth. Slide 3863 furnishes an example of such a granophyre, containing aggregates of chlorite-flakes which represent original augite.

The most acid rock is seen on the precipitous face of Blea Crag, and is also developed along the bed of Langstrath Beck, south of the Stake Pass. It was mapped by Clifton Ward as an acid dyke, and is undoubtedly connected with the Blea-Crag intrusive rocks, for, like them, it shows perfect transition from fine-grained basic to coarse acid rock. Under the microscope (3787 : Pl. XIII, fig. 2) it is seen to have a very characteristic appearance. The felspar is orthoclase, occurring either in idiomorphic oblong crystals, or in irregular masses. It is invariably surrounded by a microspherulitic growth of quartz and felspar. Quartz occurs in irregular blebs, occupying the interspaces between the spherulitic growths—chlorite nearly always accompanying it. In parallel arrangement with the quartz- and felspar-fibres of the intergrowth, occur elongated flakes of chlorite representing original biotite. Garnet is present in rounded crystals much broken and corroded, and surrounded by the spherulitic growth. We have here an association which points to the early consolidation of the garnet from the molten mass. Apatite occurs sparingly.

This rock varies somewhat in the relative proportions of the constituent minerals; but, as a type, it is perhaps the most acid rock met with in any great bulk. Xenoliths of more acid rocks do occur. In Bull Crags a fragment of micropegmatite (3862) was found containing quartz, orthoclase, plagioclase, and chlorite. The same rock is to be seen in place as a dyke in Angle-Tarn Gill, immediately above the little ravine.

A dark-green basic rock (3861), with abundant ferromagnesian mineral, was found above Bull Crags. The ferromagnesian mineral is hornblende, showing strong pleochroism, the colours being

$$\underset{\mathfrak{c}}{\text{brownish-green,}} > \underset{\mathfrak{b}}{\text{brownish-green,}} > \underset{\mathfrak{a}}{\text{yellow}}$$

The felspars are altered to white mica. Oval patches of quartz with a nucleus of calcite may represent original vesicles. This rock is a good hornblende-porphyrite.

A xenolith from the west side of Langstrath Beck (3866) shows idiomorphic felspars with albite and Carlsbad twinning, and possibly a microperthitic intergrowth. Small prisms of uralite, with multiple twinning parallel to the orthopinacoid, occur with the same felspar in the groundmass. Epidote is abundant, partly arising from infiltration and partly from decomposition of original minerals. This rock bears a strong resemblance to those found at Burtness Combe, Buttermere.

Perhaps enough has been said to give some idea of the petrological character of these rocks. Their chemical relationships are not less interesting. I have made partial analyses of four prominent types, and these are sufficient to show how closely allied the rocks are one to the other. These analyses were carried out in the laboratory attached to the Mineralogical Museum, where, by the kindness of Prof. Lewis and Dr. Hutchinson, every facility was afforded to me for the work.

| | A. | B. | C. | D. |
|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. |
| $SiO_2$ | 57·91 | 60·02 | 61·63 | 64·40 |
| $TiO_2$, $Al_2O_3$, $Fe_2O_3$ | 27·56 | 25·36 | 22·34 | 22·39 |
| MnO | 0·32 | 0·29 | 0·22 | 0·14 |
| CaO | 6·19 | 3·97 | 4·40 | 2·27 |
| MgO | 1·20 | 0·91 | 0·98 | 0·60 |
| $K_2O$ | 1·82 | 2·55 | 4·04 | 5·79 |
| $Na_2O$ | 1·64 | 2·62 | 2·51 | 2·51 |
| Specific gravity | 2·856 at 13·8° C. | — | 2·748 at 13·4°. | 2·722 at 16·1°. |

A = Fine-grained black rock of Blea-Crag summit. Slide 3750.
B = Quartz-garnet-mica-porphyrite in stream above Blea Crag. Slide 3751.
C = Quartz-garnet-mica-porphyrite in stream above Blea Crag. Slide 3776.
D = Granophyre from Langstrath Beck, south of the Stake Pass. Slide 3787.

A specimen of A taken close to the acid segregation gave 60·51 per cent. of silica; and a dark-green porphyritic rock with pinkish-white felspars, intermediate between B and C, yielded 60·49 per cent. of silica.

A very important feature brought out by these analyses is the low percentage of magnesia in all of them. The higher percentage of lime in C (as compared with B) is easily explained, when sections of the two rocks are examined. The former contains a large amount of calcite which has, to a great extent, been introduced by infiltration. In rocks that have undergone such great alteration, it is scarcely to be expected that chemical analysis will bring out that gradation which is so well shown in the field. With regard to the alkalies, the preponderance of potash over soda is hardly to be looked for, seeing that orthoclase is not found in large crystals in the intermediate rocks. It is doubtless well represented in the groundmass. The low percentage of alkalies in the dark fine-grained rock A is remarkable, and may be explained as the result of differentiation. A section shows concentration of iron-ore. The high percentage of silica may be due to infiltration.

All these rocks are plentifully veined with quartz and chlorite, or quartz and epidote. A yellow fine-grained rock is often met with, cutting through rocks of every kind. A section shows this to be an epidosite, or aggregate of quartz and epidote-grains. These veins are found very commonly along slickensided surfaces, and often give rise to considerable alteration in the adjacent rock, which becomes lighter in colour, a result due no doubt to the infiltration of quartz and epidote. It seems fairly certain that water containing substances in solution and at a high temperature percolated through these rocks along lines of weakness.

Occasionally the weathered surface of these rocks shows a series of parallel 'streaky' lines: these are seen to be due to the infiltration of epidote, etc. along minute planes. One specimen which I obtained showed a slickensided surface roughly parallel to the weathered surface of the rock; inclined to both occurred a number of fault-planes, rendered conspicuous by infiltrated epidote. We have in this hand-specimen a type of structure which illustrates exceedingly well the structure of the whole of the Lake District. The slickensided surface represents the great thrust-plane, the 'streaky' lines the traces of the lag-faults inclined to the thrust-plane. This specimen is in Mr. Marr's possession.

Again, a reticulated pattern of crossing lines producing rhombic areas may be seen on the rock-face below Bull Crag. The xenoliths which occur in the rock have their length along the diagonals. This structure has been produced by movement along two planes almost at right angles one to the other.

The dykes of the intrusive mass seen south of Sergeant's Crag are continued (according to Ward) on the east side of the Greenup Valley, and extend for some distance over Ullscarf towards Thirlmere. It is very probable that the dykes mapped in the neighbourhood of Harrop Tarn are closely associated with the Blea-Crag rocks. Numerous basic dykes are mapped near the junction of Angle-Tarn and Allencrags Gills, at the head of the Langstrath. These bear a very strong resemblance to the more basic Blea-Crag rocks, and need no further description. Farther south, a large felsite-dyke is mapped on the Tongue between the two gills. This comprises rocks varying from a dark-green, basic, rather fine-grained type, through coarser rocks of a lighter colour, to a pinkish granophyre, each of which has its representative among the Blea-Crag rocks.

## II. Intrusions in the Bow-Fell District.

Numerous basic dykes are mapped on the ground north of Bow Fell. One of these runs north-north-west and south-south-east for some distance, and shows interesting variations of rock. All types are represented, from a dark-green fine-grained rock, with garnets and a porphyritic ferromagnesian mineral, to a coarse rock with garnets and pink-white felspars (3849–3853). The ferromagnesian mineral is augite in colourless crystals, showing lamellar twinning parallel to 100. The angle between the twinning-line and the cleavage varies from 26° to 43°. The felspar is an oligoclase-andesine with edges obscured by dirty matter, and often replaced by chlorite and epidote. Quartz occurs in irregular blebs, frequently bordered by a ring of minute augite-crystals; pyrites is often associated with the quartz, and encloses the augite-crystals. A striking feature of the rocks of this dyke is the abundance of oval masses of infiltrated quartz with a kernel of calcite. On account of this occurrence, a chemical comparison of the different types would be futile. In the coarser rocks, oligoclase occurs in long laths in the groundmass; the augite is altered to epidote and chlorite.

A large intrusion seen near Buscoe Sike, south of Bow Fell, shows the same gradation of rocks as the dyke, and no doubt the two are connected. One of the most basic types (85) is a true porphyrite with phenocrysts of andesine, or an acid labradorite showing beautiful zonary banding, Carlsbad and albite-twinning. Garnet occurs, surrounded by a ring of felspar-crystals of the same species: iron-ore is separating out from the garnet, and apatite is also produced. The augite is represented by a greenish product, plentifully charged with grains of iron-ore. The groundmass is composed chiefly of plagioclase-laths with iron-ore grains.

Closely connected with the Bow-Fell dyke just described, is a mass of breccia occupying a considerable area west and north-west of Ore Gap. It contains fragments from 1 to 2 feet in diameter. When examined carefully, these fragments are found to be exactly similar to the varieties of the dyke-rock first mentioned. In addition to these, fragments of 'streaky' lavas and ashes are also included; and it is from this breccia that the best example of a 'streaky' lava was obtained. Another curious feature of this breccia is the abundance of quartz-blebs. Under the microscope (3768) lapilli of an andesitic rock are extremely abundant, the lath-shaped felspars of which occasionally show a kind of flow-structure. Fragments of the above mentioned dyke-rocks can be recognized, containing the ferromagnesian mineral (altered to epidote) and brownish pleochroic chlorite. Rounded crystals of quartz with their corrosion-borders preserved are abundant, and these are probably derived from the north-north-westerly and south-south-easterly dyke. Garnet-fragments, and portions of the same mineral with well-developed faces, are not uncommon.

Since the dyke from which the breccia-fragments are presumably derived is later than the surrounding rock, a question arises as to the age of the breccia. So far as could be gathered from a hurried traverse, the breccia-mass has its greatest length in a northerly-and-southerly direction, parallel to the iron-lode and fault of Ore Gap: consequently, it would be reasonable to suppose that the breccia originated through crushing. There are, however, none of the usual indications of crush-brecciation, and the mass seems to differ in no way from an ordinary explosion-breccia. Crush-brecciation would, moreover, hardly account for the fragments of 'streaky' lava.

A detailed mapping of the breccia, and a further study of the behaviour of the few dykes that approach its margin, are necessary before any theory of a volcanic vent can be brought forward. The dykes which run east and west across the Hanging-Knotts–Bow-Fell watershed bear a marked resemblance, in the hand-specimens, to those found on the summit of Lingmell. One variety might be described as being intermediate between an augite-porphyrite and a granophyre—the augite occurring in aggregates largely altered to chlorite; uralite is probably an intermediate product of decomposition. A similar rock runs down the face of Hanging Knotts to Angle Tarn.

A dyke running north and south along the line of Yeastyrigg Crags has a central zone of bluish quartz-porphyry, the margins being occupied by a dark-green garnet-rock. This dyke gives off an east-and-west branch which runs down to Yeastyrigg Gill. This also is a quartz-porphyry, passing at its edges into a flinty felsitic rock very hard to distinguish from the surrounding ash.

Passing on to the two small tributaries of the Esk which run down from Esk Hause, we find, about 200 yards down on the west side of the eastern tributary, one of the most interesting dykes of the district. This dyke was not mapped by Ward: it runs almost due east and west, across the Knotts of the Tongue.

A prominent buttress of coarsely-pitted rock stands out from the surrounding rock. It varies in thickness from 2 to 3 yards, and is bordered by a fine-grained, dark-green rock, with a smoother weathered surface. In the coarse rock are usually to be seen rounded masses, often 1 foot or more in diameter, weathering with a pinkish colour: a fractured surface shows needles of a green mineral in a pinkish felspar. Similar enclosed fragments also occur in the fine-grained marginal rock. These included fragments are composed of hornblende-porphyry (3758). The hornblende is in the form of long actinolite-needles, giving coffin-shaped basal sections; the mineral is strongly pleochroic. Decomposition yields chloritic iron-ore, with occasional epidote. The pink-white felspar shows a pretty microperthitic intergrowth, together with albite-lamellation and Carlsbad twinning, and is therefore microperthite. The groundmass is a granophyric intergrowth of quartz and the same felspar. Apatite is very abundant, in long needles with characteristic cross-fracture.

The coarse rock (3771) has augite in addition to hornblende; the two occurring in about equal proportions. The colourless augite changes to uralite, the fibres of which show twinning relations to one another with 100 as twin-plane. An orthoclase may be present among the turbid felspar, for in one or two crystals the turbidity is confined to irregular patches, the rest of the crystal being comparatively clear. Quartz occurs in rounded crystals with a dirty outgrowth. Epidote, calcite, and chlorite are abundant.

The fine-grained marginal rock contains augite almost to the exclusion of hornblende, and plagioclase much altered to white mica. The rock is a quartz-augite-porphyrite. The concentration of augite in the marginal portions of the dyke is interesting.

This dyke can be traced eastward towards the other tributary of the Esk. The coarse rock dies out, and the rounded inclusions become more rare until, when the western tributary is reached, only the fine-grained rock remains, and it shows banding parallel to the containing walls.

Close to the western tributary and just below the path to Scawfell Pike, a dyke 15 to 20 yards wide occurs: it is of a dark colour, contrasting strongly with the white of the flinty ash into which it is intrusive. Fragments of ash and basic xenoliths weathering light-brown are not uncommon. There are, as usual, fine-grained and coarse varieties, but all may be classed under the head of quartz-porphyrites containing pinkish oligoclase-andesine and altered ferromagnesian mineral. One section (3831) shows a garnet with a margin almost entire and the faces well developed. On one side corrosion has taken place, and here the felspar-crystals are grouped round the garnet, together with apatite and a ferromagnesian mineral altered to chlorite, and epidote and iron-ore. The occurrence of the felspar only on that side of the garnet at which corrosion has taken place, seems to prove that the garnet has contributed some constituent to the formation of the felspar, and not that the garnet has simply acted as a convenient nucleus for the growth of felspar-crystals. Ward continued this dyke in a northerly-and-southerly direction to the junction of the two tributaries, where a similar rock occurs. To connect the two together in a district where dykes are so numerous, is perhaps somewhat speculative.

## III. Basic Offshoots from the Eskdale Granite.

In the Blea-Crag dykes every type of rock, from a basic porphyrite to an acid granophyre, was found. I therefore wished to see whether the Eskdale Granite-dykes yielded the same varieties of rock. A large number of dykes are given off from the granite of Wastdale Head, and may be well seen on the slopes of Great End and Scawfell Pike to Lingmell Beck. Dropping down from the Sty-Head watershed, excellent examples of rock bearing the greatest resemblance to Blea-Crag rocks may be seen in Spouthead Gill.

Going up the grassy tongue between Piers and Girla Gills, a very typical dyke is met with 200 feet below Criscliffe Knotts. The most basic rock is a fine-grained diabase, represented in places by a greenish rock containing quartz, chlorite, epidote, and phenocrysts of indeterminable felspar.

The next type is a basic mica-porphyrite, with either andesine or an acid labradorite, mica, and uralite. The section (3855) is taken across the junction of the rock with the flinty ash. Movement has taken place between the two, with the result that the plagioclases are broken up into small fragments.

The next in order is a coarse purplish rock, with greenish-white felspar (3856). It is a quartz-porphyrite with altered andesine, mica-flakes, and rare hornblende-crystals. The felspar is altered to epidote and white mica. The groundmass consists of felspar-laths, biotite-flakes, iron-ore, and quartz. The felspar and biotite may sometimes be seen in ophitic relation, giving to the groundmass the appearance of a quartz-diabase. Aggregates of uralite occur, in addition to hornblende, and these seem to show a change into biotite. Biotite-flakes are developed at the margin of these aggregates, and the pleochroic colours of the mica may be seen in scattered areas within the mass of uralite-fibres.

The next type (3857) is a similar rock, but the felspars are of a pinkish colour. Microscopically, it differs only in the fact that quartz is most abundant, and the groundmass becomes more granophyric in character. Aggregates of mica-flakes occur instead of the uralite, and this probably indicates complete transformation of uralite into biotite. There is a good deal of evidence for this change; but occasionally the appearance of the section suggests the opposite conclusion, that is, the conversion of biotite into uralite. Apatite is abundant in this last type, and is usually concentrated in the more acid porphyrites. Garnet also is present in rounded crystals. Corrosion has occurred, with the production of brown mica in minute flakes (3833); plagioclase-laths are set at right angles to the surface of the garnet, and give the appearance of a spherulitic growth round the garnet. Apatite also occurs, and again seems to be a product of corrosion. Biotite and plagioclase too have been formed within the garnet.

The most acid rock, and that which occupies the centre of the dyke, is a pinkish granophyre. Idiomorphic felspars, either albite or oligoclase-andesine with albite, Carlsbad, and Baveno-twinning, occur in a confused intergrowth of quartz and felspar. Rounded quartz-grains are set in the centre of rudely-spherulitic growths. Chlorite with strings of epidote developed along the cleavage represents original mica.

The silica-percentages of these rocks show an interesting gradation.

| | Silica-percentages. | Specific gravities. |
|---|---|---|
| Diabase | 47·76 | 2·872 at 15·5° C. |
| Mica-porphyrite | 54·04 | 2·836 at 15·5° C. |
| Mica-porphyrite (3856) | 55·75 | 2·822 at 12·6° C. |
| Mica-porphyrite with granophyric groundmass (3857) | 62·38 | ——— |
| Granophyre (3858) | 68·66 | 2·753 at 12·1° C. |

The broad dykes which traverse Kirkfell, and are well seen in the gullies of Kirkfell Crags, are quartz-porphyries (3901) with a beautiful granophyric groundmass. They are of a purplish colour, due to aggregations of mica-flakes. The felspar is probably very close to oligoclase. Xenoliths of a basic mica-rock are also common (3898). A little to the west of Kirkfell summit a red quartz-porphyry occurs (3899), containing quartz and plagioclase, with phenocrysts of micropegmatite in a granular groundmass of quartz and orthoclase. Exactly the same features are exhibited by the Fence-Wood dyke on the opposite side of the valley.

The larger apophyses of the Wastdale-Head Granite occur in rounded patches on the summit of Lingmell, at Bursting Knott, and on each side of Piers Gill. The Lingmell rock is a good granophyre with crystals of uralite, derivative after augite. Large plagioclases occur as phenocrysts, in a micropegmatitic intergrowth of quartz and felspar. Basic xenoliths similar to those of the Kirkfell rocks are quite common.

The periphery of the Lingmell intrusion is occupied by a purple porphyrite. Making a good junction with this is a bluish-grey garnetiferous rock. This, at first, I took to be the extreme product of metamorphism of the surrounding ash, but a section (3923) shows the granophyric character of the rock. Similar grey garnetiferous rocks occur at the margin of the intrusive rock on the left bank of Piers Gill, and also at the margin of the Eskdale Granite south of Stony Tarn.

The Piers-Gill rock (3840) consists of quartz and felspar, the quartz being developed in irregular grains. Pyrites is abundant; the presence of this mineral—a typical product of contact-metamorphism—is suggestive. Tourmaline occurs in prisms with strong dichroism, and giving straight extinction parallel to their length. Garnet in rounded crystals is present, altered at the margin into white mica. Quartz-porphyries with tourmaline and garnet occur at the margin of the Eskdale Granite, undoubtedly intrusive into the surrounding ash, so the Piers-Gill rock may be of this type.

The main mass of the Eskdale Granite, of which that at Wastdale Head is a small portion, was next visited. The granite preserves its characteristic features quite close to its margin. The border itself is usually occupied by a granophyre- or quartz-porphyry. From the granite basic dykes are given off. These are exceedingly numerous, and can be well studied in the neighbourhood of Stony Tarn. They are easily distinguished by their dark colour, in contrast with the purplish tinge of the surrounding rock. The dykes run east and west, or west-north-west to east-south-east, and can be followed for considerable distances. One that occurs on the crags immediately south of Stony Tarn can be traced almost uninterruptedly from the granite-margin to the granite again, over a distance of half a mile or more. The rocks are typical diabases, containing long crystals of (3878) labradorite in ophitic relation with plates of uralite derivative of the augite. Kernels of augite are still found. Iron-ore in minute grains is also a product of the change. The uralite moreover undergoes decomposition into a serpentinous product, which pseudomorphs the plagioclases. Other varieties do not show any ophitic structure, the uralite occurring in roughly-idiomorphic crystals (3880).

When these dykes are traced to the granite, no intermediate rocks between the diabases and the quartz-porphyry are found. A great number of these basic dykes were mapped by Ward, and there are probably a greater number still unmapped. They occur on the Illgill side at the head of Wastwater, north of Slight Side, on the south-western slope of Lingmell, and in Lingmell Gill. On Yewbarrow a series of them are mapped, and there are many others besides, all of varying texture. To a large extent they determine the remarkable gullies on Yewbarrow summit—namely, Great Door and Little Door.

An excellent example of these uralite-diabases is to be seen about 80 yards north-north-west of Kirkfell Tarns (3907). Ophitic structure is well shown, slightly-purple augite occurring in the centre of the uralite-plates. The uralite-fibres tend to change into biotite and serpentine at their margins, and minute biotite-flakes are also developed in the centres of the uralite-plates. This transformation of uralite into biotite has been noticed above in the case of the Criscliffe-Knotts dyke (p. 80). The fact that the change, however it may be produced, occurs in a typical diabase lends support to the conclusion that the intermediate mica-porphyrite rocks of Criscliffe Knotts have been produced by the intermixture of an acid granophyric rock with the basic diabases. That some sort of intermingling takes place is evident from the study of the Blea-Crag rocks, but there the rocks have been much altered and do not often show the original minerals. Alternative theories will be dealt with below.

This Kirkfell dyke contained a xenolith of what appeared to be a 'streaky' rock. A section (3844) of this xenolith shows a banded felsite, with abundant mica-flakes grouped in lines. Quartz-grains surrounded by a spherulitic growth of felspar are found, together with sheaf-like aggregates of felspar-fibres resembling variolitic structure. This felsite has its nearest analogue in the banded felsite of Burtness Combe, Buttermere (see p. 84).

It seems, then, as if all these basic dykes were given off from the Eskdale Granite. Grey quartz-porphyries are very typical marginal modifications of the Eskdale Granite. They are seen to be intrusive into purple ashes and Eycott Lavas south of Brockshaw Gill, the intrusive rock sending veins into the metamorphosed rock and producing a pretty mosaic. These veins become darker close to the metamorphosed rock, a certain amount of absorption taking place. The intrusive rock (3918) consists of a micropegmatitic growth of microperthite and quartz. Tourmaline and chlorite are found, the latter derivative after biotite. The former is but sparingly developed, usually in irregular crystals with bluish pleochroic colours. Microperthite is very common in these rocks, and shows beautiful intergrowths. Patches of felspar with albite-lamellation are scattered through a large mass of orthoclase. Occasionally the intergrowth gives an effect very similar to the cross-hatching of microcline. The orthoclase is usually the more turbid mineral (3879).

Another type of acid intrusive is seen in Slide 3919. It is a typical quartz-porphyry intrusive in banded ash. As the result of metamorphism, a light-green fibrous mineral with high polarization-tints has been developed in the altered ash, and is especially abundant at the junction. This mineral (which may be a fibrous hornblende) has been absorbed by the quartz-porphyry, and occurs throughout the slide.

Immediately south of Stony Tarn a darker grey rock forms a mosaic with, and seems to be intrusive into, the purple-banded ash. Sections of this rock (3841–3846) show a granular aggregate of quartz and felspar. Irregular patches of the green fibrous mineral, together with aggregates of strongly-pleochroic biotite-flakes, occur. Garnets are abundant: they show the same characters as the garnets found in the altered ash, being irregular in outline and of a very spongy nature, freely penetrated by quartz-grains. We have, then, in this rock, three minerals found in the metamorphosed ash; if this rock be intrusive, and there seems no reason to doubt it, a considerable amount of absorption of the metamorphosed ash must have taken place.

It has been noticed above that aggregates of uralite- and mica-flakes occur in the dyke-rocks of Criscliffe Knotts. That these minerals also occur as products of metamorphism is rather suggestive. Absorption certainly does take place, but it would perhaps be going too far to ascribe the formation of these intermediate rocks of the dykes to such a process of absorption by an acid rock. The presence of the same minerals in the altered rocks and in the dykes renders it a somewhat difficult task to distinguish between a purple dyke-rock and an altered Eycott Lava. Above the granite of Oliver Gill both dyke and altered rock may be seen, and it is almost impossible in the field to say where the dividing-line comes. Another example is seen north of Great How, on the extreme edge of the rock-exposure. Here a black rock occurs, apparently intrusive. Under the microscope large phenocrysts of plagioclase are observed, often very much broken and corroded, and penetrated by aggregates of biotite-flakes. Large mica-flakes also occur. Microscopically, the rock resembles a highly-altered Eycott Lava.

The Eskdale Granite itself rarely contains garnets. In a section of this rock a small fragment of garnet occurs associated with quartz and biotite. The quartz nearly envelops the garnet, and a large biotite-flake has been produced as the result of the action of the quartz on the garnet. Chlorite occurs as an alteration-product of the garnet (3927).

## IV. The Intrusive Complex of Burtness Combe, Buttermere.

Seeing that the Buttermere Granophyre comes into contact with the Eskdale Granite at the foot of Wastwater, the basic dykes on Yewbarrow might be supposed to come from the Buttermere rock. Accordingly I visited a basic intrusion mapped by Ward on the western flank of Burtness Combe, Buttermere. It forms a roughly-oval mass, and a contorted felsite-dyke is mapped as occurring below it. This may be so, but certainly a contorted felsite-dyke runs from the south-eastern corner of the intrusion right through it, and is continued on to the main granophyre-intrusion. This varies from a light-brown to a greyish, or more rarely pink, rock, and shows good banded structure.

The basic rock through which it passes was described by Ward as a quartzose diorite. It is, however, a good diabase containing long plagioclase-crystals (3889), rather turbid and quite unlike the clear labradorite that one is accustomed to see. The extinction-angles correspond rather with an oligoclase-andesine. The ferro-magnesian mineral is uralite, in greenish fibrous masses which show twinning with (100) as twin-plane, with strings of limonite running along the cleavage. Calcite is developed along the margins of the uralite, and in small patches within the mass. Further change results in the production of an almost colourless and isotropic chlorite. Ilmenite occurs in ragged crystals, with a peripheral growth of brownish sphene. Rods of ilmenite crossing at an angle of 60° are also found. In other sections (3892) augite is present as a kernel to the uralite, and the ilmenite has good crystal-outlines.

At the junction between the basic rock and the banded felsite considerable intermixture has taken place, with the production of an intermediate rock. This intermingling is well shown by the weathered surface of the rock at the junction, which has rather the appearance of a breccia. The intermediate rock is a quartz-diabase (3890). It has the same felspar as 3889, developed in oblong crystals with Carlsbad and pericline-twinning. The ground-mass is of quartz and the same felspar—the two occurring in micropegmatitic intergrowth.

The banded felsite (3893) shows spherulitic growths of felspar-fibres, either alone or with quartz. Chlorite-flakes representing original mica occur, and these separate off iron in the form of ferric oxide. Muscovite-flakes are diffused throughout the slide. This felsite is undoubtedly connected with a beautifully-spherulitic rock, which occurs just above the wall only a few yards from the Combe Beck. The spherulites have a core of reddish earthy matter, which is seen under the microscope to be the product of the decomposition of the chlorite-flakes that occur either as a central aggregate or in rings. The felsite was probably first intruded, and the diabase came up later.

To show that intermediate rocks have been produced at the junction, I made silica-percentages of these rocks; but unfortunately, owing to a mistake in the numbering of the slides returned to me, I tested only the extreme types:—

| | Silica-percentages. | Specific gravities. |
|---|---|---|
| Diabase (3889) | 50·12 | 2·830 at 18·3° C. |
| Diabase (3892) | 49·52 | 2·831 at 16·8° C. |
| Banded felsite (3893) | 72·46 | 2·683 at 20·3° C. |
| Banded felsite | 72·21 | ——— |

These diabases resemble very strongly the diabases of Stony Tarn (3880: see p. 81). It will be seen that, both macroscopically and microscopically, it will prove difficult, if not impossible, to say definitely whether a given dyke belongs to the Eskdale or to the Buttermere intrusion. From what I have seen of the two rocks, I have come to the conclusion that, if not of the same age, they have been produced from the same rock-magma. Both show rocks of intermediate character containing garnets; in the case of the

Buttermere rock I have not seen these garnet-bearing rocks *in situ*, but the numerous loose blocks in Burtness-Combe Gill afford sufficient testimony to their occurrence.

## V. Other Garnetiferous Intrusions in the Lake District.

Acid garnet-bearing dykes occur in all parts of the district. The dyke mapped at Fox Tarn on Scawfell is a good quartz-porphyry containing quartz, microperthite, plagioclase, chlorite after biotite, garnet, and apatite. The garnets are surrounded by quartz, but they are broken up and replaced by chlorite and epidote. The occurrence of this latter mineral points to a fair percentage of lime in the garnet. A very similar rock occurs low down in the stream and on the western flank of Rosthwaite Combe, and roughly at the same horizon in a small patch on Rosthwaite Fell. This is a greenish rock, with pink-white felspars and garnet. The latter mineral has usually one or two faces well developed, but is elsewhere embayed by quartz.

More basic garnetiferous rocks occur at Dock Tarn, Harrop Tarn, and along the Wythburn valley. Many of the rocks mapped as lavas by Ward in Wythburn and on Helvellyn are in all probability intrusive. The Dock-Tarn rock is found east-north-east of Stonethwaite Church, and runs from the valley to the top of the Great Crag; the path to the top of the hill follows its outcrop very closely. It may also occur on the lower slopes of Rosthwaite Fell. It was mapped as a lava, but Mr. Marr proved its intrusive nature from the metamorphism of the surrounding ash. It is a minor sill, intrusive into garnet-breccia and banded ash. The upper limit is well defined by the altered ash, but the lower limit is hard to make out, for it is somewhat difficult to distinguish between cleaved intrusive rock and the garnet-breccias. It may be described as a sill of garnetiferous andesite, with phenocrysts of plagioclase. The rock is in parts intensely cleaved, the felspars become broken up, and the garnets are altered to chlorite and white mica with separation of iron-ore. Flakes of chlorite and sericite are developed throughout the rock. The percentage of silica is 58·08.

Similar rocks are found at the base of the Eycott Lavas, immediately south of the stream issuing from Dock Tarn, where the same kind of metamorphism occurs; and also in the triangle formed by the roads at the western end of the Thirlmere dam. Here the metamorphosed ash only becomes white and porcellanized close to the junction, no new minerals being developed.

A quarter of a mile north-west of Harrop Tarn, Ward mapped a massive lava: this Mr. Marr considered to be intrusive. The microscopical characters of the rock bear out this supposition. It is a quartz-garnet porphyrite, with highly-altered plagioclase. Quartz occurs in rounded and corroded crystals, surrounded by a zone of lighter groundmass. Pseudomorphs of chlorite, epidote, and calcite after an original ferromagnesian mineral, apatite, and pyrites are plentiful. The rock in parts is highly vesicular—quartz, calcite, and chlorite filling the vesicles. The junction of the rock with banded ash may be seen in the streams flowing into Harrop Tarn, but the metamorphism is hardly appreciable.

The quartz-porphyrites of Helvellyn and Wythburn are of the same type. The silica-percentage of a quartz-porphyrite between Greenburn and Wythburn is given by Mr. W. M. Hutchings as 60·45, with a specific gravity of 2·74.

The Armboth Dyke also contains garnets. A slide (3788: Pl. XIII, fig. 3) through one of these garnets shows beautiful corrosion by quartz-crystals. The quartz has penetrated along definite planes, and has left projecting needles of garnet. It is very probable that the Armboth Dyke is closely related to the basic dykes near it. By a mistake in the wording of the Geological-Survey Memoir, an analysis of the St. John's quartz-felsite is ascribed to the Armboth Dyke. Mr. Harker[1] has shown that the analysis does not belong here, and the numbers tabulated below support this view:—

| | Per cent. |
|---|---|
| $SiO_2$ | 75·26 |
| $Al_2O_3$ | 12·85 |
| $Fe_2O_3$ | 0·17 |
| FeO | 1·36 |
| MnO | 0·22 |
| CaO | 0·83 |
| MgO | 0·04 |
| $K_2O$ | 5·01 |
| $Na_2O$ | 2·66 |
| $CO_2$ | 0·04 |
| $H_2O$ | 1·04 |
| Loss on ignition | (1·29) |
| | 99·48 |

Specific gravity = 2·648 at 16·4° C.

## VI. Garnetiferous Rocks in the Falcon-Crag Andesite-Group.

Having dealt with the intrusive garnet-bearing rocks of the district, it would be well to take the members of the Volcanic Series in order. The lower part of the group consists of:—

Banded Ashes and Breccias;
'Streaky' Rocks;
Eycott Lavas, and associated ashes and breccias;
Falcon-Crag Lavas and Ashes.

The Falcon-Crag Group consists of andesitic lavas and ashes, typically developed round Falcon Crag on the east side of Derwentwater. Ward described them in detail, and the only rocks with which we need deal are those that contain garnets. The lowest of these is Ward's 'No. 2 ash,' well seen at the base of the small scarp beneath Falcon Crag. The ash is overlain by 'No. 2 lava,' and is of no great thickness. Garnets are

[1] 'Chemical Notes on Lake-District Rocks' in the 'Naturalist' for 1899, p. 150.

sometimes very numerous; but they are usually of small size, and present a very fragmentary appearance in hand-specimens of the rock.

A section of this rock (3753: Pl. XIII, fig. 4) shows numerous fragments of andesitic lava, with small felspars and much ragged iron-ore. There may be one or two fragments of sedimentary rock derived from the Skiddaw-Slate Series. The garnets are obviously fragmentary, and are not found in the lapilli, but in the andesitic groundmass. They sometimes have a spongy character. Felspar-crystals are occasionally seen clinging to the margin of the garnet. As the result of infiltration, greenish and almost isotropic chlorite is found, together with needles of calcite, throughout the slide. The iron-ore enclosed by the chlorite is extensively converted into brown pleochroic sphene. Quartz occurs in oval fragments. An analysis gave a silica-percentage of 54·34.

Garnets probably occur in the higher members of the series. This mineral was found in a coarse ash close to 'lava No. 6' on Brown Knotts. Again, immediately to the south of Barrow-Beck Waterfall, a bright-green ash with garnets occurs at the base of the prominent scarp. The thick garnetiferous lava 'No. 10' occurs above it, and can be traced almost continuously from Barrow to High Seat.

This lava varies greatly in appearance—sometimes forming a greyish-green rock with many felspars, and not unlike the intrusive rock at Dock Tarn; at other times it is of a very dark green, and the felspars are less numerous. A section of the latter type shows phenocrysts of plagioclase, with Carlsbad and albite-twinning and good zonary banding (3755), in a very fine andesitic groundmass. Flakes of biotite highly charged with magnetite occur, and these undergo change into chlorite, calcite, and iron-ore. The iron-ore (ilmenite) gives rise to sphene peripherally. Garnet occurs abundantly (3782, 3829), and often shows the ring of felspar, with detached fragments of garnet lying in the centre of the plagioclase-crystal. The centre of the garnet is also frequently corroded, and occupied by felspar. Iron-ore is always separated. In other cases, the garnet simply undergoes a peripheral change to chlorite. Ward mentioned the occurrence of augite. Apatite is often seen. The rock is a typical andesite, and has a silica-percentage of 61·35.[1]

Ward mentioned a higher lava 'No. 12,' as containing garnets, and he gave an analysis of it, the percentage of silica being 59·511.[2]

Garnet-bearing ashes and breccias are very abundant on the hill-side behind the hotels at Rosthwaite. Highly-cleaved garnetiferous breccia occurs in Frith Wood, and an alternating series of garnet-lavas and breccias extends from Brund Fell southward to Dock Tarn. On Brund Fell itself a fine-grained greenish ash with good banding is seen; this is the common greenish ash of the district.

[1] Harker, 'Chemical Notes on Lake-District Rocks' in the 'Naturalist' for 1899, p. 57.

[2] Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 408.

Numerous small garnets may be observed in the ash, but unless specially looked for they would escape notice.

The Frith-Wood breccia is intensely cleaved, and the garnets show an interesting transformation. They are seen to consist of a collection of irregular fragments, surrounded by a colourless substance of indefinite outline. Between the fragments flakes of what appears to be a colourless mica are developed; chlorite-flakes are also present, and possibly quartz is set free along with rods and irregular masses of ilmenite or other iron-ore.

This peculiar change takes place in all cleaved garnet-bearing rocks: the garnet-fragments become smaller and finally disappear, leaving only a few grains of iron-ore and an indefinite sericite-like growth. Examples of this change are afforded by the cleaved intrusive rock of Dock Tarn previously described (p. 85), by a cleaved lava on the lower slopes of Rosthwaite Fell, and by the garnet-rock of Cockley Beck in the Wrynose Valley.

The cleaved garnet-lava of Rosthwaite Fell (3766) shows the change very well. The garnet-fragments lose their isotropic character at the margin, and yield high polarization-tints between crossed nicols. The refractive index, however, remains the same. There seems to be no intermediate stage between this and the production of the colourless mineral, which has a refractive index lower than that of the chlorite. Cleavage-lines are often well shown, but the flakes do not always give straight extinction, the angle of extinction being sometimes as great as 15° or 18°. The mineral is exceedingly like a colourless mica, but might be either talc or kaolin. If the mineral be a white mica, it seems almost impossible to discuss the change chemically. The greater part of the iron of the garnet is eliminated and the iron-ore set free, while the chlorite would account for the rest of the iron, the magnesium, and possibly the calcium; but it is difficult to account for the alkali necessary for the production of the colourless mica. There would be no great difficulty in accounting for the production of either talc or kaolin.

Garnetiferous lava and breccia are well developed on the small plateau around Dock Tarn. A lava of considerable thickness overlies the intrusive sill, and has a silica-percentage of 64·2.[1] The same rock occurs on the other side of the valley on the lower slopes of Rosthwaite Fell. Above it is found the garnet-breccia of Papelay Crag. A sill of considerable thickness is intrusive into this breccia, producing similar metamorphism to that of the Dock-Tarn intrusive rock. Intrusive junctions are to be seen in a field south-east of Stonethwaite Village, where some friend of the geologist had done some extensive blasting, and also on the east side of the valley close to a small peat-bog. Ward mapped this rock as a lava, and, to explain the intrusive junction last mentioned, brought in a thin basic dyke from an intrusive mass occurring close to the Watendlath path. This intrusive sill is closely connected with the intrusions round the old

[1] Harker, 'Chemical Notes on Lake-District Rocks' in the 'Naturalist' for 1899, p. 57.

Borrowdale graphite-mine, and resembles in texture an intrusive rock in Sourmilk-Gill Combe. It is not a garnet-bearing rock. It probably extends some distance eastward, for a very similar rock is met with at the same horizon on Watendlath Fell.

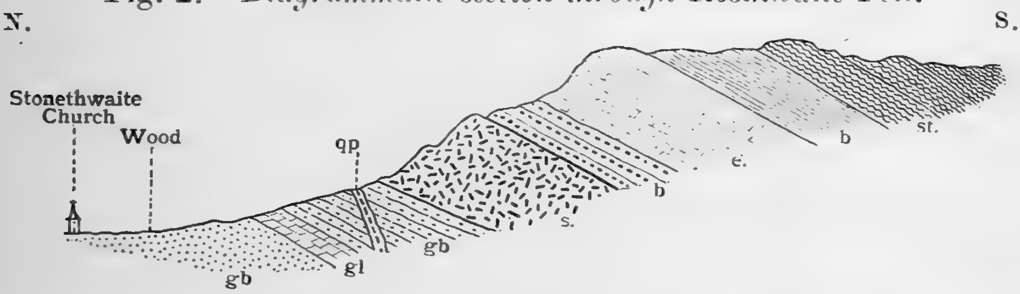
Garnet-bearing ashes and lavas are extensively developed on the high ground between Borrowdale and Thirlmere, but very little attention has been given to them. The garnet-lavas on the Dock-Tarn plateau greatly resemble the garnet-lava No. 10 of the Falcon-Crag Series (p. 87); and it is quite possible that in them we have the uppermost members of that series.

The next great group of the Eycott Lavas and associated ashes occurs immediately to the south of them, and forms prominent escarpments on both sides of the valley. Garnets do not occur in these lavas, except in the neighbourhood of intrusive masses such as the Carrock-Fell rocks, where they are doubtless the product of contact-metamorphism.

## VII. The 'Streaky' Rocks of the Central Mountain-District.

We have next to deal with the group of 'streaky' rocks. A good idea of the mutual relations of these rocks may be gathered from the appended diagrammatic section through Rosthwaite Fell.

Fig. 2.—*Diagrammatic section through Rosthwaite Fell.*




*gb* = garnet-breccia. *b* = ash and breccia.
*gl* = garnet-lava. *e* = Eycott Lavas.
*s* = intrusive sill. *st* = 'streaky' rocks.
*qp* = garnet-quartz-porphyry.

The term 'streaky' has been applied to these rocks from the characteristic appearance of the weathered surfaces. These show either a series of parallel wavy lines, or a multitude of lenticular inclusions with the same orientation. Strictly speaking, rocks showing this 'streaky' character occur in all parts of the district and at all geological horizons, but a well-developed band of them is generally found above the Eycott Lavas.

This type of structure might arise in various ways.

(1) By infiltration of substances along definite planes. This is frequently noticed, not only in the typical 'streaky' rocks, but in rocks of all geological horizons. The infiltrated substances belong to the following:—quartz, calcite, chlorite, epidote, and ilmenite. These are often introduced along the bedding-planes, and the parallel streaky lines may be separated by considerable intervals. Good examples are afforded by certain lava-like rocks on Gosforth

Crag and the lower slope of Bell Rib, Yewbarrow, also in the intrusive sill just mentioned as occurring in Rosthwaite Fell. In the last rock the lines are often separated by several inches. Quartz, calcite, chlorite, and ilmenite are found, the two first occupying the centre of the vein. The rock in close proximity to the vein takes on a speckled and dirty appearance, due to the dissemination of minute chlorite-flakes. Again, fault-planes are a determining factor. An example of this kind has already been instanced in the case of the Blea-Crag rocks, where epidote and chlorite have been introduced along what might be termed 'planes of lag-faulting.' In the 'streaky' rocks proper infiltration has taken place most frequently along the bedding-planes; but veins produced along fault-planes do occur, crossing the bedding-planes at all angles.

Very often the infiltrated products assume a lenticular shape. This is well shown by the greenish rocks of Whelter Crag (Haweswater). Dark-green lenticular patches are developed in a light-green rock, with felspar-phenocrysts. These dark-green patches consist of chlorite and calcite, sometimes accompanied by quartz; a discoloration in the rock-matrix surrounding these patches is due to the dissemination of minute chlorite-flakes (3802). The rock presents the character of a rhyolitic ash, and the infiltrations may be very similar in origin to that of quartz in rhyolites.

More rarely, infiltrated chlorite occurs in the same way as intrusive veins, penetrating a rock and enclosing fragments broken off. These fragments have chlorite introduced along the bedding-planes or other planes of weakness, and a 'streaky' character is thereby given to them. A good example of such action is afforded by a loose block found on the slope of Mickle Moss in the Haweswater district, and these phenomena may be seen in Slide 3817. The rock is a pinkish-white rhyolite, showing phenocrysts of orthoclase in a felsitic groundmass, with irregular felspar-patches. The chlorite occurs irregularly, either in long patches or in minute veins cutting across the felspars, and occasionally replacing them by chlorite-pseudomorphs. Another example of a mass of chlorite behaving as an intrusive rock is afforded by banded ash, near the junction of the streams from Bleawater and Smallwater Tarns in the Haweswater district.

We might expect to find a similar 'streaky' character:

(2) As the result of lamination in fine fragmental rocks;

(3) As the result of flow of igneous material;

(4) As the result of dynamic action on included fragments.

It may be stated at once that all four types of structure can be found, and that it would be impossible to ascribe all 'streaky' structures to one origin. At the same time, it is a very difficult matter to say definitely to which class a particular 'streaky' rock belongs.

With regard to the distribution of 'streaky' rocks, they are generally found in a zone between the Eycott Lavas and the typical

Banded Ashes. Speaking roughly, they form a ring round the highest part of the district. A very typical section of the whole group may be seen on Base Brown, which is entirely composed of them. They run obliquely across Sourmilk-Gill Combe and form the big masses of Great Gable and Green Gable. Lingmell and the stretch of rock from Slight Side to Greencove Wyke on Scawfell are entirely composed of them. They are lost to sight beneath Eskdale Moss, but appear again on Gait Crags and form the rugged and lofty ground stretching from Buscoe Tarns southward to Crinkle Crags and beyond. They probably occupy a considerable area south of Oxendale, and may extend to the Wrynose Valley. They fill the Langdale Valley to a height of 1000 feet, and run round to Easedale Tarn. Farther I have not traced them.

From Base Brown they may be followed eastward across the Derwent Valley to Hind Side and the lower slopes of Glaramara. They form the rugged plateau of Rosthwaite Fell, and run obliquely across the lower ends of the Langstrath and Greenup valleys, and occur on the top and slopes of Cold-Barrow Fell above Blea Tarn. Farther east they are absent, and are probably cut off by the north-west to south-east fault mapped by Ward.

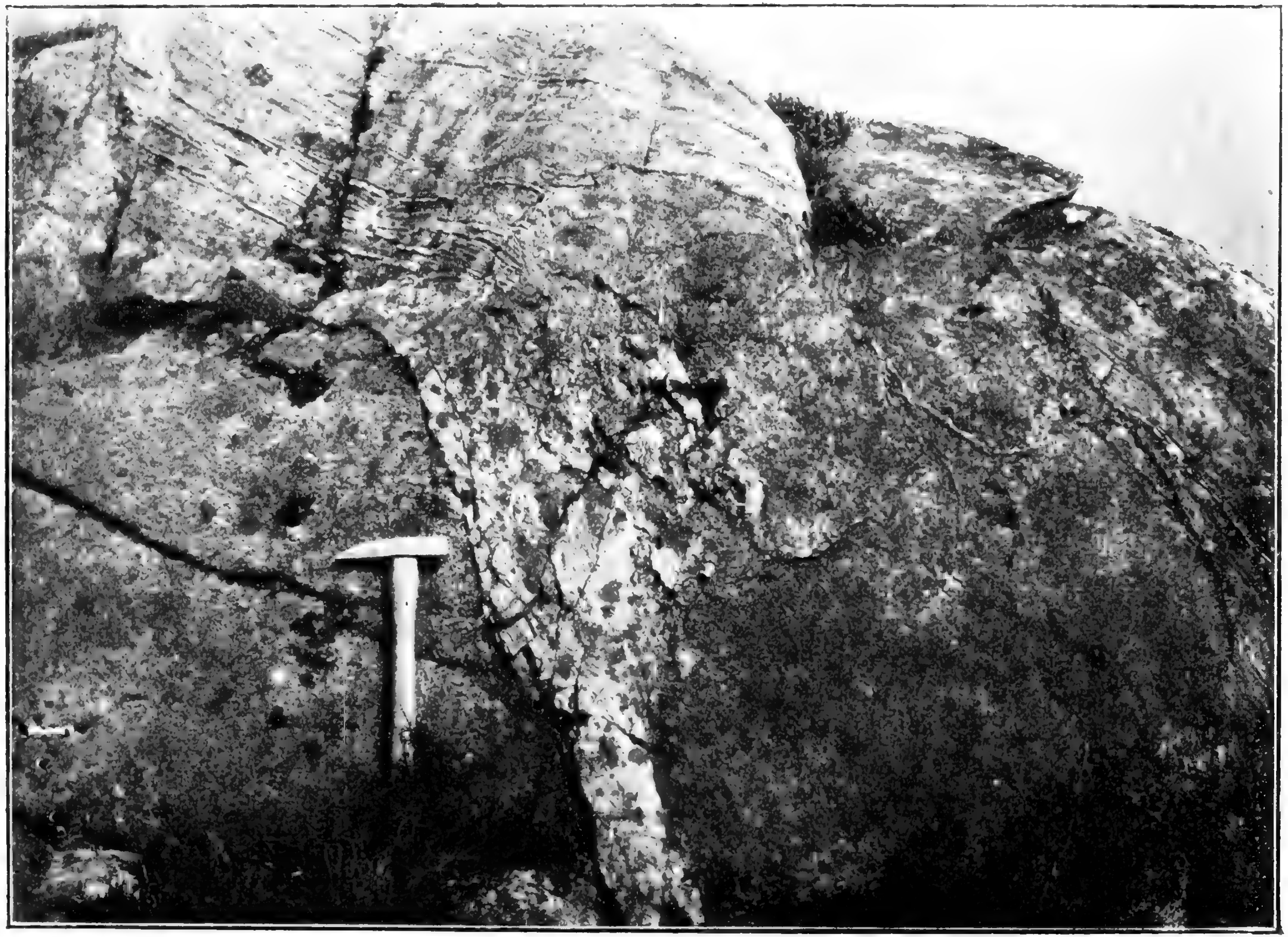
In addition to this regular outcrop, they occur in patches in many districts. They form a great part of Yewbarrow, and at Stirrup Crag is an excellent development of them. They also occur on Illgill Head (Wastwater), and on the lower slopes of Helvellyn in the neighbourhood of Whelpside Gill, where a yellow 'streaky' rock is overlain by a blue flinty ash.

Although well developed and of great thickness in the central part of the district, they do not occur between the Eycott Lavas and the slate-band in the south. Their absence in this tract of country led Mr. Marr to put them on the same footing as many of the other garnet-bearing rocks of the district, and to suggest that they were intrusive into the Volcanic Series. At first sight there appears to be a good deal of evidence in favour of such an intrusive theory, despite the obviously-fragmental nature of some of the rocks.

At their upper junction with the Scawfell Banded Ashes there is almost universally a great intermingling of the two rock-types. The banded ash seems to have been absorbed in great quantity, so as to form a complex mosaic of highly-altered, greenish-white, flinty ash and garnet-rock. This is exceedingly well shown on a rock-face, a few yards south of Buscoe Tarns on Bowfell. A good example also occurs immediately south of the gate at the Langstrath Gorge, where a white flinty ash with greenish streaks is caught up by a reddish garnetiferous rock. It is through this complex that the stream has cut so deep a gorge.

Many intrusive rocks show this phenomenon. On a minor scale the garnet-bearing intrusive rock at Great Crag, Dock Tarn (fig. 3, p. 92), is seen to incorporate the banded ash and form a mosaic. But an excellent example is afforded by the Eskdale Granite just south of Stony Tarn, where the stream from the tarn enters a small

Fig. 3.—*Banded ash and garnetiferous intrusive rock at Great Crag (Dock Tarn).*



ravine. A similar mosaic occurs in Sourmilk Gill, opposite Seathwaite Farm, where the rocks round the graphite-lode are intrusive into banded ash.

It would be impossible to conclude from the sections at Buscoe Tarns and on Aaron Crags, Seathwaite Fell, that the garnet-rock is intrusive. The appearances would be better explained on the supposition that the flinty ash was the intrusive rock. This intermingling at the junction between the two rocks has been caused by intense pressure. The bedding-plane between the soft Banded Ashes and the harder garnet-bearing rocks has very probably been one of lag-faulting; the pressure has been so great that the ash has been altered and incorporated with the garnet-rock.

An excellent section about 1500 feet up, almost due west of the Langstrath Gorge, illustrates this action. To the north the streaks are seen to dip southward, at an angle varying between 20° and 30°. As the junction with the banded ash is approached, the 'streaky' lines become horizontal. They develop into whorls, and small thrust-planes can be distinctly seen. Fragments of ash become incorporated close to the junction. If the garnet-rocks were intrusive, we should expect to find some evidence of intrusion at the lower junction. Here a complex is by no means common, and where it is absent no metamorphism has taken place.

A perfectly-gradual passage from ash to 'streaky' rock is seen on the crags west of Galleny Force, Stonethwaite. Elsewhere on Rosthwaite Fell disturbance has taken place, and we have altered flinty ash running in thin veins at right angles to the bedding. It would appear that the pressure was so great that the ash was either partly melted, or became sufficiently plastic to be forced into the surrounding rock.

The junction on the south-eastern slope of Sourmilk-Gill Combe affords evidence of great pressure. The rock at the junction is of a dark green, with bands of lighter green representing the incorporated ash. This rock is so much hardened that the softer ash has weathered away from beneath it, thus leaving a ledge of rock which projects 2 or 3 feet from the hillside.

This evidence of the operation of pressure in the production of these friction-breccias, combined with the obviously-fragmental nature of the rocks, serves to dispose of the intrusive theory. The reason of the non-occurrence of the 'streaky' rocks in the south has yet to be explained.

Many of these 'streaky' rocks contain derived fragments, and these may be lenticular or of irregular shape. A glance at the weathered surface would, in many cases, convey the idea that the rocks were fragmental; in others, that they were lavas showing flow-structure. Included fragments in lavas, especially in the rhyolites, are quite common. The intrusive rocks of the district are, moreover, full of xenoliths, so that there seems to be no insuperable difficulty in accepting the third explanation of the 'streaky' character.

We are face to face with the old difficulty of distinguishing between a rhyolite and a rhyolite-tuff, for these 'streaky' rocks show many points of resemblance to those acid rocks. Ward mapped all these rocks as ashes, but at the same time he pointed out that so thick a mass of rock would be sure to contain small lava-flows which it would be almost impossible to trace in the field.

If the garnets of these rocks are examined, it is found that they are not always perfect in form, but are often surrounded by a white ring which, under the microscope, is seen to consist of plagioclase-crystals growing out from the garnet-margin in good crystal-forms. The garnet is always very much corroded; the projecting portions are often curved, and lose their isotropic character at the extremities. Fragments of garnet occur in the felspars (3819), showing the same polarization-tints as the felspar, and only differing in refractive index.

A compact green rock from Eagle Crag in the Langstrath valley (3824) shows the association of felspar and garnet exceedingly well. Very little garnet remains, but the fragments are surrounded by eight or ten idiomorphic plagioclase-crystals of the same species as that which occurs in the rest of the rock. Iron-ore, probably ilmenite, has separated out in rods and irregular masses, and has been largely converted into a brownish sphene. Flakes of chlorite also occur. The streaks are formed by lines of felsite-material: these, as they approach a large felspar in the neighbourhood of the garnet, seem to become discontinuous and exhibit folding and crumpling. This suggests that the felspar was formed *after* the streaks of felsitic material. The formation of ferromagnesian mineral, as a result of the corrosion of garnet, is rarely seen in the 'streaky' rocks, but is fairly common in the garnet-intrusives.

Garnets, with perfectly-developed faces, occur in an ash at the base of the 'streaky' rock on Rosthwaite Fell. In section (3836) the garnet is seen to be breaking up at the margin, felspar being produced. The original outline of the garnet can, however, be traced.

A study of the garnet-intrusives has led us to believe that *the association of felspar and garnet affords evidence for the originality of the garnet*, the felspar having been produced by the action of the still liquid matter on the garnet. Garnets surrounded by felspar-growths also occur in undoubted ashes and breccias, above the series of 'streaky' rocks (3834 & 3845). It would seem, then, that this association affords no criterion for discrimination between a lava and an ash; and the fact that it occurs in true ashes throws doubt on the interpretation put upon it in the case of the intrusive rocks. In the examples of 'streaky' rocks mentioned above certain features seem to point to the formation of the felspar *after* the consolidation and compacting of the rock.

It might be urged that the garnets with a felspar-ring which occur in the ashes are fragmental. A glance at the felspar-crystals is sufficient to convince one that this is not the case: for they often show very perfect crystal-outlines, with sharp and deep re-entrant angles between contiguous felspars. This would hardly occur if the garnet and the felspar-growth were thrown out together.

Before proceeding further, it may be well to describe a few typical examples of 'streaky' rocks. The lowest rock of the series exposed on Rosthwaite Fell is a light-green rock with pinkish-white felspar in abundance. This is seen in section (3780: Pl. XIV, fig. 1) to be a plagioclase, much altered to calcite. Fragments of a granophyric rock occur, showing a pretty micrographic intergrowth and needles of chlorite representing original biotite. These granophyre-fragments resemble very closely the Buttermere Granophyre. We have, then, another piece of evidence, besides the occurrence of garnet, which serves to show how closely connected the rocks of the Volcanic Series are with the garnet-bearing rocks intrusive in them. In addition, fragments of an andesitic groundmass, with diffused iron-ore, are also present. The matrix is felspathic, and minute felspar-fragments occur with concave outlines. The rock may thus be called a tuff-porphyroid. Garnets with exquisitely-bright faces are common. Purplish flinty fragments as well as dark chloritic basic portions occur; it is the squeezing of the latter that gives the 'streaky' character to the rock.

Other types are found, in which the 'streaky' character is due to thin lines of green chloritic matter (3772). Phenocrysts of plagioclase occur at all inclinations to these lines, which are often bent as if the felspar had fallen on them from above. This chloritic matter is original, and not produced by infiltration. Running across the streaky lines are others, formed also of chlorite or more rarely of chlorite and quartz. These are true veins, infiltration having occurred along lines of faulting, for the vein may be seen to produce displacement of the fragments of a felspar through which it may pass.

At other times, the streaks are broader, and consist of a coarse felspathic matrix impregnated with quartz, chlorite, and calcite (3870). Aggregates of calcite are very characteristic of this class of rock, as well as skeleton-crystals of ilmenite enclosing a green or greenish-brown, pleochroic, serpentinous mineral. This occurs in the 'streaky' rocks of Borrowdale and Haweswater alike.

Another type of 'streaky' character consists of lenticular fragments of quite different petrological and chemical composition. Such a rock is shown in the microphotograph (3875: Pl. XIV, fig. 2) and occurs at Hindside, Seathwaite. A similar rock is to be found on the lower slopes of Scawfell. Yellowish-white lenticular patches of rhyolite occur, separated by a darker and more basic fine-grained matrix. These rhyolitic aggregates contain felspars, probably oligoclase or oligoclase-andesine, in the usual felsitic paste. The felspars are, however, not peculiar to the rhyolite-fragments, but occur throughout. Tufts and wisps of an almost colourless mineral occur, giving bright polarization-tints. This mineral is associated closely with chlorite, and seems to pass into it. The same mineral, which I am unable to identify, occurs abundantly in the Haweswater rocks.

This mixture of a rhyolitic with an andesitic matrix explains the peculiar chemical composition of these 'streaky' rocks. They have silica-percentages varying from 63 to 69, which are much lower than those of true rhyolites. The percentages of lime and magnesia are also low, but are intermediate between the percentages of these constituents in andesites and rhyolites. Potash preponderates over soda, although the difference is not by any means so great as in the typical rhyolites.

The two following partial analyses were made :—

| | A. Per cent. | B. Per cent. |
|---|---|---|
| $SiO_2$ | 68·89 | 66·92 |
| $TiO_2$, $Al_2O_3$, $Fe_2O_3$ | 19·69 | 20·50 |
| CaO | 1·19 | 1·69 |
| MgO | 0·20 | 0·22 |
| $K_2O$ | 2·61 | 3·56 |
| $Na_2O$ | 2·42 | 2·77 |
| Specific gravity | 2·679 at 18° C. | 2·704 at 12·7° C. |

A = Lowest 'streaky' rock, west of Galleny Force.
B = 'Streaky' rock, 1750-foot contour, Whelter Crags.

Ward gives the analyses of two rocks, one from Base Brown[1] and the other from Slight Side; the former has a silica-percentage of 69·673, the latter 68·421.

Mr. Harker[2] tabulates the silica-percentage of an Illgill-Head 'streaky' rock as 69·48, and its specific gravity as 2·682.

The specific gravities of 'streaky' rocks from Scawfell (3876) and Base Brown were found to be 2·706 and 2·694 respectively. An excellent example of a rock in which the andesitic and rhyolitic types occur together, is afforded by a thin band of 'streaky' rock found below the main mass of 'streaky' on Gait Crags. In it are lenticles of colourless rhyolitic substance and brownish andesitic ash, the latter containing many broken fragments of a labradorite-felspar. A less convincing example occurs at the base of the High-Goat-Gill series in the Haweswater District.

So far, I have described ashes in which the 'streaky' character is due to a large extent to lamination, but may also be produced by pressure and by infiltration of various substances. That there are also minor lava-flows in so great a thickness of rock seems probable. Ward pointed out the difficulty that would be experienced in tracing such thin lavas. He did, however, map the compact columnar rock on Base Brown as a lava. I have no slide of this rock, and have never come across a rock *in situ* that I could call a lava.

A loose block found by Mr. Marr on the path to Sty-Head Tarn from Seathwaite shows a lava-like character. It is a typical 'streaky' rock, with dark-brown streaks and enclosed fragments of

[1] Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 411.
[2] 'Chemical Notes on Lake-District Rocks' in the 'Naturalist' for 1899, p. 56.

flinty 'streaky' rock. In section (3786: Pl. XIV, fig. 3) it shows oblong orthoclase-crystals always oriented in the direction of the 'streaky' lines. There are bands of light and dark matrix, the former containing fibres of a brownish mineral which gives straight extinction parallel to the length of the fibres. Aggregates of quartz-grains in oval patches, possibly representing original vesicles, contain the same fibrous mineral. The rock is frequently faulted.

The second example of a 'streaky' lava is furnished by the rock obtained from the garnet-breccia of Ore Gap. Slightly turbid pink-white felspar, giving the extinction-angle of oligoclase, occurs in rounded and corroded crystals, thinning out in the direction of flow. Fine-grained andesitic fragments have been caught up and rounded. The groundmass is that of a true rhyolite, exhibiting the characteristic appearance of light and dark patches. Along certain lines the structure becomes coarse and lenticular, and linear aggregates are seen, consisting of idiomorphic felspars in quartz. Cubes of pyrites of a reddish tinge are common, especially in the more basic streaks; they usually possess a dark interior, and are surrounded by a ring of epidote. Ilmenite and apatite occur.

There are undoubted lavas in the Haweswater District. One of these, a typical rhyolite with a silica-percentage of 82·25, is mentioned by Mr. Harker[1] as occurring a quarter of a mile south-east of Walla Crag. A garnetiferous andesite occurs at the top of the series at Woof Crag, on the Naddle side of Haweswater. This yielded a silica-percentage of 59·70, and Mr. Harker tabulates its specific gravity as 2·698.

Above the 'streaky' rocks comes a great thickness of banded ash and breccia, filling up the syncline in the highest part of the district. A zone of crush-brecciation has been mentioned as occurring at the junction over wide areas. This plane of crushing does not, however, keep to the same horizon. It can be traced from the eastern shore of Sty-Head Tarn, over the watershed and down to Lingmell Beck. On the slopes of Lingmell 'streaky' rock is developed both above and below the line of crush-brecciation. The phenomena rather suggest a reduplication of 'streaky' rocks by thrusting.

'Streaky' rocks are developed on Illgill Head; between them and the Lingmell rocks occurs a band of andesite and Eycott Lavas. The Illgill-Head rocks have not been carefully mapped; but this intercalation of Eycott Lavas between two bands of 'streaky' rock is particularly suggestive, when the succession in the Haweswater area is considered. These patches of 'streaky' rock developed on Illgill Head and at Stirrup Crag (Yewbarrow), may, however, occur only in faulted areas, for the 'streaky' rocks elsewhere form a complete series.

The rocks immediately above the 'streaky' rocks consist of a greenish ash and breccia containing fragments of 'streaky'

[1] 'Chemical Notes on Lake-District Rocks' in the 'Naturalist' for 1899, p. 57

material. They are typically developed north of Glaramara, and are good andesitic ashes. They contain garnet-fragments, but these are not common; there can be no doubt about the clastic nature of the garnets.

The breccia found at Lining Crag (Greenup Gill) is a typical rock (3754) consisting of lava-fragments with oval vesicles; fragments of a rhyolite with perlitic structure, the cracks being filled with greenish chlorite. Garnet and felspar-fragments occur. Perlitic rhyolites are occasionally met with in fragments in many rocks. A good example (3926) occurs as an enclosed mass in Dock-Tarn Gill.

Above these greenish ashes and breccias comes a more compact series of ashes, which may assume a more or less pronounced 'streaky' character. These are well seen on Allen Crags, and south of the Angle-Tarn to Esk-Hause path: they often contain perfect garnets. In a rock from Allen Crags (3871) the 'streaky' character is produced by lenticular patches of chlorite squeezed out by pressure. Fragments of andesitic and rhyolitic rocks occur abundantly, together with infiltrations of chlorite. Felspar-fragments are also abundant. Garnets surrounded by a felspar-ring are often found in these rocks; ashes from Esk Hause, near the path to Scawfell Pike, and on Scawfell Pike itself, show this association well (3834 & 3845). A better example is afforded by the compact, blue, flinty ash above the 'streaky' rock in Whelpside Gill, Helvellyn (3839: Pl. XIV, fig. 4).

A very fine, exceedingly-compact, flinty ash, with oval concretions, is found in the centre of the syncline. Garnets are not often to be seen in this rock, on account of its fineness; but a mass of ash and breccia included in it on the Knotts of the Tongue (Esk Hause) contained garnet-fragments. Minute garnets have been found by Mr. W. M. Hutchings in the equivalent rocks of the slate-band in the south, so that all the lower members of the Volcanic Series, with the exception of the Eycott Group of lavas and ashes, contain garnets.

## VIII. The 'Streaky' Rocks of the Haweswater District.

Garnetiferous rocks are well developed around Haweswater. They present all the characteristic features of the 'streaky' rocks in the centre of the Lake District, but differ considerably in their mode of distribution. I have endeavoured on the 6-inch maps to plot them out roughly, and to this end a peculiar nodular rock—as pointed out on p. 18 of the Geological-Survey Memoir, on 'The Geology of the Country between Appleby, Ullswater, & Haweswater' 1897—forms a valuable guide. The rocks are developed in bands, separated by lavas and ashes which do not contain garnets. Now, the 'streaky' rocks in the centre of the district, with perhaps one exception, occur in one great group: the object of the mapping was to determine whether this structure was original or produced by earth-movements.

'Streaky' rocks are met with at Measand Forces, at the top of which banded ash is seen dipping eastward. Below the 'streaky' group a coarse rock occurs, which has the appearance of an Eycott Lava. The line of junction between the two is vertical, and much crushing has occurred at the junction. Between the two rocks on Sand-Hill Knotts a fine-grained, dark, basic rock occurs, and several dykes of the same traverse the 'streaky' rocks, though not the rock below.

The 'streaky' rocks run in a north-westerly direction to Colby, frequently displaced by faults. They are developed on Great and Little Birkhouse Hills; a dark intrusive rock occurs below them. Intrusive junctions may be seen, in which the 'streaky' rock becomes reddish in colour and of a flinty character. The intrusive rock is a quartz-diabase (3805). It seems very probable that the Measand rock is also intrusive, and the two, with the diabase of Walla Crag (on the other side of the lake), form a large intrusive mass.

Below the 'streaky' rock of Little Birkhouse Hill occurs a narrow band of vesicular lava, separating it from the nodular rock on Pinnacle Howe. This rock consists of oval nodules of flinty material, the centre of which is either hollow or filled with quartz. These nodules vary from half an inch to 6 inches in length. The same rock is again seen at the Old Quarry north of Fordingdale Bottom, and thence it probably extends along the hillside to Fordingdale Force, where an excellent section is exposed. It is continued along the top of the slope to Laythwaite Crags, and on round Whelter Combe in a vertical cliff about 100 feet high. The succession here is—

| | *Feet.* |
|---|---|
| Compact garnetiferous rock............................ | 20 |
| Nodular rock............................................... | 10 to 15 |
| Garnetiferous rock with vesicles............ ........ | 50 to 60 |

The nodular rock varies in thickness, and has a very irregular top and base. On Whelter Crags it splits into two, and is then lost by faulting. Occurring again in the upper part of Randale Beck, it runs to Kidsty Pike, where it is well developed in two bands. This rock is not represented on the east side of Haweswater. On p. 17, etc. of the Survey Memoir (quoted on p. 98) the rock is described as 'bomboidal,' and considered to be of fragmental origin. This is quite likely, for similar flinty fragments (with quartz developed in the centre of them) may be found in a compact ash on Eagle Crag and Rosthwaite Fell, in the Borrowdale district. Together with the quartz in the hollows, a black substance also occurs, either forming a coat on the quartz-crystals or in oval grains.

Above the great cliff of garnet-rocks in Whelter Combe, lavas possibly of the Eycott type, vesicular lavas, and ashes are developed; and these are succeeded by a yellow, much-decomposed 'streaky' rock at the top of Bason Crags.

Below the nodular rock-group, banded ash is seen, dipping north-westward at an angle of 5°. Another band of garnet-rock is found crossing the stream just above High-Whelter Farm—being continued northward towards Laythwaite Sike, and southward to Castle Crag and on to Randale Beck.

Between Whelter Knotts and Laythwaite Sike an interesting group of rocks occurs. The ground is much faulted, diabase-dykes coming in along the faults. All along the road near the School and Rowan Park a yellow rhyolitic ash with pyrites is developed. An analysis of a specimen from Rowan Park yielded a silica-percentage of 72·18.

In Laythwaite Sike a very dark-brown rock occurs, either alone, or in lenticular fragments in a yellow matrix: this gave a silica-percentage of 31·77. Microscopical examination shows the rock to be made up almost wholly of chlorite, and the low silica-percentage obtained supports this conclusion. Along the 1500-feet contour from Laythwaite Sike to Whelter Knotts this mixed yellow-and-black rock becomes converted into a schist with white quartz and a greenish mineral. Weathering of the rock produces a wonderful mosaic, the quartz standing out from the red iron-oxide produced by the decay of the green constituent. This mineral, under the microscope (3806), is seen to occur in irregular yellowish patches, giving high polarization-tints. It is derived from chlorite, for a section (3812) shows the passage of one into the other. At the margins of these patches, and scattered throughout the matrix of quartz-grains, occur minute irregular prisms of a greenish, strongly-pleochroic mineral, giving high polarization-tints and extinction oblique to the length of the prisms. Wisps and tufts of the same mineral have been noticed very frequently in association with chlorite in the 'streaky' rocks elsewhere. It must be closely allied to chlorite in composition. A compact quartz-schist has been produced by dynamic metamorphism from the yellow and brownish aggregate. The silica-percentage is intermediate between the two given above, for it is found to be 64·77.

On the east side of Haweswater 'streaky' rocks are well developed. They occur in the north between High-Laithes Pike and Walla Crag, being continued from Pinnacle Howe on the opposite shore. Cleaved Eycott Lavas form a thin band near the base of the series. They run in a narrow belt, frequently interrupted by diabase-intrusions, to the head of Naddle Beck, and then spread out over the heather-covered ground as far as Woof Crag and Powley's Hill, descending to the lake along the line of Guerness Gill. Patches of intrusive quartz-porphyry are often found, and a considerable mass of the same rock is found in them on Mardale Banks, south-east of the end of the delta.

At Woof Crag a garnetiferous andesite (already mentioned on p. 97) occurs, overlain by banded ash. Along the junction movement has taken place, with the result that the lava shows excellent crush-conglomerates. Basic dykes break through it frequently. Diabase-dykes of a dark-green colour and of fine grain are common on the west side of the lake, occurring south of Birk's Crag and above the Schools. Quartz-porphyry dykes are also found on Whelter Knotts.

The intercalation of lava and ashes which do not contain garnets in the 'streaky' rocks seems to be an original feature. A study, both microscopical and chemical, of these lavas is necessary, before it can be asserted that the Eycott Group is associated with the 'streaky' rocks in one area and that it is older than them in another.

## IX. The Characters of the Garnets.

These are of no very great interest from the crystallographic point of view. In the intrusive rocks and the majority of the 'streaky' rocks they do not usually show good faces. The well-developed garnets are found in abundance in the ashes of Illgill Head, High-Goat Gill (Haweswater), and Sty-Head Tarn.

The only two forms met with are the icositetrahedron (211) and the dodecahedron (110). The icositetrahedron is occasionally found singly, but I have never met with the dodecahedron alone. The majority of the garnets show a combination of the two forms, the relative size of the respective faces varying considerably. Garnets a quarter of an inch in diameter are quite common, but the extreme limit is half an inch.

The occurrence of a ring of felspar round the garnet, with the production of ferromagnesian mineral and separation of iron-ore, has already been considered (pp. 73, 94). The conversion of the garnet into a sericitic substance by dynamic metamorphism has also been noticed (p. 88).

The garnets found in the greenish rock of High-Goat Gill, a tributary of Naddle Beck (Haweswater), show somewhat peculiar features. This rock is an andesitic ash, containing many felspar-crystals in a greenish matrix charged with chlorite. The silica-percentage is 56·45. The garnets are extremely abundant and almost perfect in outline, but usually show a small indentation occupied by the greenish matrix. This cavity may occur anywhere on the crystal, and has no relation to the crystallographic axes. It may be either five- or six-sided, according to the number of faces which it cuts, but it is often roughly circular in outline. A series of step-like projections running round the cavity occur all the way down to the bottom, and seem to represent the layers of garnet-growth. This phenomenon is singularly suggestive of a metamorphic origin for the garnets. The rock is an undoubted ash, therefore the cavities could not be formed by corrosion. There may be two such cavities in one garnet, and nearly all the garnets show the same phenomenon. It is extremely improbable that such hollows would be found in fragmental garnets. If the garnets are metamorphic, it is difficult to understand how such metamorphism has been produced, for the rock is far removed from an intrusion of any great magnitude.

Chemically, the garnets are iron-alumina garnets, with small quantities of calcium, magnesium, titanium, and manganese-oxides, and therefore belong to the almandine-type. This was proved by qualitative analysis, and by quantitative estimation made on those garnets which could be procured in some quantity with little trouble: these are to be found only in the ashes at the upper and lower limits of the 'streaky' rocks. To obtain sufficient amounts of the mineral from the intrusive rocks for analysis it would be necessary, in the majority of cases, to have recourse to separation by heavy liquids. The garnets analysed were obtained from the garnet-ash of High-Goat Gill, the 'streaky' ash of the prominent crag west of Galleny Force, and the ashes of Illgill Head and Sty-Head Tarn. Titanium is present in all four, and only a small percentage of the iron is in the ferric state. It is not unlikely that water may occur in these garnets, but no estimations were made.

The most frequent change that the garnets undergo is a conversion to greenish chlorite with separation of iron-ore. Generally, the change proceeds irregularly from the outside to the centre. In a 'streaky' rock from Lady's Seat (Mardale), the garnets give rise to flakes of chlorite in a direction at right angles to that of the cleavage in the rock. Under great pressure the garnets lose their reddish colour, become a dirty brown, and pass gradually into an aggregate of chlorite and a sericitic mineral.

I wish here to express my thanks to Mr. Charles Smith, formerly at the Mineralogical Museum, Cambridge, for all the help which he gave in the preparation of rock-sections containing special garnets.

## X. Metamorphism of the Volcanic Rocks.

The metamorphism of volcanic rocks by a granitic intrusion has been thoroughly dealt with by Messrs. Harker & Marr [1] in their papers on the Shap Granite and associated metamorphic rocks, and by Mr. Harker [2] in his paper on the Carrock-Fell Gabbro.

The metamorphosed rocks round the Eskdale Granite show very much the same characters. The rocks in which new minerals are developed are either ashes or Eycott Lavas. These become chocolate-brown in colour, owing to the development of aggregates of flakes of an intensely-pleochroic brown mica, probably produced from chlorite. Close to the intrusive junction a very pale-green mineral is developed, forming either irregular masses or elongated prisms giving high polarization-tints. This mineral, as before mentioned, becomes absorbed into the intrusive rock. The mineral may be a fibrous hornblende.

The extreme type of metamorphism is furnished by xenoliths of purple ash, enclosed in the intrusive quartz-porphyry. Examples occur west of Stony Tarn (3887) and at Piers Gill. Numerous brown mica-flakes occur in a holocrystalline mass of quartz and plagioclase. The two last-named minerals are hard to distinguish one from the other, both being perfectly clear.

Garnets with very irregular outline are also produced, the border being of a very spongy character freely penetrated by quartz and plagioclase. The process of formation of these garnets appears to be most interesting. At first, there is a confused mass consisting

[1] Quart. Journ. Geol. Soc. vol. xlvii (1891) pp. 292–309 & vol. xlix (1893) pp. 360–65.

[2] *Ibid.* vol. l (1894) pp. 331–34.

of chlorite-flakes, a minute granular aggregate, and comparatively-large pieces of a brownish isotropic mineral with occasional triangular outline. This has rather the appearance of sphene, but the mineral is isotropic: it may be one of the spinels—picotite, perhaps. In the next stage we find a highly-refracting mineral with peculiar blue and bluish-green polarization-tints, massed round the grains of spinel. This mineral has a higher refractive index than the spinel, and seems to be a garnet of non-isotropic character. The brownish spinel loses its colour, and changes into an opaque iron-ore. This becomes gradually absorbed, and a true isotropic garnet is produced.

The non-isotropic garnet might very well be grossularia, for the polarization-tints are characteristic of that mineral, and there is no difficulty in this assumption when the large amount of plagioclase present is considered. It is a curious fact that the larger masses of garnet show no trace of the spinellid mineral, but at their outer edges pass into the non-isotropic garnet. That some such change as this does occur seems fairly certain, but it is very desirable to obtain confirmation by chemical methods.

The flakes of biotite in this rock show numerous pleochroic halos, and apatite seems to occur as a product of contact-metamorphism.

The production of garnets in the ash is limited to fragments caught up and enclosed by the intrusive rock. The purple ash does not usually contain them. It appears therefore somewhat absurd to ascribe the perfect garnets of Illgill Head and Sty-Head Tarn to the same metamorphic action.

Lavas, possibly of the Eycott type, come close to the garnets just north of Stony Tarn, and also at Brockshaw Gill. The product is a purplish rock, with greenish-white felspar-substance. Under the microscope aggregates of mica-flakes are seen to be very common, set in a mass of plagioclase. Nearer the junction north of Brockshaw Gill the purple colour is lost, and we get a grey rock with occasional garnets (3930). This rock is not found further than 2 feet above the line of junction, and passes into the purplish rock above.

A metamorphosed Eycott Lava in Oliver Gill shows the production of brown mica and a light greenish hornblende.

A purplish 'streaky'-like rock south-east of the head of Wastwater exhibits minute biotite-flakes, aggregated round ragged patches of iron-ore (3793). Biotite is often observed in association with a greenish hornblende. Aggregates of quartz-grains are frequently associated with biotite in these rocks, but there is nothing to show that such aggregates are the result of metamorphism.

Coming to the examples of contact-metamorphism by a small intrusive mass, we find these in the ash above the intrusive garnet-bearing rock of the path to Dock Tarn, and in a similar ash at the upper limit of the intrusive sill on Rosthwaite Fell. The phenomena are the same in both, consisting of a production of black crystals and flakes of chlorite. In the Rosthwaite-Fell metamorphosed rock (3778) irregular flakes of greenish chlorite are developed, enclosing portions of the groundmass. Calcite occurs in small grains and patches, often resembling felspar in outline and possibly replacing that mineral. Ragged ilmenite-aggregates occur, extensively altered to sphene. In the Dock-Tarn rock the chlorite shows well-developed faces. Close to the junction this mineral is not developed, the ash becoming white and porcellanized, and the metamorphic minerals pyrites, chlorite, etc., are found at some distance from the junction-line. These spotted ashes are probably closely allied to the 'spilosites.'

The same minerals occur in a very compact flinty ash enclosed in garnetiferous rock, at the junction of the 'streaky' rocks and Banded Ashes at the Langstrath Gorge. The ash is whitish, with greenish streaks and patches. These patches consist of chloritic aggregates, with irregular masses of calcite (3765). That the pressure at the junction was intense is proved by the occurrence of these minerals in whorls, the minute chlorite-flakes forming concentric rings. It is quite probable that the heat produced by the intense pressure has been the cause of the production of new minerals.

It has been mentioned elsewhere that a considerable thickness of fine flinty ash occurs in the highest parts of the district; it would seem that the flinty character has been produced by the joint agency of heat and pressure. A small fault occurs in garnet-bearing rocks near Black Hall in the Wrynose Valley. Fragments of ash have been dragged along this line, and a flinty rock produced. In other cases, the compact flinty character is due entirely to contact-metamorphism. Round the intrusive Blea-Crag rocks occurs on both sides of the Langstrath an aureole of flinty ash and breccia, and to a great extent this compact flinty character is produced by heat derived from the intrusive rock.

## EXPLANATION OF PLATES XIII & XIV.

### Plate XIII.

Fig. 1. Slide 3751: corroded garnet, surrounded by a plagioclase-ring, with biotite in the embayments. Magnified 12 diameters. (See p. 73.)

2. Slide 3787: garnet and orthoclase, surrounded by a microspherulitic growth of quartz and felspar. In parallel arrangement with this growth elongated flakes of chlorite are seen. Magnified 16 diameters. (See p. 74.)

3. Slide 3788: from the Armboth Dyke, showing corrosion of garnet by quartz. Magnified 16 diameters. (See p. 86.)

4. Slide 3753: ash from the Falcon-Crag Group. Magnified 16 diameters. (See p. 87.)

### Plate XIV.

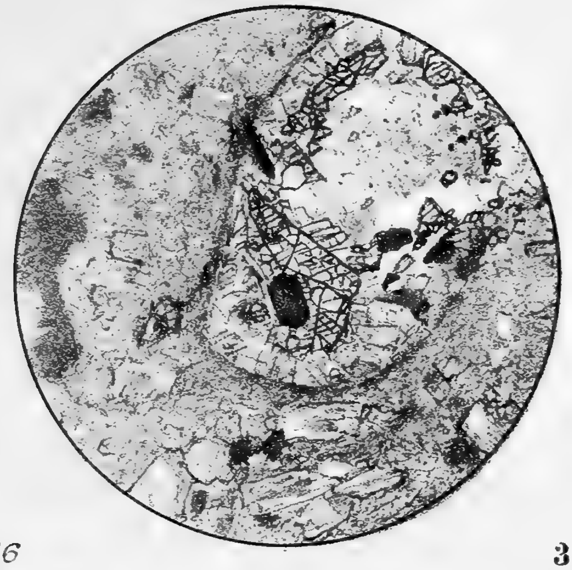
Fig. 1. Slide 3780: 'streaky' rock from Rosthwaite Fell, containing fragments of granophyre. Magnified 14 diameters. (See p. 95.)

2. Slide 3875: 'streaky' rock from Hindside (Seathwaite), showing pale patches of rhyolite separated by a darker and more basic matrix. Magnified 14 diameters. (See p. 95.)

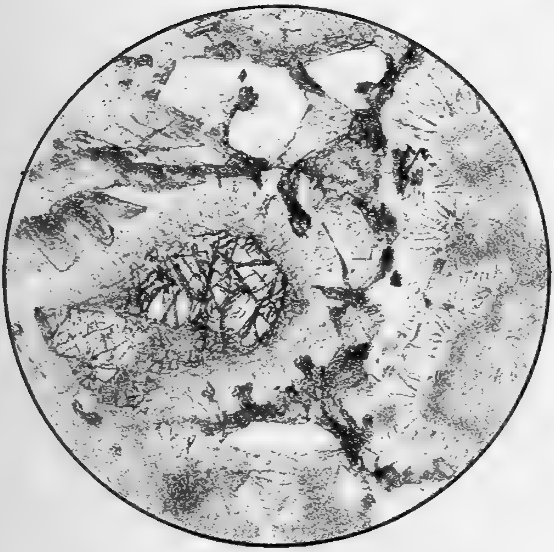
3. Slide 3786: 'streaky' rock from a loose block on the path between Sty-Head Tarn and Seathwaite. Magnified 8 diameters. (See p. 97.)

4. Slide 3839: blue flinty ash, above the 'streaky' rock, Whelpside Gill (Helvellyn). Magnified 12 diameters. (See p. 98.)

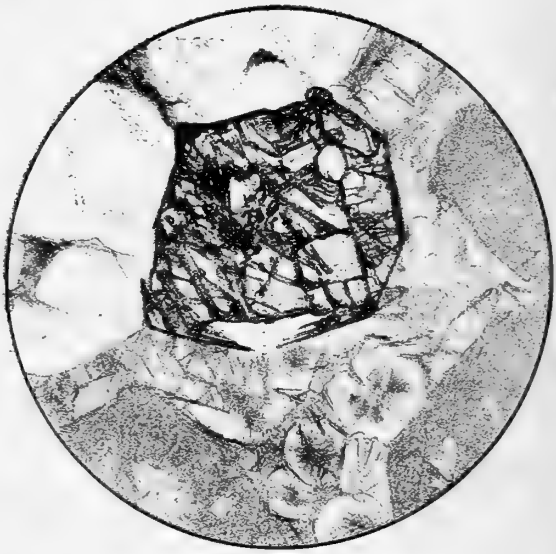
1. × 12



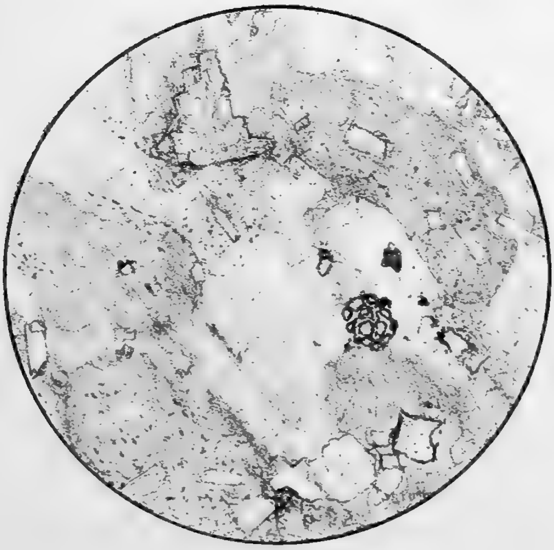
2. × 16



3. × 16



4. × 16



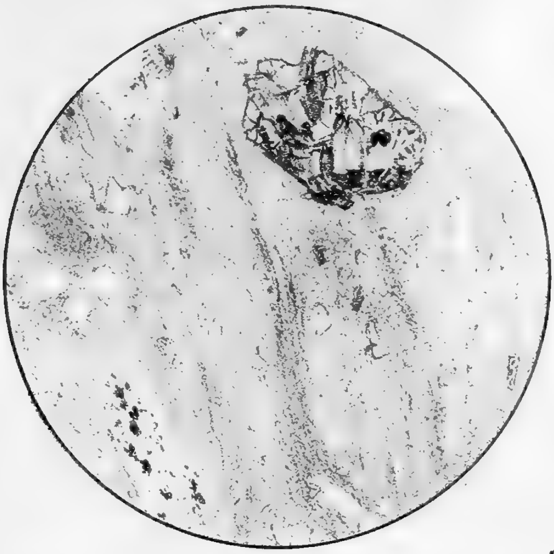
F. H. Michael del. et lith.

Mintern Bros. imp.

ROCKS FROM THE BORROWDALE VOLCANIC SERIES.

Quart. Journ. Geol. Soc. Vol. LX, Pl. XIV.

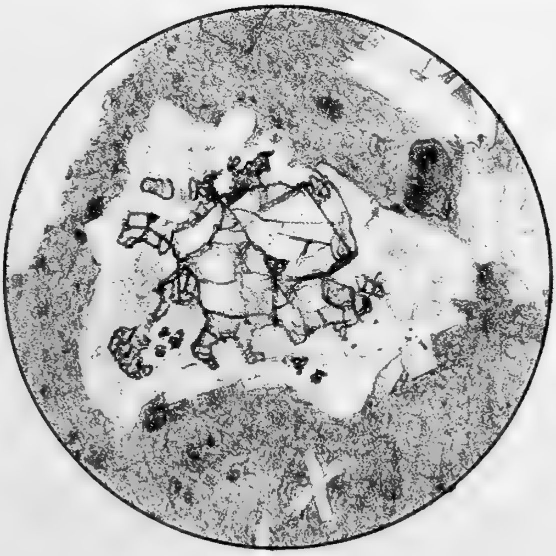
1. X14



2. X14

3. X8

4. X12



F. H. Michael del. et lith.

Mintern Bros. imp.

ROCKS FROM THE BORROWDALE VOLCANIC SERIES.

### Discussion.

Mr. Harker said that to listen to this paper made one regret more keenly that the Author had not been spared to continue the work so well begun. The remarkable relations described in the paper between intimately-associated basic and acid intrusions had escaped his (the speaker's) notice when working with Mr. Marr in the Lake District; but they found a parallel, even in some of the minor details, among the Tertiary intrusions of the Inner Hebrides.

The origin of the garnets, so striking a feature of the Lake-District rocks as a whole, was an important question, upon which the Author's researches would undoubtedly throw light. The uneven distribution of the mineral pointed to a metamorphic origin, and the detailed nature of the distribution was such as to connect the garnets with metamorphism of the dynamic kind.

Prof. Sollas said that he joined in the previous speaker's expression of regret at the premature loss to science of so gifted an observer as the Author. Much subjectivity attached to the various interpretations of the mixtures of igneous rocks. In reality different explanations could account for similar phenomena, and the supposed simultaneous fluidity of basic and acid rocks was by no means indispensable to explain the facts. Further, the igneous magmas were already differentiated before they were erupted at the surface of the earth.

Mr. Barrow remarked that Mr. Maynard Hutchings (who was unfortunately not present) had worked at these very Lake-District rocks some time ago. Mr. Hutchings had no doubts as to the metamorphic origin of the garnets in the ashes, although he did not feel sure that he could account for it.

## 8. *On a* PROBABLE PALÆOLITHIC FLOOR *at* PRAH SANDS (CORNWALL).

By CLEMENT REID, Esq., F.R.S., F.L.S., F.G.S., and ELEANOR M. REID, B.Sc. (Read January 6th, 1904.)

ABOUT 7 miles east of Penzance a shallow bay lies between a rocky headland of slate and elvan on the one side, and the Godolphin granite on the other. Into this bay sand, principally shell-sand, has drifted, so as to show at low tide a mile or so of sandy foreshore, behind which occur low cliffs and sand-dunes. This tract is known as Prah Sands. In its leading characteristics it is a typical Cornish bay, dating from the period of the raised beach, but subsequently rendered less important, and partly obliterated, by changes of sea-level and the accumulation of drift.

The drift in the low cliff at Prah was described in 1879 by Mr. W. A. E. Ussher[1]; but nothing exceptional seems to have been visible at that date, nor was anything unusual observed during two visits made by one of us in 1901. The ordinary succession of angular 'head,' on raised beach, resting upon a wave-worn rocky platform, was all that was noticed.

During the severe gales of 1902 and 1903 the sea washed away much of the talus and sand which masked the foot of the cliff between Sydney Cove and Hoe Point, and also removed so much of the beach as to lay bare numerous patches of the rocky floor below. The sections thus exposed are of such great interest as to justify a detailed description, for they yield what we believe to be the first evidence of Palæolithic man yet found in Cornwall.

The section lies between Sydney Cove (where the road comes down to the beach) and the well-known 'Prah Elvan,' less than 300 yards away, and close to the western horn of the bay. The general relation of the deposits will be readily understood from the accompanying section (fig. 1, p. 108).

An uneven, wave-worn, rocky platform rises to about 15 feet above high-water on the south-western side of the elvan. Beyond and behind it is a much-degraded ancient sea-cliff, with traces of caves, now well above the reach of the sea. This buried cliff trends inland, and then strikes eastward at a distance of about 200 yards from the present coast. On the rocky platform and banked against the cliff rest patches of shingly beach (mainly of elvan and killas), with big boulders and much sand, the whole deposit seldom reaching 10 feet in thickness; the beach-material has been entirely decalcified, and is now cemented by iron into a solid mass. About 60 feet of angular rubble or 'head,' loamy at the bottom and full of large blocks of elvan throughout, at this point rests upon the raised beach, forming the modern sea-cliff.

On the east side of the elvan-dyke the rocky platform gradually

[1] 'The Post-Tertiary Geology of Cornwall' 1879, 8vo, Hertford (privately printed) pp. 18, 19.

sinks to mean-tide level on the foreshore; and at 70 yards from the elvan it is lost under recent beach, or has sunk beneath the sea: it has also a slight seaward tilt. Bedded ferruginous sand, with well-worn pebbles and large rounded boulders, can be seen at various points to rest upon this rocky platform and to rise to about high-water mark; these deposits, however, do not directly concern us, and need not here be more fully described.

The strata to which we wish particularly to draw attention are those now visible at the foot of the cliff, where they rest upon the ancient marine deposits, and are clearly seen to pass under a great thickness of rubble-drift or 'head.' Perhaps the clearest way to show their relation is to give detailed measurements at a point where the cliff is nearly vertical and free from talus, and where the recent beach opposite has been swept away, so as to lay bare part of the foreshore. Such a section was measured at about 150 yards east of the elvan :—

| | *Thickness in feet.* |
|---|---|
| Soil | 3 |
| 'Head' or coarse angular rubble of local rocks (elvan, slate, and some greenstone) | 20 |
| Loamy 'head,' mainly consisting of vein-quartz | 12 |
| Black loam, with fragments of charcoal, burnt bone, and burnt earth | $0\frac{1}{2}$ |
| Grey sandy loam, with small stones and traces of roots throughout | 8 |
| Clean grey sand (marine) | 1 |
| Ferruginous gravelly beach | $0\frac{1}{2}$ |

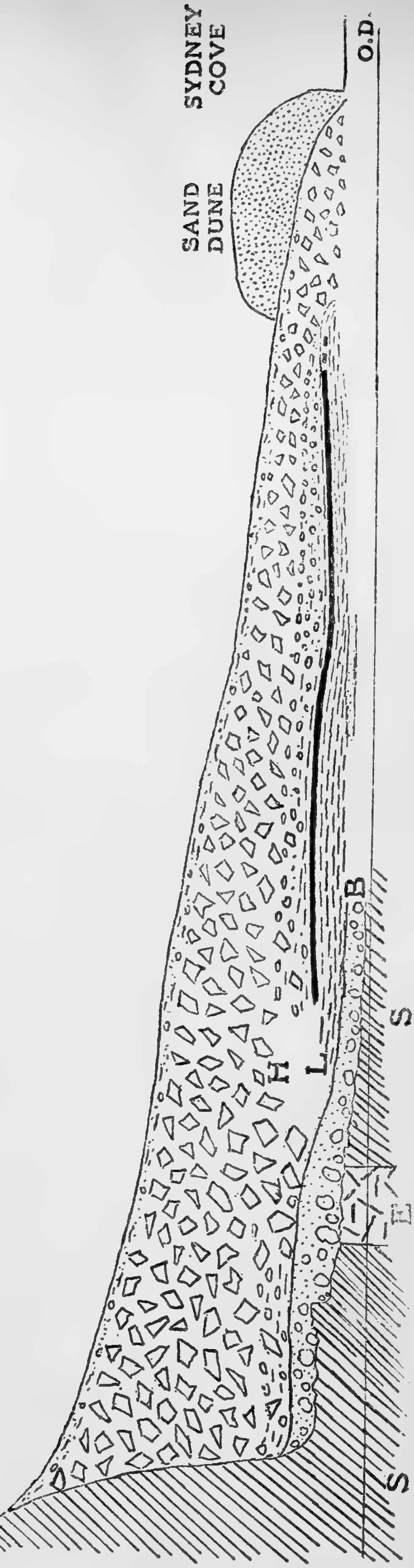
At this point the rocky platform could not be reached, the lowest bed seen only lying a foot or two below high-water mark.

It will be noticed that in the section just described, the marine beds are succeeded by a few feet of sandy loam or brickearth. This loam is traceable for about 200 yards, and is seen wherever the foot of the cliff is free from talus. In part it may be only worked-up material formed from the marine strata below; but, in the main, it seems to be an ordinary soil washed from the slopes above, for it is full of small chips of vein-quartz, though larger stones are uncommon. Towards the ancient buried cliff which formerly bounded the old bay on the west, the loam becomes more stony and like the 'head' above; but unfortunately that part of the section was somewhat obscured by landslips, and we could not ascertain exactly where the change occurs.

Careful examination shows that the loam was at one time a true land-surface, for it is full of small vertical roots. Unfortunately, these are preserved only as ochreous casts, too much decayed for miroscopic examination. Towards the top of the loam occurs a black seam, usually about 6 inches thick. At first this was thought to be peaty; but on washing a quantity of the material, we could find no trace of seeds or other fossils. We found, however, that the black colour was due to abundance of small fragments of charcoal, mixed with small splinters of carbonized bone, and fragments of burnt earth. On further examination, we ascertained that this charcoal was particularly abundant at several spots where the loam, as a rule nearly clean, contained groups of three or four blocks or flattish slabs of stone, which were generally of elvan. At these spots the black loam was commonly full of pieces of quartz, usually small, possibly the remains of larger blocks shattered by fire.

As we had evidently found a true land-surface, on which man had made hearths and lighted fires, a careful search was made in this black layer. Unfortunately, the deposit seems to have been thoroughly decalcified and the fossils destroyed by percolating water, for only carbonized remains are preserved. We found, however, that some of the larger pieces of vein-quartz in this layer were apparently fashioned into rude implements[1]; but these had been battered into shape, not flaked. This absence of flaking seems, however, to

Fig. 1.—*Section of the cliff at the western end of Prah Sands.* (*See p. 106.*)



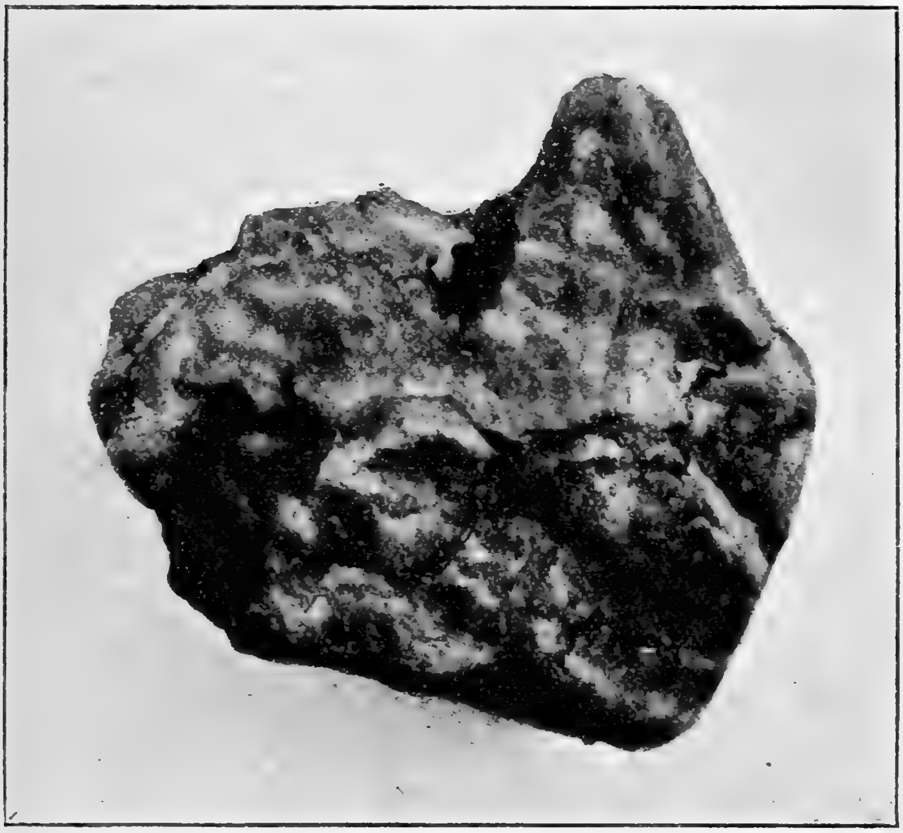

[Scales:—Horizontal: 180 feet=1 inch; Vertical: 80 feet=1 inch.]

H=Angular 'head.' L=Loam. B=Raised beach. E=Elvan-dyke. S=Slate.

[1] The specimens mentioned in this paper have been deposited at the British Museum, Bloomsbury, W.C.

be due to the intractable nature of the only material available. Vein-quartz breaks with a rough, splintery, fracture, for each lump is usually made up of portions of many crystals, and the material will not flake like Chalk-flint or like large crystals of quartz. No other local material is suitable for flaking into implements, for Chalk-flints are rare here and seldom occur in big pieces, while the granite, elvan, and slates are unworkable. The greenstone found in the neighbourhood is an extremely-tough rock, difficult to trim: but, though it is so suitable for hammer-stones, we found only one or two small pieces of it in the black seam. These, like the slate, were much decayed, and apparently had not been used.

Fig. 2.—*Rude implement (?) made of vein-quartz.* *(See p. 110.)*



[Photographed natural size.]

The quantity of charcoal observed, and the number of hearths found (six or seven) were surprising; but this bay must have been a particularly-favourable locality for occupation. It faces south, is sheltered by high land, and behind the terrace of raised beach the old sea-cliff in all probability furnished many dry caves suitable for dwellings. Within a few yards was also a stream of fresh water.

Above the black seam just described come several feet of loamy drift, in which the stones consist almost entirely of vein-quartz. Such a material is at the present day the ordinary soil of the country, where time has allowed of the decay of all other rocks. Under present climatic conditions similar material is being washed down the slopes, to accumulate in the flat-bottomed valleys, such as this must have been. This quartzose base of the 'head' also yielded a few doubtful implements, one of which is shown in fig. 2 (p. 109).

The quartzose loam passes upward into the well-known 'head' or rubble-drift of Cornwall, which consists of an obscurely stratified mass of local rocks, in blocks of all sizes, included in a more or less loamy matrix. This deposit is so porous that any fossils have disappeared, if such existed, and we are still without direct evidence as to the climatic conditions under which it was formed; but the evidence seems decidedly in favour of the generally accepted view, that it belongs to the later stages of the Glacial Period. Its mode of occurrence strongly suggests soil-cap movement, or movement aided by snow-slopes or masses of half-melted snow. The blocks which it contains are fresher, larger, and have travelled farther down gentle slopes, than is possible under present-day conditions. It differs from the modern rainwash and soil, and from that below in which the supposed implements are found; but these land-surfaces so closely resemble one another, that it is not easy to distinguish them where landslips have brought the two into juxtaposition.

Though palæontological evidence is still deficient in Cornwall, yet the succession in these Pleistocene deposits corresponds so exactly with that found along the Sussex coast, that we cannot refrain from thinking that the strata are of the same date. The 'head' of the Cornish coast seems to be equivalent to the 'Coombe-Rock' of the Sussex coast. The raised beaches of the two districts correspond. In each case we seem to find between them Palæolithic and old alluvial deposits.

## Discussion.

Mr. E. T. Newton explained that, among the North American implements which he exhibited in illustration of Mr. & Mrs. Reid's paper, some beautifully formed arrow-heads were made from an easily-worked material; but one was made from vein-quartz, a very intractable substance, from which only very rough implements could be produced.

Sir John Evans congratulated the Authors on having discovered what was very possibly a Pleistocene land-surface in Cornwall, but he objected to the use of the term 'Palæolithic floor.' The word 'Palæolithic' had a definite significance, and he could not accept the implements exhibited from Prah Sands as Palæolithic. They were naturally-formed fragments of vein-quartz, which might indeed have been utilized by the people whose remains were found associated with the hearthstones. The question was only confused by terming them Palæolithic: there was no evidence to determine absolutely the age of the land-surface. All that could be said was that it was the oldest, of human times, yet known in Cornwall.

Mr. STRAHAN considered that the paper was of wide interest. The raised beach which is recognizable at intervals for many miles along the coast of South Wales had been shown by Mr. Tiddeman to be overlain by the Glacial deposits of the neighbourhood. That it was of earlier date than those deposits admitted of no dispute, but Mr. Tiddeman had further expressed an opinion that a part of the raised-beach series was continued into the caves, and was there associated with the cave bone-beds. He (the speaker), while believing this to be highly probable, thought that it had not been actually demonstrated.

This Welsh beach corresponded, without much doubt, to that which occurred at Weston-super-Mare and at intervals along the coast of Devon and Cornwall. It seemed, therefore, to be highly probable that, although no Glacial deposits had been recognized in Cornwall, the band described by the Authors corresponded in position and age to beds which in South Wales were overlain by such deposits, and were probably associated with Pleistocene mammalia.

Doubt had been thrown upon the implements. But it seemed to him that the facts that stones of a special character had apparently been assembled for the definite purpose of making hearths, and that they were associated with charcoal, possessed the greatest significance. It would be necessary to prove, however, that the black fragments were really burnt wood, and not vegetable remains carbonized through lying in a porous matrix.

Mr. A. M. BELL congratulated the Authors on their having found an inhabited surface of Quaternary time; such were found more commonly on the Continent than in Britain, as, for example, in Moravia, on the central water-parting of Europe. The speaker had once, at a depth of 32 feet in unaltered river-gravel, found carbonized remains in Oxfordshire, but was unable to find implements along with them. Of the quartz-implements shown, he considered that some of them were probably used as tools, and resembled rude implements of Quaternary time.

Mr. W. SHONE said that there could be little doubt that the raised beaches of the South of England were post-Glacial, as compared with the Glacial Drift north of the Thames. The late Sir Joseph Prestwich had already pointed this out [1] :—

> 'There is the absence also in the Raised Beaches of such northern shells as *Astarte borealis*, *Leda pernula*, *Fusus islandicus*, *Natica grœnlandica*, and others common in the Glacial drifts. The Raised-Beach mollusca agree therefore pretty closely with the molluscan fauna now living in the British seas, and this accords with the stratigraphical evidence, which leads us to place the Beaches with the latest of the River-valley Deposits.'

The speaker's own observations confirmed Prestwich's conclusions.

Mr. G. CLINCH enquired whether the Authors could furnish such particulars as to the number and position of the hearths as might throw some light upon the approximate length of time during which

[1] Quart. Journ. Geol. Soc. vol. xlviii (1892) pp. 301–302.

this spot was inhabited. He thought that it would be interesting to know something more as to the character of the hearths and the exact position of the so-called 'implements' in relation to them.

Mr. P. F. Kendall observed that the relation of the raised beaches to the 'head' was clearly shown; the question turned on the mode of origin of the latter. He referred to the 'head' at Porthleven, which (as Searles-Wood, Jr., had suggested) was probably the result of soil-creep. The pulpy condition ensuing on the break-up of a severe frost might well produce such a 'creep.' It was very suggestive that the materials of which the hearths consisted were derived from elvans.

Mr. O. A. Shrubsole asked for further evidence as to the age of the carbonaceous layer. The fragments of vein-quartz were not in themselves sufficiently definite.

Mr. Reid, in reply to Mr. Strahan, explained that charcoal is almost indestructible, and the crumbs found in the loam have the rectangular fracture characteristic of charcoal. Unburnt vegetable remains might be found carbonized, but would occur as splinters, twigs, leaves, or seeds, none of which were seen. The only traces of plants, besides the charcoal, were small vertical roots, represented by fibrous ferruginous cylinders, too much decayed for microscopic examination. The charcoal appeared to be crushed and trampled into the soil, and the Authors had not yet been able to extract a piece sufficiently large for the determination of the wood, although the cell-structure was well preserved.

The Authors would not like to speak confidently as to any one of the stones exhibited being an implement; but the evidence was cumulative. The common occurrence of vein-quartz in a layer containing hearths of the fire-resisting elvan, the discovery of abundant crumbs of charcoal, the stratigraphical position of this layer, which seemed to coincide with the Palæolithic layer of the Hampshire coast, all pointed to the presence of man. If these rude tools were not implements, then we were confronted by the strange occurrence of numerous signs of human occupation, but no associated implements.

## 9. *On the* PROBABLE OCCURRENCE *of an* EOCENE OUTLIER *off the* CORNISH COAST. By CLEMENT REID, Esq., F.R.S., F.L.S., F.G.S. (Read March 9th, 1904).[1]

DURING the new geological survey of the Hampshire Basin fresh evidence was discovered of the westerly extension of certain of the deposits, in the form of Eocene river-gravels.[2] This evidence tended to link more closely the Eocene deposits of Devon with those of the Hampshire Basin; but it did not seem to throw any light on the Eocene geology of Cornwall, nor of any part of the area west of Dartmoor.

Some years since (in 1897) during a holiday-visit to the Lizard, I was much impressed by the character of the material which forms the extensive shingle-beach at Gunwalloe, on the western side of the Lizard promontory, not far from Mullion. The shingle, which was being extensively carted away for gravel, was so perfectly rounded, and in appearance was so unlike anything that I had expected to find in Cornwall, that I examined it closely, taking away samples to give to the Museum of Practical Geology, Jermyn Street. The coarser beach proved to consist largely (about 70 per cent. by weight) of Chalk-flint and Greensand-chert, only 30 per cent. being Palæozoic at the spot where it was examined. A large quantity of the fine shingle yielded:—

| | per cent. |
|---|---|
| Chalk-flint | 86·0 |
| Greensand-chert | 2·0 |
| Quartz | 9·0 |
| Grit | 2·5 |
| Serpentine | 0·5 |
| | 100·0 |

At the time, I was unable to carry the matter further; for, although well aware that scattered Chalk-flints were not uncommon in Cornwall, I could not understand why so many had collected at this spot, almost to the exclusion of the local rocks. The absence of Chalk-flints from the Pliocene gravels of St. Erth seemed to suggest that the Mullion gravel might be a Pleistocene deposit of glacial origin, or derived from some such deposit.

In 1901 and 1903, during the completion of the maps bordering on Mount's Bay for the Geological Survey, an opportunity was given for an examination of the deposits of Chalk-flint which are known to occur in the neighbourhood of Penzance, especially in

[1] Communicated by permission of the Director of H.M. Geological Survey.

[2] 'The Eocene Deposits of Dorset' Quart. Journ. Geol. Soc. vol. lii (1896) pp. 490–95; & 'The Eocene Deposits of Devon' *ibid.* vol. liv (1898) pp. 234–36.

Ludgvan. An excellent description of these deposits was given, as long ago as 1758, by William Borlase, the Cornish geologist, who was rector of the parish in which they are found. His account is as follows:—

'It has been generally held by Naturalists that we have no flints native in Cornwall, but this is a mistake. Betwixt the towns of Penzance and Marazion there is a beach of pebbles two miles and three quarters long, among which many hundred flints may be picked up every day; and lest it should be insinuated that these flints may possibly be foreign, and brought in ballast by ships, I must observe, that in the low-lands of the parish of Ludgvan, scarce a musket-shot from the said beach, in a place called the Vorlas, there is a *stratum* of clay about three feet under the grass: the clay is about four feet deep. In this clay, immersed from one to four feet deep (sometimes deeper) flints are discovered in great numbers, their size from the bigness of a man's fist to that of a bean, their coat nearly of the colour of the clay, (as in chalk we find their exteriour infected with the chalk-bed in which they lie) and their inward part died with the same colour more than half way; the other part, near the middle, a common, corneous, brown flint. In the same bed of clay, I find sea-pebbles of opake white quartz, and some shingle; sufficient and evident vestiges of the universal deluge. I find also many small blue killas stones, with all their angles on . . . . The flints of this bed of clay are brown within, but on the beach we have a remarkable variety, and one now before me of an opake white, is of as fine texture, and as high a polish, as any Carnelion I have ever seen' [probably the chalcedonic Greensand-chert of Haldon].[1]

The gravel is still dug at the place that Borlase names; it occurs, as Borlase pointed out, away from the sea and above the sea-level (usually 20 or 30 feet above), therefore it cannot be accounted for by any transportation as ballast. Though the name 'the Vorlas' is now forgotten, the old gravel-pits will be found on the landward side of Marazion marsh. In the small pits now open the flints are subangular, often up to 2 or 3 pounds in weight, and are mixed with Greensand-chert and a considerable amount of the local Palæozoic material, in a matrix of sandy loam. The origin of this loam, which is certainly not the original matrix, I do not propose here to discuss: it probably forms part of the raised beach which fringes Mount's Bay; but the sections now seen are scarcely satisfactory. It only concerns us here to point out that the large quantity of flint-gravel is not ballast, but was apparently there before the land was inhabited.

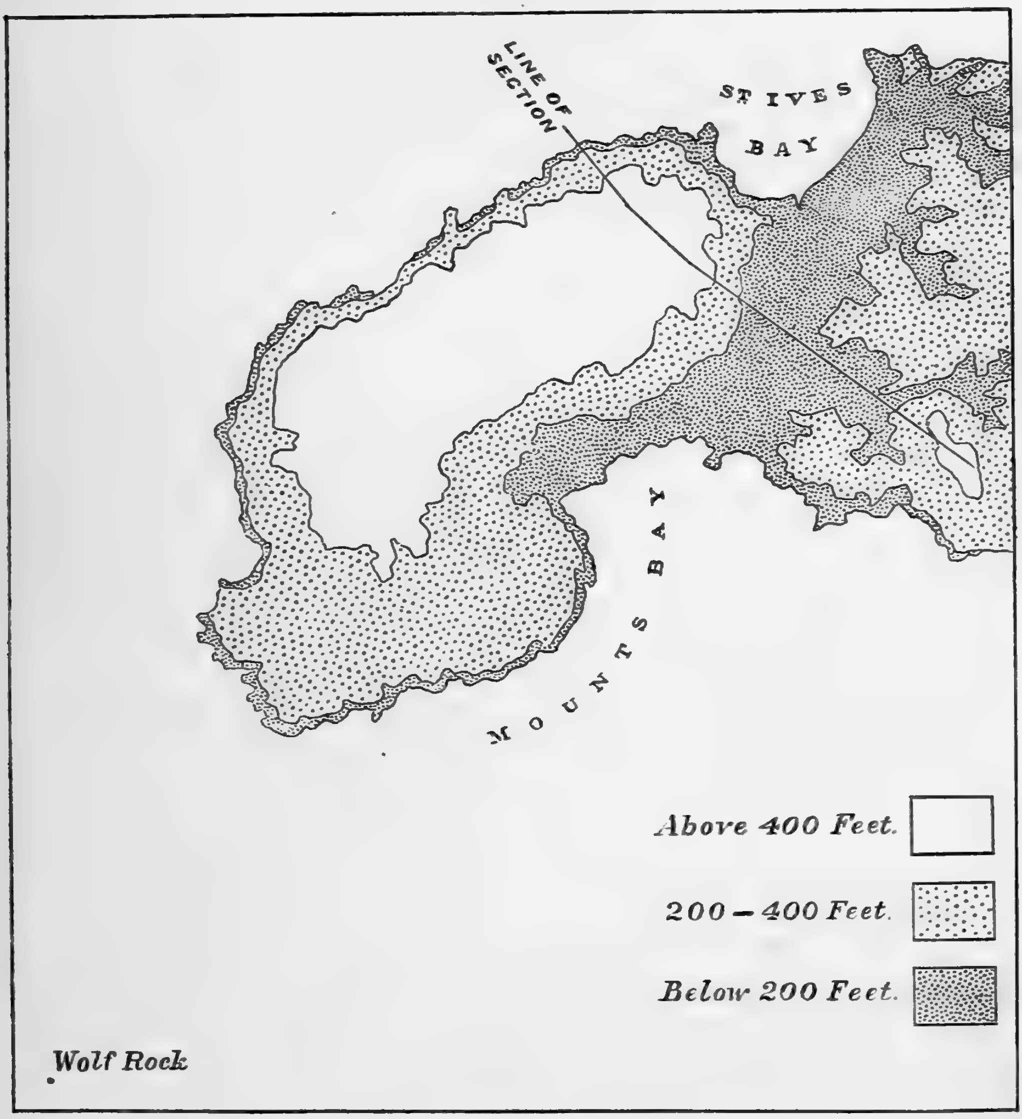
Certain striking characteristics of these flints seem not to have attracted the attention that they deserve. Though so far from any exposure of Cretaceous rock, they are subangular; and they are weathered and 'annealed' in the same curious way that is seen in the flints of the Eocene gravels of Devon and Dorset. In fact, the resemblance of the material to that of Haldon is so striking, that I feel sure that both flint and chert are derived, not directly from Cretaceous rocks, but through the intermediary of some Eocene river-gravel, such as was described in the two papers already published.

So far as we know, there is no reason to suppose that any Eocene outlier still exists in the county; but the curious localization of an

[1] 'Natural History of Cornwall' folio, 1758, p. 106.

extensive deposit of angular Chalk-flints at Ludgvan, and the occurrence of a mass of beach-pebbles of the same flints to the leeward at Mullion, convince me that an Eocene outlier is preserved, or lately existed, under the sea not far from St. Michael's Mount. The stones from this deposit were probably thrown up by storms and carried up entangled in seaweed, until they formed a considerable part of the raised beach opposite. They were also drifted by the

Fig. 1.—*Map of South-Western Cornwall, on the scale of 6 miles to the inch.*




prevalent wind right across Mount's Bay, becoming smaller and more rounded, till they were reduced to the smooth bean-like pebbles which we find at Gunwalloe.

The curious distribution of the flints, which elsewhere in Cornwall seem to occur only as scattered ice-borne erratics, combines with the striking contour of the bay (see fig. 1) in which the angular flints occur to localize the outlier; but there is a further piece of evidence, of which the bearing was not at first seen.

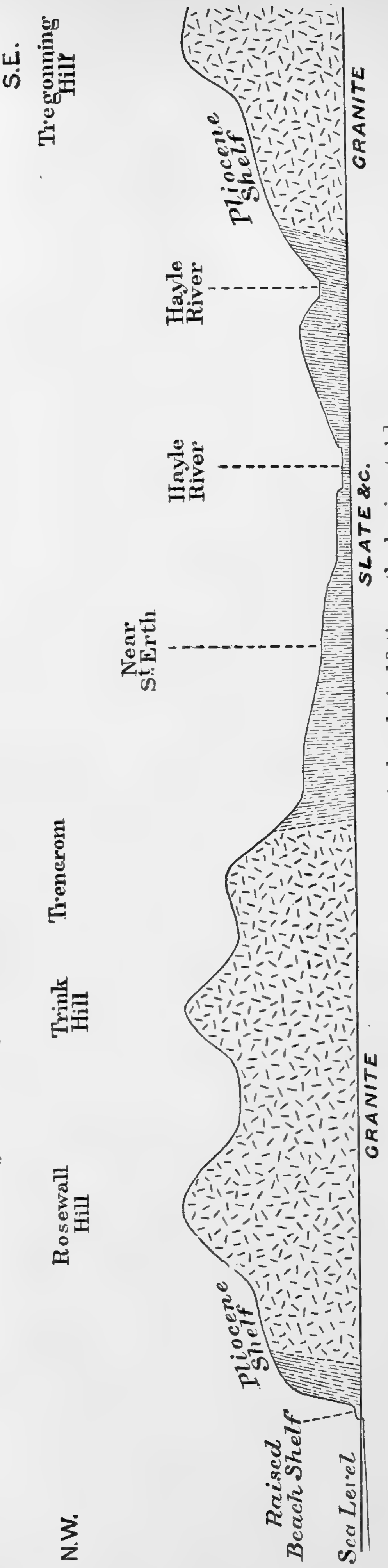



Fig. 2.—*Diagrammatic section across the St. Erth Valley (Cornwall).*

[Length=about 10 miles; the vertical scale is 10 times the horizontal.]

While examining the Pliocene deposits of Cornwall in 1886, I was puzzled to account for the valley (fig. 1) which crosses Cornwall from north to south, from St. Ives Bay to Mount's Bay, almost isolating the Land's-End district. This depression is partly occupied by Pliocene strata; but it obviously did not originate in Pliocene times; it is something older, something that does not fit in with the late-Tertiary denudation of Cornwall. A more extended knowledge of Cornish geology suggests that this Pliocene strait was once an Eocene river-valley, now so truncated at both ends that we cannot say whether it ran from south to north or from north to south.

The diagrammatic section (fig. 2) shows the relation of the Land's-End mass to the rest of Cornwall. It will be noticed that at about 400 feet above the sea there is a strongly-marked shelf, or plane of marine denudation, of Pliocene date, this plane bearing no fixed relation to the limits of the granite. The upper boundary of this plane is a degraded cliff, which may cut obliquely across any geological boundary. The Pliocene shelf is a striking feature throughout West Cornwall, especially on the windward side. But the Pliocene deposits are not confined to this shelf, patches being found near St. Erth at a much lower level, near the bottom of the wide open valley, which existed before the notch was eroded in its sides. The notch is the plane of marine denudation which was formed in Pliocene times near the sea-level; the parts of the pre-existing valley below that level, either remained unaltered, or tended to fill up with Pliocene sediments, outlying patches of which are still preserved.

The occurrence of an Eocene outlier at a low level opposite the southern end of the valley just described, suggests that the river flowed from north to south (more exactly from north-east to south-west); but this evidence is by no means conclusive, for we must remember that Miocene earth-movements played an important part in the Hampshire Basin, and disturbances of this character may have extended into Cornwall, quite altering the drainage.

The little evidence yet available suggests that Eocene rivers radiated from the high ground of Dartmoor, flowing westward as well as eastward, and that one of these rivers turned southward to cut through the depression leading to Mount's Bay.

Whether the Eocene gravel which seems to occur beneath the waters of Mount's Bay is a mere isolated patch or no is not clear. It may be an outlier belonging to an extensive Tertiary basin underlying the western part of the English Channel, and comparable in importance to the Tertiary basin of Hampshire. I would not venture to make this suggestion, were it not for a piece of evidence which cannot be ignored in a paper dealing with the Eocene geology of West Cornwall. Some 20 miles south-west of St. Michael's Mount lies the isolated mass of phonolite known as the Wolf Rock, on which stands the celebrated lighthouse. This volcanic rock has been a standing enigma to the geologist: there is nothing like it in Cornwall, the only lavas of this type in Britain being of Palæozoic date, and occurring in Ireland and Scotland. On the Continent the phonolites are mainly Tertiary. It has already been suggested by more than one writer that the phonolite of the Wolf Rock may be of Eocene date, for, unlike the Palæozoic igneous rocks of Cornwall, it is neither altered nor sheared.[1] The occurrence of a lava of this exceptional type, thus placed in the course of an Eocene valley, may perhaps be pointed to as a confirmation of the view that an Eocene basin may lie under the sea in the western part of the English Channel.

## Discussion.

Prof. W. W. Watts observed that one of the many interesting points of the paper just read was connected with the occurrence of phonolite at the Wolf Rock, at one time regarded as unique in the British area. Geologists had long been searching for evidence as to the date to which it could be assigned. However, Dr. Hatch had since discovered Carboniferous phonolite in the South of Scotland, and the speaker had discovered one associated with Carboniferous

[1] S. Allport, 'On the Microscopical Structure & Composition of a Phonolite from the Wolf Rock' Geol. Mag. 1871, p. 247; and 'Note on the Phonolite from the Wolf Rock' *ibid.* 1874, p. 462.

rocks, but possibly of later date, in the South of Ireland. If the Tertiary age of the Wolf Rock were proved, then it must belong to a distinct petrographical province, as all other Tertiary igneous rocks in the British area were free from nepheline.

Mr. H. W. Monckton said that the decayed flint-pebbles exhibited by the Author were very unlike the black and singularly well-preserved flint-pebbles characteristic of the Eocene pebble-beds of the London Basin. At Highcliff, near Christchurch, however, there were, no doubt, decayed flints in a Bracklesham pebble-bed.

Mr. P. F. Kendall said that the origin of the superficial deposits of Cornwall had given rise to much speculation and controversy. He did not think that the Author had offered very conclusive proofs of the age of the deposits, but he could not altogether agree with the previous speaker. The most corroded flint-pebbles that he had ever observed were from an excavation in Blackheath Beds at Mile End. They were actually pulverulent, yet distinct and characteristic. He had not understood the Author to imply that all the pebbles in Eocene deposits were corroded, but that such altered flints were characteristic of Eocene rather than of Pleistocene gravels. The paper constituted a bold attempt to solve the problem of the widely-extended deposits of subangular pebbles in Southern England and Southern Wales. He did not think that the phonolite of the Wolf Rock had any very direct bearing on the question. Prof. Cole had pointed out that the volcanic rocks of Ardtun, in Mull, were exceedingly rich in alkalies, and further search would possibly reveal the presence of phonolites there.

Dr. A. E. Salter asked whether the Author had detected fragments of any other materials, besides Greensand-chert and flints, similar to those found in old river-gravels, derived from the Dartmoor area to the east, as, for example, at Hardy's Monument (Dorset). The speaker had searched in vain some few years ago for evidences of a western drainage from Dartmoor, in Cornwall. On Crouza Down, in the Lizard district, at an altitude of about 360 feet above sea-level, is an extensive deposit of gravel, but the rolled fragments consist mainly of quartz. He agreed with previous speakers in doubting the advisability of relying upon the degree and manner of weathering of flints as evidence in proving the Eocene age of a deposit.

Mr. H. B. Woodward, adverting to the striated stone from the Scilly Isles exhibited by Mr. Barrow, asked whether the Author could not account for the transport of the accumulations of flints by some form of ice-action.

Mr. Barrow remarked on the curious distribution of pebbles in the Scilly Isles, some of them being found up to the highest levels on St. Martin. The noteworthy hollow which extends from St. Ives to Mount's Bay is a phenomenon repeated over and over again in the Scilly group.

Mr. Whitaker objected to calling most of the stones exhibited 'pebbles,' as they hardly deserved that description. Despite the great mass of the pebbles in the Eocene of the London Basin being black flint, there were exposures where decomposed flints were found, and these in old descriptions of Eocene sections were termed (wrongly) 'Chalk-pebbles.' It would be remembered that in the Chalk itself there were decomposed or 'thick-skinned' flints. He took it that the Author regarded the Eocene of Cornwall as consisting largely of river-gravels. In such deposits we must expect variety rather than a monotonous uniformity.

The Author, in reply to Mr. Monckton, thought that the characteristic internal alteration noticed in flints from Eocene deposits was not confined to the Hampshire Basin, but was equally common in the neighbourhood of London, at Highgate, Hampstead, and Stanmore. It could not be described properly as 'weathering,' for it was apparently a change that took place while the flints were embedded in the sandy or clayey matrix.

In reply to Mr. Kendall, he thought that the perfect rounding of the Cretaceous material in the beach of Gunwalloe was due to the drifting of the flints, for 15 or 20 miles across the bay from near Marazion, where the flints were both subangular and larger.

Mr. Woodward's suggestion that these angular flints might have been brought by drift-ice would not explain their occurrence in large quantities at one spot, while bays on either side only yielded the flints sporadically. These sporadic stones, in all probability, pointed to the agency of drift-ice in Mount's Bay in Pleistocene times, as did the striated erratic from Scilly exhibited by Mr. Barrow.

## 10. Implementiferous Sections *at* Wolvercote (Oxfordshire). By Alexander Montgomerie Bell, Esq., M.A., F.G.S. (Read January 6th, 1904.)

A section at Wolvercote, a village 1½ miles north of Oxford, has been open for the past ten years, and will reward study by geologists interested in the phenomena of Pleistocene time, whether their object is to study the changes of land and climate, or whether, as was the case with the writer, they seek for some detail in the fragmentary story of Palæolithic Man.

The section contains four parts, which may thus be named in the order of their age: (1) the Oxford Clay beneath, which is largely quarried for bricks; (2) an old surface, in which pits or troughs chiefly filled with gravel are seen enveloped in weathered clay; (3) a river-bed, containing gravel at the base, and layers of variously-coloured clay above; and (4) a surface-layer of humus over all, about 2 feet thick, containing Neolithic remains. The relation which the various parts bear one to the other is also plain. The old Pleistocene surface lies upon eroded Oxford Clay; the river-bed has worn a channel in the old Pleistocene surface; between the river-bed and the Neolithic surface is the trail usually named 'warp,' which, however, is not discussed in this paper.

The river-bed first attracted my attention; it lies on the summit of land between the Isis and Cherwell, at an equal height above either river. There seems to be no reason to doubt that it represents the deposits of a stream which contained the united waters of both rivers, at a time before they became separated to their present levels by the erosion of the soft clay. The channel is 17 feet in depth from the present surface to the clay beneath; it is seen descending on the western side from about 3 feet from the surface to 17; it has a considerable breadth, as about 40 yards of the old bottom are visible, and the bank of the stream on the eastern side is not laid bare.

The riverine section itself has two parts: at the base, to a depth of about 2½ feet, is a bed of gravel and sand, largely current-bedded, and containing many quartzite-pebbles of medium size. There are also exceptional stones, about 2 feet square, both of quartzite and of sandstone.[1] A quartzite-stone of this size, but little weather-worn, is an anomaly in the Thames Valley, though its appearance in the river-bed requires no further explanation than deposition from river-ice, or from the roots of a floating tree in which it had been embedded. The lighter stones point north and south, showing that the current flowed in the same direction as the present Isis and Cherwell.

At the top of this gravel-bed was a thin lenticular layer of

[1] It has been suggested to me that these may be greywethers, but the sandstone is probably Lower Greensand.

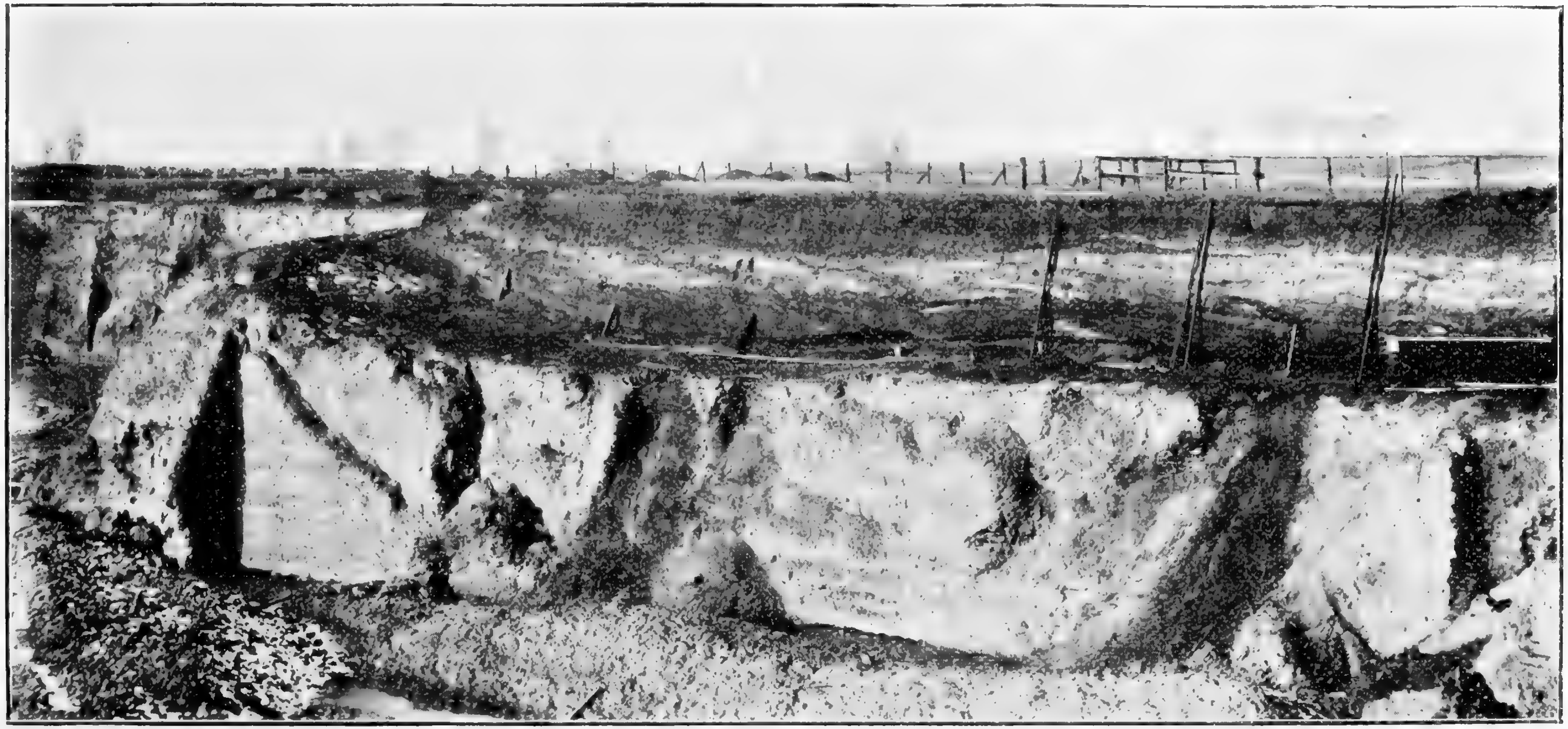
peat and sand, not more than 2 inches thick. Mr. Clement Reid, F.R.S., examined a portion of it, and rightly described it not as originally having been a land-surface with vegetation growing upon it (which I had at first thought it to be), but as a water-surface, which had caught and deposited in a backwater a number of plant-remains floated down the stream. It is material to an examination of the bed that this layer, now below 15 feet of soil, must at the time of its formation have been at the surface of the water. Peaty substance would not form at the bottom of a flowing stream.

The 15 feet of strata between the gravel and the present surface have a different appearance. They are conformable to the gravel below, and have been laid down by water, as is manifest from the long and even lines of deposition. But there is no gravel and little sand, only successive layers of mud or clay—sometimes blue Oxford Clay, very little altered, at others the layers are coloured yellow and red by the oxidation of iron. The whole upper part has the appearance of having been laid down in a lake, or in a large river-pool, but not in a running stream such as deposited the gravel below the lakes. Prof. Phillips [1] wrote, no doubt correctly, of lakes which had existed and disappeared in the earlier stages of the formation of the Thames Valley. The position at the head of the gorge at Goring is one that naturally suggests a prehistoric lake; and at the present day it forms a lake in times of flood. The Wolvercote site in its present condition bears no resemblance to one where a lake would be likely to form, as there is a natural fall in the ground to the eastward, the direction of the stream, and there are no approaching spurs of higher ground on either side. If we consider that the beaver was a tenant of the valley in Pleistocene times, we have, I think, no improbable reason for the surface of the stream to have risen in height, and for the formation of a pool instead of a running stream. Beavers' dams are sometimes 300 yards in length, and a barrage of this size would completely account for the change visible in the section. Had I found fossil remains of the beaver in the bed, I should have offered this explanation of the upper part of the section without any hesitation. I have, however, found neither beaver nor anything else in this portion of the section; nor have I seen remains of the beaver except in a Neolithic peat near Faringdon. At the same time, the beaver was a Pleistocene creature, and his influence in altering a river-landscape was probably at that epoch little interfered with by man. Even in later times the influence of the beaver should be looked for; probably many flat plains upon the reaches of our rivers owe much of their form to the handiwork of this busy creature in the Neolithic and early historic ages.

To complete the description of the river-bed, it should be added that the Oxford Clay beneath the gravel is curiously pitted. This gravel does not lie in a horizontal plane above the clay, but fills innumerable contiguous pits measuring about 3 feet in diameter and 1 foot in depth. The clay beneath the deposit which I have

[1] 'Geology of Oxford & the Valley of the Thames' 1871, pp. 462–63 & 468.

Fig. 1.—*River-valley section at Wolvercote (Oxfordshire).*



[On the right and in the centre is a gravel-bed, with a lacustrine deposit above it—both fluviatile. On the left is seen the older surface: troughs in the weathered Oxford Clay, filled with sand and gravel, not of fluviatile origin.]

named the 'older surface' is not pitted in this manner, so I attribute the phenomenon to a form of river-action, which I am unable to explain.

## The Associated Fossils.

The gravel-bed has proved richly implementiferous. The implements are formed of flint taken freshly from the Chalk, or of quartzite-pebbles of the Northern Drift, and they are remarkable for their size, beauty, and freshness. As usual, they have a facies of their own; the oval type is rare, and the pointed examples are very frequently flat or nearly so on one side, belonging to what Sir John Evans has named the 'shoe-shaped' type.

Many of the usual mammalian remains are also found: *Elephas primigenius*, *Equus caballus*, *Bos primigenius*, *Cervus elaphus*, are all of frequent occurrence, and *Rangifer tarandus* has been once obtained. For smaller mammals I have searched, but unsuccessfully. Neighbouring gravels at a lower level, but probably of similar age, have yielded examples of *Rhinoceros*, *Hippopotamus*, and *Felis leo*, var. *spelæa*.

In the sand mixed with the gravel were found a number of fluviatile shells, of which eleven species were identified by the late Prof. A. H. Green and his assistant. They did not include the distinctive *Corbicula fluminalis*, which does, however, occur at several places in the neighbouring gravel about half a mile distant.

The layer of peat has also disclosed some of its treasures. It cannot be separated as to age from the gravel beneath it, for it contains the fragments which floated on the water of which the gravel formed the bottom. The late Prof. Green associated it with the implementiferous gravel, with which it was conformable in deposition and in the shells contained in both. It was also conformable to the water-formed layers above; all three (gravel, peat, mud) formed portions of a single deposit, clearly marked off by the warp above from the Neolithic layer of the surface. It is necessary to say this, because Mr. Clement Reid[1] regards the deposit as 'of uncertain age.'

While disagreeing with him on this point, I am sincerely grateful for his courtesy in identifying the flowering-plants found in the bed. They are thirty in number, and include four species of *Ranunculus*, three of *Potamogeton*, three of *Carex*, two of *Scirpus*, also *Zannichellia*, *Ajuga*, *Lycopus*, *Heraclium*, *Thalictrum flavum*, a *Rumex*, *Hippuris*, and *Betula*. This list contains nothing distinctive, nothing characteristically northern or characteristically southern, but it harmonizes very well with the flora obtained by Mr. Reid from deposits which he names Interglacial. From the animals with which they are found, the natural inference is that the plants belong to that great section of our flora which entered our island—then a portion of the Continent—from Eastern Europe and Western Asia, coming at the close of a great glaciation to cover with verdure the lands which the ice-cap had left bleak and barren.

[1] 'The Origin of the British Flora' 1899, p. 85.

The evidence yielded by the mosses is more remarkable, and strengthens to certainty the inference derived from the flowering-plants and animals. For identification of the moss-collection I have to thank, first, Mr. A. Gepp, F.L.S., of the British Museum (Natural History), who kindly looked over the first examples found; and, secondly, Mr. H. N. Dixon, M.A., F.L.S., of Northampton, who took great pains to examine and name a large number of specimens placed in his hands. The following list consists of Mr. Dixon's verifications:—

*Amblystegium filicinum*, De Not.
*A. Kochii*, B. & S.
*A. serpens*, B. & S.
*Aulacomnium palustre*, Schwægr.
*Brachythecium glareosum*, B. & S.
*Br. rutabulum*, B. & S.
*Bryum erythrocarpum*, Schwægr.
*Camptothecium nitens*, Schp.
*Climacium dendroides*, W. & W.
*Dichodontium pellucidum*, Schp.
*Eurhynchium Schwartzii*, Hobk.
*Eu. speciosum*, Schp.
*Homalia trichomanoides*, Brid.
*Mnium affine*, Bland.
*Mn. rostratum.*
*Philonotis fontana*, var. *ampliretis*, Dix.
*Thuidium decipiens*, De Not.
*Th. recognitum*, Lindb.
*Webera albicans*, Schp.
*W. nutans*, Hedw.
*Hypnum aduncum*, Hedw.
*H. aduncum*, var. *pseudofluitans.*
*H. capillifolium*, Warnst.
*H. chrysophyllum*, Boisd.
*H. commutatum*, Hedw.
*H. cordifolium*, Hedw.
*H. cuspidatum*, Schreb.
*H. exannulatum*, Gümb.
*H. falcatum*, Brid.
*H. fluitans*, L.
*H. fluitans*, var. *falcifolium*, Rœm.
*H. giganteum*, Schp.
*H. intermedium*, Lind.
*H. lycopodioides*, Schwægr. (doubtful).
*H. revolvens*, Sow.
*H. Sendtneri*, Schp. (probable).
*H. stramineum*, Dicks.

The list is interesting, and points to one of the largest collections of mosses yet secured from a Pleistocene deposit. About two-thirds of these mosses may still be found in the neighbourhood. This corresponds with the flowering-plants. On the other hand, *Hypnum capillifolium*, Warnst., is not now found in Britain, and has only once been obtained before, from a deposit at Mundesley, where it was got from the Arctic Freshwater-Bed at a depth of 59 feet. This species of moss now occurs in Siberia, in Central and Northern Europe, and in America in Vancouver and other northern regions. It is not, however, recognized as a boreal plant.

*Thuidium decipiens*, De Not., is perhaps equally important. It is a rare moss, found in wet places on mountains, and in this country confined to the Highlands of Scotland. These are the two most important; one denoting an Alpine plant, another a plant no longer British, and closely approaching the Alpine flora.

Of the others the following are no longer found in the county of Oxford:—*Camptothecium nitens*, Schp., *Dichodontium pellucidum*, Schp., *Hypnum giganteum*, Schp., *H. revolvens*, Sow., *H. stramineum*, Dicks, which all occur in mountainous or subalpine regions.

Seven at least of the species identified no longer grow in the county: one has left Britain, and a second has retired to the Scottish Highlands.

Some conclusions doubtless may be legitimately drawn from these facts:—(1) The Glacial flora had not entirely withdrawn. It is still marked by one, if not by two species. (2) The land was more elevated than it is now; the considerable percentage of mountainous species seems to call for this conclusion, which on other grounds is also demanded. (3) The land appears to have been very wet, almost waterlogged. A high rainfall is also called for by many phenomena of Pleistocene time, and would follow from the previous conclusion. If the Cotteswold water-parting were from 400 to 600 feet higher than it now is, the rainfall of the Thames Valley would undoubtedly be greater than the channels can properly deal with. (4) From the number of now-existing species I infer a warmth of climate fully equal to that of the present day.

A collection of elytra and other parts of beetles was also secured, numbering probably 30 species; these have not, as yet, been determined.

In the lacustrine or still-water portion no fossil has been found. Fragments of shells are here and there visible, but no fragment of wood or bone, or determinable plant.

The deposit as a whole is a typical river-valley deposit. Implements, mammalia, mollusca, flora, all are characteristic of such a formation as Sir John Evans describes in the 2nd edition (1897) of his well-known work on the 'Ancient Stone-Implements of Great Britain' (pp. 662, 679, 686):—

> 'I have made no scruple in treating them hitherto as being river-drift. . . . . The character of the beds, consisting as they do, of gravel, sand, and fine silt, brickearth or lœss, and their manner of deposition, are also absolutely in accordance with the river-hypothesis. . . . . The discoveries in the gravels capping the North Downs, and those made near Ightham and Limpsfield in the transverse valley at the foot of the Downs, seem at first sight difficult to reconcile with any river-theory. But, assuming that the beds capping the hills were at one time continuous with others in the Wealden area, and that the transverse valley was produced by denudation at a later date, the difficulties disappear.'

His general theory is, that practically all implementiferous deposits are of a similar character and of fluviatile origin.

It appears to me, however, that the other part of this section affords convincing evidence of an earlier stage of Palæolithic life, not preserved in a river-gravel. The previous surface already mentioned (p. 120), which has been wasted away where the river-gravel lies, is instructive. Before describing the section, I should like to quote the words of the late Prof. A. H. Green. On my going with him to the spot, after I had found implements beneath the peat-bed above described, he said:—

> 'I have never paid particular attention to Palæolithic gravels for their relation to human remains, but I have often visited this section for another purpose. You observe the remains of an old surface which has been hollowed out by a river. You see hollows in the clay filled by pebbles of the Northern Drift. All these pebbles you will find re-arranged in the bottom of the river-bed, and I have often brought my pupils here to show them how a newer bed is formed by the destruction and re-arrangement of an older deposit. . . . You have not, I imagine, found implements in the upper gravel or old surface?'

I replied that I had not: that I had examined the exposed parts, but found nothing. He remarked that it was unlikely that I should find them.

This previous surface has now proved to be implementiferous; there are side by side two implement-bearing deposits, different in character and different in age.

This surface consists of a series of troughs formed in the clay, and filled with gravel, sand, and earth. The stones which the troughs contain consist largely of quartzites, lydian-stone, and quartz-pebbles. These pebbles all belong to the 'Northern Drift,' by which name Prof. Green told me to style the deposit. In this Prof. Phillips would, I imagine, have agreed with him. In the 'Geology of Oxford & the Valley of the Thames' (1871) pp. 457–58, Phillips wrote:—

> 'To these I assign the title of Hill-deposits, not that they are exclusively found on elevated ground, but because this fact is characteristic of them, in contrast with the others. Scattered materials of these hill-gravels are often found in low ground mixed with those in the true valley-deposits, under circumstances which indicate the anterior date of the former.'

This exposure was not expressly mentioned by Phillips, although it was in his time exposed in a railway-cutting, which adjoins the section now under discussion. At the same time, besides the northern pebbles, we also find in the troughs much gravel from the Thames Valley, limestone-pebbles, and Oolitic fossils, together with sand. The presence of these materials has led me to regard the Drift as not the true Northern Drift, which caps the hills around at a level of about 500 feet, while the Wolvercote level is 240 feet, but as a Thames-Valley Ice-Drift, consisting largely of a remaniment of the Northern Drift.

The Wolvercote Drift shows itself in somewhat flask-shaped holes in the clay, filled up by gravel, and with columns of clay between, still attached to the unbroken Oxford Clay beneath. The question arises as to how such a drift is formed. Is it a drift of rainwash?; or is it perchance no drift at all, but the result of underground water forming holes in the clay, which are filled up by the infall of surface-stones?; or, again, is it an ice-drift? It is not a rainwash-drift, because, if it were, it would not have narrow inlets at the top, which spread out beneath, but would be spread out over the surface, with slight traces of bedding. Nor has it been caused by underground water, as the action of water would be visible at the lowest point where the flow was continuous; the stones at the sides would also have a tendency to drop towards the centre, when the stream was carrying away material. There are no traces which lead me to attribute it to this cause.

It is otherwise when the ice-drift hypothesis is tried; for here there are several salient facts which find an explanation. The troughs are fan-shaped. The pebbles in the centre have their longer axes pointing downward, while at the sides they are horizontal. This seems to show that they were pressed down by a weight above them, which, as it forced them to move into the yielding clay on the sides also, caused them there to take up a horizontal position, along the line of least resistance.

Again, the material is not only free from any bedding, but lumps of sand are stuck in beside masses of Thames gravel in a manner which suggests that they were frozen or half-frozen when they were shoved in; otherwise it is hard to account for the oblong lumps of sand.

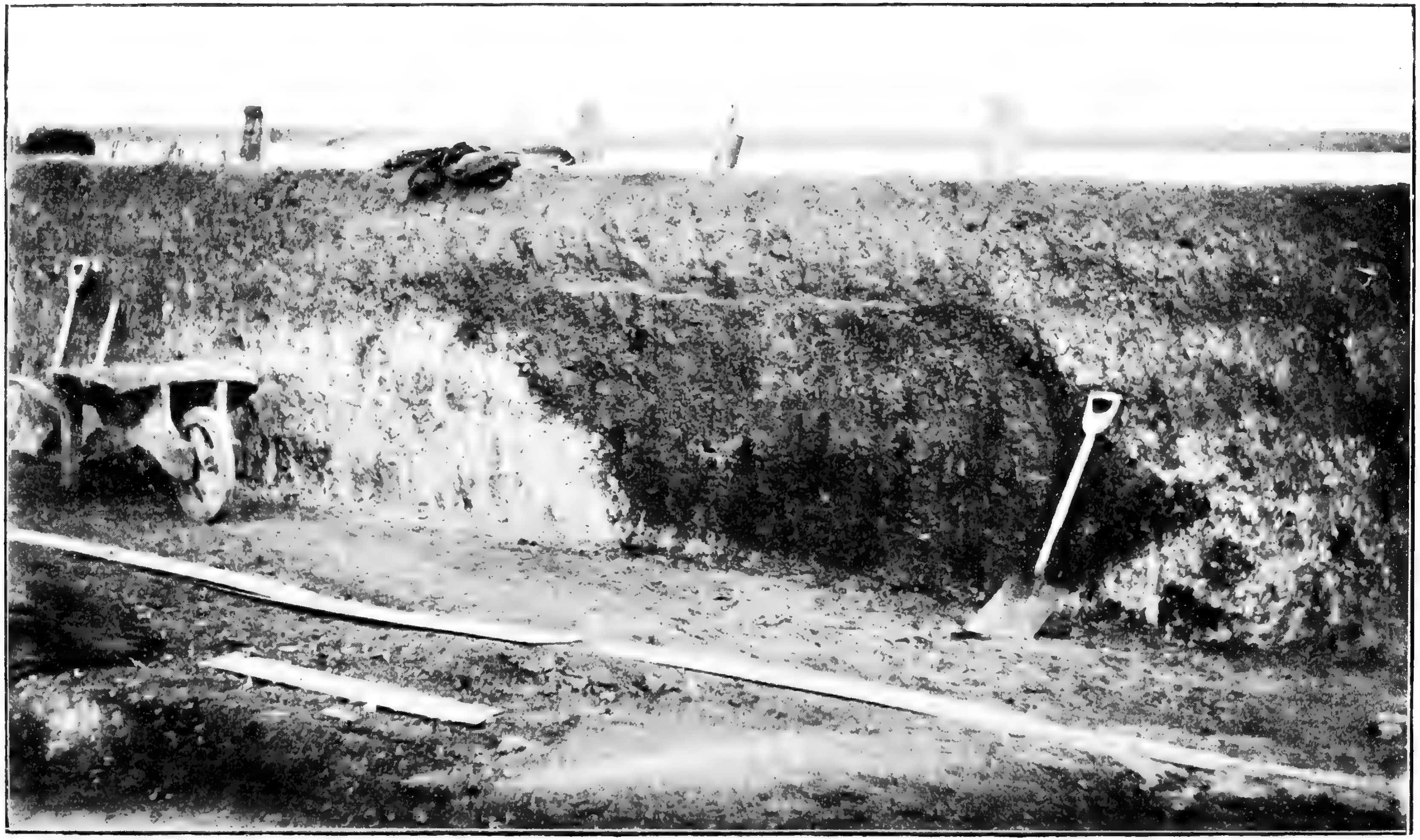
Another circumstance was to my mind decisive, both as to the age of the Drift in relation to the gravel-bed, and the nature of the cause to which the Drift is due. It is this: the Oxford Clay beneath the Drift is weathered to the depth of about 10 or 12 feet; it seems to have been shaken, and penetrated so far by surface-water. This line of weathering is constant beneath the Drift; and when it approaches the gravel-bed, it goes under it for a certain distance until it is cut off by the descending depth of the river-gravel. Beneath the deeper part of the old river-valley the blue clay is quite unweathered. Three facts are here proved: (1) The weathered band of clay was older than the ancient river, because the river destroyed it; (2) the force of the river did not weather the clay beneath; (3) the force of the Drift did weather the clay, and must consequently have been a heavy and a powerful force. A rolling drift of ice, snow, stones, and mud would be heavy and powerful, and might, I think, act so as both to shake the clay beneath and to shove portions of its own gathering mass into the softened clay beneath its passage. This, at least, is the only explanation of the section that I can suggest as satisfactory. I consider it to be an ice-drift, and to mark an important epoch in the Glacial Age.

At a distance of about half a mile, at a place called Peartree Hill, and on an elevation similar to that of Wolvercote, there is another section of the Drift (see fig. 2, p. 128). Its features are quite similar to those which I have described; it also contains implements, and the clay beneath it is also weathered and shaken in the same manner as the clay at Wolvercote. There is at Peartree Hill no trace of any river-action: there is solely the Drift.

From the Drift at Wolvercote no fossil has been obtained, except the implements, which constitute at least a trace of life. From Peartree Hill I have obtained from a workman (and the staining corresponds with the gravel) the canine tooth of a wolf—an unsatisfactory fossil, as it gives no indication of the age of the gravel.

The implements obtained from the two beds are in two ways distinct. Those found in the river-bed are very large, of beautiful shapes, of chalk-quarried flint, and very little stained. Those from the Drift are small, of very ordinary shape, formed of flint taken mostly, if not altogether, from the Drift. To the simplicity or rudeness of form I do not attach much importance: partly, because few implements only have been found, not a sufficient number on which to base a general judgment; partly also, because very simple forms are found in use throughout all Palæolithic time; partly, because very beautiful forms of implements occur in other

Fig. 2.—*Section in the Drift at Peartree Hill (Oxfordshire).*



[The above section shows one of the troughs of sand and gravel driven into weathered Oxford Clay. Implements were found at the base of these troughs.]

gravels, which it is difficult to believe of later age. It is of some importance if an implement has been made from a weathered pebble of the surface. When I first began to collect and examine these tools in the parish of Limpsfield in Surrey, where they lie largely on the surface, I found two classes, often very distinguishable—tools of surface-flints, and later tools of quarried flint. This distinction appears again in Oxfordshire, and is probably of some importance.

The last distinction is one which I must consider of great importance. The river-bed flints are slightly weathered, or not at all; while the Drift-flints are deeply weathered, white or brown, usually all over, always at least partially. Flint-fragments from the river-bed present a totally different appearance from fragments taken from the Drift: from the river-bed they are black or transparent; from the Drift they are ochreous and opaque. This is an important fact; and I draw from it two inferences, which are also important and may provoke discussion. I was told, twenty years ago, by one of the fathers of this study:

'From the weathering of a flint no inference can be drawn. I have frequently found in the same bed, side by side, worked flints—one quite fresh, the other weathered and worn.'

This silenced me at the time; but a proper answer would have been:

'Yes; but your two flints were not of the same age. The unweathered flint was contemporary with the bed where you found it; the weathered one originally lay in another bed, where it was stained; it was dislodged after a long burial, exposed and rolled, and finally deposited in a fresh bed, where it was a fossil detached from an earlier deposit.'

It is certain that the weathered character explains many difficulties in classifying implements. For example: at Iffley, a mile below Oxford, there is another implement-bearing gravel. It stands at a lower level than those previously described; its base is very nearly on a line with the surface of the present river, about 300 yards distant. It is consequently of a later age than either of the Wolvercote deposits; but it does not follow that all its contents are of a later age, or contemporary with the deposition of the gravel-bed in which they lie. Quite the contrary; it is an *omnium gatherum* of all the débris that ever rolled in the Thames Valley: Oolitic fossils, Cretaceous fossils, Tertiary conglomerate, Northern-Drift quartzites, jaspers, and volcanic rocks, gravel, and sand. When in this gravel an unweathered implement occurs, I think that I am justified in correlating it with the unweathered river-bed implements of Wolvercote; whereas, if the implement has an ochreous staining, I consider that it once belonged to the Drift-bed, of which so few fragments now remain *in situ*. Such an inference encroaches upon certainty: I feel inclined to add that all ochreous or deeply-patinated implements are of the same or similar age, wherever they are found.

My second inference is, that the time between the Drift and the river-bed was prolonged; that there is a great interval, perhaps as great as that which separates the river-bed from ourselves. The evidence consists in the patination of the two groups of flints. We must remember that these two groups of flints lie under similar influences; they are both in gravel and sand; they are both permeated by water depositing carbonate of lime and oxide of iron. Why should they be so completely different—one class deeply patinated, the other little altered? Why were they as deeply patinated when the second stage began as they are now? They seem to have been so, from the evidence of secondary work on the edges of ochreous implements. I, at least, cannot explain it, except on the supposition that the ochreous class has been exposed to weathering influences for a far greater length of time than the other: in other words, that there is a great gap between the two beds. If the Drift-bed has been rightly attributed to a return of cold conditions, and if the return of cold conditions destroyed all the ordinary flora of the country, then the return of the flora, so marked a character of the river-bed, would be a kind of measure: it would mean that between the first bed and the second practically the whole of our recent flora had returned to our shores.

I endeavoured for many years to work on Sir John Evans's theory of river-action alone. If I may be allowed to give my present hypothesis, it is that implement-bearing deposits are of different kinds, and fall into three classes:—(1) River-gravels, which Sir John has eloquently described. (2) Rainwash-drifts, which occur at high or low levels under circumstances well described by Mr. Clement Reid in the following words [1]:

'The South of England, during the second period of glaciation, seems to have suffered from dry, cold winters, which froze the ground unprotected by snow, and allowed the summer rains to fall on soils rendered impervious by deep freezing. This led to enormous and rapid denudation, over areas where the rain now sinks in and is slowly given out as springs. Masses of loose flint and chalk-débris were swept off the South Downs, and spread out in a wide sheet extending several miles over the lowlands.'

If any geologist, with these words in his mind, will examine the section at Knowle Farm, in Savernake Forest, he will find in them a fitting explanation. The gravel is loosely thrown together, and has no horizontal layers; the newest implements are fresh, and lie at the base, where they were covered by the descending débris, which frequently contains weathered and worn implements of earlier age. It is a gravel caused by excessive rainwash on a sloping hill. (3) These are ice-drifts, such as that which has been described in the foregoing pages. I would set in this class the gravel-bed of Limpsfield Common in Surrey, a deposit which, more than twenty years ago, was the origin of my interest in these studies, and of my resolution to grapple with their perplexities.

[1] 'The Origin of the British Flora' 1899, pp. 44–45.

## Discussion.

Prof. Sollas congratulated the Author on the successful conclusion to which he had brought his arduous and protracted labours. With regard to the evidence of ice-action afforded by the Wolvercote pit, he could not regard it, taken by itself, as conclusive. When the Author had first shown him the curious disturbances in the Oxford Clay, he had been much impressed by them, particularly when he found in them the singular tea-leaf structure which was sometimes associated with imperfectly-foliated Glacial clay; but, while suggestive, the evidence was not demonstrative, for other agencies, such as subterranean erosion, might conceivably have produced similar results. The Author had also shown him flint-implements bearing fine striæ, but observations on implements from Amiens revealed the presence of similar striæ on them, and it remained possible that river-ice or internal movements of the gravels might be responsible for these markings. In any case, the evidence had not been sufficient to produce conviction either in himself or others. Later observations, with which the Author had been made acquainted, on Shotover and Cumnor Hills, had, however, thrown an entirely-new light on this matter, and there could now be little doubt that the disturbances in the Oxford Clay at Wolvercote were of the same nature as those exhibited elsewhere in the district on a grander scale, which were to be explained by ice.

The speaker thought that some attempt might be made at a closer analysis of the problem than was implied by the use of the term 'Palæolithic.' Prof. Moritz Hœrnes, from a review of the whole body of evidence furnished by observations in Europe, had been led to subdivide the Palæolithic Period into three stages, characterized by their fauna, geological horizon, and state of culture: these are the Chelléen-Moustérien, the Solutréen, and the Magdalénien. An examination of the implements exhibited by the Author showed that they were plainly Chelléen: there were no pointes à feuille de laurier, no pointes à cran, nothing to remind one of Laugerie Haute or Crô-Magnon, still less of La Madeleine. Therefore the evidence from culture-stages would assign this find to the lowest subdivision of Hœrnes. Turning to the fauna, it was especially characterized by horse and mammoth, and thus should be referred to the second stage. Finally, the terrace to which the gravels belonged was the lowest in the Thames Valley, and must be referred by hypothesis to the last inter-Glacial stage, or third subdivision of Hœrnes. They were thus presented with a very remarkable problem—the three characters on which Hœrnes depended spoke each with a different voice—the implements pointed to Chelléen, the fauna to Solutréen, and the geological horizon to Magdalénien.

Mr. Clement Reid said that he had spoken of the flowering-plants as of 'doubtful age,' because they came from a deposit overlying the implement-bearing gravel, and not from the same deposit as the implements. Also, these plants were all species of wide climatic and geographic distribution, and were still living near Oxford. The determination of several species of boreal mosses showed that the plant-bed was of Pleistocene date; but it did not necessarily prove that the plant- and implement-beds were contemporaneous.

Mr. P. F. KENDALL thought that Prof. Sollas had convincingly demonstrated, either the entire unreliability of the Continental classification, or its inapplicability to the succession in England. Some of the implements could be matched with those from Hoxne, which were of very late Glacial, perhaps the very latest Glacial age. He concurred with the Author in believing that land-ice had come down to the Thames Valley, and he had suggested this himself some time ago.

The AUTHOR thanked the meeting for the hearing which they had given to his paper, and especially Prof. Sollas for acknowledging the value of his work and correctness of his general conclusions. With other English students he had not neglected the study of the Moustérien, Solutréen, and Magdalénien epochs, but he, like others, had failed to find in English deposits any traces of the same stages of culture. This method, so successful in Southern France and in Austria, had hitherto proved unprofitable in England. A better one for our conditions had been adopted and patiently pursued for twenty-five years by Mr. Clement Reid. His attempt had succeeded in differentiating several important stages of the prolonged epoch, and the 'Origin of the British Flora' had been to the speaker a *lux in tenebris*. He had, however, to acknowledge Prof. Sollas's gentle censure, and to apologize to his audience for broaching on partial evidence such a subject as ice-action in the Thames Valley. No one knew better than himself that so large a subject demanded to be treated by corroborative testimony drawn from a wide area. This, from lack of time, he had been unable to do. The main object of his paper was to prove a distinction between two stages of Palæolithic life; he thought that he had done so by a convincing section, the only thorough geological proof. Of corroborative evidence he had not spoken, but it was so great that he had perhaps only given a definite geological explanation of facts so generally acknowledged that their solution was also generally surmised. He rejoiced to think that a fuller treatment of the greater subject—the glaciation of the Thames Valley—was in most capable hands, and would ere long be dealt with satisfactorily.

## 11. *On the* JAWS *of* PTYCHODUS *from the* CHALK. By ARTHUR SMITH WOODWARD, LL.D., F.R.S., F.L.S., F.G.S., of the British Museum (Natural History). (Read January 20th, 1904.)

[PLATE XV.]

IN 1887 [1] I pointed out that the teeth of *Ptychodus* from the Chalk were arranged in the mouth not like those of the Cestraciont sharks, but rather like those of some of the Myliobatid rays. This arrangement has subsequently been observed in new specimens, both in England and America.[2] Hitherto, however, no traces of the cartilaginous jaws have been found in association with the dentition, and their shape and relations have thus remained unknown. Quite lately, a new specimen, partly showing the jaws, has been obtained from the Lower Chalk of Glynde by Mr. Henry Willett, and he has kindly submitted it to me for study, to supplement my former description, which was chiefly based on the Willett Collection in the Brighton Museum.

The new fossil evidently belongs to a small variety or young individual of *Ptychodus decurrens*, the species previously discussed, and its principal characters are shown in the accompanying plate (XV). It comprises fragmentary remains of both jaws, each bearing many of the characteristic teeth arranged in their natural order. The rami of the jaw which may be identified as mandible (Pl. XV, figs. 1 & 2, *md*) are remarkably slender, and meet in an acute angle at the symphysis, which is shown to have been elongated, though it is disintegrated by the formation and oxidation of iron-pyrites. The upper jaw or pterygo-quadrate cartilage (fig. 2, *ptq*) is represented only by shapeless fragments. The dentition is confined exclusively to the symphysial region, where the teeth are arranged in the usual parallel antero-posterior rows.

Of the lower teeth, some are preserved in natural order above the hinder part of the symphysis, while a few are scattered in front on the decomposed anterior end of the jaw. Of the large median series (fig. 2, o), three teeth are exhibited, displaying all the typical characters of *P. decurrens*. To the left of these are teeth of four paired lateral series (I–IV) in natural arrangement; while a very small displaced tooth (V) seems to represent a fifth series at the extreme outer border. It is to be observed that the dentition does not curve backward at the side to spread along the mandibular ramus, although the more laterally-placed teeth exhibit the usual slight oblique distortion. If the larger scattered teeth on the symphysis belong to lateral series I, as seems probable, it is also to be

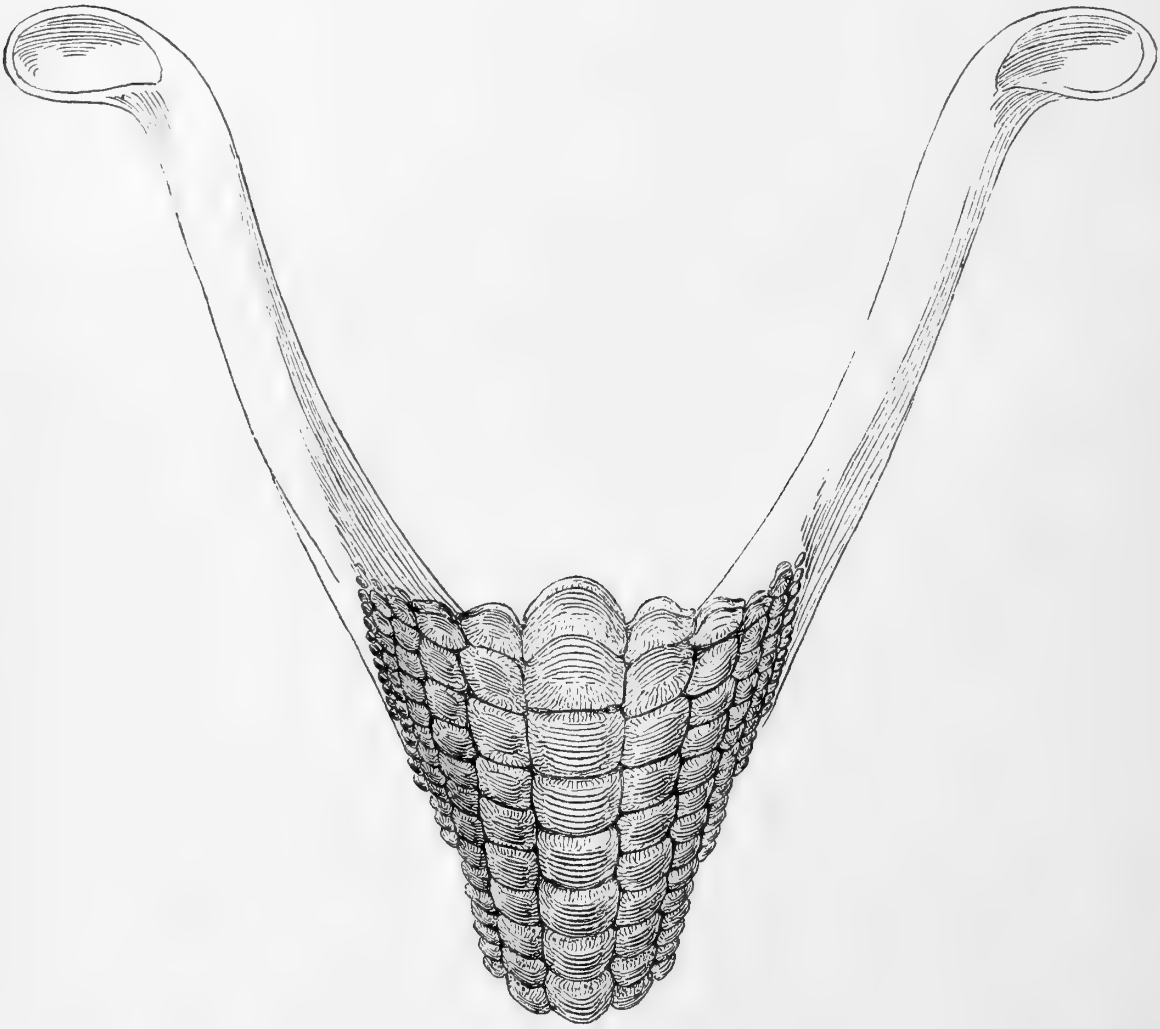
[1] 'On the Dentition & Affinities of the Selachian Genus *Ptychodus*, Agassiz' Quart. Journ. Geol. Soc. vol. xliii (1887) pp. 121–30 & pl. x.

[2] S. W. Williston, 'Cretaceous Selachians & Pycnodonts' Univ. Geol. Surv. Kansas, vol. vi (1900) p. 239 & pls. xxv–xxvii.

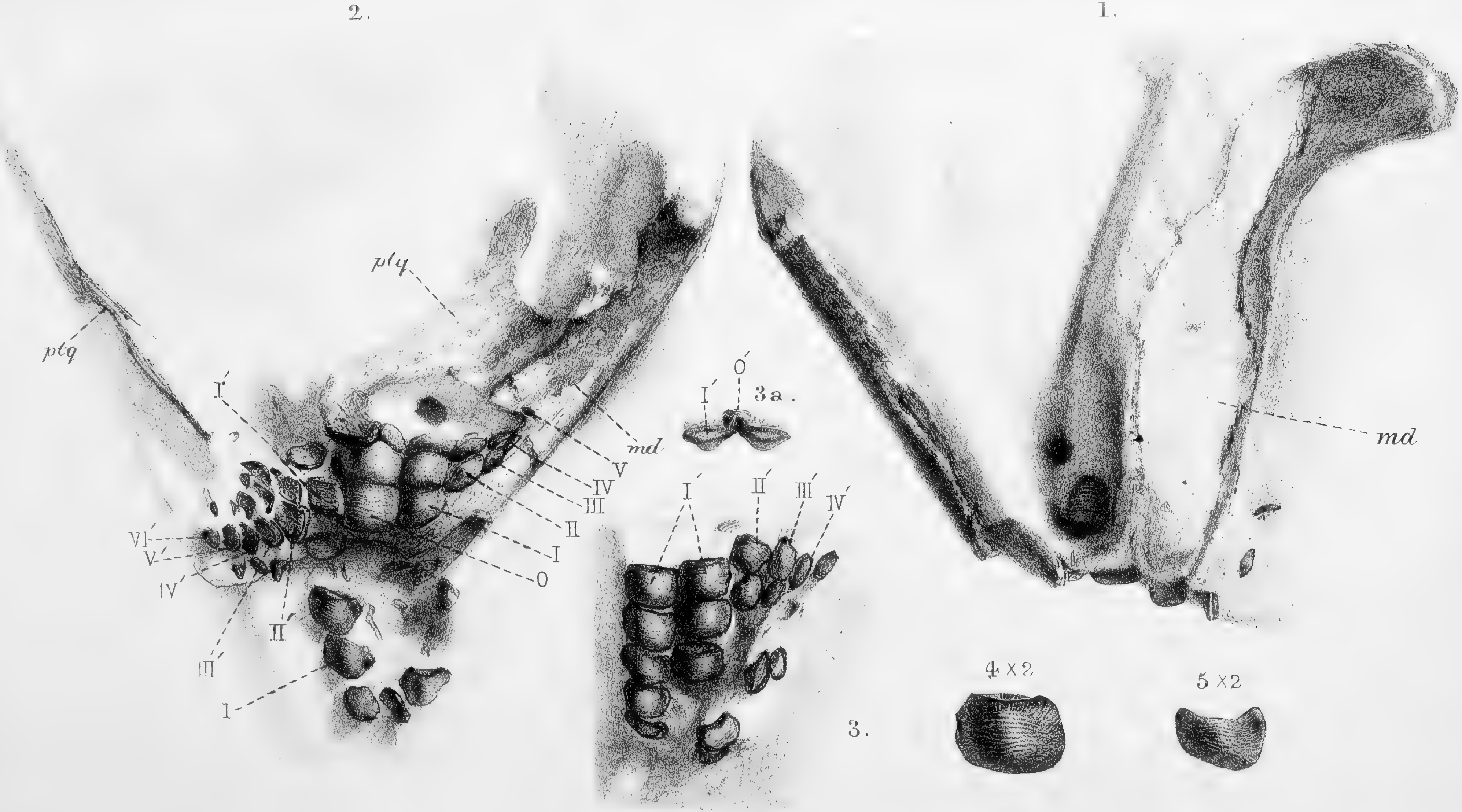
noticed that they exhibit a more decided obliquity, with a smaller median elevation, than the corresponding teeth farther behind. The transverse measurements (in millimetres) of the teeth of the several series at the back of the symphysis are as follows:—o, 8; I, 6·5; II, 5; III, 4; IV, 3; V, 2.

The upper dentition of the right side is partly exposed from its decayed attached face (Pl. XV. fig. 2, I′–VI′), partly seen from its oral

Ptychodus decurrens, *Ag.; oral aspect of the mandible of a small variety or young individual, restored natural size; from the Lower Chalk of Glynde (Sussex).*



aspect on a detached piece of chalk (fig. 3). The median row of very small teeth is scarcely visible in the fragment just mentioned, the large teeth of the first paired series being crushed together to obscure it, but it is shown in back-view (fig. 3*a*, o′). Of the first paired series (I′) three teeth are preserved on the right and six on the left side, all in natural sequence. They are about as large as the teeth of the same series in the opposing jaw. The two or three hindermost teeth (fig. 4) correspond with those ordinarily forming




F.H. Michael del. et lith.

Mintern Bros. imp.

PTYCHODUS DECURRENS, Ag.

this series in *P. decurrens*, but as they are traced forward towards the end of the symphysis, they become shorter in proportion to their width and more obliquely distorted, while their median coronal elevation is smaller (fig. 5). The remaining lateral teeth are more or less displaced, but they are clearly arranged in six paired series altogether (fig. 2); and near the back of the symphysis the teeth have the following transverse measurements (in millimetres):—o′, 4; I′, 6·5; II′, 5; III′, 4; IV′, 3·5; V′, 3; VI′ (?).

The specimen therefore proves that, notwithstanding the powerful nature of the grinding-dentition of *Ptychodus* and the straightness of its transverse rows, the supporting jaws had not assumed the peculiarly-effective disposition characteristic of the living Myliobatidæ, as I formerly supposed. Although it is quite likely that the angle between the mandibular rami seen in fig. 2 (Pl. XV) is slightly altered by accidental distortion, the fossil clearly shows that this cannot have exceeded a right angle. The teeth must thus have been supported by the elongation of the symphysis, of which there is very distinct evidence. This arrangement is peculiar, not to the Myliobatidæ, but to the closely-allied Trygonidæ, which have often a powerful dentition. In fact, while *Ptychodus* is most closely related to the Myliobatidæ by its teeth, as pointed out on former occasions,[1] it is now shown to resemble the Trygonidæ by its jaws.

The probable explanation of the new discovery is that, in the Cretaceous Period, the great rays of the 'families' Myliobatidæ and Trygonidæ had not become fully differentiated. Prof. O. Jækel[2] has already arrived at such a conclusion from general considerations, and proposed to place all these fishes in one comprehensive family termed Centrobatidæ. If this arrangement be adopted, *Ptychodus* represents a primitive sub-family, Ptychodontinæ, which still awaits definition from lack of complete specimens; while the Trygoninæ, Myliobatinæ, and Ceratopterinæ are equivalent sub-families which survive at the present day.

## EXPLANATION OF PLATE XV.

*Ptychodus decurrens*, Ag.; remains of jaws and dentition, natural size, with two teeth (figs. 4 & 5) enlarged twice.—Lower Chalk (zone of *Holaster subglobosus*); Glynde, near Lewes, Sussex. Collection of Henry Willett, Esq. *md* = mandible; *ptq* = upper jaw; o–v = teeth of lower jaw; o′–VI′ = teeth of upper jaw.

Fig. 1. Lower aspect, without symphysis.
2. Upper aspect, showing the extent of the decayed symphysis.
3. Part of upper dentition, oral aspect; 3 *a*, posterior end-view.
4. Posterior tooth of the upper first paired series, left side.
5. Anterior tooth of the same series.

[1] A. S. Woodward, Quart. Journ. Geol. Soc. vol. xliii (1887) p. 129; also Proc. Geol. Assoc. vol. x (1888) pp. 294–98, and 'Catal. Foss. Fishes Brit. Mus.' pt. i (1889) pp. 132–52.

[2] 'Die eocänen Selachier vom Monte Bolca' 1894, pp. 115–38.

## Discussion.

Prof. Seeley remarked on the great interest of the communication, as establishing the possibility of the existence of an intermediate group between the Sharks and the Rays. The specimen brought forward by the Author showed that, while the dentition in *Ptychodus* was parallel, the jaws protruded forward in a way never observed in typical Rays; and while the teeth of *Ptychodus* were undoubtedly used for crushing, the jaw was prehensile.

## 12. *The* Igneous Rocks associated *with the* Carboniferous Limestone *of the* Bristol District.

By Prof. Conwy Lloyd Morgan, LL.D., F.R.S., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S. (Read December 16th, 1903.)

[Plates XVI & XVII.]

Contents.



### I. Introduction.

In the 'Summary of Progress' of the Geological Survey for 1898 (pp. 104–11) Sir Archibald Geikie & Mr. Aubrey Strahan contributed an admirable section on the Volcanic Group associated with the Carboniferous Limestone of Northern Somerset. Although in this summary the evidence for the contemporaneous character of the igneous rocks is clearly set forth, the subject is of sufficient interest and importance to justify some further record.

The earliest-published reference to these volcanic rocks, with which we are acquainted, occurs in a note contributed by the Rev. D. Williams to the Geological Society on June 10th, 1840.[1] The note refers to the occurrence of 'fine porphyritic trap' in the Uphill Cutting, near Weston-super-Mare, of the Bristol & Exeter (now Great Western) Railway-line. In the figure which accompanies Williams's short paper the igneous rock is described as 'trap, apparently substituted for the originally continuous limestone, by slow fusion and conversion.' Dean Buckland appears, however, to have observed the occurrence of igneous rocks at another locality in the district as early as 1817, though the first-published record of the fact occurs in his Presidential Address to the Somersetshire Archæological & Natural History Society in 1849.[2] Although no detailed evidence is given, his brief statement suggests that he had recognized the volcanic nature of the beds. 'The vents,' he says, 'that have discharged igneous rocks in the hills of Somerset are few,' and adds that one of these occurs 'on the N.W. shoulder of

[1] Trans. Geol. Soc. ser. 2, vol. vi. pt. ii (1842) p. 561.
[2] Proc. Somerset. Arch. & Nat. Hist. Soc. vol. i (1851) p. 18.

Broadfield Down near the upper terminus of Brockley Combe.' Dean Buckland said that he was not aware that it had been recognized by any subsequent observer. And this statement still holds true, unless (as is probable) that, speaking from memory, when he said 'Brockley Combe' he meant the neighbouring Goblin Combe, near the upper end of which the fragmental deposits of the nature of coarse tuffs are well seen.

In the geological map of the Bristol Coalfield by William Sanders, which was begun in 1840, at the instance of Sir Henry de la Beche, and published in 1864, the following exposures of 'trap' are given :—

(1) In the Uphill Cutting, 2 miles south of Weston-super-Mare (Sheet 12).
(2) At Spring Cove, a little to the north-east of the pier, Weston-super-Mare (Sheet 12).
(3) At Middle Hope, to the west of Woodspring Priory, 3 miles north-east of Weston-super-Mare (Sheet 8).
(4) In Goblin Combe, $1\frac{1}{2}$ miles north-east of Wrington (Sheet 9). Four exposures are marked, erroneously associated with Old Red Sandstone.
(5) Near Cadbury Camp, 3 miles east-north-east of Clevedon (Sheets 5 and 9). Two exposures are marked.

With the exception of the last, all these are indicated in the Geological-Survey maps (1865). Two exposures are marked in Goblin Combe, and the supposed association with Old Red Sandstone is corrected.

In 1868 David Mackintosh [1] noted the occurrence of the igneous rock at Spring Cove, describing it as a conformable mass of trap. He says that it

'has, I believe, hitherto been regarded as intrusive. But a comprehensive inspection will, I think, show that it is a bed which, in a fused state, must have flowed over the limestone beneath, before the limestone above was deposited.'

In the same footnote Mackintosh states that Mr. Ravis, of Bristol, had informed him that a similar bed of trap occurred in the limestone near Sandpoint. This had, however, been previously recorded in Sanders's map. In the same year Ravis [2] described the Middle Hope trap, apparently regarding it as intrusive, but stating that it was probably injected during the deposition, although before the elevation of the limestone.

In Mr. Horace B. Woodward's Survey Memoir on 'The Geology of East Somerset,' published in 1876, a section, by Sanders, of the cutting at Uphill is given (pl. iii, facing p. 24), in which the igneous rock is entered as 'trap dyke.' A note is contributed by W. T. Aveline on the 'large igneous dyke' at Middle Hope 'running

[1] Quart. Journ. Geol. Soc. vol. xxiv (1868) p. 282.
[2] 'Supplementary Notes on some of the late Movements on the Somersetshire Coast' Proc. Bristol Nat. Soc. ser. 1, vol. iii (1868) p. 89.

with the beds of limestone and shale and altering them above and below' (p. 22), and a section is given, drawn by Aveline. The volcanic breccia at Cross Combe (Goblin Combe) is mentioned (*loc. cit.*), but the occurrence of 'trap' is not recorded. In an Appendix (p. 210) Mr. Rutley describes the rock from Woodspring Hill (Middle Hope) as a much-altered basalt, to which a specimen from Cleve Combe (Goblin Combe) is closely similar; and that from Wrington Warren, which is not identified as part of the Goblin-Combe exposures. as a volcanic breccia. 'It is just possible,' says Mr. Rutley, 'that this breccia may be derived from the margin of a dyke' (p. 210). He had evidently not seen the rock in the field. Figures are given of some of these rocks.

Prof. Sollas writing,[1] in 1880, an account of the Geology of the Bristol District, in connection with an excursion of the Geologists' Association, makes passing allusion to

> 'an episode of igneous activity, which has left its traces in the thick beds of volcanic ash associated with once vesicular but now amygdaloidal basaltic lava, to be seen interbedded in the limestone along the coast-section from Weston-super-Mare to Swallow Cliff.'

Whether this refers to Spring Cove or Middle Hope is not clear; but probably the latter locality was intended.

In the 'Annual Report' of the Geological Survey for 1896 brief allusion was made to the records of contemporaneous volcanic activity at Middle Hope (pp. 61-62). One of us made brief reference to them in the British Association Handbook published in 1898 (Bristol Meeting), and also drew attention to beds of volcanic ash on Worle Hill to the east of the camp (above Kewstoke Steps). Finally, in the 'Summary of Progress' of the Geological Survey for 1898, Sir Archibald Geikie & Mr. Strahan gave the fuller account, already mentioned, of the Northern Somerset volcanic group.

## II. The Evidence for the Contemporaneous Origin of the Igneous Rocks.

### (1) At Middle Hope (Woodspring).

The evidence for the contemporaneous origin of the igneous rocks in this locality has been so well set forth by Sir Archibald Geikie & Mr. Strahan that little need here be added. There are four exposures, three of which are described in the 'Summary of Progress' of the Geological Survey for 1898. The fourth lies farther to the east, where the coast-line trends sharply southward

[1] Proc. Geol. Assoc. vol. vi (1880) p. 378.

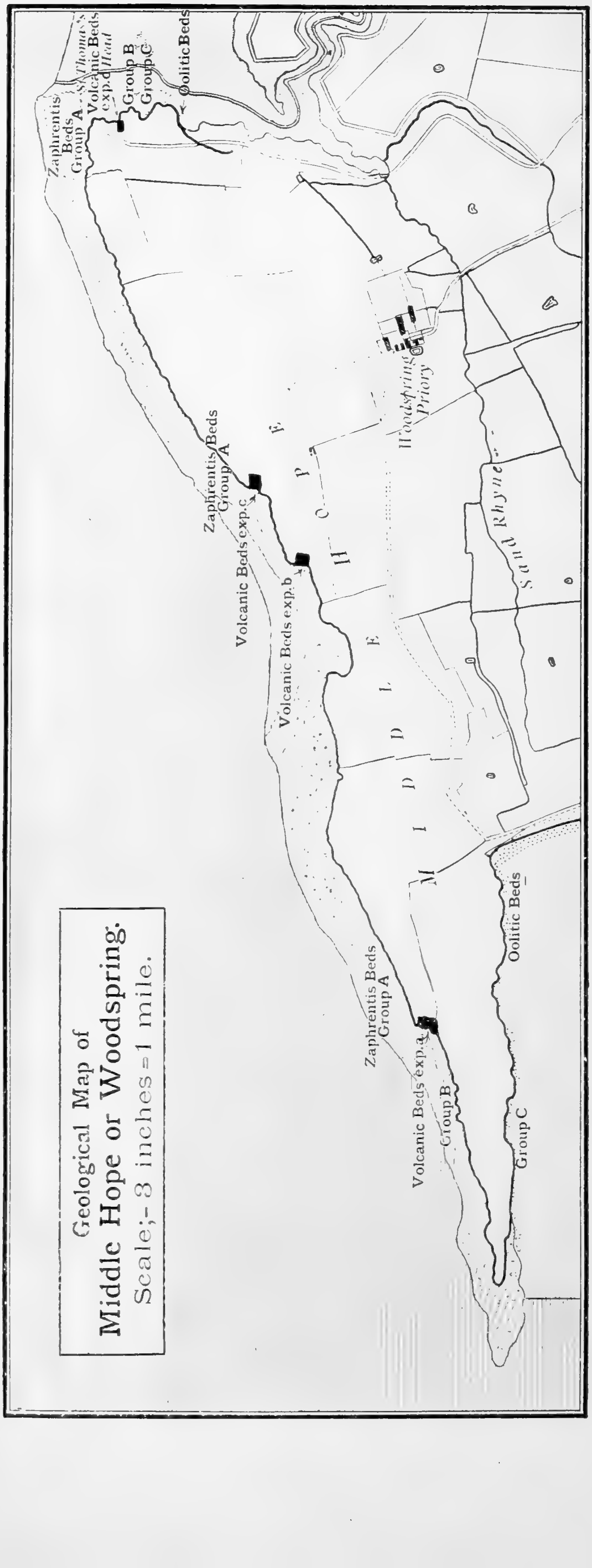



Fig. 1.

from St. Thomas's Head. The repetition of the exposures is due to several small faults running at right angles to the coast-line.

(*a*) In the first or western-most exposure, bedded crinoidal limestone, with abundant *Zaphrentis*, is succeeded by an alternation of limestone and red or green tuffs, in which organic remains are frequently embedded, and well-marked lapilli are abundant. Then comes the 'pillowy,' much-altered, amygdaloidal basalt, which has in parts degenerated into a brown sandy-looking material, wherein little can be made out except the amygdules. This is followed by further alternations of limestone and tuff passing up into the massive limestone, throughout the lower 7 or 8 feet of which big lapilli, reaching a length of 2 inches, are fairly plentiful. (See figs. 2 & 3, pp. 142–43.)

(*b*) In the second exposure, three-quarters of a mile farther east, alternations of reddish-brown or green tuff, with lenticular bands of limestone, occur. But there is here no basalt, and the volcanic series is thinner.[1] (See fig. 4, p. 144.)

(*c*) The third exposure, some 200 yards still farther east, shows brown tuffs and nodular or lenticular limestones in alternating layers. The volcanic series is still thinner.

(*d*) In the fourth, and easternmost, occurrence of the tuffs, hitherto unrecorded, and lying two-thirds of a mile north-east of that last named, they are reduced to 6 or 7 feet in thickness. But in the lower part of the section there is no rock-exposure. Here, however, a coarse fragmental deposit, 2 feet thick, with well-marked lapilli, is one of the most characteristically-volcanic beds of the whole series. The gradual attenuation of the volcanic ejectamenta to the eastward and the occurrence of lava only in the westernmost exposure, support the conclusion arrived at in the 'Summary of Progress' that the centre of volcanic activity probably lay yet farther west.

[1] The details of this section are as follows:—

| | Thickness in feet | inches. |
|---|---|---|
| 20. Thick crinoidal limestone to the top of the cliff. | | |
| 19. Weathered grit, with red shale visible at the eastern corner | 10 | 0 |
| 18. Limestone | 12 | 0 |
| 17. Green and red ash | 5 to 7 | 0 |
| 16. Sandstone, with vertical cylindrical bodies | 2 | 6 |
| 15. Fine ash | 2 | 0 |
| 14. Lenticular limestone-band | 0 | 3 to 6 |
| 13. Coarse ash, with highly-calcareous bands in the lower part, numerous large fragments of limestone and some of grit in the upper part | 11 | 6 |
| 12. Coarse ash | 3 | 6 |
| 11. Brown ash, very much decomposed and veined | 1 | 2 |
| 10. Limestone | 0 | 4 |
| 9. Ash as above (11), the upper part containing numerous lamellibranchs (*Edmondia*) | 22 | 0 |
| 8. Reddish crinoidal limestone | 1 | 0 |
| 7. Ash, as above | 2 | 0 |
| 6. Argillaceous limestone | 1 | 0 |
| 5. Ash, as above | 3 | 6 |
| 4. Compact, somewhat argillaceous limestone | 0 | 6 |
| 3. Ash, as above | 11 | 0 |
| 2. Limestone, in bands 3 to 6 inches thick, with partings of red shale and, at about a foot from the top, one of green ashy material; the uppermost band of limestone is very argillaceous | 7 | 0 |
| 1. Massive limestone, with much chert, to the base of the section ... about | 90 | 6 |

Fig. 2.—*Westernmost exposure of the volcanic series on the shore, at Middle Hope or Woodspring.*

S. H. R. photogr.

Fig. 3.—*Sketch illustrating the details of the above exposure.* (*See pp. 139–141.*)

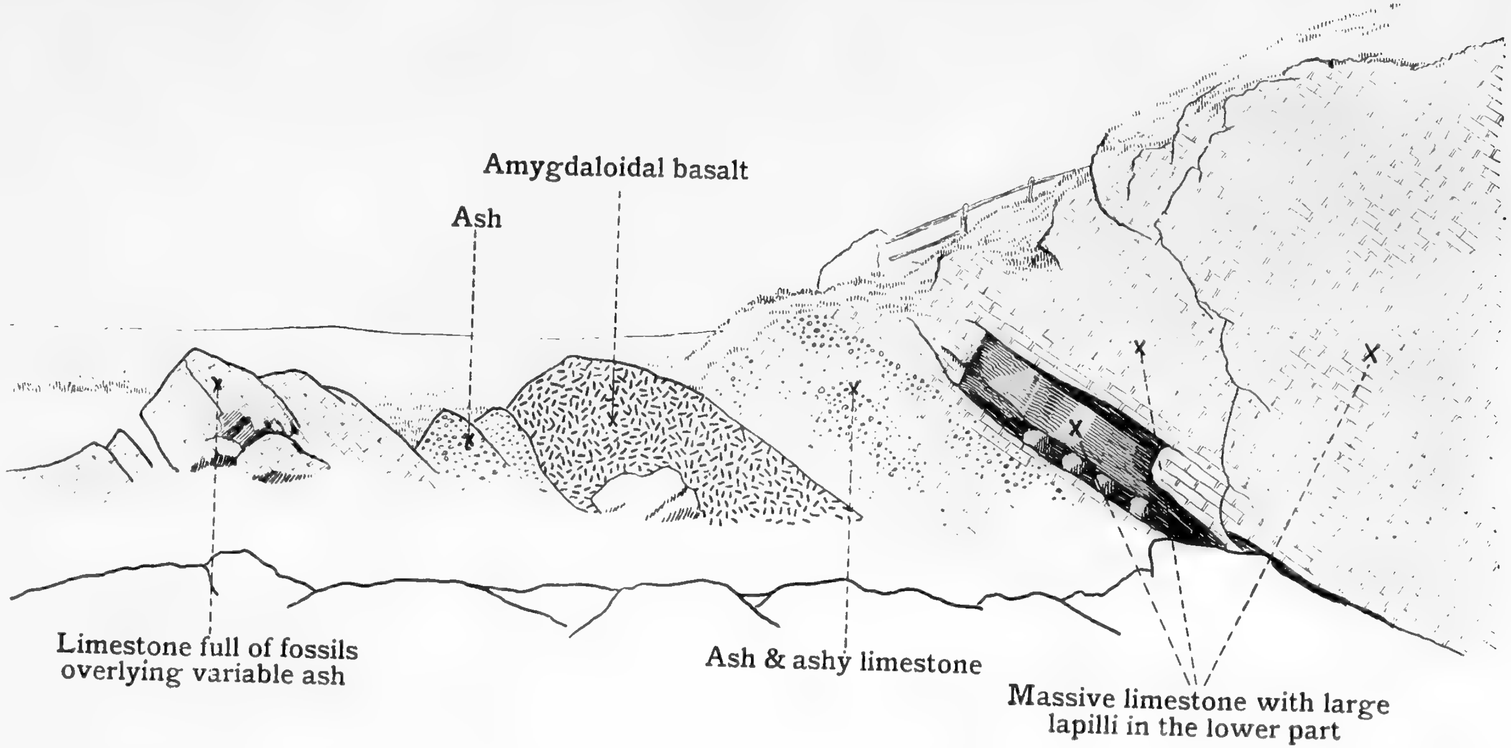


Fig. 4.—*Upper part of the volcanic series at Woodspring, second exposure.* (*See p. 141.*)

[Length of section = about 3 feet.]

Coarse ash. | Thin band of limestone. | Fine ash, much veined with calcite. | Sandstone, with vertical cylindrical bodies.

### (2) At Spring Cove, Weston-super-Mare.

In the limestone above the altered, and in parts variolitic, olivine-basalt, Sir Archibald Geikie & Mr. Strahan found fine volcanic dust for about 3 feet above the surface of the lava. We have, however, a rock-slice taken from a height of 8 feet above the basalt which is full of small lapilli. On the other hand, although there are several ashy-looking lenticular bands below the lava, our four rock-slices taken from these beds at several different levels show no conclusive evidence of the occurrence of distinct lapilli. We are therefore unable fully to endorse the statement that 'through some 30 or 40 feet of its mass' the limestone 'below the basalt is full of disseminated volcanic particles.'[1] A soft, red, ashy-looking bed, close to the path leading down into the cove, contains abundant large corals belonging to the genus *Campophyllum*.

### (3) Above Kewstoke, Milton Hill.

In the 'Summary of Progress' for 1898 (p. 106) it is stated that

> 'fragments of the amygdaloid were found by Mr. Spencer Perceval at the Tollgate, which show that this rock extends inland for a mile and a half. But immediately to the east, over the bare limestone-surface above Kewstoke or Milton Hill and the ground towards Worle, Mr. Strahan could find no trace of it.'

Mr. Spencer George Perceval writes to one of us:

> 'Which Tollgate is meant I do not know. In the fields immediately outside the wood on Worle Hill at the eastern end, north of the Lodge, I found in 1890 that an overflow of trap occurred, not visible at the surface, but at a slight depth underneath. I got specimens with the limestone and trap in contact. I certainly should not term the trap an amygdaloid.'

In a further communication, Mr. Perceval has courteously supplied extracts from his notes made at the time. It is quite clear from these notes that he then discovered an extensive run of the 'trap' on Milton Hill. In gardens west of the road running from Milton to Kewstoke he instituted a series of diggings, which showed that the 'trap-bed' was there *in situ*. It was also found, by digging, in the garden of the lodge just outside the wood, on the western end of Worle Hill. 'Trap' was also found in places within the wood along the same strike. These observations leave no doubt of the extension of the lava in this direction. One of us became acquainted (without any knowledge of Mr. Perceval's previous discovery) with the 'trap'-fragments, some of them very vesicular, which are scattered over the gardens in the north-western angle of the cross-tracks, one leading along the crest of the hill, the other crossing

[1] 'Summary of Progress of the Geological Survey for 1898' p. 105.

from Milton to Kewstoke. A cottager, who was digging in the garden, pointed out a strip running across the field where, he said, all the stones turned up in digging were of this kind. Another man in 1902 made a similar statement. From this field we have ourselves collected many fragments of lava, and a few of a brecciated rock. Moreover, in 1894, at a spot 150 yards down the track leading to Kewstoke, one of us observed a small excavation in which unmistakable volcanic ash was seen *in situ*. This exposure was shown at the time to Mr. A. C. Pass, then Secretary of the Geological Section of the Bristol Naturalists' Society, who was satisfied as to the nature of the rock. Unfortunately, when we visited the spot, in 1902, we found that the excavation had been walled in, stone-lined, and converted into a small pond. A note made in 1894 is here transcribed:—

'Volcanic ash in field [near track] leading down to Kewstoke Steps. Soft, friable, reddish beds, seemingly greener when not exposed (that is, when dug into with the hammer). Numerous vesicular lapilli up to half an inch in diameter.'

In 1903, round a small pond just above the upper extremity of Kewstoke Steps, we found abundant fragments of lava (? lapilli) in a red, earthy, surface-material. Farther eastward we have found no trace of lavas or ashes.

## (4) At Uphill.

The relations of the amygdaloidal basalt or dolerite to the limestone are not well seen here. The ground is much faulted. There is, in our opinion, nothing to enable us to decide whether the igneous rock is a sill or a contemporaneous lava-flow. Nor have we been able to find in the limestones, either above or below, any traces of ash or lapilli. As will be seen, however, under the next heading (p. 150), the igneous rock occupies exactly the same position in the stratigraphical series as that which the volcanic rocks occupy in other localities.

## (5) In Goblin Combe.

The Carboniferous Limestone of this upland area, lying north of Wrington, forms an anticline or dome. The volcanic rocks occur in two patches, the more westerly being about a third of a mile south of Warren House, the more easterly about half a mile south-east of this house. Sir Archibald Geikie & Mr. Strahan suggest that the two exposures form parts of the same volcanic series, repeated on the two sides of the anticline. In this, as we shall see, they are probably correct.

(*a*) In the more westerly exposure a much-weathered and highly-amygdaloidal olivine-basalt is seen *in situ*, although it seems to have escaped the notice of Mr. Strahan, who observed only scattered blocks. The fragmental beds are here found above the lava, but there is an interval in which there is no exposure. They consist of a reddish ashy limestone and a thinly-bedded, greenish, ashy and gritty limestone, coarser below and finer above, in which oolitic granules occur plentifully.

(*b*) The more easterly exposure affords perhaps the most characteristic and convincing section of ashy beds in the district. The lenticular bands of coarse greenish tuff, the limestone-intercalations, the close admixture of lapilli, limestone-fragments, and oolitic grains, the whole appearance of the 13 or 14 feet of rock exposed in a vertical mural face are stamped with the hall-mark of submarine volcanic action. The beds seem to cross the track about 200 yards to the north-west, as it ascends the hill near an orchard. No lava occurs *in situ* here; but a remarkably-fresh olivine-dolerite is abundantly found in small blocks (among which are some of breccia) scattered over the field to the west of the main exposure. It may therefore be inferred, since the dip is easterly, that the lava closely underlies the breccias and tuffs, as in the other Goblin-Combe exposure.

### (6) Near Cadbury Camp.

Beyond the occurrence of fragments of 'trap' thrown out from rabbit-burrows in Wood Lane, at the angle between Round Wood and St. John's Wood, we have found no indication of the exposures marked in Sanders's map. There is nothing to show whether or not the trap is contemporaneous.

## III. The Approximate Horizon of the Igneous Rocks.

In the 'Summary of Progress of the Geological Survey' no attempt is made to assign to the volcanic rocks any definite place in the stratified series which constitutes the Carboniferous Limestone. In 1898 one of us stated, in the British Association Handbook (Bristol Meeting), that the Middle Hope beds were of an age slightly anterior to that of the band of oolitic rock which occurs at the foot of the Gully in the well-known Clifton section; and, from observations made in 1894-95, he had tentatively assigned to the Spring-Cove lava a position about 150 feet below this oolitic band. In endeavouring to work out the position of the volcanic series with greater precision we have had the advantage of much palæontological assistance from Mr. Arthur Vaughan, B.Sc., F.G.S., who is engaged on the zoning of the Carboniferous Limestone of the district under consideration. We tender him our hearty thanks for his ungrudging assistance. He has supplied for our guidance, and allows us to quote, the following table, wherein certain broadly-marked horizons which bear on the subject in hand are indicated:—

| | Position of Beds referred to the section north of the Avon at Bristol. | Sequence. | Palæontological characteristics. |
|---|---|---|---|
| | Lower part of Great Quarry and underlying Dolomitic Beds. | Higher Beds. | Marked by the entrance of *Lithostrotion*, *Producti* belonging to the *giganteus*-group, and Athyrids of the *ambigua*-group (*Seminula*). |
| About 135 feet. | Oolitic beds in the quarry at the foot of the Gully. / Beds between the Gully & the Black-Rock Quarry. | Group C. | Marked by the great abundance of *Orthotetes* (*Streptorhynchus*) *crenistria*, *Chonetes papilionacea*, and *Ch.* aff. *comoides*. In these beds *Spirifer* aff. *laminosus* reaches its maximum. |
| About 100 feet. | Upper third of the Black-Rock | Group B, resting immediately upon or forming the | Marked by the abundance of a Zaphrentid of the *cylindrica*-type (*Campophyllum* = *Zaphrentis cylindrica* of Edw. & Haime).[1] |
| | Quarry. | beds of Group A. | Containing cornute Zaphrentids in great abundance. |
| | Lower and middle thirds of the Black-Rock Quarry. | Lower Beds. | Marked by the rarity of Zaphrentids and by the gradual increase downward of Spirifers of the *bisulcatus*-group and of the *glaber*-type (*Martinia*); Athyrids of the *Royssii*-type (*Cleiothyris*); Orthids of the *Michelini*- and *resupinata*-types, *Leptæna analoga*, and *Productus* of the *punctatus*- and *Martini*-types. |

As will be seen by the sequel, the volcanic group lies approximately on the horizon of Group B, a position which accords with that assigned to the Middle-Hope and Spring-Cove lava by one of us—that is to say, somewhat anterior in time to the Gully oolite.

## (1) At Middle Hope, Woodspring.

The beds below the volcanic series, which are well displayed on the coast-line, unquestionably belong to Group A, and contain cornute Zaphrentids in great abundance. Mr. Vaughan has identified *Zaphrentis Phillipsi*, M.-Edw., *Z.* aff. *Enniskilleni*, M.-Edw., *Z.* aff. *Griffithi*, M.-Edw., and *Z.* sp. nov.; *Michelinia*, sp., *Leptæna analoga*, Phill., *Orthis Michelini*, L'Éveillé, *Productus punctatus* var. *elegans*, M'Coy. The lower ashy beds are probably in Group B. On the southern coast of the peninsula that terminates in Swallow Cliff the *Chonetes* and *Streptorhynchus* characteristic of Group C occur; and similar beds may be found 150 feet above the more easterly exposure of the tuffs.

[1] [Mr. A. Vaughan has more recently, in Proc. Bristol Nat. Soc. vol. x, pt. ii, p. 102, revived M'Coy's genus *Caninia*, to cover the Zaphrentid-group which is typified by *Campophyllum cylindricum*.—March 14th, 1904.]

## (2) At Spring Cove, Weston-super-Mare.

In a red ashy bed, which marks the earliest stage of the volcanic phase, large examples of *Campophyllum cylindricum*, Scouler, indicative of the upper part of Group B are conspicuous. In the lowest bed on the foreshore cornute Zaphrentids occur

'together with a coral which exhibits characters transitional between those of the *Cyathophyllum- (Strephodes)* and *Campophyllum*-types.'

Again, about 100 feet above the lava, in a mural face below the western end of Worlebury Camp, occur in abundance the characteristic fossils of Group C. Commenting on the fossils obtained thence, Mr. Vaughan says

'*Streptorhynchus crenistria, Leptæna analoga, Productus Martini, Pr. elegans*, and *Spirifer cuspidatus* leave no possible doubt of the horizon.'

The Spring-Cove volcanics, therefore, occupy approximately the same position as those at Middle Hope. It may be mentioned, however, that on the road through Kewstoke Woods, in a position which seems to be well below the volcanic series, occur fossils which unquestionably indicate a much higher level—that marked 'Higher Beds' in the foregoing table (p. 148). There is some faulting which brings these beds down to their present position.

## (3) Above Kewstoke, Milton Hill.

Here, again, faulting has complicated the problem. At Kewstoke Steps the limestones are well displayed. There can be no question that they belong to the higher beds. *Producti* belonging to the *giganteus*-group, Athyrids of the *ambigua*-type, and abundant *Lithostrotion* beautifully weathered-out, are conclusive. But shortly below these rocks—assuming that the stratigraphical sequence is unbroken—come the volcanic ash (noted in 1894) and the scattered fragments of lava and breccia. On the southern side of Milton Hill, however, there are two quarries, the beds in which should, taking dips and distances into consideration, overlie the volcanic series. In one of these, a disused quarry, lying to the right of the road from Milton to Kewstoke, just below the crest of the hill on its southern side, the fossils indicate that the beds lie on the same level as those of the mural escarpment above Spring Cove. *Chonetes*, *Streptorhynchus*, and *Spirifer laminosus*, M'Coy, occur, and a typical *Productus Martini*, Sow., as also above Spring Cove. The other quarry, which lies farther west, and is now being extensively worked, does not afford conclusive evidence. But at the top occurs a coral of the same transitional type as that noted at Spring Cove, which, in Mr. Vaughan's opinion, cannot occur below the very top of the Black-Rock Quarry. In the lower beds of the quarry occur

'*Streptorhynchus* (large resupinate var.), *Spirifer cuspidatus*, Martin, a small *Athyris* of the *seminula*-group, and a rather characteristic *Athyris* of a transverse *Roysii* type.'

No cornute Zaphrentids were found, and the probability is that the beds belong to Group B. On the whole, therefore, evidence again points to the conclusion that the volcanic rocks here too occupy approximately the same position as those at Spring Cove and Middle Hope. That there is a strong fault between the Kewstoke rocks and those in the quarries on Milton Hill, so as to thrust up the former beds to their present position, is certain. And this is in line with the facts already noted under the head of 'Spring Cove.'

## (4) At Uphill.

We have not been successful in obtaining many fossils from the limestones above and below the 'trap' here. We submitted, however, a number of fragments to the etching effect of weak acid, partly with a view to the disclosure of any lapilli which might be, but were not, present. Mr. Vaughan kindly examined some specimens from below the 'trap.' He says:—

'I am convinced that the Uphill specimens denote beds on the level of the upper portion of the Black-Rock Quarry, and therefore on exactly the level of the Woodspring specimens. *Zaphrentis Phillipsi*, M.-Edw., a bisulcate *Spirifer*, and small cylindrical crinoid-stems are the only fossils to be seen. Of these, *Z. Phillipsi* ranges from the middle of Press's Quarry (just below the Black Rock) to the *Campophyllum*-beds (B) at the top of the Black Rock; but its main development is at the top of the Black Rock (never above). Bisulcate Spirifers in isolated examples (as here) point to the same horizon (or very much lower, which is rendered impossible by the associated *Zaphrentis*).'

As before noted, there is here no distinct evidence of the contemporaneous origin of the 'trap.' But the palæontological evidence that it occurs at the same horizon as the Middle-Hope and Spring-Cove lava, makes its volcanic nature, as a submarine outflow at any rate, highly probable.

## (5) In Goblin Combe.

(*a*) Easterly exposure.—Fossils taken from a level about 100 feet above the mural exposure of breccia and tuffy limestones contain *Chonetes papilionacea*, Phill., *Streptorhynchus crenistria*, Phill., *Athyris Royssii*, L'Éveillé, and *Spirifer cristatus* (var. *octoplicatus*, Sow.). These, in Mr. Vaughan's opinion, mark the lower part of Group C, and are therefore in exactly the same relative position as at Middle Hope and at Spring Cove. There is no exposure immediately beneath the volcanic rocks; and the level of the rocks, just west of the orchard, cannot be readily calculated, as the dips are changing near the summit of the anticlinal arch. These beds, which may lie 100 feet or so below the tuffs, contain *Zaphrentis Phillipsi*, M.-Edw., *Z. Enniskilleni*, M.-Edw., *Z.* sp. nov. ('the very commonest,' says Mr. Vaughan, 'of the Zaphrentids of Clevedon, also found in the Avon section, Tytherington, etc., but not yet figured or described'); also a specimen of *Spirifer* aff. *clathratus*, M'Coy (small and presumably uncommon). The highest bed seen contains *Campophyllum cylindricum*, Scouler. These fossils point to

Group A and the lowest part of Group B. Here, again, therefore, the horizon of the volcanic rocks may be assigned to the same position as in other localities.

(*b*) Westerly exposure.—The only definite piece of evidence of the position of these beds is the occurrence of a fossiliferous band, at a level of about 120 feet above the exposure of the lava. It lies some 200 yards south of Warren House, on the edge of the plateau where it overlooks Goblin Combe. The fossils include *Chonetes* aff. *comoides*, Sow., *Streptorhynchus crenistria*, and a bisulcate *Spirifer*: all of which points conclusively to Group C. We have not, however, succeeded in finding evidence of the underlying *Zaphrentis*-beds. But little limestone is visible below the lava, which is nearly the lowest bed exposed by denudation in the excavation of the Combe. Such evidence as there is in this locality points again to the same horizon as elsewhere in the district.

### (6) Near Cadbury Camp.

Since the volcanic rocks are not here exposed *in situ*, we do not attempt to discuss the question of their horizon. They seem, however, to lie in about the same position. Mr. Vaughan tells us that in cuttings by the side of the track which follows the telegraph-posts along the top of the ridge, that is to say, at a stratigraphical level somewhat below the probable outcrop of the 'trap,' the *Zaphrentis*-beds are strongly in evidence, and he has collected most of the typical fossils of Group A.

It will be seen that in all the localities where the position can be approximately determined, the evidence is sufficient to justify the conclusions (1) that there is one igneous group marking a single volcanic episode, and (2) that this occurred at a period which is marked by the occurrence of the marine fauna indicated by Group B in the table supplied by Mr. Vaughan (p. 148), to whom we desire again to offer our thanks for his assistance.

## IV. The Petrology of the Igneous Rocks.

But little has been written on this subject. In Appendix I to the Survey memoir on the Geology of the East Somerset & Bristol Coal-Fields are descriptions by Mr. Rutley, of the Uphill and Woodspring traps, and one of the ashes from Wrington Warren. In Sir Archibald Geikie's & Mr. Strahan's account, the petrology is incidentally dealt with, and a description of the Spring-Cove lava by Mr. Teall is given. These will be again referred to in due course.

### (A) The Lavas. (Pl. XVII, figs. 1–3.)

The freshest and most interesting lavas are those of Goblin Combe and Spring Cove, and it will perhaps be best to describe these somewhat fully.

## (1) Description of the Lavas of Goblin Combe.

The rock seen *in situ* at the more westerly exposure is a highly amygdaloidal olivine-basalt. In a hand-specimen it shows pseudomorphs after olivine, and vesicles which may be more than half an inch in diameter, and are sometimes empty, sometimes filled with calcite and a green chloritic mineral. Microscopically, the most prominent mineral is altered plagioclase, in laths having an average length of about 0·4 millimetre and a diameter of 0·04 mm. The spaces between the laths are partly filled up by a brown, nearly-isotropic substance, but chiefly by green patches of serpentinized pyroxene and by calcite. Dark rods, once magnetite, but now replaced by the peroxide, are very plentifully scattered. The phenocrysts, which are large and prominent, are entirely represented by patches of a carbonate, probably calcite, and from the perfect preservation of the form of some of these it is clear that they represent olivine-crystals.

The olivine-dolerite or basalt which occurs in blocks on the surface of the ground near the more easterly of the Goblin-Combe exposures is the handsomest of all the igneous rocks of the district. It consists of fresh plagioclase-laths with a maximum length of about 0·5 millimetre; fresh brown augite, occurring in grains filling up the interstices between the laths, and also forming phenocrysts and polysynthetic crystals which reach a length of slightly over a millimetre; magnetite in long needles; and olivine, now completely converted into green serpentine, but showing the crystalline form excellently. (See Pl. XVII, fig. 1.)

## (2) Description of the Lava of Spring or Birnbeck Cove, Weston-super-Mare.

The lava here is a rather interesting basalt, and resembles all the other rocks of the section in being stained a deep red. No phenocrysts are visible in a hand-specimen, but there are, as a rule, numerous amygdules of calcite which reach a maximum diameter of 3 millimetres. Hand-specimens, too, taken from certain parts of the flow, show numerous other circular red bodies which prove, when examined microscopically, to be varioles. The groundmass is abundant, and is seen in section to show numerous felspar-needles; apart from these, it is practically isotropic, and must have been originally, to a large extent, glassy. It is, however, much obscured by the abundant red oxide of iron. The varioles above referred to reach a large diameter (3 millimetres), and are very sharply defined. They are, however, much altered, and are obscured by the iron-oxide which is sometimes uniformly distributed through them, sometimes forms a peculiar network traversing them, and is occasionally collected along lines which radiate inward from the circumference for a short distance with extreme regularity. (See Pl. XVII, fig. 3.)

The chief phenocrysts present are a few felspars in a greatly-altered state. The large amygdules are filled with well-cleaved calcite, with sometimes in addition a brown, possibly chloritic, mineral occurring in collections of irregular spherulites. Mr. Teall's description of a lava from Spring Cove, quoted by Sir Archibald Geikie & Mr. Strahan,[1] is as follows :—

'The lava from Spring Cove, Weston-super-Mare [E. 3212 (23)], is a fine-grained, chocolate-coloured rock, composed of pseudomorphs after olivine, and probably augite, in a groundmass showing microlitic structure. The phenocrysts are represented by pseudomorphs in carbonate. The microlitic felspars of the groundmass are colourless, but they no longer show their characteristic optical properties. The groundmass is deeply stained with ferric oxide. Although all the minerals have been destroyed, the structure has been perfectly preserved, and there can be no doubt whatever that the original rock was an olivine-basalt.'

Most of our sections from Spring Cove did not show the carbonate-pseudomorphs above referred to, which are so clearly seen in the Goblin-Combe rocks, but they were met with in one section.

### (3) Summary of the Characters of the Lavas.

The rocks vary a good deal in coarseness, the coarsest-grained being those from Uphill and from near Cadbury Camp, of the contemporaneous character of which there is no direct evidence. The Goblin-Combe rocks come next in degree of coarseness, while the finest-grained are those from Spring Cove and Milton Hill.

All the rocks are clearly basaltic in character, and consist essentially of plagioclase-needles, laths, or phenocrysts, with pyroxene and iron-ore, and, as a rule, olivine. The pyroxene is generally undoubtedly augite, but sometimes, as in the Uphill rocks, the unaltered mineral may have been enstatite. The freshest augite is seen in the rock from the eastern end of Goblin Combe, where it occurs both in small grains and large plates. Plates of fairly-fresh augite are seen in the Cadbury-Camp and one of the Milton-Hill rocks; and serpentinized pyroxene, probably augite, is abundant in the rock from the western Goblin-Combe exposure.

Olivine is never preserved in an unaltered state in these rocks, though in most cases the original form of the crystals is very well seen (Goblin Combe—eastern end, Milton Hill, Woodspring). Sometimes the olivine is completely converted into bright green serpentine (Goblin Combe—eastern end), sometimes a very large amount of ferric oxide is associated with the serpentine (near Cadbury Camp), sometimes the olivine is replaced by pseudomorphs in carbonate, probably calcite, with which dense masses of ferric oxide are associated (Milton Hill), sometimes it is apparently simply replaced by pseudomorphs in carbonate (Goblin Combe—western exposure, and some specimens of the Spring-Cove rock).

The occurrence of long needles of peroxidized magnetite is a characteristic feature of the Goblin-Combe rocks.

The variolitic character of much of the Spring-Cove lava is an interesting feature.

[1] 'Summary of Progress of the Geological Survey for 1898' p. 106.

Some of the rocks are highly-amygdaloidal (Woodspring, Spring Cove, Goblin Combe—western exposure, Milton Hill, and Uphill in part). Others are not (Uphill in part, near Cadbury Camp, Milton Hill in part, Goblin Combe—eastern exposure).

## (B) The Tuffs. (Pl. XVII, figs. 4–6.)

### (1) Description of the Tuffs from Middle Hope, Woodspring.

The prevalent type of tuff in all four exposures is a rather soft, dull-green, much-decomposed, and earthy-looking rock, with patches and veins of calcite and many small green lapilli, which in the sections examined do not, as a rule, reach a greater length than 2 millimetres.

In section the lapilli are seen to consist entirely of a highly-amygdaloidal rock, with a groundmass which is almost completely isotropic, and must have originally formed a basic glass, now altered into green palagonitic material. The amygdules are generally composed of a chloritic mineral, sometimes of calcite. The matrix in which the lapilli are embedded usually consists of well-cleaved calcite, through which are scattered numerous minute ashy fragments similar to the larger lapilli. In addition to these there occur at certain levels, especially in the ashy limestone above the trap at the westernmost exposure, large lapilli, frequently reaching a length of an inch or more, of a quite different type from those described above. The groundmass of these lapilli, which is much iron-stained, contains numerous felspar-needles, but apart from them is isotropic, and shows no sign of palagonitic modification. The vesicles are very abundant, and in one slide are filled with well-cleaved calcite, precisely similar to that forming the main mass of the surrounding limestone in which they are embedded. In a second slice the only difference is that the calcite filling the vesicles is, as a rule, granular and not well cleaved.

### (2) Description of the Tuffs from Goblin Combe.

Most of the rocks are, in the main, limestones of a non-oolitic character, but they contain a variable proportion of oolitic grains and many quartz-grains, with ashy fragments as well. The proportion of ashy fragments is far greater in some of the rocks from the eastern exposure than in any of those from the western, but nearly all are best described as ashy and gritty oolitic limestones. Sections taken from the lowest bed in the more westerly exposure show that angular quartz-grains are far more plentiful than either lapilli or oolitic grains. The latter reach a diameter of 4 millimetres. Some of the lapilli are identical with the basalt, which, as already mentioned, probably underlies the ashy limestones; they contain the same patches of yellow chlorite or serpentine, and rods of peroxidized magnetite. The red calcareous ash, of the more easterly section, is the most conspicuous of all the igneous rocks of Goblin Combe. It varies much in coarseness and in the proportion of oolitic grains present. Angular grains of quartz are always plentiful. The lapilli are of two chief varieties: (1) a highly-vesicular, glassy rock, which sometimes shows green palagonitic alteration, sometimes is so loaded with ferric oxide that nothing can be seen except the vesicles; (2) a basalt with felspar-laths, patches of serpentine or chlorite, and peroxidized magnetite-rods—resembling, in fact, the lava of the western end of the Combe.

### (3) Summary of the Characters of the Tuffs.

They are all highly calcareous, and most are best described as ashy limestones. The proportion of lapilli is very variable. In some rocks, such as those from the western Goblin-Combe exposure and some of those from the eastern, lapilli form less, perhaps, than a hundredth part of the material. In others, such as some of those from Woodspring and from the eastern Goblin-Combe exposure, they form more than one-third. While, in some districts (as is well known) many of the lava-fragments in the tuffs are of a quite different type from the lavas which flowed on the surface, that is not the case with regard to this district, as all the lapilli are basaltic in character, like the lavas. At Spring Cove and the western exposure of Goblin Combe the lapilli consist of the same type of basalt as the associated lava. At Woodspring they are, as a rule, of a green, highly-vesicular rock, like a basaltic pumice. In the ash from the eastern end of Goblin Combe both types of lapillus are represented. Attention has already been drawn to the abundant quartz-grains of the Goblin-Combe rocks and to their frequently-oolitic character.

## V. Conclusions.

The observations described in this paper support the conclusions reached by those previous writers who have indicated the existence of a volcanic episode in Lower Carboniferous times within the Bristol district. They render it probable that the 'trap' of Uphill and near Cadbury Camp is a product of contemporaneous volcanic action. They have somewhat extended the number of recorded localities in which lava or tuff is exposed. They establish the fact that in all cases the lavas are basaltic in type, and that the lapilli found in the adjacent beds are of the same basaltic character. And they show that the volcanic episode in all cases occurred during the deposition of the upper part of the *Zaphrentis*-beds, and before the strata characterized by *Chonetes* and *Streptorhynchus* were deposited.

## EXPLANATION OF PLATES XVI & XVII.

### Plate XVI.

Map to illustrate the distribution of the Carboniferous volcanic rocks in the Bristol district, on the scale of 2 miles to the inch.

### Plate XVII.

Fig. 1. Olivine-dolerite or basalt from Goblin Combe eastern exposure. This shows several crystals of serpentinized olivine, surrounded by plagioclase-laths, the spaces between which are often occupied by grains of augite. (See p. 152.)

2. Olivine-basalt from Milton Hill, Weston (not *in situ*). A group of three crystals of altered olivine is seen, and with them much ferric oxide is associated.

3. Variolitic basalt from Spring Cove, Weston-super-Mare. Several varioles are seen, varying considerably in size; also veins and amygdules of calcite. (See p. 152.)

4. Calcareous ash from Spring Cove, Weston-super-Mare (3 feet above the lava). This shows small basaltic lapilli, embedded in an abundant matrix of calcite.

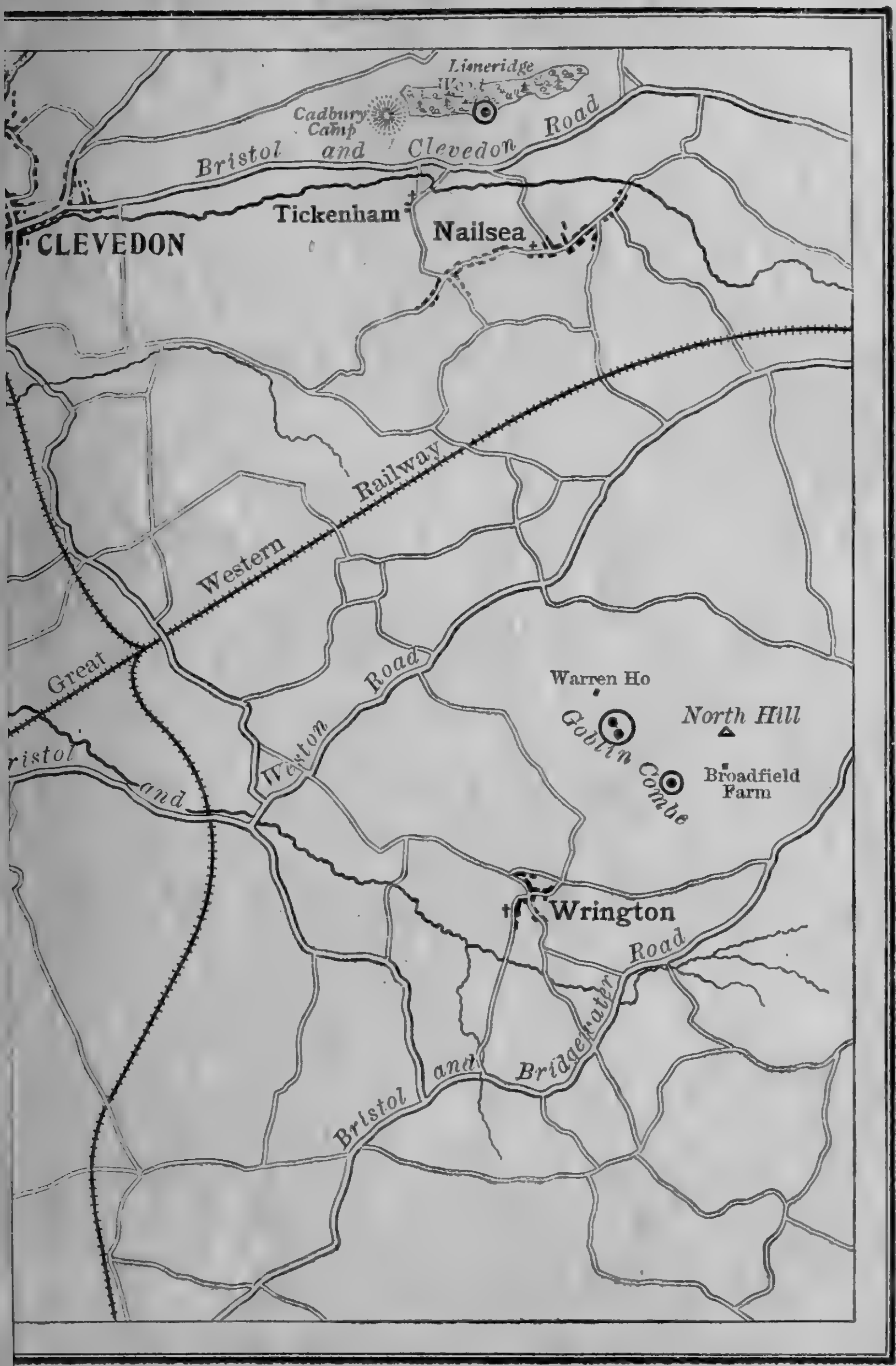
5. Calcareous ash from the extreme top of ash, Woodspring, exposure (*b*). This shows abundant lapilli of amygdaloidal basalt, embedded in a matrix of calcite. (See p. 154.)

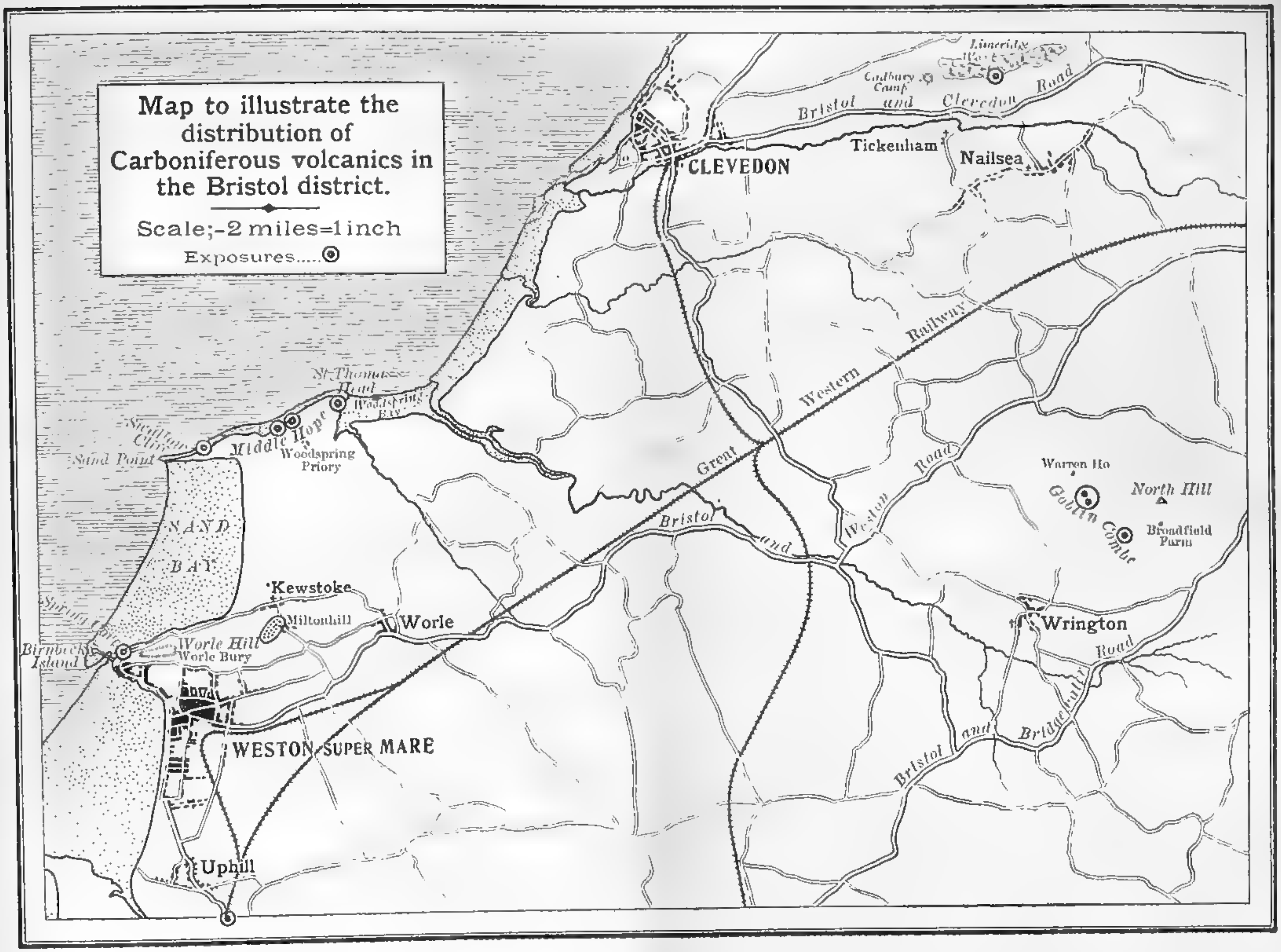
6. Ashy oolitic limestone from Goblin Combe, eastern exposure. This shows abundant oolitic grains and well-marked lapilli, embedded in a calcareous matrix. (See p. 155.)

### Discussion.

Mr. A. Strahan said that he had listened with pleasure to the careful description of these interesting rocks. The Authors had added much to our knowledge; for they had not only recorded two new occurrences, but (what was more important) had determined that the volcanic rocks of the various localities occurred at the same horizon in the Limestone. The object of the traverse made by Sir Archibald Geikie and himself had been mainly to complete the Cardiff sheet of the 1-inch Geological-Survey map; and although the advisability of subdividing the Limestone and determining the horizon of the volcanic rocks had been discussed, no opportunity had arisen of carrying out the work. With the assistance of Mr. Vaughan, the Authors appeared to have proved that the tuffs all occurred at the same horizon. He (the speaker) had suggested that the vent lay somewhere to the west, probably under the Bristol Channel. Whether tuffs could have been so evenly and widely distributed from one vent only was perhaps open to doubt. He congratulated the Authors on the interesting results of their investigation.

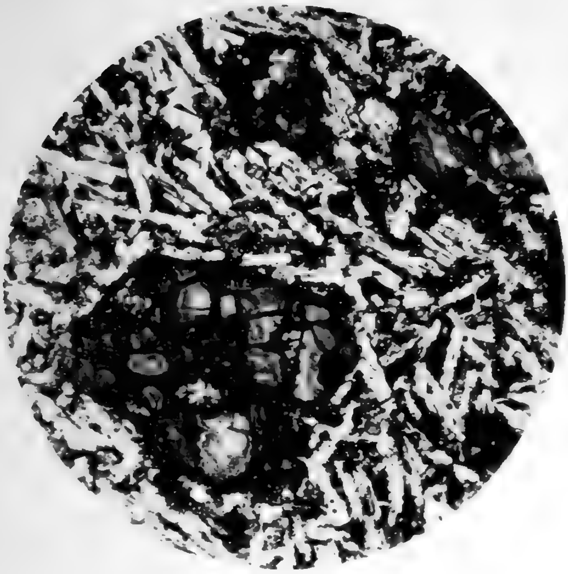
The Chairman (Sir Archibald Geikie), alluding to the description of the volcanic rocks given by Mr. Strahan and himself, to which the Authors had referred, said that the examination of these rocks had been undertaken by them, not with the view of making a detailed study of the subject, but for the purpose of correcting the


Limeridge
Cadbury Camp
Bristol and Clevedon Road
Tickenham
Nailsea
CLEVEDON
Great Western Railway
Weston Road
Warren Ho
Goblin Combe
North Hill
Broadfield Farm
Wrington
Bristol and Bridgewater Road

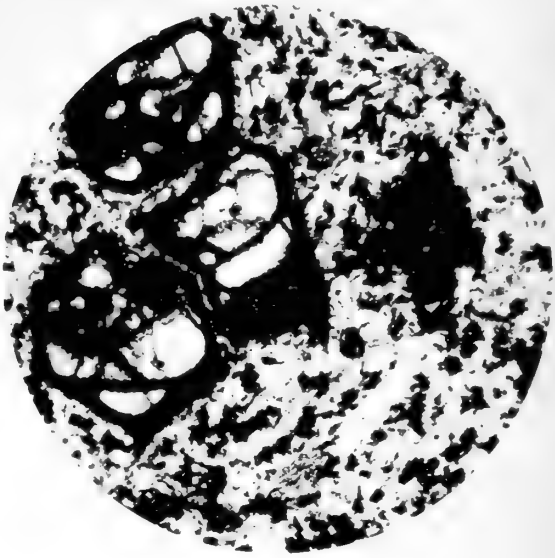


Map to illustrate the distribution of Carboniferous volcanics in the Bristol district.
Scale;-2 miles=1 inch
Exposures.....
CLEVEDON
Tickenham
Nailsea
Cadbury Camp
Bristol and Clevedon Road
Sand Point
Middle Hope
Woodspring Priory
St Thomas Head
Woodspring Bay
SAND BAY
Kewstoke
Miltonhill
Worle
Worle Hill
Worle Bury
Birnbeck Island
WESTON SUPER MARE
Uphill
Great Western Railway
Bristol and Weston Road
Warren Ho
North Hill
Goblin Combe
Broadfield Farm
Wrington
Bristol and Bridgewater Road

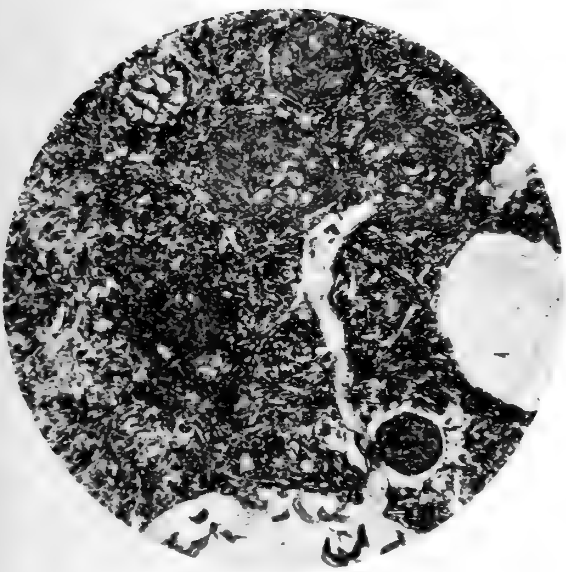
1. × 25



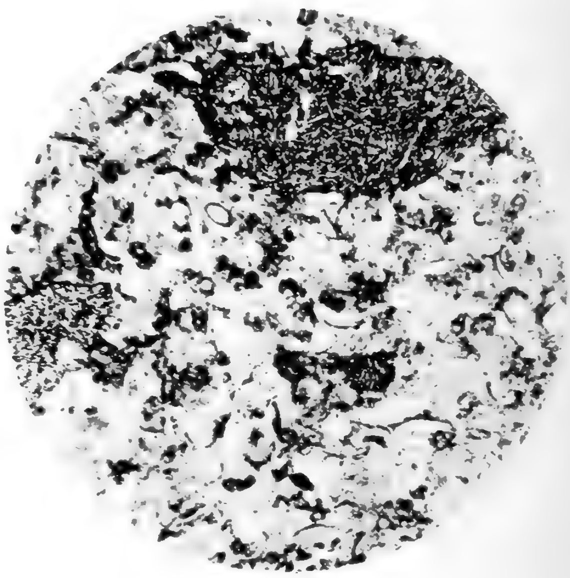
2. × 25



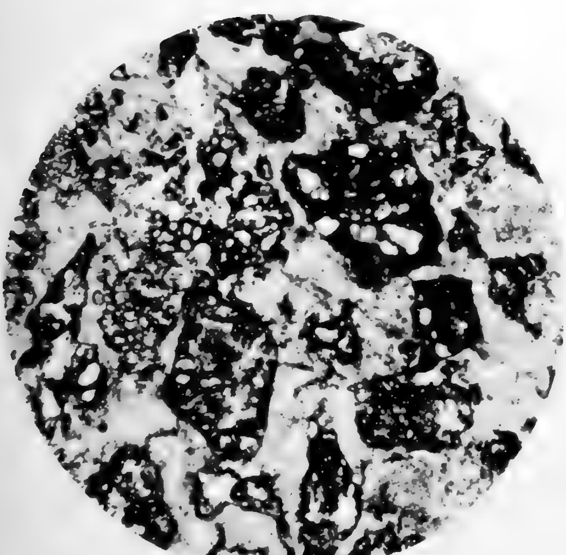
3. × 12½



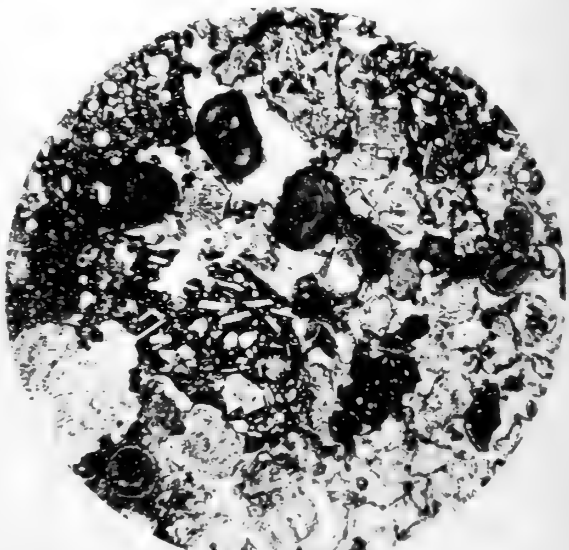
4. × 12½



5. ×12½



6. × 12½



IGNEOUS ROCKS FROM THE BRISTOL DISTRICT.

*Photomicro, H. A.-B.*

*Bemrose, Collo.*

erroneous interpretation which had prevailed and was expressed on the maps of the Geological Survey. The specimens first collected by Mr. Strahan left no doubt in the speaker's mind that the rocks in question formed a volcanic series contemporaneously intercalated in the Carboniferous Limestone. In order to put this question beyond possibility of dispute, he subsequently went over the ground with Mr. Strahan, and the description of the lavas and tuffs given in the 'Summary of Progress of the Geological Survey' was the result of that visit. His colleague and he could not attempt to define the particular horizon in the Carboniferous Limestone on which this volcanic intercalation lay, nor whether there were more horizons than one. He was glad that their conclusions had been so amply confirmed by the Authors of this paper; and especially that the definite platform appeared to have been ascertained, on which the records of the Carboniferous-Limestone volcanic eruptions of the Bristol district had been preserved.

Prof. Watts enquired as to the exact method of occurrence of the variolitic type in the lavas. Was it confined to lavas, or did it occur in rocks the exact origin of which was unknown? He congratulated the Authors on having determined, in this instance, that the volcanic rocks occupied a definite horizon in the Carboniferous Series.

Prof. Reynolds, in reply to the last speaker, stated that varioles were met with only in the rock from Spring Cove, of the contemporaneity of which there could be no doubt. The varioles only occurred in certain parts of the rock.

## 13. *On the* Igneous Rocks *at* Spring Cove, *near* Weston-super-Mare.

By William S. Boulton, Esq., B.Sc., A.R.C.S., F.G.S., Lecturer in Geology at University College, Cardiff. (Read January 20th, 1904.)

### I. Introduction.

In the Summary of Progress of the Geological Survey for 1898 (pp. 104–11), Sir Archibald Geikie & Mr. Strahan, in a description of a 'Volcanic Group in the Carboniferous Limestone of North Somerset,' published for the first time the evidence for the contemporaneity of these igneous rocks.[1] The authors refer briefly to the basalt and associated tuffs at Spring Cove, immediately to the west of the town of Weston, and describe in more detail the basalt-lava and beds of tuff interbedded with the fossiliferous limestone along the ridge of Middle Hope, 2 miles north of Weston.

At the time of the publication of this account, I had already made a detailed examination of these rocks in the field, and of microscopic and chemical preparations; but as my results seemed in general accord with those of the authors named, especially in regard to the rocks of Middle Hope, I felt that little or nothing was to be gained by the publication of my work as a whole.

In the rocks at Spring Cove, Weston, however, there appear to me to be points of considerable interest which are only briefly touched upon, or not mentioned at all, in the account to which I have referred, and I therefore venture to submit some additional observations in regard to them.

### II. General Description of the Rocks.

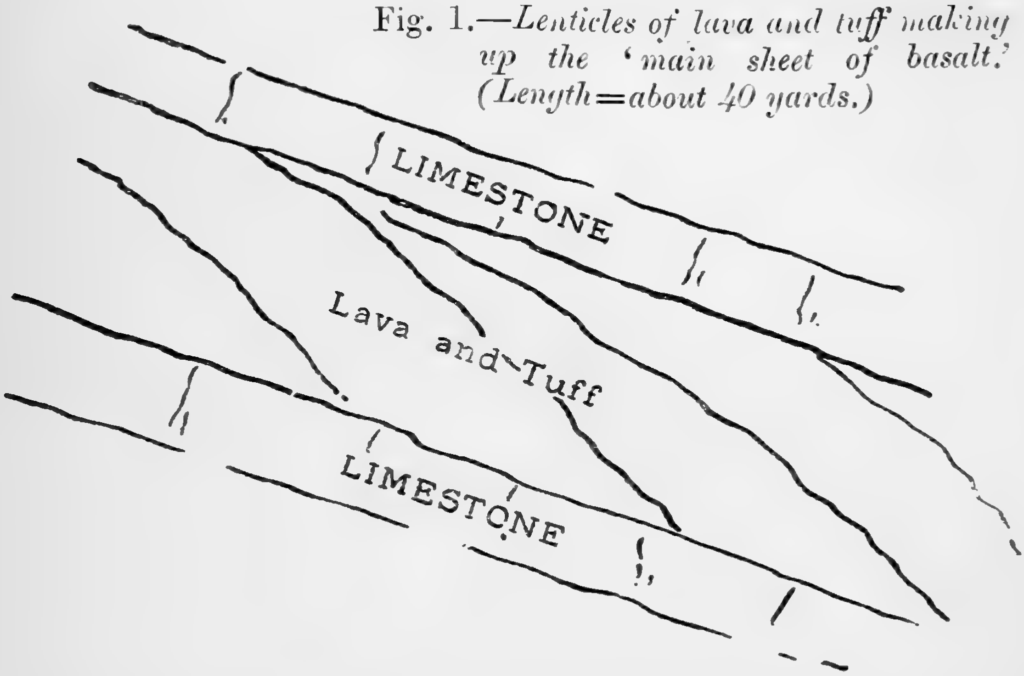
The basalt at Spring Cove, immediately north of Weston Pier, runs obliquely to the high road, and is exposed from low-water mark along the foreshore into the face of the cliff, the exposed length being about 150 yards. The massive beds of Carboniferous Limestone, between which the basalt is intercalated, strike north-eastward, and dip south-eastward (towards Weston) at about 40°. The basalt-sheet is parallel to the bedding of the limestone, and has a thickness of about 45 feet.

A traverse from end to end of the exposure shows clearly that the rock varies considerably in structure and appearance, and that it is by no means a simple basalt-lava flow. Starting from low-water mark, the rock is a hard, compact, red, slightly-amygdaloidal

[1] In this account reference is made to the observations of previous investigators.

olivine-basalt, containing very occasional lumps of limestone, from a few inches to a foot or more across. For the first 100 yards its upper junction with the limestone cannot be seen, because of the accumulated boulders at the foot of the cliff, while the lower junction is covered with water, even at lowest spring-tide. Then, a little more than halfway from the low-water end, and along to the cliff, the basalt changes in character somewhat suddenly. It now contains big lumps of burnt limestone, and the whole mass becomes broken up into a very coarse tuff or agglomerate, containing great lenticular masses of highly-slaggy basalt, 5 to 6 feet long, together with lumps and bands of limestone, often considerably fractured, and up to 10 or 12 feet in length. About 20 or 30 yards farther on, and as far as the end of the exposure in the cliff, the rock is more uniform in character, being a 'pillowy' basalt, though considerably brecciated and very amygdaloidal, with comparatively little tuff. But it still contains masses of limestone, even larger than those in the middle of the exposure.

Fig. 1.—*Lenticles of lava and tuff making up the 'main sheet of basalt.' (Length=about 40 yards.)*




The whole mass appears to consist of great lenticles of basalt, or tuff, or both confusedly mixed, together with the included limestone. The median planes of these lenticles run obliquely to the limestone-beds above and below, so that the lenticles dip at a steeper angle than the sheet as a whole (fig. 1). It would thus appear that the mass is capable of being roughly divided into three portions. Commencing at the cliff-end to the north (in which direction the vent was probably situated), the rock for the first 30 yards is a 'pillowy' basalt, with tuff and limestone often occupying irregular spaces between the spheroids of amygdaloidal basalt; then, for about 20 yards, the rock is mainly a coarse agglomerate, with lapilli and bombs of basalt and lumps of limestone; while, for the remaining 100 yards or so, it is an ordinary basalt-coulée, with very few, and always small, lumps of burnt limestone.

### III. Relation of the Basalt to the Limestone below it.

The basalt rests upon a hard bed of pink limestone, about 9 feet thick. Immediately under the basalt the red coloration is intense, but passes down into reddish-yellow and yellow; and the limestone, especially in its upper portion, is markedly crystalline to the naked eye. Below this bed is the typical, purplish-brown, fossiliferous limestone about 25 feet thick; and this again is underlain by a soft, pink, nodular rock, showing oblique lamination, and containing the remains of corals and encrinites. This last bed is somewhat tuffy-looking, but an examination of the residue, after treatment with boiling hydrochloric acid, shows that it is an excessively-fine red mud, without any recognizable volcanic lapilli, but probably derived from some volcanic centre. This residue is in striking contrast with those from the calcareous tuffs at Middle Hope, all of which show abundant lapilli of basalt-glass, felspar-crystals, etc.

Sir Archibald Geikie & Mr. Strahan tabulate the following succession of these rocks at Spring Cove (*op. cit.* p. 105):—

'Massive limestone, full of fossils. The lowest 3 feet of the rock are crowded with fine volcanic dust, which, under the microscope, is seen to consist of fine vesicular lapilli.

'Highly-amygdaloidal altered basalt, having a "pillow"-structure, and with abundant calcareous and hæmatitic veins, and threads of carbonate of copper; about 35 or 40 feet.

'Red limestone, full of fine volcanic dust, and passing down into the ordinary grey, fossiliferous limestone.'

In the limestone under the basalt I have been unable to detect any undoubted igneous fragments, of the nature of volcanic dust or lapilli (despite a diligent search in thin slices under the microscrope), from the basalt-junction down to a depth of 9 feet in the limestone. But the soft red rock, some 35 feet below the basalt, may represent, as stated above, very fine volcanic dust, while a section of the reddish-purple limestone, 8 feet below the basalt [23],[1] has a very tuffy appearance, as remarked below.

The following is a description of some of the sections cut from this underlying limestone:—

[3] Reddish limestone, in contact with the basalt. The slice clearly shows elliptical and rounded oolitic grains, set in a matrix of calcite, occurring in small, irregularly-outlined crystals, and with well-marked cleavage. As the rock approaches the junction with the basalt, the oolitic structure gradually disappears, and the rock comes to consist of a confused aggregate of minute calcite-

[1] The numerals in square brackets, throughout this paper, refer to the numbers of the slides in the Author's 'Weston collection.'

crystals, with no definite outlines or cleavage. With this change comes in much reddish-brown colouring-matter, occurring in irregular veins and fissures. In places the brown substance shows distinct rhombohedra, sometimes with curved faces and projecting into the vein, which is filled up with clear secondary calcite. This brown substance, which is bright yellow and red by reflected light, is doubtless carbonate of iron, carried down by percolating waters from the basalt above, deposited in the limestone as chalybite, and subsequently oxidized, giving to the limestone its pronounced red tint, more especially for the first few feet below the junction.

[28] Another junction-specimen is a reddish-brown rock, with the appearance of a breccia in the hand-specimen. Under the microscope, the basalt can be seen penetrating and absorbing the limestone. The contact has evidently much affected both rocks. The basalt is represented at the actual junction by a host of minute, pale-green or nearly colourless needles (? tremolite), which are largely masked by iron-oxide. These needles are associated with some brown and yellow glass and much secondary calcite, forming a fine groundmass. The limestone is reddish-brown, structureless, and polarizes faintly.

[24] Another junction-specimen is intensely red, and shows under the microscope the 'ghosts' of the original oolitic grains.

[21] A slice from a specimen taken 3 feet below the junction shows, besides the usual reddish-brown ferruginous matter in the spaces between the oolitic grains, which in places has a marked superficial resemblance to fragments of palagonitized glass, a large number of nearly colourless rhombs of dolomite, fringing cavities or veins filled with water-clear calcite.

[23] A sample taken 8 feet below the junction, of a reddish-purple colour, effervesces strongly with acid, and has a very tuff-like appearance. Under the microscope it shows angular and rounded fragments of oolitic limestone in a dark reddish-brown matrix, and the borders of the fragments are strongly marked with the same colouring-matter. But even here no certain igneous material was detected, although it is possible that the highly-coloured matrix is fine volcanic dust, and not colouring-matter brought down in solution from the overlying basalt.

## IV. Relation of the Basalt to the Limestone above it.

The determination of the precise nature of this junction is obviously important, as bearing on the contemporaneity or intrusion of the basalt. In the Survey account referred to above it is stated (p. 106) that

> 'fine volcanic dust appears in the overlying limestone for about 3 feet above the surface of the lava, and thereafter the calcareous rock assumes its usual highly-fossiliferous character.'

I have cut and examined sections at and near the junction and for about a foot above it, and can confirm the above observation. At the actual junction, and for about a foot from it, lapilli of basalt, one-eighth to one-sixteenth of an inch across, are very numerous, often with the typical concave surfaces, due to fracture across vesicles. In among these lapilli, calcite-crystals occur, and round their borders is a brown, yellow, or red ring of iron-oxide derived from the basalt-fragments, while fringing some lapilli are clusters of small, pale-yellow rhombs of dolomite, showing patches of bright yellow and borders of red iron-oxide by reflected light.

## V. Some Special Characters of the Basalt-Sheet.

The characters of this igneous flow which are of especial interest are (*a*) the 'pillowy' structure, together with the tuffy or agglomeratic structure; and (*b*) the included lumps and masses of limestone.

Fig. 2.—*Oval, slaggy lumps of basalt-lava surrounded by fluxion-tuff.*

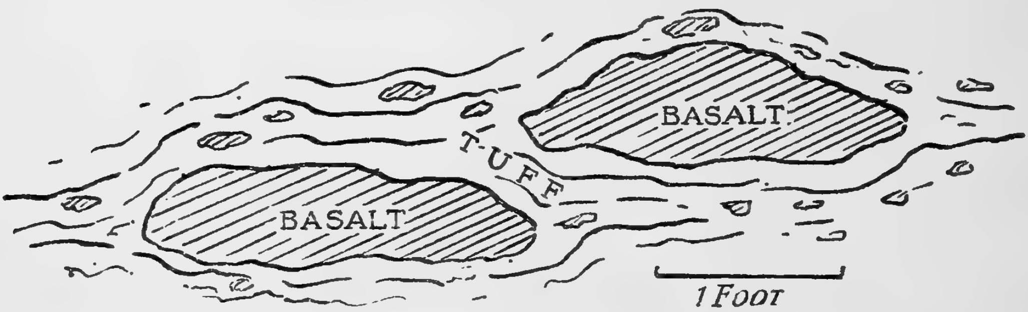
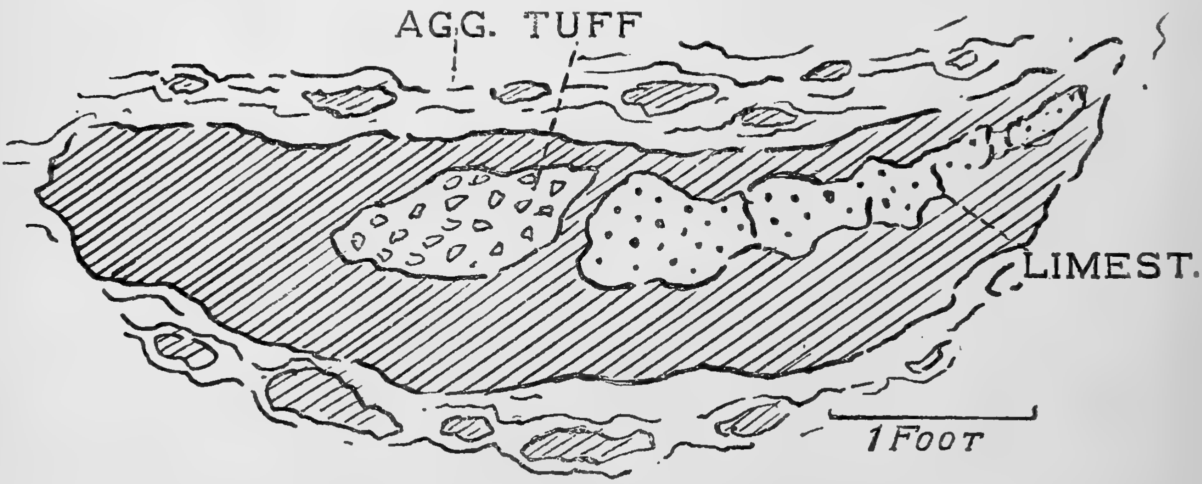


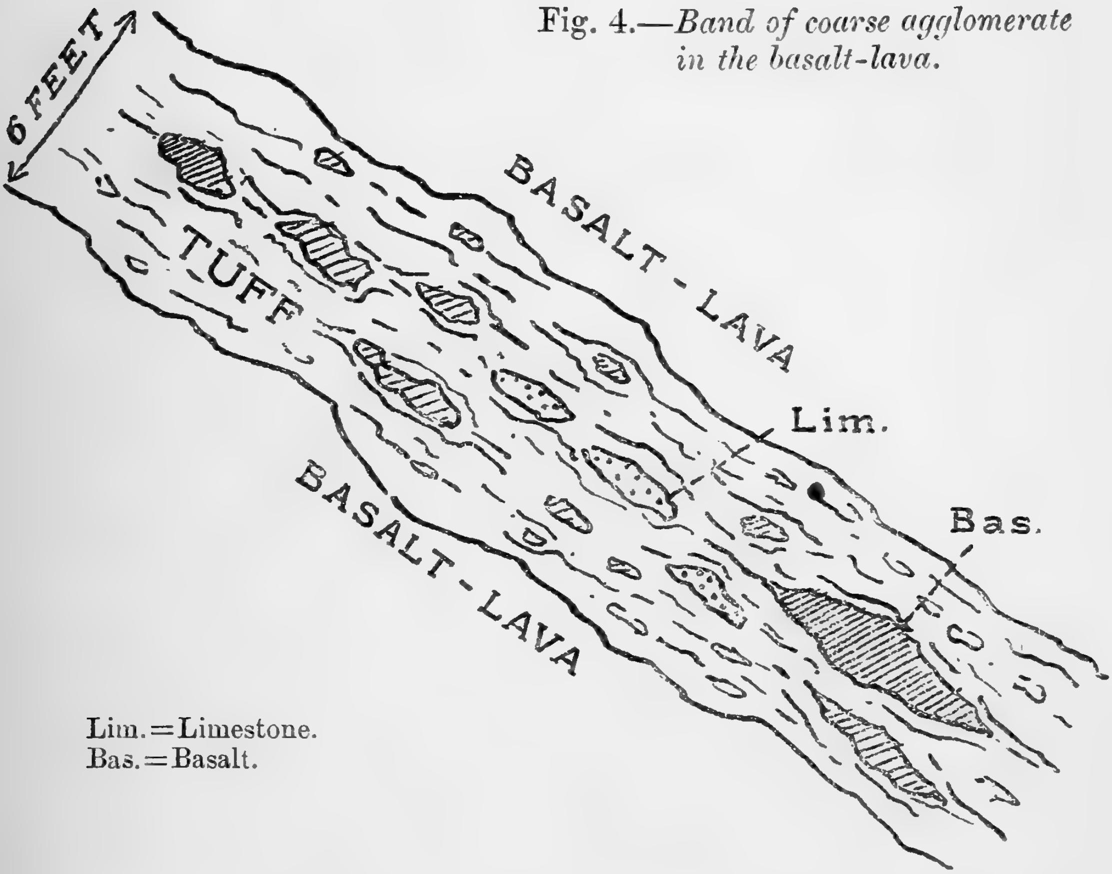

Fig. 3.—*Lump of basalt-lava, enclosing a lump of tuff and of limestone, and itself enclosed in coarse fluxion-agglomerate.*




The pillowy, oval, or spheroidal masses of basalt, 2 to 8 feet across, usually very amygdaloidal, especially round their periphery, and sometimes containing small oval or angular cores of a slightly different and earlier lava, are usually embedded in a tuff made up of lapilli up to 2 or 3 inches across (figs. 2 & 3).

Near the middle of the sheet, covered and underlain by massive lava, is a band 5 to 6 feet wide, with a dip roughly parallel to the other lenticular masses, consisting of a confused mass of coarse tuffy material, made up of angular fragments of lava 1 to 2 inches across, embedded in a fine red-and-green matrix, and containing lenticular cakes of vesicular lava, phacoids (often broken and torn) of limestone, and higher up the cliff larger spheroidal lumps of lava. The whole band suggests forcibly the augen-structure characteristic of gneisses. It probably represents, however, a torrent of agglomeratic material that flowed down a slope on the surface of an already-extruded bed of lava, carrying in among the finer

Fig. 4.—*Band of coarse agglomerate in the basalt-lava.*




Lim. = Limestone.
Bas. = Basalt.

lapilli larger, irregular, and plastic masses of scoriaceous basalt-lava of the nature of bombs, together with lumps and fragments of limestone, which from their form and broken character suggest that they were ejected from the vent with the basaltic material (fig. 4).

In all cases where the phacoidal or lenticular structure is seen, whether on a large or on a small scale, the material forming the groundmass is fragmental and tuff-like, while the included phacoidal masses consist of vesicular lava, or limestone, or very occasionally masses of coarse tuff (figs. 2, 3 & 4).

A thin slice of the typical tuffy matrix [20] shows small subangular or rounded, closely-fitting, equal-sized lapilli, about an

M 2

eighth of an inch across, with little or no interstitial matter except secondary calcite and iron-oxide. The lapilli consist of basalt-glass crowded with felspar-microlites, and in all general characters suggest strongly an analogy with the 'volcanic sand' of the recent West-Indian eruptions, so graphically described by Dr. T. Anderson & Dr. J. S. Flett.[1]

It is highly probable that this basaltic mass, like other pillowy lavas containing portions of sedimentary material, was ejected under water; and it is certain, I think, that the tuff or agglomerate was not in the main forced into the air by an eruption and deposited in the sea-water. There is no evidence of sedimentation, or the quiet accumulation of dust and lapilli; all the appearances point to flow. It might be termed a fluxion-tuff or agglomerate.

Possibly, if the vent had been situated in very shallow water, or on the land, much of this fragmental material would have been blown into the air, fallen in the water, and settled down quietly on the sea-floor, as, indeed, appears to have been the case with much of the tuff at Middle Hope, 2 miles to the north. At Weston, however, the greater weight of water above may have prevented this, and compelled the fragmental material to flow as lava. Or again, as in the West-Indian examples already cited, the expansive force of the imprisoned vapours may have been sufficient to break up the lava within the vent, but insufficient to do more than just force the tuff over the lip of the vent, whence it flowed along the sea-floor in obedience to gravity, and impelled forward, in part, by the expanding gases.

One of the most remarkable features of the sheet is the abundance of lumps and irregular masses of limestone, enclosed in the amygdaloidal and 'pillowy' basalt, or occurring as phacoids and lumps in the tuffy material.

In the accompanying diagrams (figs. 5, 6, 7 & 8, pp. 165–67) some of these masses are shown, ranging in size up to 10 or 12 feet, often broken and torn, in part eaten into and absorbed by the basalt, and sometimes tailing off into smaller and smaller fragments. Characteristic features are the concave surfaces of the limestone, often due to the fact that the latter occupies an irregular space between a number of spheroids or 'pillows' of the basalt, looking as if either the limestone had been absorbed by the hot lava, or, more probably, squeezed into its present shape by the distending and moving spheroidal masses.

There can be no doubt that this limestone is not secondary, due to the deposition of calcareous material from aqueous solution subsequent to the outflow and consolidation of the lava; nor has it been deposited as sediment in irregular spaces between the spheroids after the cooling of the basalt; but it is unquestionably part of the calcareous floor upon which the basalt-flow rests. Many of these included masses are oolitic, the structure being visible sometimes to

[1] Phil. Trans. Roy. Soc. ser. A, vol. cc (1903) pp. 448–49.

the naked eye, while a microscopic examination shows the oolitic grains distinctly, together with the remains of encrinites, etc.; and the basalt has penetrated, fused, and absorbed the limestone along its borders.

Fig. 5.—*Junction of the basalt and an included mass of limestone.*

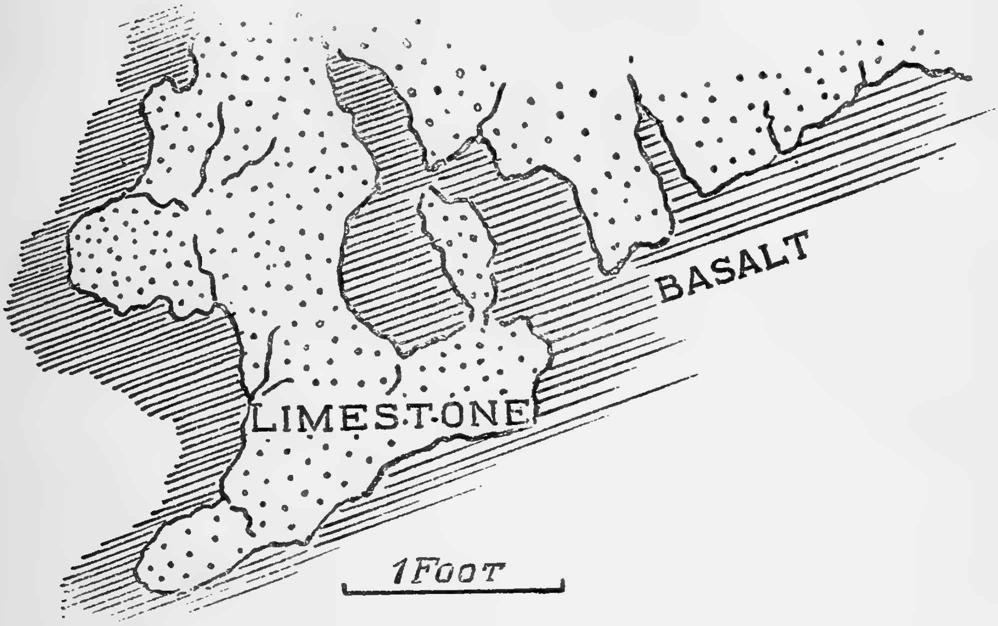
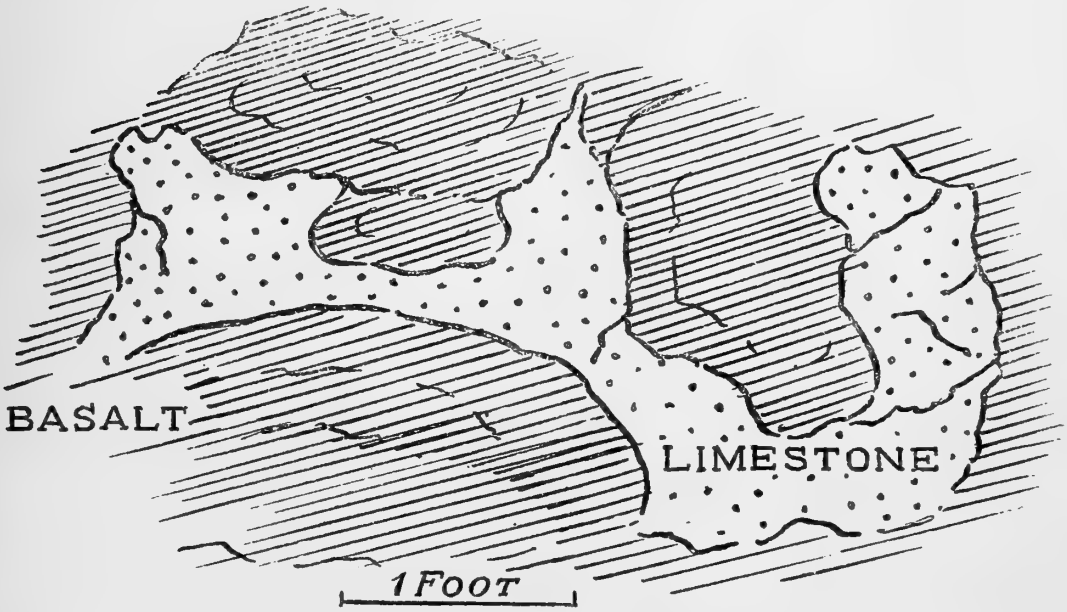



Fig. 6.—*Included lump of limestone in basalt.*




A thin slice through the junction of the basalt and an included mass of limestone [30 *c*] shows that the basalt, here a brown, yellow, red, or green glass, in places distinctly variolitic, penetrates and absorbs the limestone, which is turned yellow and red, owing to the staining of iron-oxide; while, along the edge of the limestone at the junction, occur wavy bands of reddish-brown and yellow alteration-material, reminding one of agate-structure. Here, as

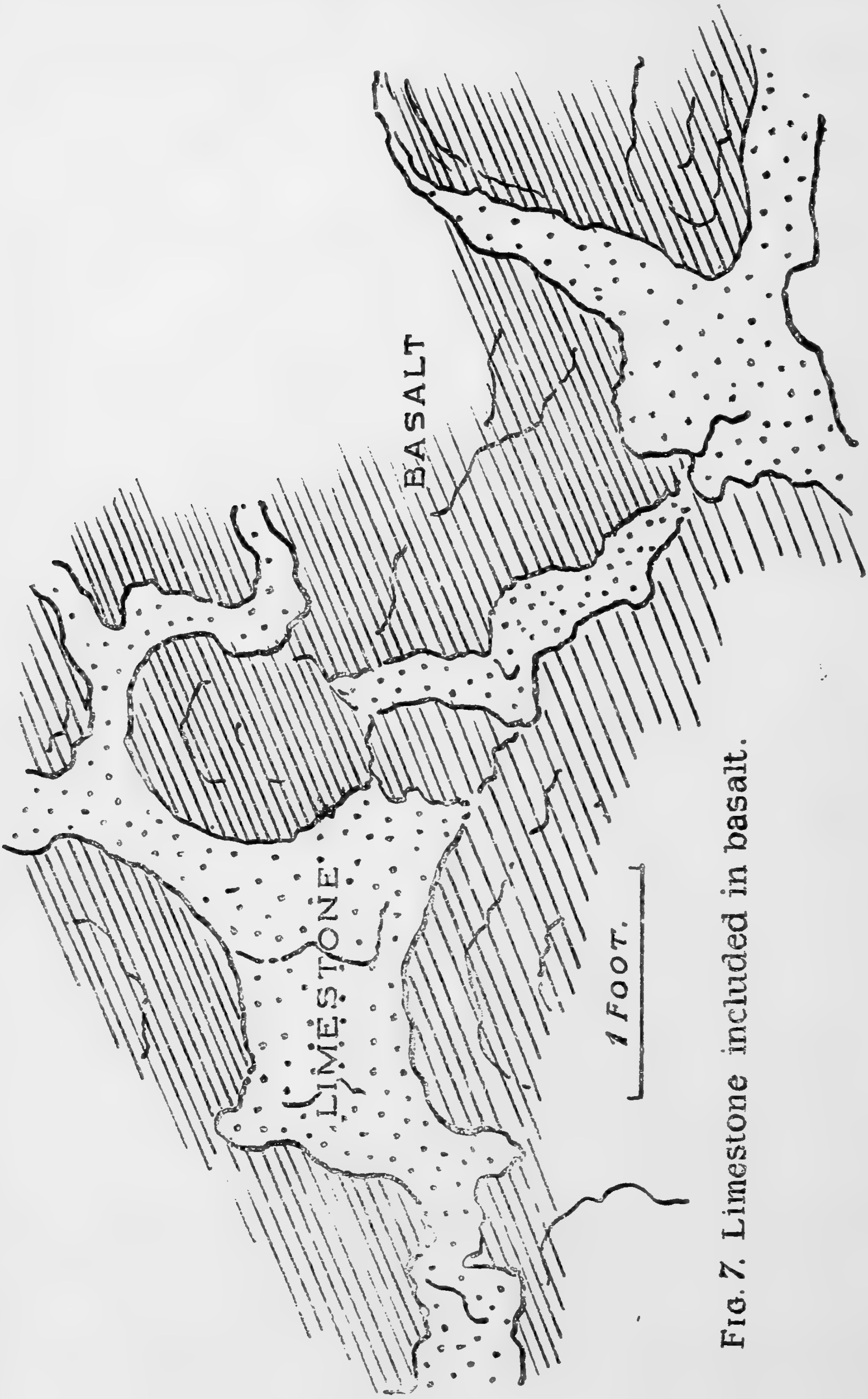
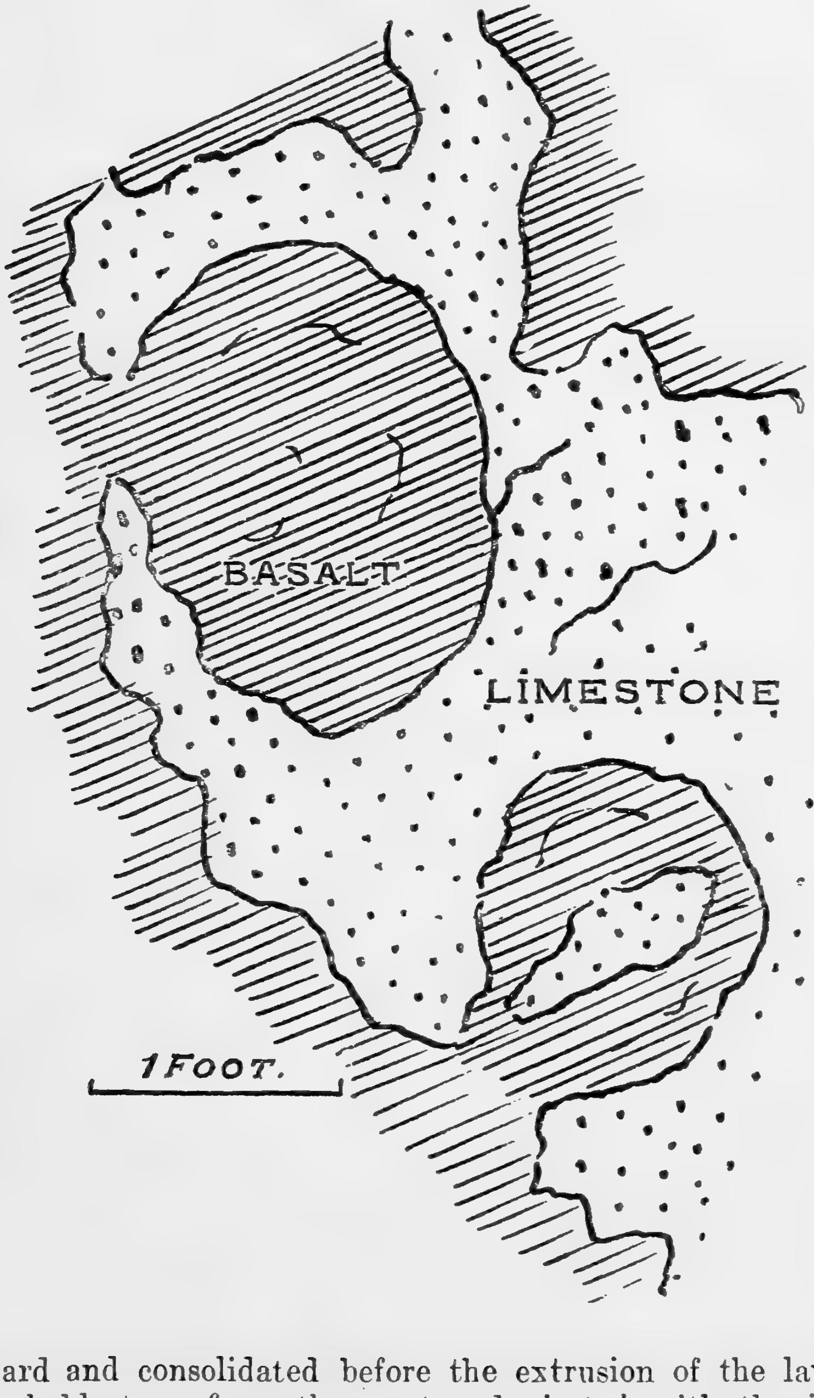



FIG. 7. Limestone included in basalt.

in the limestone under the basalt, rhombs of chalybite fringe the walls of drusy cavities and veins, the rest of the space being filled in with clear secondary calcite, while limonite and hæmatite have been subsequently deposited.

In some instances the limestone, more especially that occurring as irregular lumps in the tuff, is so cracked and broken, evidently during the movement of the flow, as to suggest that it must have

Fig. 8.—*Portion of an included lump of limestone in basalt.*




been hard and consolidated before the extrusion of the lava, and was probably torn from the vent and ejected with the igneous matter.

Small oval bodies, generally a few inches long, occur in the basalt; these, when broken, show a yellow or red shell of carbonate of lime, the rest being filled with pure white, secondary calcite, and in some cases quartz; indeed, in a few instances, rounded or oval bodies up to a foot in length consist entirely of silica. These may be lumps of limestone, burnt and hardened on the outside by the hot lava, their centres being subsequently removed in solution, the hollows thus formed serving as receptacles for secondary calcite or quartz; while in a few cases the whole lump of limestone has been replaced by silica. It is possible, however, that some of them may be large vesicles filled with secondary minerals.

But, in most cases, the general shape and behaviour of the limestone-masses, particularly between the spheroids of basalt, seem rather to suggest that the calcareous material must have been only in part consolidated, so that it behaved as a pulverulent or more or less plastic substance, and got rolled in or picked up by the lava, and was able to fit itself in between the moving and distending spheroidal masses.

In this connection, it is interesting to compare the general shape and appearance of these included masses with those in other localities, as, for example, in the Arenig lavas of Ballantrae and elsewhere, with their marked pillowy structure, so well illustrated and described by Sir Archibald Geikie and the officers of the Geological Survey.[1] There the included material is jasper, radiolarian chert, graptolite-shale, and limestone. In the memoir describing these rocks in the Ballantrae district it is stated (*op. cit.* p. 432) that

'the calcareous matter does not seem to have penetrated far down through the successive beds, being confined mainly to the surfaces of the flows.'

In the case at Weston it must be admitted, as already pointed out, that the calcareous material did not come from above, but from the underlying floor.

In the account of these Weston rocks by the officers of the Geological Survey, it is suggested that the vent from which the rocks of Spring Cove were derived lay somewhere to the west, where now the Bristol Channel lies; but from the fact that the included masses of limestone dwindle rapidly in size and number from north to south, and that the lenticular sheets of lava and tuff, representing individual minor flows, also slope from north to south, it would seem more probable that the vent lay somewhere to the north of this Spring-Cove exposure.

Except for the presence of lapilli of basalt in the base of the limestone resting at once on the basalt, it might be difficult to show that the whole is not an intrusive sheet. The conditions in these submarine flows appear to be very like those in a sill or intrusive sheet, where, as Prof. Lapworth has suggested, we may get tuffs, lava, and included masses of sedimentary material confusedly mixed, and drawn out into lenticles as here described.

[1] Mem. Geol. Surv. (1899) 'Silurian Rocks of Britain' vol. i, Scotland.

## Discussion.

The Chairman (Sir Archibald Geikie) remarked that, since the publication of the joint description with Mr. Strahan, referred to by the Author, he had had an opportunity of re-examining the fine series of intercalated lavas in the Carboniferous Series of Fife. In most, if not in all, of those basalts which show the pillow-structure the materials that now fill up the interspaces between the ellipsoids have come from above and evidently belong to the series of sediments—tuff, sandstone, shale, limestone, etc.—which followed the emission of the lava. There is no trace of an explosive character in the lavas themselves; and he greatly doubted the possibility of a lava which had once escaped from the vent and flowed for some distance, subsequently blowing itself to pieces by the expansion of its own imprisoned vapours. No doubt, sudden contact with water might cause some lavas to break up; yet it was nevertheless the fact that in the case of those in question, though they had all flowed out over the bottom of a lagoon or the floor of the more open sea, none of them showed more than the usual irregular cracked surfaces. He did not think that there was ever much resemblance between the behaviour of a sill and that of a submarine lava-flow. He welcomed the additional information now supplied regarding an exceedingly-interesting little volcanic district, and hoped that the Author might be induced to study the other exposures in the same careful and detailed manner.

Prof. Watts remarked that the paper constituted a very important contribution to volcanic geology. It enabled us to realize that conditions of vulcanicity prevailed in Carboniferous times similar to the vulcanicity of the present day. He was greatly impressed with the suggestion that the eruption described in the paper was of the Peléan type: the lava was blown to atoms, and the pulverized material formed a fluxion-tuff. In the Llandeilo of the Shelve district the speaker had formerly been perplexed how to classify a rock similar to that described by the Author. There was no reason why lava should not be blown to dust beneath the sea as well as on land, and the pressure of the water would induce conditions reminiscent of an intrusive sill. The Author had satisfactorily proved that most of the sedimentary material caught up in the lava had been derived from below, and his evidence was not inconsistent with that brought forward by the Geological Survey from the Southern Uplands of Scotland.

The Author thanked the Fellows for their reception of the paper. He quite agreed with the Chairman that limestone, and sedimentary material generally, found within the body of pillowy lavas, might have come about in different ways in different cases, and that in some cases the material had doubtless come from above, either in solution or as sediment; but, from the evidence at Weston, it appeared certain that it might have come from below, ejected from the vent or picked up by the moving lava from the sea-floor. He did not think that it was necessary to assume a great depth of water at Weston during the outpouring of the lava.

## 14. *A* DESCRIPTION *of some* RHÆTIC SECTIONS *in the* BRISTOL DISTRICT, *with* CONSIDERATIONS *on the* MODE *of* DEPOSITION *of the* RHÆTIC SERIES.

By A. RENDLE SHORT, Esq., B.Sc., M.B., B.S. (Communicated by Prof. S. H. REYNOLDS, M.A., F.G.S. Read December 16th, 1903.)

CONTENTS.



### I. INTRODUCTION.

THIS paper is a condensation of a longer memoir, the parts omitted being chiefly lists of fossils and remarks on the same. It embodies the results of some five years' study of the Rhætic Series, chiefly in the Bristol district, made easier by the fact that I reside in that district.

### II. DESCRIPTION OF FOUR NEW RHÆTIC EXPOSURES.

#### (A) Redland, Bristol.

A number of exposures have been recently made here in cutting a new road. One of these has already been briefly dealt with in a local memoir by Mr. W. H. Wickes (46),[1] and again by Mr. Parsons (47). I give, with slight modifications, Mr. Wickes's classification of the beds, and his list of fossils, enumerating those that I have found in addition. The lettering corresponds to that used by the late Edward Wilson for the Pylle-Hill section (36). The fossils are not obtained solely from the exposure originally described, but from the newer exposures as well. It is impracticable to separate them, as the material thrown out has been mixed.

| | *Feet* | *inches.* | |
|---|---|---|---|
| S. Five beds of hard, blue, shelly limestone, with brown shaly partings. | 2 | 8 | *a.* (In the upper two bands.) *Ammonites torus.* (*Am. planorbis* found, but not in place.)<br>*b.* (In the lower bands.) *Pleuromya Crowcombeia, Modiola minima, Cardium rhæticum, Pecten Pollux, Monotis decussata* (rare). |

[1] Numerals in parentheses throughout this paper refer to the Bibliography § VI, p. 190.

| | Feet | inches | |
|---|---|---|---|
| | | | c. (Precise horizon not specified.) *Ostrea liassica, O. lævis, O. multicostata, O. irregularis, Lima gigantea, L. valoniensis, L. hettangiensis, Pecten calvus, P. dispar, Cardinia Listeri, Pholadomya glabra, Plicatula intusstriata, Unicardium* sp.; *Rhynchonella calcicosta, Terebratula* sp.; *Nautilus striatus; Cidaris Edwardsi (?)* spines; *Pentacrinus; Montlivaltia* sp.; *Serpula* sp.; burrows, etc. |
| R. Thick hard limestone ... | 0 | 5 | Similar fossils to S. |
| Q. Rubbly limestone......... | 0 | 7 | *Pleuromya Crowcombeia, Cardium rhæticum, Plicatula intusstriata.* |
| P. White shaly and rubbly limestone. | 0 | 9 | *Modiola minima, Pleuromya Crowcombeia, Cardium rhæticum, Plicatula intusstriata, Pholadomya glabra, Arca (?) Lycetti, Monotis decussata.* (Mr. Wickes records insect-fragments.) |
| O. Yellow clay-parting ... | 0 | 1½ | |
| N. Cotham Marble, a continuous band. | 0 | 8 | *Modiola minima, Monotis decussata, Chemnitzia nitida.* |
| M. Blue and brown and greenish clay, with white shaly partings. | 2 | 0 | *Plesiosaurus*-vertebra; *Darwinula.* |
| L. Thinly-bedded, siliceous, white limestone. | 1 | 0 | (Barren.) |
| K. More thickly-bedded but fissile, siliceous limestone (see below). | 2 | 0 | *Naiadita lanceolata* (very abundant), *Axinus cloacinus, Cardium rhæticum, Pecten valoniensis* (a few), *Myacites* sp.; *Estheria minuta, Darwinula; Acrodus minimus, Hybodus minor, Saurichthys acuminatus, S. apicalis,* bones, coprolites. (Mr. Wickes records *Pholidophorus, Lepidotus,* and *Legnonotus.*) |
| I. Dark, shelly, hard, thickly-bedded limestone, weathering brown, but with a bluish-black core. | 0 | 8 | *Pecten valoniensis* (very abundant), *Axinus cloacinus, A. concentricus, A. elongatus, Cardium rhæticum, C. cloacinum, Cardinia regularis, C. suttonensis, Modiola minima, Pleurophorus elongatus, Pleuromya Crowcombeia, Plicatula intusstriata, Gervillia præcursor, Anomia valoniensis; Discina Townshendi; Gyrolepis Albertii, Saurichthys apicalis, S. acuminatus, Acrodus minimus, Hybodus minor, H. cuspidatus; Termatosaurus Alberti, T. crocodilinus, Sphærodus minimus;* coprolites, scales, spines, etc. |
| H. Dark shaly clay ......... | 0 | 5 | (Barren.) |
| G. Limestone resembling I, with a layer of fibrous calcite (='beef') above it. | 0 | 4 | *Avicula contorta, A. solitaria, Axinus cloacinus, Pecten valoniensis, Modiola minima.* |
| F. Crumbly black shales ... | 3 | 0 | (Just here I have found no fossils. The Lower Rhætic is better displayed in a fresh section.) |

Such is the original exposure, which furnished the material for Mr. Wickes's paper.

The next section to be opened, about a quarter of a mile or less away, displayed upturned beds of Upper Carboniferous Limestone, cut off flat, with the Rhætic Beds deposited on them unconformably. The limestone-beds are very massive, and dip at 35° south 80° east. Between these beds little pockets of yellow clay pass down for a variable distance, due to greater erosion along the planes of stratification.

On the east, the Carboniferous platform gradually slopes down at an angle of about 10°, quickly becoming steeper, beneath the Rhætic Beds, and is lost to sight. The Rhætic Series overlying this has been briefly touched upon by Mr. Parsons (47), who explored it with me in the first place, but since then I have found the Bone-Bed and many more fossils.

| | Feet | inches. | |
|---|---|---|---|
| S. Three beds of blue limestone. | ...... | | *Ostrea liassica*, *Modiola minima*, *Pleuromya Crowcombeia*, *Pholadomya glabra*, etc. No ammonites. |
| R. Thick, hard, blue limestone. | 0 | 5 | (Same fossils as above.) |
| Q. Rubbly white limestone (incompletely exposed). | | | |
| A short distance from this, the Rhætic Series is again exposed. | | | |
| N. Cotham Marble ......... | 0 | 4 to 8 | *Modiola minima*, *Monotis decussat* an insect-wing. |
| M. Laminated blue and yellow clay. | 2 | 0 | (Barren.) |
| K, L. *Naiadita*-beds ...... | 2 | 0 | A very few specimens of *Naiadita*. |
| I. Inconstant black limestone, weathering brown. | 0 | 4 to 6 | *Pecten valoniensis* (abundant), *Axinus cloacinus*, *Modiola minima*, teeth and scales of fishes. |
| H, F. Black shales, crumbly above, hard and fissile below; with ferruginous bands ........... about | 6 | 0 | (Barren.) |

About 3 feet down are a few nodular, red limestone-masses, containing *Avicula contorta*, *Modiola minima*, and *Placunopsis alpina*.

| | Feet | inches. | |
|---|---|---|---|
| A. Bone-Bed ...... | 0 | 2 | *Acrodus minimus* (very abundant), *Gyrolepis Albertii* and *Saurichthys acuminatus* (abundant), *S. apicalis*, *S. listroconus*, *Hybodus minor*, *H. cuspidatus*, *H. orthoconus*, *H. raricostatus*, *H. sublævis*, *Sphærodus minimus*, *Squaloraia (?)*, *Sargodon tomicus*, *Sphenonchus hamatus*, *Termatosaurus Alberti (?)*, *T. crocodilinus*; various doubtful fossils discussed later, coprolites, ribs, vertebræ, scales, bits of bone, and *Hybodus*-spines. |

The most interesting bed in this series is the Bone-Bed. It lies directly upon the flat, eroded edges of the Carboniferous-Limestone strata, and is so tightly cemented to them that, on hammering, it nearly always breaks up instead of separating from the limestone. Its thickness is very variable, and it is over considerable areas absent. In the clay-pockets that lie between the beds a very few teeth may be found. It never fills up these pockets, but is only found on the cut-off surfaces of the limestone-bands.

The Bone-Bed contains very numerous fish-remains, all except the smallest being fragmentary, tightly cemented together by a reddish-brown, gritty, calcareous sandstone. The whole is very hard, and fossils are difficult to knock out entire. In addition to the teeth, scales, and bones mentioned above, there are:—(i) numerous coprolites, sometimes an inch in diameter; (ii) small rounded quartz-pebbles, with a peculiar resinous surface in many cases, varying in size from that of a millet-seed to that of a small walnut; (iii) angular or subangular pebbles of Carboniferous Limestone; and (iv) well-rounded pebbles of sandstone from the Upper Carboniferous-Limestone Series, fairly numerous, and often measuring 2 inches in diameter.

Between the two exposures above described, an extensive cutting, displaying the Lower Rhætic beds especially, has been made; the succession is as follows:—

| | *Feet* | *inches.* | |
|---|---|---|---|
| Q. Rubbly limestone. | 2 | 0 | |
| N. Cotham Marble, very inconstant, in patches about a yard across, and 4 to 6 inches thick. | 0 | 4 to 6 | |
| M. Laminated blue and yellow clay, with white bands. | 3 | 4 | |
| K, L. *Naiadita*-beds — fissile, thinly-bedded, cream-coloured limestones. | 2 | 0 | *Naiadita lanceolata*, etc. |
| I. Hard, dark, shelly limestone, weathering brown. | 0 | 5 | *Pecten valoniensis* (very abundant), other fossils as in the first section. |
| H. Shaly parting............ | 0 | 4 | |
| G. Limestone like I; 'beef' above and below. | 0 | 5 to 8 | *Avicula contorta*, *Pecten valoniensis*, etc. |
| (The shaly parting is in places absent, and G and I are then conjoined.) | | | |
| F.—II. Crumbly black shales and clay, with siliceous bands, containing *Cardium rhæticum*. | 2 | 0 | *Avicula contorta*, *Pecten valoniensis*, *Axinus cloacinus*, *A. concentricus*, *A. depressus*, *A. elongatus*, (?) *Anatina Suessi*, *Cardium rhæticum*; *Gyrolepis Albertii*, *Hybodus minor*, *Saurichthys acuminatus*. |
| I. Thin but constant ferruginous band. | | | |
| E. III. Black laminated clay. | 2 | 0 | |
| II. Ferruginous band. | | | |
| I. Black and green laminated clay. | 1 | 0 | *Avicula contorta*, *A. solitaria*, *Axinus cloacinus*, *A. depressus*, *Cardium rhæticum*, *Gervillia præcursor* (young), (?) *Anatina Suessi*, *Placunopsis alpina*. |

| | Feet | inches. | |
|---|---|---|---|
| D. Thickly-bedded, fissile, hard, black shales, not crumbly: = 'Paper Shales,' with shaly concretions. | 1 | 9 | Very barren; a few specimens of *Axinus cloacinus* and *A. concentricus.* |
| C, A. III. Bone-Bed, containing Carboniferous-Limestone and sandstone-pebbles; very crumbly. | 0 | 2 | Very few organic remains, except coprolites; *Acrodus minimus, Saurichthys acuminatus, Gyrolepis Albertii.* |
| II. Green and black marl. | 0 | 6 | (Barren.) |
| I. Ferruginous band | 0 | 1 | |
| (KEUPER). II. Brown sandstone (variable). | 0 | 0 to 5 | |
| I. Hard, sandy, green and brown marlstone, with dendritic markings. | 3 | 0 | |

This section is of interest, as showing how ill-developed the Bone-Bed becomes when receding from the old shore; as it is not coherent, it is not very recognizable.

The next exposure to be considered is beyond that described second (p. 172). Here, in laying a sewer, another interesting succession came to light:—

| | Feet | inches. | |
|---|---|---|---|
| Q, R, S. Blue and white Lias, etc. | 4 | 2 | (Fossils as usual.) |
| P. Hard, white, fine-grained limestone. | 0 | 3 | *Monotis decussata.* |
| O. Hard, thickly-bedded, black shale, crumbly on its upper surface. | 0 | 6 | *Modiola minima, Monotis decussata; Gyrolepis Albertii.* |
| N. Cotham Marble, chiefly of the variety which I have described as 'False Cotham Marble' (53). | 0 | 3 to 6 | |
| M. Blue and yellow clay ............... about | 2 | 0 | |
| K, L. *Naiadita*-beds, not seen in place. | | | |

Instead of being cream-coloured fissile limestones, these beds are thin, hard, sandy, argillaceous slabs, breaking into thin but large pieces. They are grey in colour, and often sprinkled with tiny mica-flakes. They are, moreover, extensively ripple-marked, the distance between the waves being usually about 2 inches. Exquisitely-preserved worm-tracks, sometimes 3 inches long, are very common.

Yet another exposure remains to be described, but it is in the Trias rather than the Rhætic. Still, it throws light on some of the problems of the latter series. It is situated nearer Bristol, about a quarter of a mile away, at a level about 20 or 30 feet below the Black Shales. The succession is :—

About 1 yard of surface-soil.
V. Red marl : 2 feet.
IV. Celestine-bed : 2 to 8 inches.—Rather inconstant, confined to the one horizon.
III. Red marl : 3 inches.
II. Hard typical green marl : 4 inches.
I. Red marl : 15 feet.—Contains a few calcareous plates and nodules. At the top it is full of nodules about the size of a cricket-ball, composed of carbonates of strontium and calcium, in the proportion of 37·63 per cent. of the former, and 62·36 per cent. of the latter.

The celestine, IV, contains an unusual proportion of strontium-carbonate ($SrSO_4$=68·43 per cent. ; $SrCO_3$=31·56), and is badly crystallized, but shows a distinct blue colour.

The whole Rhætic Series described above dips gently east-north-eastward at a somewhat variable angle, usually about 10°. On the Cotham-Marble horizon the rare mineral baryto-celestine may be found, chiefly in drusy cavities inside concretions.

Since writing the foregoing account, I have found in the *Pecten-valoniensis* zone two or three ovoid, well-rounded blocks looking exactly like charred wood. On analysis, these turn out to be chiefly carbon and carbonate of lime, with no phosphate, so that they can be neither bone nor coprolite, and indeed must be fragments of drifted wood. As they measure, though very incomplete, $\frac{3}{4}$ by $\frac{1}{3}$ inch, there must have been trees or very big bushes growing near the water, or by streams, at that time.

Messrs. Tutcher & Vaughan have described the Lower Lias and White Lias of these sections in a paper published in February 1903 by the Bristol Naturalists' Society (52).

## (B) Stoke Gifford.

In a railway-cutting recently made in connection with the new line from Filton, near Bristol, to Wootton Bassett, the Rhætic has been well exposed at Stoke Gifford, quite close to Filton.

The whole series dips at 5° towards 10° west of north.

The Lias has been described by Messrs. Reynolds & Vaughan (50), and it is unnecessary to repeat their description, except to add that I found *Monotis decussata* in their '*Ostrea*-beds.'

The succession is as follows :—

| | Feet | inches. | |
|---|---|---|---|
| N. Cotham Marble, in a continuous band. Top not so ridged as usual. | 0 | 4 | *Rhynchonella calcicosta ; Axinus* sp., *Monotis decussata.* |
| M. III. Grey laminated marl. | 2 | 0 | (Barren.) |
| II. Thin but constant band of siliceous limestone. | 0 | 5 | |

| | Feet | inches. | |
|---|---|---|---|
| I. Grey laminated marl, with mica-flakes. More thickly-bedded siliceous layers at the base, showing ripple-marks, the ridges running north-eastward and south-westward. | 3 | 3 | *Estheria minuta*, var. *Brodieana*; insects. |
| L, K II (*a*). Massive but banded, grey, siliceous limestone on the north side of the cutting. | 2 | 0 | (*a*) Usually barren, but about 10 inches down are several horizons of *Estheria minuta*. |
| (*b*) On the south side, thinly-bedded, cream-coloured, fissile limestone like the *Naiadita*-beds of Redland. | | | (*b*) *Naiadita lanceolata* on the south side. |
| I. Greenish-black calcareous shales (absent on the south side). Many of the fossils are pyritized. | 1 | 0 | *Pecten valoniensis, Axinus depressus, Cardinia suttonensis, Pteromya Crowcombeia, Saurichthys acuminatus, Gyrolepis Alberti, Naiadita lanceolata*, and especially many elytra of beetles and wings of insects, usually fragmentary. |
| I–H. Black flaky marl, very fossiliferous. (Messrs. Reynolds & Vaughan found here a hard black limestone-band with *Pecten*). | 0 | 10 | *Pecten valoniensis* (very abundant), *Avicula contorta* (scarce), *Axinus depressus, A. concentricus, A. cloacinus, A. elongatus, Anatina Suessi, (?) Gervillia ornata, Cardium rhæticum, C. cloacinum, Pteromya Crowcombeia, Pt. simplex; Gyrolepis Albertii, Hybodus*-spine, *Saurichthys*-teeth. |
| G. Dark siliceous limestone. | 0 | 3 | A few fish-scales. |
| F. II. Crumbly black shale. | 5 | 0 | |
| I. Pyritous sandstone... | 0 | 0¼ | |
| E. Crumbly black shales, with pyritous sandstone-bands, 15 and 22 inches respectively below F I. | 2 | 6 | *Avicula contorta, Axinus depressus, A. cloacinus, A. concentricus, A. elongatus, Cardium rhæticum, C. cloacinum.* |
| D. Hard, thickly-bedded black 'Paper-Shales.' | 2 | 0 | *Axinus; Gyrolepis.* (Very barren.) |
| C, B, A. (Absent.) | | | |
| Keuper: V. Grey, fine-grained, argillaceous sandstone. | 5 | 0 | |
| Keuper: IV. Grey shales . | 5 | 0 | |
| Keuper: III. Red marl ... | 1 | 6 | |
| Keuper: II. Grey shales . | 0 | 8 | |
| Keuper: I. Red marl ... | 12 feet exposed. | | |

(The thickness of the Rhætic Series here = 21 feet.)

The principal features of interest are: the continuous well-developed Cotham Marble; the insect-bed; the poor development of the *Pecten-valoniensis* limestone; and, finally, the absence of the Bone-Bed.

## (C) Cotham Road, Bristol.

The next section to be described was exposed for a few days, in cutting a channel in connection with the Oakfield Road Waterworks. It is interesting as passing Cotham House, where Edward Owen first found Cotham Marble in 1754. Although incomplete above and below, there are features that make it well worth recording. I may say that, as more than a few feet of the section were never exposed in one place, the measurements are rather approximate.

| | *Feet* | *inches.* | |
|---|---|---|---|
| S. Hard blue limestone, weathering yellowish-brown. (Not found in place.) | | | *Ostrea liassica, Pleuromya Crowcombeia, Modiola minima.* |
| N. Cotham Marble, poorly developed, usually absent. A few poor 'landscape-stones.' Frequently represented by concretions (see p. 178). | 0 | 6 | |
| M. Yellow marl .............. | 1 | 6 | |
| L, K. Hard, yellow, fissile limestone, like the *Naiadita*-Beds at Redland. Lower down, it becomes very massive, not fissile, with a grey homogeneous core and yellow exterior. Usually barren, but splits along surfaces covered with | 3 | 0 | *Naiadita lanceolata.* |
| There are also many bands, about a quarter of an inch thick, of brown, very shelly limestone, sometimes jointed into tiny squares and polygons. The shells are arranged horizontally parallel one to the other, in a way very suggestive of Purbeck Marble. | | | *Pecten valoniensis, Cardium cloacinum, Cardinia regularis, Modiola minima; Acrodus minimus, Gyrolepis Albertii, Saurichthys acuminatus;* coprolites. |
| I. Thick, hard, shelly, non-jointed black limestone. | 0 | 4 to 6 | *Pecten valoniensis* (very abundant), *Axinus cloacinus, A. concentricus, A. depressus, Cardium rhæticum, Modiola minima, Anomia valoniensis, Monotis* sp., *(?) Gervillia ornata; Natica Oppeli; Gyrolepis*-scales. |
| H, G. (Absent.) | | | |
| F, E. Crumbly black shales, with pyritous flakes; a few thin siliceous bands. | | | *Avicula contorta* (large and abundant), *A. solitaria, Pecten valoniensis* (only at the top), *Axinus concentricus, A. depressus, Cardium cloacinum, Myophoria Emmrichi* (very perfect and abundant), *Modiola (?) minima, Placunopsis alpina; Gyrolepis Albertii;* pyritous elytra of beetles. |
| D. Hard, more thickly-bedded, black 'Paper-Shales.' | | | A few specimens of *Avicula contorta* and *Axinus.* |
| Bone-Bed (absent). | | | |

The Black Shales are about 15 feet thick: the fossils in them are the best that I have ever seen. Below come about 15 feet of yellowish marl and then red sandstone, but this part of the section was very indifferently exposed.

The horizon of the Cotham Marble is interesting. It is remarkable that at the very birthplace of the name, so little good 'landscape-stone' should be found. Instead, there are several large, flat concretions of a texture very like that of Cotham Marble, about $1\frac{1}{2}$ feet in diameter and 4 to 6 inches thick, revealing cavities in their interior, lined with calcite and containing the rare mineral baryto-celestine, of a pale-blue colour, in which the sulphates of strontium, barium, and calcium are all found.

The beds K & L are of considerable interest also. They are much more massive than at Redland, and show no ripple-marks or suncracks. It is remarkable how the *Naiadita* keeps to special horizons containing no other fossils. Careful search failed to reveal *Estheria minuta*.

Finally, we may note the apparent absence of the Bone-Bed.

## (D) Aust.

It may, perhaps, be thought that on so classic a section as Aust nothing new could have been written. For many years it has been one of the type-exposures of the Rhætic, and Agassiz had immortalized its vertebrate fauna long before the Rhætic Beds were recognized as a formation. The principal references to Aust are by Agassiz ('Poissons Fossiles'), Etheridge (15), Davis (29), and the Clifton-College Scientific Society (18). Of these, the detailed account of the stratigraphy is given by Etheridge, whose table I copy and supplement. Now in this table a vacancy of 13 feet was left at the top, in a most interesting series of beds, because they were inaccessible from below. I therefore had myself let down from the top of the cliff by a rope, measured this gap, and studied its contents both in place and in fallen pieces:—

| *No.* | *Feet* | *inches.* | FORMATION. | FOSSILS. |
|---|---|---|---|---|
| 23. | 3 | 0 | Blue Lias .................... | *Ostrea liassica, O. multicostata, Pleuromya Crowcombeia, Pecten Pollux.* |
| 22. | 0 | 5 to 8 | Cotham Marble ............ | *Modiola minima, Monotis decussata; Gyrolepis Albertii, Pholidophorus Higginsi, Saurichthys apicalis, Legnonotus cothamensis, Sphærodus minimus;* insect-wings and elytra. |
| 21. | 4 | 2 | Yellow shaly clay ......... | (Barren.) |
| 20. | 2 | 6 | Hard, fine-grained, argillaceous limestone, cream-coloured outside, greyer inside; often fissile. | *Naiadita lanceolata; Estheria minuta.* |
| 19. | 5 | 0 | Yellow, thinly-bedded, very argillaceous limestone, often crumbly. | (Barren.) |

| No. | Feet | inches. | Formation. | Fossils. |
|---|---|---|---|---|
| 18. | 0 | 5 | Upper *Pecten*-Bed, hard grey limestone. Usually double, with 4 inches of shale intervening. The top often covered with crushed shells. | *Pecten valoniensis, Placunopsis alpina.* Locally it is thinly-bedded and crowded with *Acrodus minimus, Pleurophorus elongatus, Saurichthys apicalis, S. acuminatus, Gyrolepis, Hybodus*-spines, bones, coprolites, etc.; *Ichthyosaurus, Plesiosaurus, Termatosaurus.* |
| 17. | 8 | 0 | Black shales, with '*Pullastra*'-bands. | *Avicula contorta, Axinus, Cardium rhæticum.* |
| 16. | 0 | 8 | Lower *Pecten*-Limestone; shaly on the top, full of *Pecten.* Locally very pyritous. | *Pecten valoniensis, Avicula contorta, Axinus cloacinus, A. concentricus, Cardium rhæticum, C. cloacinum, Gervillia præcursor, Modiola minima, Myacites striato-granulata, Anatina, Anomia; Gyrolepis Albertii.* |
| 15. | 4 | 0 | Black shales, with arenaceous bands. | Fish-scales; the arenaceous bands contain '*Pullastra.*' |
| (15 *a*. | | | The upper part of this is hard, fissile 'Paper-Shale,' very barren, 16 inches thick.) | |
| 14. | 0 | 1 to 6 | Bone-Bed. | |
| (13–1.) | | | (See Etheridge's paper, *op. supra cit.*) | |

In addition to the fish-remains enumerated above, the *Pleurophorus*-bands (18), which are very abundant on the beach, yield numerous rounded quartz-pebbles, varying in size up to half an inch. There are no other pebbles, and the general grain of the bed is fine. These will be referred to later (p. 182).

The discovery of *Estheria* and *Naiadita* is interesting, as linking Aust with other Rhætic exposures, notably that of Westbury-on-Severn. These fossils are by no means common, but I have obtained several specimens of each.

## III. The Physical Geography of the Rhætic Period.

### (A) An Account of the Constituent Beds, with special reference to the Conditions of their Deposition.

(*a*) The infra-Bone-Bed Series.—Some would include here the Tea-Green Marls, which will be discussed later. But there are occasionally Rhætic strata below the Bone-Bed. As will be seen in the next section, by the Bone-Bed I mean a layer low down in the Black Shales containing bones, teeth, and pebbles or rolled marl, thus distinguishing it from other layers rich in teeth.

At Watchet the infra-Bone-Bed Series is fossiliferous (6). At Redland, and at Stanton-on-the-Wolds (31), Black Shales lie beneath the Bone-Bed.

(*b*) The Bone-Bed.—This is one of the most characteristic of the constituents of the Rhætic Series, not only in England but also in Germany, France, etc. Yet, despite its wide distribution, from Gainsborough (12), and Nottingham (31), through Penarth, Aust, Watchet, and Bristol to the Mendips at Emborough (48), and thence to the Continent, it is often absent at intermediate places, as at Droitwich (27), Stoke Gifford, and locally at Aust and Penarth. The conditions, therefore, to which it is due, were operative over a wide area, but only in certain parts of that area.

An interesting feature is the frequency with which the Bone-Bed occurs in pockets on a flat surface, or spread out over that surface. I have already described its occurrence in this way spread out on, and closely cemented to, a planed-off surface of upturned Carboniferous-Limestone bands at Redland (Bristol). At Penarth I found it lying in pockets on a surface of hard, tea-green, calcareous marlstone, which has been worn into irregular hollows and ridges in a way that suggests contemporaneous erosion. Here it contains, besides teeth and scales, fragments of rolled marl, more or less rounded pebbles of Carboniferous Limestone (sometimes as much as 2 inches in diameter), pebbles of quartzite up to 1 inch in diameter, and small well-rounded quartz, occasionally black on fracture. The organic remains are not often entire, unless quite small; the larger fossils have usually been broken up. This deposit has also been noted by Storrie (32). At Chipping Sodbury, again, the Bone-Bed occurs in pockets in a surface of Carboniferous-Limestone bands that have been upturned and cut off flat, and here also I found pebbles of Carboniferous Limestone embedded in the Bone-Bed. There are, as well as these, smaller pebbles of hard sandstone from the arenaceous bands in the Upper Limestone Series, which are exposed quite near.

It is well known that at Aust, too, the Bone-Bed includes rolled pebbles of marl, etc. The true Emborough Bone-Bed, described by Profs. Lloyd Morgan & Reynolds (48) under (*e*), contains more pebbles than teeth; it is a closely-packed, rather loosely-cemented conglomerate full of pebbles, usually about the size of a pea, chiefly consisting of rolled Carboniferous Limestone, but also of chert and quartz.

Pebbles are also recorded in the Bone-Bed at Garden Cliff, where I take it that the lower, though less conspicuous band, is the true Bone-Bed, and at Bourne Park (54). They are often mentioned in Continental records also, as, for example, in Lorraine, at Hildesheim, etc. (62).

The conglomeratic nature of the Bone-Bed, however, has frequently been noticed, and further examples are not necessary.

In the Bone-Bed certain fishes tend to preponderate locally. At Aust it is *Ceratodus* that, although not now abundant, is yet the prominent feature. At Redland, *Acrodus minimus* is most abundant, though *Saurichthys* and *Gyrolepis* follow closely. At Chipping Sodbury it is *Saurichthys*, and at Penarth *Sphærodus minimus* that is most prominent. *Ceratodus* is fairly common at Chipping Sodbury.

Now, we may ask, what were the conditions under which the Bone-Bed was laid down?

I. They must have been conditions of extensive and shallow water, or of flats just above water-level. This is proved by the wide distribution of the conglomerates. It was not along a beach or shore-line that these beds were deposited: that is to say, they do not form a narrow band between a shore of older formations and a deep Rhætic sea, for they do not occur along any single line. Nothing is more striking than the widespread character of the deposit. Then, again, at Penarth and elsewhere the Bone-Bed lies in pockets of a contemporaneously-eroded surface of hard, tea-green, calcareous marl. In many localities that marl was firm enough to be rolled into balls. Lee noticed 'rills on the Marl' at Gold Cliff (35). At Lavernock Point the Bone-Bed fills sun-cracks in the marl (35): here, then, must have been extensive sun-dried flats, which were overflowed by the sea that laid down the Bone-Bed. There are ripple-marks in it at Wainlode Cliff (54). From this facies there is every gradation to that in which no conglomerate at all is to be found, but only a few scales and teeth, or not even that. Here, of course, the water was somewhat deeper, perhaps several fathoms: probably these deeper parts were of the nature of channels and pools.

I conclude, then, that at the time when the Rhætic Bone-Bed was laid down, the great Keuper lake had been nearly dried up in some localities, or silted up in others. The shallower parts had been left as muddy flats a few inches above water-level, the deeper parts as very shallow and extensive lagoons, of course highly saline, and connecting these were occasional deeper channels or pools. The exposed flats were rippled and sun-cracked. Then the sea entered from the German area, and along certain of the channels a Rhætic fauna spread.

II. At a period when the conditions were such as those just described, and shortly after the Rhætic sea had entered, but before it had done more than freshen and send its fauna into some of the main channels, into a set of which it had gained access, came a period of rough weather.

The points in favour of regarding the Rhætic Bone-Bed as a storm-deposit are as follows:—

It was not due to the first inrush of the Rhætic sea, for that had already entered.

It was due to a cause operative over the whole of England, and, probably at the same time, over part of the Continent.

It resulted in the overflowing of dry flats a little above water-level.

The movements were such as to scatter pebbles, roll fragments of marl, break bones and teeth that were large, and often round off the smaller ones.

For some reason the cause that determined this conglomerate-bed also determined the death of immense numbers of fishes, their disintegration, and the scattering of their remains far and wide. But in certain localities, presumably where the water was deeper, these results did not take place, consequently the fishes were not killed, and the water at the bottom was not so disturbed as to lay down a conglomerate.

An interesting modern analogy has been described by Leith Adams.[1] In September 1867 a violent storm killed such numbers of fishes in the Bay of Fundy, by driving them into shallow water, that the coast was in places covered with their bodies to the depth of a foot.

Raised by the storm, the waters overflowed most of or all the mud-flats, scattering pebbles from the Carboniferous Limestone and other beaches of the old Keuper lake. These pebbles had, of course, been rounded long before on the beaches, and the storm merely spread them out over the flats.

We may here notice the abundance of small rounded quartz-pebbles that are often recorded in the Bone-Bed. I have found them at Redland, Aust, Chipping Sodbury, Penarth, Emborough, etc., and they frequently occur elsewhere. They are often observed far away from any quartziferous rocks, apart from any other siliceous pebbles. They are seldom more than half an inch in diameter, and are usually smaller, but are seldom smaller than hemp-seed. They are fairly well-rounded as a rule, and if angular the sharp edges have always been just blunted. They usually have a peculiar resinous appearance.

These quartz-pebbles frequently occur under similar conditions in Germany, and were thought by Quenstedt (56) to have been swallowed by *Ichthyosaurus* and other vertebrates for digestive purposes. My attention was first called to this hypothesis by Mr. A. Vaughan. Quenstedt succeeded in demonstrating them in the position of the stomach, inside an *Ichthyosaurus*-skeleton. Such an explanation fits in well with their peculiar distribution, referred to above. The characteristic surface and the rounding-off of the edges would be very likely under such circumstances. But the most important proof of the theory, to my mind, was furnished when I noticed their abundance on the surface of the argillaceous limestone numbered 18 at Aust, which is covered with *Pleurophorus elongatus*, fish-remains often large, slender and yet perfect, coprolites, and these quartz-pebbles, but no others (see p. 179). The bed is not in the least conglomeratic—in fact is fine-grained, and nevertheless these pebbles, of this particular description only, are found with the fish-remains on the surface. They cannot possibly have been washed there by water; they must have been dropped.

I need scarcely say that all the pebbles in the Bone-Bed did not have such an origin. Angular pebbles of limestone are frequent, which could never have survived a passage through an animal's alimentary canal. Moreover, the Carboniferous-Limestone and siliceous-grit and marl-pebbles are generally much bigger, and more irregular in size and shape, than the quartz-pebbles ever are.

(*c*) The Black Shales.—These are very constant, and too well known to need description.

In the Bristol district there is always a zone of very firm, well-

[1] Quart. Journ. Geol. Soc. vol. xxix (1873) p. 303.

laminated black shales near the bottom of the series, well deserving the name of 'Paper-Shales' when dry. This zone is very barren.

Mr. Parsons has observed, at the base of the Black Shales at Redland, a very curious type of passage-beds between these shales and the underlying beds, which are often yellowish-brown shales or clays, sometimes typically-green laminated marl. Instead of a bed of well-marked Black Shale resting upon one of brown or green marl, the shales of the two series dovetail one into the other, and in one and the same bed pieces in some parts black, in others green, may be found. Moreover, it is common to find a horizon chiefly of Black Shale overlain by one chiefly of green, or red, or yellow shale or marl. In fact, at the junction every variety of admixture may be noted. Mr. Parsons explains it by assuming that the whole was originally black, and has been bleached by oxidation through the agency of pyrites. He is even prepared to assume that the whole of the Green Marls were so produced (47).

Concerning the truth of his observation there is no doubt. But I think that a much more probable explanation is that the Black Shales are simply the brown or green clays with organic matter added. Just when the Rhætic sea entered and brought this animal life, it is not at all surprising that it should be patchy in distribution at first. Then the interlocking would be readily explained. This is all but proved by a somewhat parallel case. In my description of the shale just above the Cotham Marble at Redland, numbered O, I have mentioned that it is usually yellow, and is barren. But in one place it becomes fossiliferous, and has yielded *Modiola minima*, *Monotis decussata*, etc. (see p. 174). And here it is no longer yellow, but black; of exactly the same appearance, in fact, as the *Avicula-contorta* shales.

The Black Shales include several inconstant bands of siliceous or pyritous grit, often marked with the obscure fossil that was formerly called '*Pullastra*.' They are somewhat pyritous all through. Ripple-marks (27) and sun-cracks are recorded (31). Occasionally, seams rich in teeth and scales and coprolites occur, which have been dignified with the name of Bone-Beds, as at Emborough in the Mendips (48), and at Garden Cliff (2). At Cotham, in the section that I have described, elytra of beetles probably occur.

What conclusions can we draw from the foregoing observations as to the physical conditions of deposition of these beds? After the Bone-Bed storms, the depth of the water evidently increased, partly due to rains, and partly to depression of the land. The salinity had now been corrected, and the open communication with the sea kept up the relative freshness. In fact, the Rhætic Period in England seems to have been a good deal more rainy than the Triassic, and the waters ultimately became brackish. During the Black-Shale time-interval, however, they were probably of ordinary oceanic salinity. Although deeper than before, the Black-Shale sea was still shallow, and occasionally patches were left dry to sun-crack. Rippling and the occurrence of insects also indicate fairly-shallow water.

(*d*) The *Pecten*-Limestones.—Just above the Black Shales it is usual to find one or more seams of very hard, thick, badly-jointed shelly limestone, usually blue inside and yellowish-brown when weathered, rich in *Pecten valoniensis*. There are frequently two such bands, and occasionally, as at Aust and Watchet (6), three. Where absent, they are represented by a shale very rich in *Pecten valoniensis*, which is also found always in the Black Shale immediately beneath them. These limestones are not usually ripple-marked or sun-cracked; they are probably the relics of an ancient shelly ooze, deposited in rather deeper water than the rest of the Rhætic. The transition from shale to limestone is due to the following of a dry period, with less washing down of mud by the streams, upon a wet one; and at the same time to the importation of many molluscs, and very likely minute calcareous organisms as well.

(*e*) The *Naiadita*-Beds.—Above the *Pecten*-Limestones occurs a series of thinly-bedded limestones and calcareous shales, originally blue when massive, but weathering yellow or grey, containing *Estheria minuta*, var. *Brodieana*, and *Naiadita*. These beds are recorded at most of the important Rhætic exposures.

They are seldom very fossiliferous, and are not at all like the shelly *Pecten*-Limestones. Nearly all, usually all, their fossils occur along certain shelly or plant-covered horizons. Otherwise, they are fine-grained and barren. It is interesting to note how *Estheria*, *Naiadita*, and the shells (*Pecten*, *Axinus*, *Cardium*, etc.) tend to avoid each other's horizon. I have never seen *Estheria* and *Naiadita* together; shells and *Naiadita* only occur in company occasionally.

Most noticeable about these beds is the abundant and often striking evidence of shallow-water conditions, or even exposure, that they commonly afford. At Redland this is excellently shown by a fine series of ripple-marks, sun-cracks, and worm-tracks. It is common to find worm-tracks on a rippled surface, in a grey thinly-bedded marlstone, looking exactly like a modern beach. I have found specimens of sun-cracked argillaceous limestone showing most excellently the fine flaking-off of the top layers of dried mud. Further evidence of shallow water is given by the frequency of wings of insects, as, for example, at Stoke Gifford and Redland. These shallow-water conditions prevailed over an extensive area, not merely along a shore-line. They are well marked at Redland, Stoke Gifford, Penarth, Watchet, etc.

The chemical composition of these beds is variable. One specimen from Redland, more calcareous in appearance than most, contained 60 per cent. of carbonate of lime. Others contain less. I found on microscopical examination only tiny calcite-crystals and shell-fragments, but no foraminifera. It is true that the examination was a somewhat imperfect one.

(*f*) The Clay-Beds.—In practically every British Rhætic section there is a variable but often considerable thickness of blue, yellow, or grey clayey beds above the shaly *Naiadita*-limestones, and below the Cotham Marble. Those beds are almost invariably barren of organic remains.

(*g*) The Cotham Marble.—I have discussed the origin of this rock elsewhere (53), and merely state here that my theory demands a chemical origin, by precipitation of carbonate of lime, under a hot sun, in an extensive, very shallow lagoon with occasional deeper pools.

The Cotham-Marble horizon, when that stone is absent, is usually represented by white rubbly limestone, or else yellow clay or shales. Sometimes *Chemnitzia nitida* and *Monotis decussata*, the most characteristic representatives of the Cotham-Marble fauna, occur in these, as at Pylle Hill (36), where Wilson subsequently found the Landscape-Stone in his bed N (45).

(*h*) The White Lias.—With this may be here included all the beds between the Cotham Marble and the lowest *Ammonites planorbis* or *Am. torus.*

The White Lias itself usually consists of rubbly, white, calcareous beds, with a good deal of siliceous matter. The occurrence of insects in these shows that they were laid down in shallow water (1). They are, as a rule, shelly.

Above these, beds exactly like those of the overlying Liassic limestone (that is to say, thinly-bedded, blue shelly limestone weathering yellow or brownish-yellow, with yellow or brown shaly partings) generally occur. Sometimes, as at Aust and Stoke Gifford, these follow immediately upon the Cotham Marble, with at most a shaly parting, but no rubbly limestone.

Around Bath is sometimes found the stratum, called the Sun-Bed, which Moore and others take to mark the upper limit of the Rhætic. It is hard, with conchoidal fracture, very fine-grained, cream-coloured, blue, or white; the upper surface is corrugated, and some consider it sun-cracked. It is marked by worm-tubes, which are very common in the White Lias in some places (as, for example, at Redland), and contains *Modiola minima* and *Ostrea liassica.* I think that to this bed, which is extremely local, has been accorded an importance which it does not deserve. Its chief interest, in conjunction with the occurrence of insect-wings in the White Lias, is the evidence provided of the persistence of the shallow-water conditions that prevailed throughout the Rhætic Period until this time.

## (B) A General Account of the Physical Geography of the Rhætic Period in England.

The most important paper that has appeared on this subject was by Sir Andrew Ramsay in 1871 (16). He argued that the Keuper was laid down in a great inland sea, which gradually dried up, becoming extremely saline, like the Dead Sea to-day. He remarked (*op. cit.* p. 196):—

'The thin Rhætic beds of North-Western Europe might have been deposited in great part in shallow seas and in estuaries, or in lagoons, or in occasional salt-lakes of small or great dimensions, separated from the sea by accidental changes in physical geography.'

Moore (13) referred to the Rhætics as oceanic, and Etheridge spoke of Penarth as being in the middle of the Rhætic ocean (17).

Some writers, following a suggestion by Brodie (1), have considered that the Rhætic Series is estuarine. Now it is, I think, generally admitted that Ramsay's theory of the Keuper is correct. There was a vast lake covering a large part of England, which gradually evaporated. The conditions were probably desertic. Therefore over that area there would be a more or less uniformly-horizontal surface, with perhaps very gently-shelving shores, and occasional deeper pools and channels. The Triassic lake seems to have evaporated nearly to dryness, except in the pools and channels which were a few feet deeper. The evidence of this is to be found in the minerals—rock-salt, for instance, indicating great concentration—and in the footprints on the Keuper shores.

Thus, before the Rhætic sea entered, the conditions were as favourable as could be for the deposition of very shallow-water beds over a very wide area. When matters stood thus, a gradual depression of the land allowed the Rhætic sea from Germany and France to enter, very gently at first. The channels that it more particularly entered were freshened, and the Rhætic Series of the infra-Bone-Bed horizon at Watchet, etc. was laid down, while Black Shales commenced to form in various places. Then came the storms which produced the Bone-Bed, and swept the waters over the just uncovered flats. Probably this storm also broke up the dry weather, and ushered in a wetter season. Owing to this, and to continuance of the slight depression, nearly the whole area of the old Keuper lake was covered by the shallow Rhætic sea. Although most of the Rhætic has now been removed by denudation, it is nearly always found where any beds resting upon the Trias have been left; and that not only along the Jurassic escarpment, but also at Watchet, Penarth, and near Burton-on-Trent (16). The chief exception is in part of Lincolnshire, where the Rhætic and *Planorbis*-zones are said to be absent (21). Throughout the whole Rhætic Period, the same conditions of extensive very shallow-water conditions, over the entire Triassic lake, prevailed. There was, of course, communication with the Alpine and Germanic Ocean to the south. Owing to the pauses in depression, the sea was in most places nearly silted-up by the time when the *Naiadita*-Beds were laid down, and every evidence of shallow water, and occasional exposure to the air, over wide areas, has been preserved. The ripple-marks, sun-cracks, and insect-wings, the paucity of big saurians between the Bone-Bed (which was laid down by a storm such as still washes whales into shallow water and breaks them up) and the White Lias—all these tell the same tale.

Slight depression then again occurred, and clays were laid down. Once again the depression was balanced by silting-up, and the

Cotham Marble was laid down in very shallow water. Only after the White-Lias period did the water finally become moderately deep. We may conclude, then, that the Rhætic Series was laid down in a gigantic shallow lagoon connected with the open sea to the south.

The waters were probably brackish on the whole, but with great variations at different times and places. Such extensive sheets of very shallow water must have been extremely apt to dry up whenever the sun was hot, especially in isolated pools. It would in these become very saline; the animal life would die, and rock-salt and gypsum would be deposited. As Ramsay remarks, the Rhætic Beds do occasionally and very locally contain gypsum and pseudomorphs after rock-salt. Around Bristol baryto-celestine is common, which is here a mixture of sulphates of barium, strontium, and calcium, and probably results from precipitation in a concentrating lagoon.

On the other hand, in many pools fed rather by streams and rain than by the open sea, the water would be brackish or even quite fresh. Prof. T. Rupert Jones claims that *Estheria minuta* and *Darwinula* were fresh- or brackish-water forms. Probably *Naiadita* only flourished in fresh or slightly saline-water.

It will be seen from the foregoing remarks that I do not believe that the Rhætic Beds were laid down in an estuary, and that for the following reasons:—

(*a*)—They obviously follow the distribution of the Triassic lake pretty closely, as they occur at places so far apart as Gainsborough, Uplyme in Dorset, Watchet, Penarth, Burton-on-Trent, and along the Jurassic escarpment. It would have been indeed extraordinary if in so short a time an enormous river had developed, the estuary of which should correspond so closely to the Triassic lake. The shape of the area over which the various Rhætic exposures are distributed does not at all suggest an estuary.

(*b*)—The principal evidences suggesting an estuary in geology are the abundance of land-plants and animals, and the presence of a brackish-water fauna. Now, the Rhætic Beds do not display these at all well. The only certainly land-derived remains are *Microlestes*, which is found in the infra-Bone-Bed Series, the wings of insects, and a few pieces of drift-wood, some of which I have recorded from Redland. Most of the fossils are not brackish-water, but oceanic.

## IV. The Stratigraphy of the Rhætic Series.

### Zoning of the Rhætic Beds in England.

In 1861, Moore, in his classic paper (4), zoned the series between the Keuper and the *Planorbis*-beds as follows (*op. cit.* p. 487):—

(*Planorbis*-Beds.)
Enaliosaurian Zone.
White Lias. } Rhætic.
*Avicula-contorta* Beds. } Rhætic.
(Keuper.)

It is curious that no more definite palæontological zones should have since been decided on, seeing how well the Jurassic has been zoned. I would suggest the following:—

| | |
|---|---|
| (*Planorbis*-Zone.) | |
| *Pleuromya-Crowcombeia* Zone. | (= { Some beds of Blue Lias. White Lias. ) |
| *Monotis-decussata* Zone. | (= Cotham Marble and just above). |
| *Naiadita* and *Estheria-minuta*, var. *Brodieana*-Zone. | (= *Naiadita*-Beds). |
| *Pecten-valoniensis* Zone. | (= *Pecten*-Beds). |
| *Avicula-contorta* Zone. | (= Black Shales). |
| Bone-Bed. | |
| (Keuper.) | |

*Pecten valoniensis* is recorded in the Black Shales, and also in the White Lias. Except those specimens that occur just at the top of the Black Shales, however, I believe that nearly all the former are really *Cardium cloacinum*, which has but lately been recognized in England by Mr. L. Richardson and Mr. A. Vaughan; and most, if not all, the White-Lias forms are probably *Pecten dispar* (Terquem), which, however, is not very different (Vaughan).

*Naiadita* was originally described by Buckman and Brodie as occurring above the Cotham Marble at Aust, Horfield, etc. In all the places that they mention it certainly occurs below, and never (to my knowledge) above the Cotham Marble. All later writers agree in this.

*Pleuromya Crowcombeia* is not the same as *Pteromya Crowcombeia* (which is a fossil from the *Pecten*-Beds). It is very common in the White Lias and in the lowest beds of the Blue Lias, and appears to be recorded under the most various names. It becomes extremely rare when the ammonites begin.

The ranges of *Cardium rhæticum*, *Modiola minima*, and *Ostrea liassica* are too long to allow of their being used for zoning. The saurians are inconstant.

It is not contended that the zone-fossils are confined to their own horizon: for example, *Monotis decussata* is occasionally found in the Lias; but they are only met with in any abundance there, and are of very practical service.

(i) With regard to the constancy of these zones throughout England, I would submit that they are fairly constant, and would especially refer to the four sections described in this paper, and to Garden Cliff (54), Wainlode (54), Wood Norton near Evesham (51), Stratford-on-Avon (2, 20), Watchet (6): here *Pecten valoniensis* is recorded below the Bone-Bed—this is unique, and there appears to be doubt about it, for Etheridge, whose determination it was, afterwards marks it with a query (17), Camel Hill (13), Nottingham (31), Pylle Hill (36), and Penarth (17). The other sections are less perfect, but there are no difficulties that a fresh search would not probably remove, as indeed has happened at Garden Cliff, where Mr. Richardson's observations bring it better into line than did the older records of Wright (2). Even in the north, the succession may be fairly-well made out by combining sections at Gainsborough, Leicester, and Market Weighton, except that *Pleuromya* is recorded with *Monotis decussata* above it.

(ii) These zones do not fit in with the oceanic type of the Alps and Mediterranean—a harmony which, however, could scarcely have been hoped for. But they receive considerable support from the German, and less perhaps from the French sections, at any rate in the lower four members.

Especially well do they harmonize with some German sections described by Schlönbach (57 & 58), as, for example, at Steinloh and Salzgitter. Here are recorded, in descending order :—

*b.* Layer with plant-remains.
*c–p.* (Fossils not mentioned.)
*q.* 'Upper Bone-Bed': in which *Pecten cloacinus* (=*P. valoniensis*) and *Avicula contorta* are described by Quenstedt (56).
*r.* Black Shales, with *Avicula contorta.*
*s.* 'Lower Bone-Bed,' conglomeratic.
*t.* Greenish-grey marl.

## V. Summary.

I. Descriptions of sections :

(*a*) At Redland, distinguished by a bone-bed and an excellent suite of fossils.
(*b*) At Stoke Gifford, with an insect-bed, but no bone-bed.
(*c*) At Cotham Road, with an excellent Black-Shale fauna, and well-developed *Naiadita*-Beds.
(*d*) At Aust.

II. The Bone-Bed is a storm-deposit in very shallow water and over exposed flats.

III. The Rhætic Beds of England were laid down in a vast, very shallow lagoon or bay, and derived their fauna from Germany.

IV. The English Rhætic presents more affinity for the Jurassic than the Triassic.

V. The following zones may be recognized :—

1. Zone of *Pleuromya Crowcombeia*= { Some beds of Blue Lias. White Lias.
2. ,, *Monotis decussata*=Cotham Marble and just above.
3. ,, *Estheria minuta* var. *Brodieana*, and *Naiadita.*
4. ,, *Pecten valoniensis.*
5. ,, *Avicula contorta*=Black Shales and a limestone-bed.
6. ,, Bone-Bed.

---

The pleasantest page in this paper is to me the one on which I now record my sincere and hearty thanks to all those to whose kindness, consideration, and help I owe so much. Especially am I grateful to Mr. Arthur Vaughan, F.G.S., for directing my attention to various memoirs, and for some suggestions as to fossils; to

Dr. A. Smith Woodward, F.R.S., for examining some of the contents of the Redland Bone-Bed for me; to Mr. L. Richardson, F.G.S., for several interesting communications and references; to my fellow-student, Mr. James Parsons, F.G.S., whose advice and co-operation in field-work was of the utmost value to me at the commencement of my research: and last, but not least, to Prof. Lloyd Morgan and Prof. S. H. Reynolds for much kind help.

## VI. Bibliography.

This does not profess to be by any means an exhaustive bibliography of the Rhætics. At the same time, I believe, it includes nearly all the English papers of any great importance bearing on the subjects that I have discussed. Only a few Continental authorities have been included: namely, those whom I happen to quote.

The bibliography of the Cotham Marble I have collected elsewhere.

### A.—British Literature.

(1) Brodie, Rev. P. B. 1845. 'History of the Fossil Insects in the Secondary Rocks of England' pp. 51–104.

(2) Wright, T. 1860. 'On the Zone of *Avicula contorta* & the Lower Lias of the South of England' Quart. Journ. Geol. Soc. vol. xvi, pp. 374–411.

(3) Moore, C. 1860. 'On the so-called Wealden Beds at Linksfield, & the Reptiliferous Sandstones of Elgin' *Ibid.* pp. 445–47.

(4) Moore, C. 1861. 'On the Zones of the Lower Lias & the *Avicula-contorta* Zone' *Ibid.* vol. xvii, pp. 483–516 & pls. xv–xvi.

(5) Jones, T. R. 1862. 'A Monograph of the Fossil *Estheriæ*' [*E. minuta* & varieties] Monogr. Palæont. Soc.

(6) Dawkins, W. B. 1864. 'On the Rhætic Beds & White Lias of Western & Central Somerset, &c.' Quart. Journ. Geol. Soc. vol. xx, pp. 396–412.

(7) Wright, T. 1864. 'On the White Lias of Dorsetshire' Rep. Brit. Assoc. (Bath) Trans. Sect. p. 75 & Geol. Mag. vol. i, pp. 290–92.

(8) Bristow, H. W. 1864. 'On the Rhætic (or Penarth) Beds of the Neighbourhood of Bristol & the South-West of England' Rep. Brit. Assoc. (Bath) Trans. Sect. pp. 50–52.

(9) Tawney, E. B. 1866. 'On the Western Limit of the Rhætic Beds in South Wales, & on the Position of the Sutton Stone' Quart. Journ. Geol. Soc. vol. xxii, pp. 69–93 & pls. iii–iv.

(10) Duncan, P. M. 1867. 'On the Madreporaria of the Infra-Lias of South Wales' *Ibid.* vol. xxiii, pp. 12–28.

(11) Bristow, H. W. 1867. 'On the Lower Lias or Lias-Conglomerate of a Part of Glamorganshire' *Ibid.* pp. 199–207.

(12) Burton, F. M. 1867. 'On the Rhætic Beds near Gainsborough' *Ibid.* pp. 315–22.

(13) Moore, C. 1867. 'On Abnormal Conditions of Secondary Deposits, &c.' *Ibid.* pp. 459 *et seqq.*

(14) Stoddart, W. W. 1868. 'Notes on the Lower Lias-Beds of Bristol' *Ibid.* vol. xxiv, pp. 199–204.

Groom-Napier, C. O. 1868. 'On the Lower Lias-Beds occurring at Cotham, &c.' *Ibid.* pp. 204–205.

(15) [Etheridge, R.] 1868. 'Notes upon the Rhætic Beds at Aust Cliff, with relation to those at Westbury-on-Severn' Proc. Cottesw. Nat. F.C. vol. iv, pp. 13–18.

(16) Ramsay, A. C. 1871. 'On the Physical Relations of the New Red Marl, Rhætic Beds, & Lower Lias' Quart. Journ. Geol. Soc. vol. xxvii, pp. 189–98.

(17) Etheridge, R. 1871. 'On the Physical Structure & Organic Remains of the Penarth (Rhætic) Beds of Penarth & Lavernock' Trans. Cardiff Nat. Soc. vol. iii, pt. ii (1872) pp. 39–64 & pls. i–ii.
(18) Wills, H. 1871. 'Aust Cliff' Trans. Clifton Coll. Sci. Soc. pt. iii (1872) pp. 49–56 & plate.
(19) Judd, J. W. 1873. 'The Secondary Rocks of Scotland' [The Rhætic ?] Quart. Journ. Geol. Soc. vol. xxix, pp. 145–49.
(20) Brodie, Rev. P. B. 1874. 'Notes on a Railway-Section of the Lower Lias & Rhætics, &c.' *Ibid.* vol. xxx, pp. 746–49.
(21) Cross, J. E. 1874. 'The Geology of North-West Lincolnshire' *Ibid.* vol. xxxi (1875) pp. 115 *et seqq.*
(22) Harrison, W. J. 1876. 'On the Occurrence of the Rhætic Beds in Leicestershire' *Ibid.* vol. xxxii, pp. 212–17.
(23) Ussher, W. A. E. 1876. 'On the Triassic Rocks of Somerset & Devon' *Ibid.* pp. 367 *et seqq.*
(24) Wright, T. 1875. [Presidential Address to Sect. C] Rep. Brit. Assoc. (Bristol) Trans. Sect. pp. 47 *et seqq.*
(25) Woodward, H. B., &c. 1876. 'Geology of East Somerset & the Bristol Coalfields' Mem. Geol. Surv. pp. 69–90.
(26) Tate, R., & Blake, J. F. 1876. 'The Yorkshire Lias' chapt. v, pp. 30–37.
(27) Harrison, W. J. 1877. 'On the Rhætic Section at Dunhampstead Cutting, &c.' Proc. Dudley Geol. Sci. Soc. vol. iii, pp. 115–25 & plates.
(28) Tawney, E. B. 1878. 'On an Excavation at the Bristol Waterworks Pumping-Station, Clifton' Proc. Bristol Nat. Soc. n. s. vol. ii, pp. 179–82.
(29) Davis, J. W. 1881. 'Notes on the Fish-Remains of the Bone-Bed at Aust' Quart. Journ. Geol. Soc. vol. xxxvii, pp. 414–25 & pl. xxii.
(30) Etheridge, R. 1882. Presid. Address [Rhætic or *Avicula-contorta* Beds] *Ibid.* vol. xxxviii, *Proc.* pp. 138–40, &c.
(31) Wilson, E. 1882. 'The Rhætics of Nottinghamshire' *Ibid.* pp. 451–56.
(32) Storrie, J. 1882. 'The Fossils at Penarth' Trans. Cardiff Nat. Soc. vol. xiv, pp. 100–103.
(33) Wilson, E., & Quilter, H. E. 1884. 'The Rhætic Section at Wigston, Leicestershire' Geol. Mag. pp. 415–18.
(34) Woodward, H. B. 1887. 'Geology of England & Wales' 2nd ed. pp. 242–51.
(35) Woodward, H. B. 1888. 'Notes on the Rhætic Beds & Lias of Glamorganshire' Proc. Geol. Assoc. vol. x (1889) pp. 529–38.
(36) Wilson, E. 1891. 'Section of the Rhætic Rocks at Pylle Hill (Totterdown)' Quart. Journ. Geol. Soc. vol. xlvii, pp. 545–49.
(37) Fox-Strangways, C. 1892. 'Jurassic Rocks of Britain' vol. i (Yorkshire) Mem. Geol. Surv. p. 384.
(38) Fox-Strangways, C. 1892. 'Jurassic Rocks of Britain' vol. ii (Yorkshire) Mem. Geol. Surv. pp. 25–123.
(39) Woodward, H. B. 1893. 'Jurassic Rocks of Britain' vol. iii (Lias of England & Wales) Mem. Geol. Surv. pp. 54, 55, &c.
(40) Brodie, Rev. P. B. 1892. 'Cestraciont & other Fishes in the Green Gritty Marls, &c.' Quart. Journ. Geol. Soc. vol. xlix (1893) pp. 171–74.
(41) Tomes, R. F. 1893. 'New Genus of Madreporaria from the Sutton Stone' *Ibid.* pp. 574–78 & pl. xx.
(42) Newton, R. B. 1893. 'Molluscan Remains in the English Keuper' Rep. Brit. Assoc. (Nottingham) p. 770.
(43) Browne, M. 1893–94–96. 'Vertebrate Remains from the Rhætic Beds of Britain' *Ibid.* pp. 748–49; (Oxford) pp. 657–58; & 'Rhætic Bone-Bed of Aust Cliff, &c.' *Ibid.* (Liverpool) pp. 804–805.
(44) Jones, T. R. 1894. 'On the Rhætic & some Liassic Ostracoda of Britain' Quart. Journ. Geol. Soc. vol. l, pp. 156–68 & pl. ix.
(45) Wilson, E. 1894. 'The Rhætic Rocks of Pylle Hill, Bristol' Proc. Bristol Nat. Soc. n. s. vol. vii, pp. 213–31.
(46) Wickes, W. H. 1899. 'A Rhætic Section at Redland' *Ibid.* vol. ix (1901) pp. 99–103 & pl. i.
(47) Parsons, J. 1899. 'Additional Observations on the Rhætic Beds at Redland' *Ibid.* pp. 104–108.
(48) Morgan, C. Lloyd, & Reynolds, S. H. 1900. 'Triassic Deposits at Emborough' *Ibid.* pp. 109–17 & pls. ii–iii.
(49) Sollas, Igerna B. J. 1901. 'Structure & Affinities of the Rhætic Plant *Naiadita*' Quart. Journ. Geol. Soc. vol. lvii, pp. 307–12 & pl. xiii.

(50) REYNOLDS, S. H., & VAUGHAN, A. 1902. 'Jurassic Strata cut through by the South-Wales Direct Line' *Ibid.* vol. lviii, pp. 719–52.
(51) RICHARDSON, L. 1903. 'Two Sections of the Rhætic Rocks in Worcestershire' Geol. Mag. pp. 80–82.
(52)) VAUGHAN, A., & TUTCHER, J. W. 1903. 'The Lower Lias of Keynsham' Proc. Bristol Nat. Soc. n. s. vol. x, pp. 3–54 & plates.
(53) SHORT, A. R. 1903. 'On the Cotham Marble' *Ibid.* pp. 135–149.
(54) RICHARDSON, L. 1903. 'The Rhætic Rocks of North-West Gloucestershire' Proc. Cotteswold Nat. F.C. vol. xiv, pp. 127–74 & pl. v.

[In addition to the foregoing, numerous references to Rhætic geology, etc. will be found in various Geological Survey Memoirs.]

B.—FOREIGN LITERATURE.

(55) OPPEL, A. 1856–58. 'Die Jura-Formation Englands, Frankreichs, & des südwestlichen Deutschlands' [§ 1, der Untere Lias].
(56) QUENSTEDT, F. A. 1858. 'Der Jura' pp. 25 *et seqq.* [Vorläufer des Lias & Unterer Lias].
(57) SCHLÖNBACH, A. 1860. 'Das Bonebed & seine Lage gegen den sogenannten obern Keupersandstein im Hannöver'schen' Neues Jahrb. f. Min. &c. pp. 513–34 & pl. iv.
(58) SCHLÖNBACH, A. 1862. 'Beitrag zur genauen Niveau-Bestimmung des auf der Grenze zwischen Keuper & Lias im Hannoverischen & Braunschweigischen auftretenden Sandsteins' *Ibid.* pp. 146–77 & pl. iii.
(59) DITTMAR, A. VON. 1864. 'Die *Contorta*-Zone: ihre Verbreitung & ihre organischen Einschlüsse' Munich, 8vo.
(60) BRAUNS, D. 1871. 'Der Untere Jura im nordwestlichen Deutschland' Brunswick, 8vo.
(61) BERTRAND, M., & KILIAN, W. 1889. 'Mission d'Andalousie' [Infralias] Mém. Sav. Étrang. Acad. Sci. Paris, ser. 2, vol. xxx. pp. 408 & 605.
(62) LAPPARENT, A. DE. 1900. 'Traité de Géologie' 4th ed. pp. 1053–68 [Etage rhétien].

## DISCUSSION.

Mr. H. B. WOODWARD complimented the Author on the clear exposition that he had given of his views. The instances of intercalation of grey marl and black shale confirmed other evidence of the passage between Keuper and Rhætic, but he (the speaker) doubted whether the Bone-Bed could be regarded as a definite horizon. Reference might have been made to Edward Forbes's view of the formation of the White Lias in an inland sea like the Caspian, before depression had introduced the open-sea conditions of the Lias. He did not agree with the Author in linking the zone of *Pleuromya Crowcombeia* with the White Lias, as that fossil was characteristic of the basement-portions of the Blue (Lower) Lias throughout England—specimens which he had collected at Dunball, near Bridgwater, were identical in all respects with others obtained by Mr. George Barrow at Northallerton. By taking the basement portions of the Lower Lias into the Rhætic formation, the Author had accentuated its Liassic affinities. The White Lias had considerable local importance, as it extended from Bath to Lyme Regis; and, as Charles Moore had pointed out, the junction with the Lower Lias was usually well marked. In the Bristol area and northward the White Lias appeared to be extensively overlapped, and there was evidence in places of a remanié bed at the base of the Lower Lias.

The Rev. J. F. Blake asked whether the Author could give any more information about the grey beds which yielded *Microlestes*. This at least seemed to indicate terrestrial conditions, but the Bone-Bed was the commencement of the Liassic deposits. This kind of bed was often the introduction to a new group of strata—the Rhætic forming the base of the Lower Jurassic, as the Cornbrash formed the base of the Upper Jurassic. They always contained some fossils of the older rocks mixed with those of the newer types, and thus were aggregates; but they could not be called 'passage-beds', as the change was rapid and both sets of fossils were introduced together.

The Author replied that, although there were several horizons at which teeth and bones were abundant, there was one well-marked horizon near the base of the Black Shales, containing pebbles. This he called the Bone-Bed. Although a Rhætic mammal, *Microlestes* appeared in the infra-Bone-Bed Series in England, because it could wander over the land when the Rhætic Era had commenced, a little earlier, in Germany.

## 15. *The* Rhætic Beds *of the* South-Wales Direct Line.

By Prof. Sidney Hugh Reynolds, M.A., F.G.S., and Arthur Vaughan, Esq., B.A., B.Sc., F.G.S. (Read February 3rd, 1904.)

[Plate XVIII—Fossils.]

Contents.



### I. Introduction.

The Rhætic Beds of the South-Wales Direct Line have been briefly described by the following geologists:—

1. Mr. H. B. Woodward, in the 'Summary of Progress of the Geological Survey' for 1898, p. 191.
2. The Rev. H. H. Winwood, in the Report of 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. 148.
3. Mr. A. Strahan describes the Lilliput section in the 'Summary of Progress of the Geological Survey' for 1902, Appendix V, p. 192.
4. Mr. A. Rendle Short describes the Stoke-Gifford section in a paper read before the Geological Society on December 16th, 1903, and now published in the same part of the Quarterly Journal as the present paper.

### II. Description of the Exposures.

The Rhætic Beds are finely exposed in the large cutting near Stoke Gifford; they come on above the Keuper rocks west of the Carboniferous-Limestone outcrop at Lilliput Farm, and an excellent section occurs resting upon the Carboniferous Limestone, from Lilliput Bridge as far east as Chipping-Sodbury railway-station.

#### (*a*) The Stoke-Gifford Section.

As Mr. Rendle Short informed us that he was engaged on a detailed examination of the Stoke-Gifford Rhætic, we have confined ourselves to a general account of the section, and have only included the results of our independent observations in this paper. Had we omitted all reference to the Stoke-Gifford section, our account of the Mesozoic strata of the South-Wales Direct Line would have been rendered incomplete, which seemed to us undesirable.

On the north side of the line, at Stoke-Gifford railway-station, the following series occurs, underlying the Lower Lias described by us in a former communication [1]:—

[1] Quart. Journ. Geol. Soc. vol. lviii (1902) p. 719.

| | | COTHAM MARBLE. | *Thickness in feet* | *inches.* |
|---|---|---|---|---|
| UPPER RHÆTIC. | V. | Dark-grey shale | 1 | 7 |
| | | White argillaceous limestone: ostracods, *Estheria*, and insects | 0 | 3 |
| | | Dark-grey shale | 3 | 0 |
| | IV. | White argillaceous limestone, with variable shaly partings and lenticular beds of hard gritty limestone. *Estheria minuta* var. *Brodieana* is common in the white limestone | 4 | 0 |
| LOWER RHÆTIC. | III. | (ii) Black shale, often very papery. *Pecten valoniensis*, *Cardium rhæticum*, and *Schizodus Ewaldi* are abundant, *Avicula contorta* rare: with them occur bands full of fish-scales, teeth, and vertebræ | 6 | 0 |
| | | (i) Hard, black, compact limestone, sometimes pyritous. *Pecten valoniensis* and *Cardium rhæticum* are abundant | 4 | 0 |
| | II & I. | Shales etc. not well exposed for examination. | | |
| | | (Grey or Tea-Green Marl.) | 18 | 10 |

At the western end of the south side of the very wide cutting at Stoke Gifford, the Upper (but not the Lower) Beds of the Rhætic Series are exposed. The series is somewhat thicker than that on the north side of the line, as is seen from the following section, the beds on the two sides being numbered in correspondence :—

| | COTHAM MARBLE. | *Thickness in feet* | *inches.* |
|---|---|---|---|
| V. | Dark-grey shale | 3 | 8 |
| | White argillaceous limestone | 0 | 5 |
| | Dark-grey shale | 4 | 6 |
| IV. | Thinly-bedded argillaceous limestone, with *Naiadita* | 2 | 0 |
| | Pale shale to base of section | 0 | 6 seen |
| III. | *Pecten*-bed, shown in a drainage-cutting at the base of the slope. | | |

The most noteworthy feature of this section, as compared with that (which will be described on p. 197) lying to the east of Lilliput, is the complete absence of the Bone-Bed.

## (*b*) The Lilliput or Chipping-Sodbury Section.

A section of the Rhætic occurs, overlying the Keuper, at the end of the Carboniferous-Limestone section west of Lilliput Bridge. The beds here were, unfortunately, already much overgrown when we first visited them. The section is as follows :—

| | | *Feet* | *inches.* |
|---|---|---|---|
| | Compact limestone (Sun-Bed), with a somewhat doubtful representative of the Cotham Marble. | | |
| V & IV. | Brown or greyish shale | 2 | 0 |
| | Pale argillaceous limestone | 0 | 5 |
| | Greyish shale | 3 | 0 |
| | Argillaceous limestone | 0 | 7 |
| III, II, I. | Darker, more crystalline limestone, with *Pecten valoniensis* and bands of fibrous carbonate of lime ('beef') | 0 | 3 |
| | Black, often papery, shale | 12 | 0 |
| | (Tea-Green Marl.) | 18 | 3 |

Fig. 1.—*The Black Shales of the Rhætic, resting unconformably upon the Old Red Sandstone, west of Chipping-Sodbury railway-station.*

S. H. R. photogr.

The thickness of the Rhætic Series here is practically identical with that at Stoke Gifford, and the correspondence between the Upper Beds at the two localities is very close. The two sections agree, too, in the absence of the Bone-Bed.

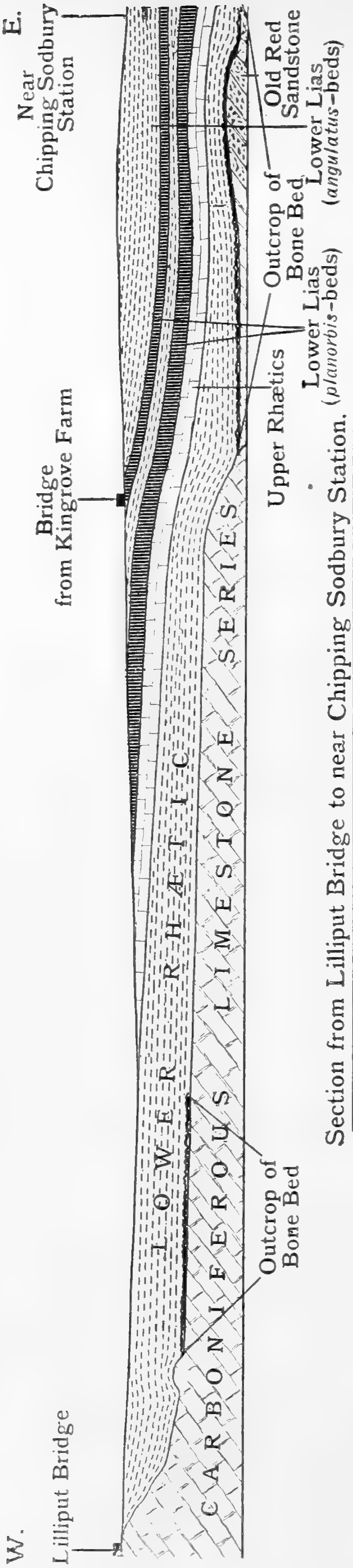
East of Lilliput Bridge a splendid Rhætic section comes on, and extends as far as a point to the east of the Old-Red-Sandstone outcrop lying west of Chipping-Sodbury railway-station. The series varies a good deal in thickness, being thickest where the Palæozoic rocks have been much denuded. At two points where large rounded hummocks of the Palæozoic project into the Rhætic, the Black Shale is deposited on them in an arched manner, forming an anticline of bedding. The section is remarkable for the occurrence of a very rich Bone-Bed at the base, but this is not uniformly distributed. It is first met with as one passes east from Lilliput Bridge at a point about 150 yards from the bridge: it extends for a distance of about 130 yards, and then again disappears, reappearing after some 200 yards, and extending continuously to the end of the Palæozoic outcrop.

The Upper Rhætic agrees more closely with that of Stoke Gifford, and shows less lateral variability than the Lower. A point 100 yards to the east of the bridge for the road from Kingrove Farm (see fig. 2, p. 198) gave the following section:—

| | | Cotham Marble. | *Thickness in feet* | *inches.* |
|---|---|---|---|---|
| Upper Rhætic. | V. | Grey shale, containing plant-beds at 15 and at 18 inches from the top. *Darwinula* and *Estheria* | 2 | 3 |
| | | Brown unfossiliferous shale | 1 | 0 |
| | IV. | Argillaceous limestone | 0 | 6 |
| | | Brown or grey shale, with lenticular beds and concretions of argillaceous limestone at two or three levels. Fragmentary shells, *Cardium cloacinum* etc. | 5 | 0 |
| Lower Rhætic. | III. | Black shales, with dark calcareous bands: *Pecten valoniensis*, *Cardium rhæticum*, and *C. cloacinum* are very abundant, *Avicula contorta* rare. | | |
| | II. | Black shales, with thin sandy layers: *Avicula contorta* and *Schizodus Ewaldi* are very abundant; *Cardium cloacinum* and *Myophoria postera*, plentiful; *Modiola sodburiensis* teems in the sandy layers; *Pecten valoniensis* is apparently absent. | 9 | 0 |
| | I. | Non-fissile black shale, with a rare tooth or vertebra. | | |
| | | Soft black clay, crowded with vertebrates | | |
| | | Hard Bone-Bed, containing quartz-pebbles and crowded with vertebrates; *Plicatula cloacina* is not infrequent | 0 | 3 |

The foregoing constitutes a typical section of the Sodbury Rhætic: but the beds show considerable lateral variability, lenticular hard bands sometimes of a gritty nature, though generally of limestone, appearing at various levels in the Black-Shale Series.

Fig. 2.




Section from Lilliput Bridge to near Chipping Sodbury Station.

Horizontal scale:- 1 inch = 300 feet; Vertical scale:- 1 inch = 75 feet.

## III. Correlation with the Rhætic of Neighbouring Areas.

The earliest local Rhætic section to be described with sufficient detail was that at Pylle Hill (Bristol), by the late Edward Wilson,[1] and within the last few years a number of Rhætic exposures in North-West Gloucestershire [2] (including the important sections at Wainlode Cliff and Garden Cliff) have been examined or re-examined, with equal care and wealth of detail, by Mr. Linsdall Richardson. A section at Redland (Bristol) has been carefully described by Mr. W. H. Wickes [3]; while, quite recently, Mr. A. Rendle Short has undertaken the minute re-examination of this section, as well as of the Stoke-Gifford cutting and of Aust Cliff. Since, however, at the time of writing Mr. Short's paper is not yet published, and Mr. Wickes has himself correlated the Redland section with that at Pylle Hill, it is only necessary for us to point out the correspondence of the Rhætic sections on the South-Wales Direct Line with those described by the late Edward Wilson and Mr. L. Richardson.

Taking account merely of the main features, all the local Rhætic sections exhibit the following general sequence :—

[1] 'On a Section of the Rhætic Rocks at Pylle Hill (Totterdown), Bristol' Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 545.

[2] 'The Rhætic Rocks of North-West Gloucestershire' Proc. Cottesw. Nat. F. C. vol. xiv (1903) p. 127.

[3] 'A Rhætic Section at Redland' Proc. Bristol Nat. Soc. vol. ix, pt. ii (1899) p. 99: issued in 1901.

COTHAM MARBLE (or its equivalent).

UPPER RHÆTIC.

V. Shales, with usually a thin limestone-band containing ostracods (*Darwinula*) and not infrequently *Estheria* and insects.

IV. Shales and argillaceous limestone (usually nodular or concretionary) containing the maximum of *Estheria minuta*, var. *Brodieana*.

This is the horizon at which *Naiadita* is abundant.

LOWER RHÆTIC.

III. Dark shales (usually with one or more very hard beds of dark limestone), containing the maximum of *Pecten valoniensis*.

II. Black shale (with occasional thin sandy bands), containing the maximum of *Avicula contorta*, and probably also of *Schizodus Ewaldi* and *Myophoria postera*.

I. Non-fissile black shale, with few fossils. Beds poor in mollusca, but frequently teeming with vertebrate remains.

The notation here adopted may be approximately correlated with that employed by the late Edward Wilson and Mr. L. Richardson, as follows:—

| | | | | |
|---|---|---|---|---|
| V | includes beds in | the neighbourhood | of | 1 of Richardson and *m* of Wilson. |
| IV | ,, | ,, | ,, | 3 of Richardson and *k* of Wilson. |
| III | ,, | ,, | ,, | 7 of Richardson and *g* of Wilson. |
| II | ,, | ,, | ,, | 8 to 12 of Richardson and *d* of Wilson. |
| I | ,, | ,, | ,, | 15 of Richardson and *a* of Wilson. |

A closer correlation seems neither practicable nor desirable, and all attempts made to find the exact equivalent in a distant locality of each thin hard layer appears to us, from the very nature of the deposits, to be doomed to certain failure.

If, instead of considering maxima, we regard entire ranges, it would be impossible to maintain even the small number of divisions that we have adopted in this paper. For example:—

Ostracods are found throughout IV as well as in V.

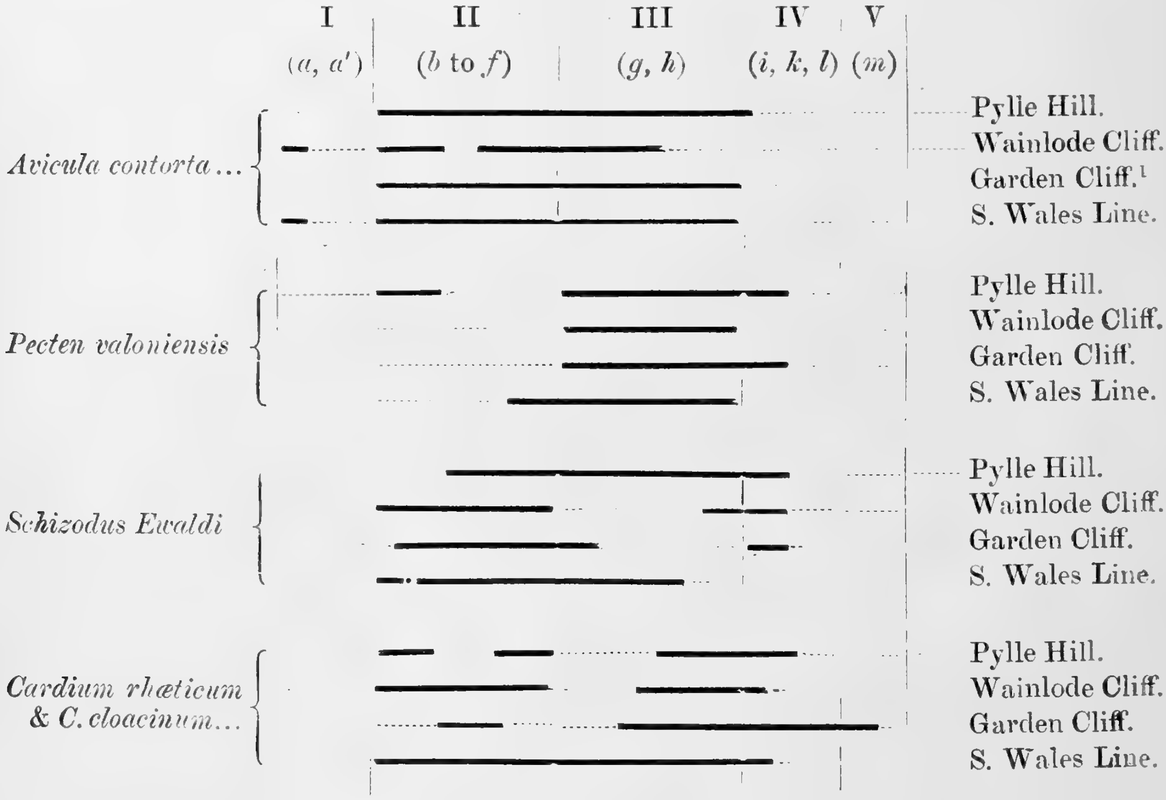
*Estheriæ* are found in V as well as in IV.

*Pecten valoniensis* is found quite commonly in most localities associated with *Avicula contorta* and *Schizodus Ewaldi*: in fact, the Lilliput section is almost unique in the rarity with which this association takes place (for example, at Pylle Hill *Pecten valoniensis* and *Avicula contorta* co-occur in *b*, that is, at the bottom of II; while *Pecten valoniensis* and *Schizodus Ewaldi* co-occur in *i*, that is, at the bottom of IV). The vertebrates occur throughout the entire Lower Rhætic, and even extend into the Upper Series (for instance, in *i* at Pylle Hill); while in certain sections it is almost impossible to fix even the position of their maximum.

Unfortunately, it has not been the general practice to estimate the maximum of a species, but merely to register its occurrence in each bed without any remark on its relative abundance. For this reason, the comparison of the various sections loses a great part of its value; for a straggler which has escaped notice at one section may have been recorded at another, and given a weight equal to that of the commonest fossil at the horizon. In this way a completely-deceptive difference between the two sections is falsely suggested.

Bearing this fruitful source of error in mind, the appended table may be considered to render as exact an account as is possible of the range of the best-known Rhætic mollusca at those sections within the Bristol and Gloucestershire areas which have been most exhaustively described.

Table I.—Comparison of the Ranges of the typical Rhætic Mollusca.




That the information conveyed by the above table may be as exact as possible, the following remarks seem necessary:—

*Avicula contorta.*—As a general rule, the determination of this fossil is possible, even from very small fragments, on account of its entire dissimilarity from the associated mollusca; but in I, where *Plicatula cloacina* is not uncommon, the determination is rendered more difficult (see p. 203).

*Pecten valoniensis.*—The determination of this fossil by an accurate observer may be unhesitatingly accepted.

[1] We have ventured to dissent somewhat from Mr. Richardson's correlation of the beds at Garden Cliff. Seeing that *Avicula contorta* and *Schizodus* occur plentifully **below** his Bone-Bed (Bed 15), it does not appear to us that this bed can be considered to be on the same horizon as that at Sodbury, which is well below the level at which these mollusca commence to occur in any abundance. It seems more probable that the section at Garden Cliff is one of the numerous instances which illustrate the great variability of the position of the Bone-Bed.

*Schizodus Ewaldi*.—Wherever the species is stated we have accepted the determination as correct; we are somewhat doubtful as to the value of the information where the genus alone is cited, and are still more dubious in regard to forms entitled '*Pullastra*' (*Schizodus*).

*Cardium rhæticum* and *C. cloacinum* (? = *Cardium* sp. of Wilson). —These species seem, to a certain extent, to replace each other in relative abundance at different localities. They are, therefore, best treated together, a course which also eliminates errors of determination.

## IV. Palæontological Notes.

### (*a*) Invertebrata (Mollusca). By A. V.

The numerical references in parentheses, throughout the notes on the invertebrata, are to the following authors:—

(1) Moore, C.—Quart. Journ. Geol. Soc. vol. xvii (1861) p. 483 & pls. xv–xvi.
(2) Quenstedt, F. A.—' Der Jura' 1858, pl. i.
(3) Dumortier, E.—' Les Dépôts jurassiques du Bassin du Rhône: I. Infra-Lias' 1864.
(4) Terquem, O.—' L'Étage inférieur de la Formation liasique de Luxembourg & de Hettange' Mém. Soc. Géol. France, ser. 2, vol. v (1855) p. 219.
(5) Brauns, D.—' Der untere Jura' 1871.
(6) Portlock, J. E.—' Report on the Geology of Londonderry, &c.' 1843.
(7) Goldfuss, A.—' Petrefacta Germaniæ' 1826–33.
(8) Oppel, A., & Suess, E.—' Ueber die muthmasslichen Æquivalente der Kössener Schichten in Schwaben' Sitzungsber. k. Akad. Wissensch. Wien, vol. xxi (1856) pp. 544 *et seqq.* & pls. i–ii.

Anomia sp. (Pl. XVIII, fig. 1.)

Upper valve.—Dimensions: vertical = 23 millimetres; horizontal = 25 mm. (estimated).

Contour orbicular, with short, nearly straight hinge-line and small, slightly-projecting beak; convexity greatest near the beak.

Shell extremely thin and minutely puckered, with strong concentric wrinkles.

Lower valve unknown.

Since the only specimen that I have seen is this imperfect upper valve, it seems advisable to await more material before assigning a specific name.

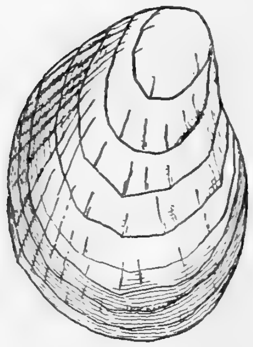
The shell-structure is similar to that of *Placunopsis alpina*, Winkler, as figured by Moore (1) in his pl. xvi, figs. 4–5, and the dimensional ratio is about the same; but in our specimen the concentric wrinkles are much stronger and the beak and hinge-line different.

Our species differs entirely from *Anomia (?)* figured by Quenstedt (2), in which the transversity is even more marked in the young than in the adult (the first growth-line in Quenstedt's figure has a transversity of $\frac{3}{2}$, whilst in our specimen the young form is elongated).

The specimen was obtained from the main *Avicula*-horizon at Sodbury.

Plicatula cloacina, sp. nov. (Text-fig. 3 & Pl. XVIII, fig. 5.)

Fig. 3.—*Diagram of* Plicatula cloacina, *sp. nov., constructed from numerous fragments.*



[Magnified 2 diameters.]

Upper valve.—Largest dimension about 20 millimetres.

Valve strongly convex, narrowing towards the beak.

Shell thin, and composed of slightly-overlapping, concentric bands which have free ragged edges. Fine, sharp, radial ribs cross these bands at irregular intervals, and end on the free edges in projecting points. The outermost bands are ornamented with fine, close, parallel, concentric, rounded striæ. To the left of the valve, the radial ribs and spines are much more numerous and strongly marked, several of the ribs are continuous, and the spines closely packed, short, and tubular.

Lower valve very imperfectly known. The specimens all occur in the Bone-Bed (hence the specific name).

Lima valoniensis.

Fragmentary and crushed specimens are not uncommon at the main *Pecten*-horizon.

Pecten valoniensis, Defr. (Pl. XVIII, figs. 2 & 2 *a*.)

The general characters of this species are :—

The byssus-valve is flat, with a narrow beak-angle (80° to 85°), and ribs usually in pairs. The larger valve is convex, with a broader convex beak (beak-angle about 100°), and ribs more equal, but usually containing a few intercalated shorter ones. Concentric lines of growth not forming erect scales on the ribs.

The most striking characters are: the transversity of the valves, and the absence of symmetry, characters which are especially marked in the convex valve.

This species was excellently figured by Dumortier (3) in his pls. ix & x. Under the name of *Pecten cloacinus*, Quenstedt (2) gave two figures, both of the convex valve. Both figures illustrate the transversity of the species, but the larger figure is more symmetrical than is usually the case, and the left wing seems to be erroneously drawn.

A maximum in the upper part of the Lower Rhætic (III): see p. 200.

Avicula contorta, Portlock (6) [including *Avicula solitaria*, Moore (1)].

Of the special characters shown by our specimens, we may note the following :—The anterior convex portion of the large valve is almost smooth, and this smoothness extends to some distance round the lower margin in big specimens. Small specimens exactly resemble *A. solitaria*, Moore, in the absence of intercalation; but, in all adult forms, intermediate ribs make their appearance.

Fragments of shell are found in the Bone-Bed, which exhibit the characteristic ribbing of *Avicula contorta*; but, since they occur in close juxtaposition to fragments of the *Plicatula* described on p. 202, it is a little doubtful whether they may not be small portions of the more strongly- and continuously-ribbed part of that shell. The weight of evidence seems, however, against this view, as I have never seen, on any specimen of the *Plicatula*, any ribs which run for so long a distance without forming spines. Hence we may say that *Avicula contorta* extends downward into the Bone-Bed. Upward it occurs, very rarely, just beneath the *Estheria*-bed.

Avicula fallax, Pflücker = *Monotis decussata*, auctt. [*non* Münster, *fide* Brauns (5)].

We have found one or two specimens, as already noted, in the uppermost beds.

Modiola sodburiensis, sp. nov. (Pl. XVIII, figs. 3 & 3 *a*.)

The largest dimension varies from 5 up to 19 millimetres.

The shell is extremely thin; both valves are exactly similar; in the young form the valves are strongly convex, but in the adult they become flatter.

The beaks are close to the front end, and there is a slight indentation just in front of them. Behind the beaks the hinge-line ascends straight and obliquely, and the valves are broadest where the straight hinge-line merges into the posterior curvature.

The front margin is uniformly rounded, and only projects slightly in front of the beak. The posterior margin is also uniformly rounded, though in adult forms it projects slightly more near the base. The lower margin is always convex, but becomes nearly flat in the adult.

The young form is almost perfectly oval in contour, the beak small, the hinge-line short, and the interior almost smooth.

In the adult, concentric growth-lines are well-marked, and a few faint radial striæ can be made out. A scarcely-perceptible ridge runs from the beak, diagonally backward, across the valve, but there is no distinctly-separated, swollen, anterior portion below it.

The interiors (which are extremely abundant) show no trace of pallial line, muscular impressions, or teeth.

Figs. 12, 13, 27, & 33 (*pars*) in pl. i of 'Der Jura,' all bear a strong resemblance to our form, but the peculiarity of the hinge-line is best expressed in figs. 12 & 27. Of these figures, Quenstedt (*op. cit.* pp. 29, 30) remarks that figs. 12 & 13 may belong to the Lithophagi, and that fig. 27 recalls *Astarte obliqua*. The absence of teeth and the thinness of the shell, as well as the straightness of the hinge-line, remove our species from *Astarte*; while the manner of occurrence prevents its inclusion among the borers.

Abundant in a sandy micaceous bed, near the maximum of *Avicula contorta*.

MODIOLA MINIMA, Sow.

Our specimens agree well with Moore's large figure (1), pl. xv, fig. 27.

The anterior, upper slope (formed by the hinge-line) is somewhat shorter than the posterior, and rises at an angle of about 20°; the posterior slope is nearly straight; the angle between the two slopes is about 145°. The greatest breadth occurs at the junction of the two slopes, and is nearly half the largest dimension. The lower border is nearly straight. The front end is pointed, but there is no distinct separation of a lower, anterior, swollen portion.

Specimens are not uncommon throughout the Rhætic.

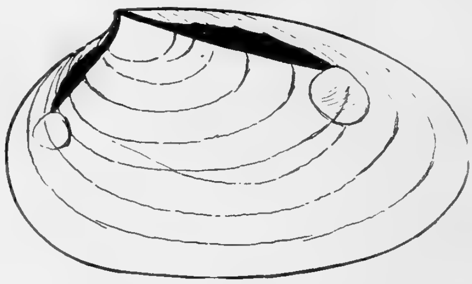
MYOPHORIA POSTERA, Qu. (2).

Especially common at the maximum of *Avicula contorta*.

CARDINIA CONCINNA, Sow. aff. REGULARIS, Terq. (Pl. XVIII, fig. 4, & text-fig. 4.)

General contour uniformly oval; lower border broadly and uniformly convex; hinge-line nearly straight, and only slightly converging. Curvature of anterior and posterior borders nearly equal. Beak not prominent: lunule small. The growth-lines form strong concentric bands.

Fig. 4.—*Diagram of* Cardinia concinna, *Sow.* (*aff.* C. regularis, *Terq.*).



[Magnified 2 diameters.]

DIMENSIONS IN MILLIMETRES.

| | Spec. 1. | Spec. 2. |
|---|---|---|
| Horizontal | 21 | 30 |
| Vertical | 13 | 16·5 |
| Position of beak | 5–16 | 7–23 |
| Radius of curvature of anterior border | 5 | 5 |
| Radius of curvature of posterior border | 5 | 4·5 |

As Brauns points out (5), p. 338, it is impossible to separate the species of *Cardinia* on slight changes of form, between which there is every possible mutation. He has consequently limited the number of Lower Jurassic species to three, namely: *C. concinna*, *C. crassiuscula*, and *C. Listeri*.

The separation of the elongate, regularly-oval *concinna* from the tall triangular *Listeri* is a matter of the utmost simplicity; but the allocation of intermediate forms is extremely difficult, and is usually almost valueless, as representing nothing more than the individual weight attached to certain variable characters by a particular author. For example, Brauns distinguishes *C. crassiuscula* from *C. concinna* by the following characters (*op. cit.* p. 340):—

| | *C. crassiuscula.* | *C. concinna.* |
|---|---|---|
| Dimensional ratio (horizontal / vertical) ... | $\frac{5}{3}$ or less. | 2·2 or more. |
| Position of beak (from anterior)... | Never less than $\frac{1}{3}$. | $\frac{1}{4}$ to $\frac{1}{6}$ of length. |

The other characters are the same for both, namely: small and non-prominent beak, general oval form, rounded anterior margin, and gently convex lower margin.

It is, however, just at our Rhætic forms that the above distinctions break down; for, in dimensional ratio and position of beak, our form might be considered to be either a *crassiuscula*-like mutation of *concinna*, or a *concinna*-like mutation of *crassiuscula*. In fact, any distinction based upon the numerical ratio of dimensions is confessedly artificial; in our case, these distinctions would separate the young form (shown by the growth-lines), as a typical *crassiuscula*, from the adult form, which approximates to *concinna*.

It seems best to group our forms broadly under *C. concinna*, which may be considered to connote: elongate oval form, uniformly- and strongly-convex anterior and posterior margins, and uniformly- but gently-convex lower margin.

The figure which most nearly approaches our form is that of *C. regularis*, Terq. (4), pl. xx, fig. 2, which agrees remarkably well in all respects, except that the convexity of the anterior margin is greater (in the figure) than that of the posterior margin.

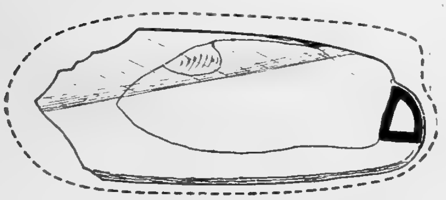
Specimens are common in the main *Avicula*-beds.

Pleurophorus elongatus, Moore (? = *Anoplophora postera*, Deffner & Fraas). (Text-fig. 5.)

There is no doubt as to the identity of our fossils with Moore's species (1); the general contour, and the fold which runs diagonally backward, render recognition easy. There is, however, more difficulty as to the genus.

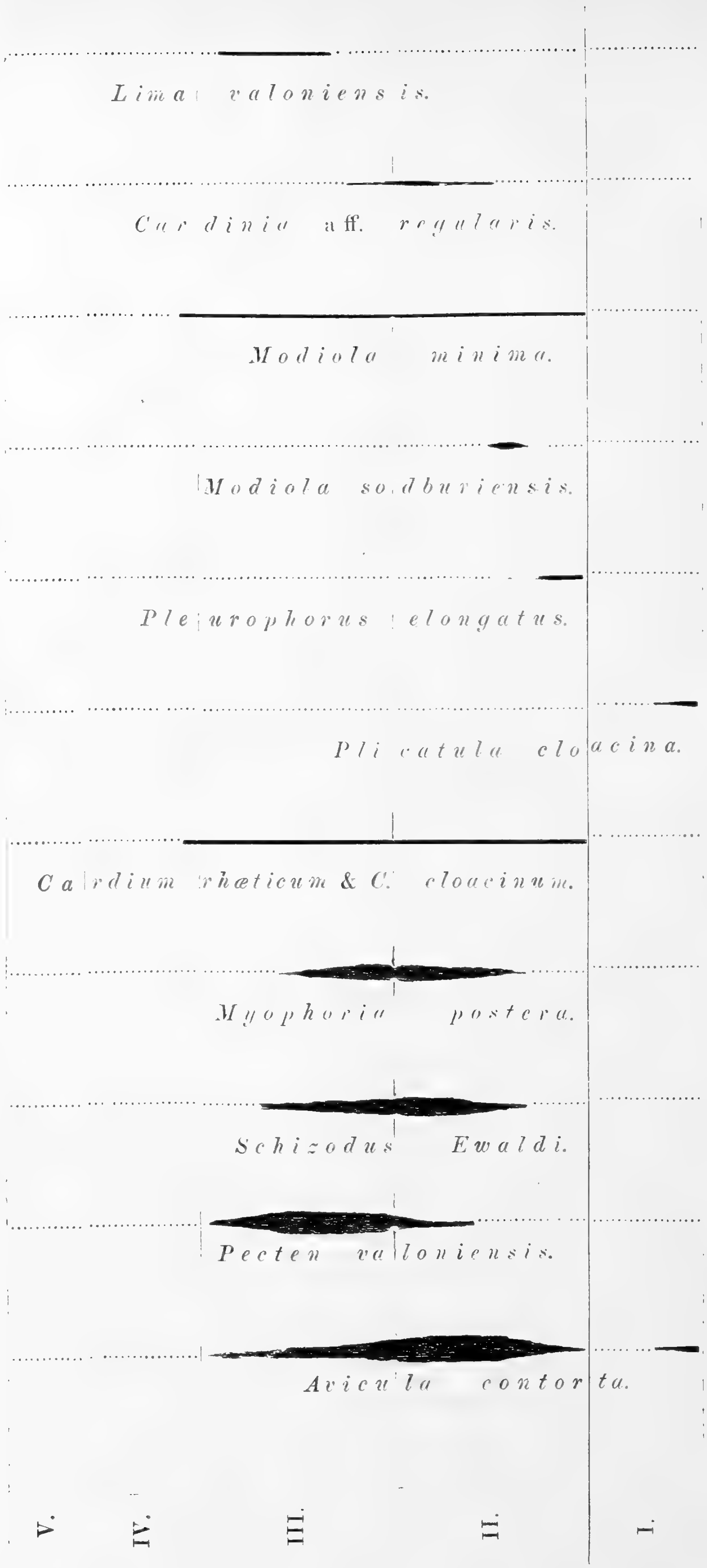
The cast exhibits the following characters:—Upper and lower margins nearly parallel, but slightly diverging backward; a prominent anterior muscular impression, in front of the beak, circumscribed by a deep furrow; a pallial line of continuous curvature, ending in a less prominent posterior muscular impression; a very blunt beak-region; a sharp indentation, in front of the beak, continuous with the deep groove which forms the hinder boundary of the anterior muscular impression. All these characters of the cast, except the blunt beak-region, would apply to any one of the genera *Pleurophorus*, *Anoplophora*, or *Myoconcha*.

Fig. 5.—Pleurophorus elongatus, *Moore (magnified $1\frac{1}{2}$ diameters).*



Since *Anoplophora* has no teeth, and *Myoconcha* only a long ridge-like tooth, running backward from the beak close along the hinge-

TABLE II.—RANGE-DIAGRAM OF THE COMMONEST RHÆTIC MOLLUSCA AT SODBURY AND STOKE GIFFORD.



line, the cast of a specimen of either genus shows a sharply-pointed beak.

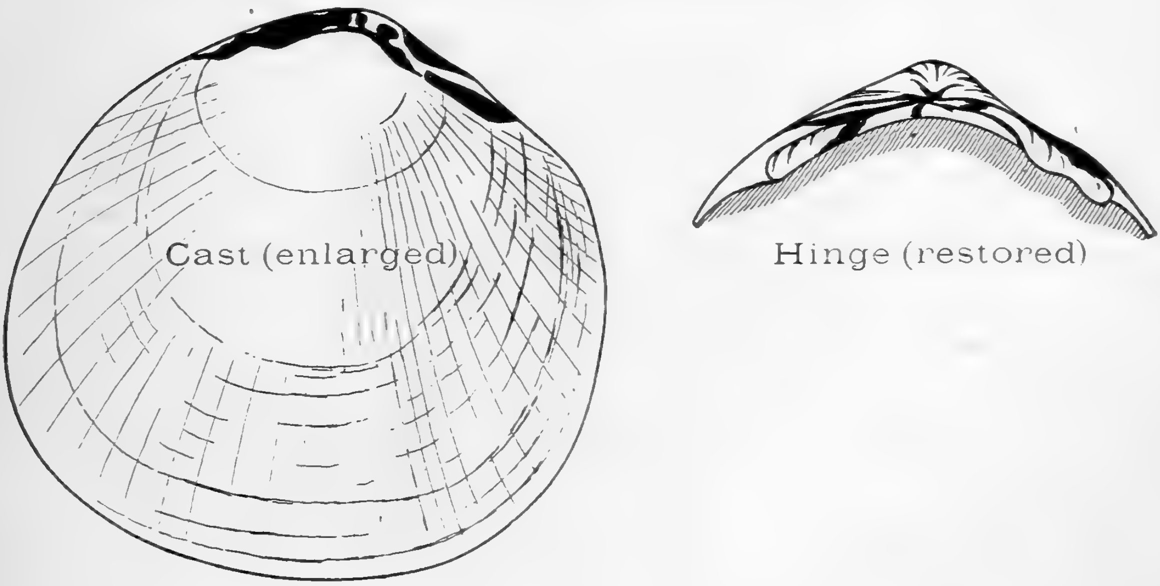
On the other hand, *Pleurophorus* had a large hinge-plate, bearing strong cardinal teeth, so that the cast should be broad and blunt beneath the beak (as in casts of *Cardinia*, so common in the Lower Lias). There seems, then, to be little doubt that Moore correctly diagnosed the genus. Quenstedt ('Der Jura' pl. i, fig. 32) figures a somewhat similar form, but the upper and lower borders converge backward: it can, therefore, scarcely be considered as identical with our specimen. Brauns (5) unhesitatingly refers Quenstedt's figure to *Anoplophora postera*, and only doubtfully includes Moore's species as a synonym. It seems, therefore, very uncertain whether we have found the species that is so common in the bottom beds in Germany.

Our specimen was derived from the main *Avicula*-beds.

CARDIUM CLOACINUM, Qu. (Text-fig. 6.)

Average dimensions: horizontal, $14\frac{1}{2}$ millimetres; vertical, 13 mm. The largest specimen that we found measured $22\frac{1}{2}$ mm., vertically.

Fig. 6.—Cardium cloacinum, *Qu. (magnified $3\frac{1}{2}$ diameters).*




In the fact that the curvature of the ribs is concave towards the front, and that they increase in breadth towards the posterior margin, the shell has a somewhat *Cardita*-like aspect. But the beaks are scarcely, if at all, turned towards the front, and the teeth are of the typical *Cardium*-pattern. There is considerable variability in the number and breadth of the ribs, as well as in the transversity and convexity of the valves.

The ribs are broad and, apparently, flat-topped, separated only by linear grooves (exactly after the pattern of the radial ribs seen in *Cardium rhæticum*). The concentric growth-lines are also well-marked, and produce, in crossing the ribs, the facetted type of ornament; a few of the growth-lines are much stronger than the others (producing the frill-type of ornament).

The species is figured by Quenstedt (2), and by Oppel & Suess (8). It seems impossible to include this form under *Cardita Heberti*, Terq., as has been done by Brauns (5), pp. 326–27.

This is the commonest species at Sodbury, and ranges from the base of the *Avicula*-bed up into the *Estheria*-bed.

CARDIUM RHÆTICUM, Merian.

The specimens are usually large (22 millimetres along the first radial rib).

The hinder part of the valve is bent along a radial fold, and the area thus formed is concave; but there is never a ridge at the fold. There are three or four ribs in front of the fold. The ribs are broad and flat, and are separated by linear grooves.

Very common in the main *Pecten*-bed.

SCHIZODUS EWALDI, Bornemann (= *Axinus cloacinus*, Moore).

Especially common in the main *Avicula*-bed.

### (*b*) Vertebrata, with Notes on the Position of the Bone-Bed. By S. H. R.

The vertebrate fauna of the Rhætic Bone-Bed of the Chipping-Sodbury section is rich and varied, nearly as rich as that of Aust, which it much resembles. The following species were met with, the nomenclature adopted being that of Dr. Smith Woodward & Mr. Sherborn.[1]

REPTILIA.

*Plesiosaurus costatus*, Owen.—Teeth and vertebral centra occur occasionally, but are not so plentiful as at Aust.

*Rysosteus Oweni*, Owen.—Small, presumably reptilian, vertebræ with the characters to which Owen applied the above name are not uncommon. Mr. Montagu Browne[2] notes that, in certain respects, these vertebræ have amphibian affinities.

Coprolites and broken undeterminable bones are very common.

AMPHIBIA.

? *Metoposaurus diagnosticus*, Meyer.—This species, which is well-known from Aust, might be expected to occur at Sodbury, but its occurrence can hardly be said to be clearly established. A

[1] 'Catalogue of British Fossil Vertebrata' 1890.
[2] Rep. Brit. Assoc. 1894 (Oxford) p. 658.

fragment of bone belonging to Mr. W. H. Wickes (to whom we are greatly indebted for the opportunity of examining a large collection of Rhætic Bone-Bed material from Sodbury) shows the peculiar pustulated surface seen in a fragment of bone figured by Meyer & Plieninger[1] as part of the breast-bone of a labyrinthodont, and also in many fragments of bone of undoubtedly-labyrinthodont origin in the British Museum (Natural History) and elsewhere. But, on the other hand, this character occurs in bones labelled *Hybodus* in the Stuttgart collection, and in a jaw of *Saurichthys* figured by Dr. Smith Woodward.[2] In connection with the latter specimen, attention may be drawn to Mr. Montagu Browne's suggestion,[3] that jaws bearing teeth of two kinds, which have been described as *Saurichthys*, may really belong to labyrinthodonts.

## Pisces.

### Elasmobranchii.

*Hybodus cloacinus*, Quenstedt.—Teeth agreeing closely with Quenstedt's figure[4] occur somewhat sparingly. The large fin-spines, described by Mr. J. W. Davis[5] under the name of *Hybodus austiensis*, are fairly common, though always in a fragmentary state and generally much rubbed. We follow Dr. Smith Woodward & Mr. Sherborn in considering that they are best provisionally referred to *Hybodus cloacinus*. Mr. W. H. Wickes obtained an example of the curious cephalic dermal spines of *Hybodus*, described by Agassiz[6] under the name of *Sphenonchus*.

*Hybodus minor*, Ag.—One small tooth, with a high, slender, median cone, is probably to be referred to this species.

*Acrodus minimus*, Ag.—The teeth of a small species of *Acrodus* occur in thousands, but always detached. They and the teeth of *Saurichthys* are the two commonest fossils in the Bone-Bed at Sodbury, just as they are at Aust and probably all the other Rhætic Bone-Bed localities in the Bristol district. They show a considerable amount of variability, but are at present, no doubt, all to be included under *Acrodus minimus*.

Small, deeply-biconcave, vertebral centra, 4 to 5 millimetres in diameter, occasionally occur, as they do at Aust and Emborough. Apparently they have not yet received a name.

### Dipnoi.

*Ceratodus latissimus*, Ag.—*Ceratodus*-teeth are not uncommon at Sodbury, though less plentiful than at Aust. They are grouped in the comprehensive species *C. latissimus* = *C. polymorphus*, Miall.

[1] 'Beiträge zur Paläont. Württ.' 1844, pl. ix, fig. 8.
[2] Ann. & Mag. Nat. Hist. ser. 6, vol. iii (1889) pl. xiv.
[3] Rep. Brit. Assoc. 1894 (Oxford) pp. 657–58.
[4] 'Der Jura' 1858, pl. ii, fig. 15.
[5] Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 416 & pl. xxii, fig. 1.
[6] 'Poiss. Foss.' vol. iii (1833–43) p. 201.

Teleostomi.

*Saurichthys acuminatus*, Ag.—The teeth to which this name is commonly applied occur in very large numbers, and are, with the exception of those of *Acrodus minimus*, the most plentiful fossils met with. Dr. Smith Woodward [1] remarks on the close relationship between the imperfectly-known genus *Saurichthys* and the better-known genus *Belonorhynchus*, and tentatively suggests that the two may really belong to the same genus. Mr. Montagu Browne,[2] on the other hand, suggests that *Saurichthys* is 'a non-existent piscine genus,' and that the teeth referred to under this name can be assigned to labyrinthodonts, *Plesiosaurus*, *Hybodus*, *Gyrolepis*, and perhaps *Colobodus*. The Sodbury material consists entirely of isolated teeth, and affords no assistance in the settlement of this question.

*Sargodon tomicus*, Plien.—Small teeth with long roots and somewhat chisel-shaped crowns, described under the above name by Plieninger,[3] occur somewhat sparingly, as they do at Aust and many other Rhætic localities in the Bristol district. With them are found teeth which differ from them only in having knob-like instead of chisel-shaped crowns, and have been described under the name of *Psammodus orbicularis* by Meyer & Plieninger and under that of *Sphærodus minimus* by Agassiz. Plieninger suggested, and the suggestion is supported by Dr. Smith Woodward,[4] that these belong to the same animal as the typical chisel-shaped teeth. Mr. Montagu Browne [5] suggests that the knob-like teeth are to be referred to *Colobodus maximus* (Quenstedt).

*Gyrolepis Albertii*, Ag.—The small striated scales of *Gyrolepis* are very common. They vary a good deal in size and in the state of preservation, some being much rubbed. Agassiz recognized several species, based on the form of the scales; but Dames [6] showed that probably the form of the scale varied in different parts of the animal's body, and that the three forms of scale described by Agassiz may all belong to one and the same fish. This view is accepted by Dr. Smith Woodward.[7]

## Notes on the Position of the Bone-Bed.

Although the extreme variability of the Rhætic Bone-Bed or Beds in number, position, and development is well known, it may perhaps be worth while to summarize its (or their) distribution in the Bristol district. The typical position of the Bone-Bed may be said to be at the base of the Black-Shale

[1] Ann. & Mag. Nat. Hist. ser. 6, vol. iii (1889) p. 302.
[2] Rep. Brit. Assoc. 1894 (Oxford) p. 657.
[3] Jahresh. Ver. vaterl. Naturk. Württ. vol. iii (1847) p. 165.
[4] Catal. Foss. Fishes Brit. Mus. pt. iii (1895) p. 67.
[5] Rep. Brit. Assoc. 1891 (Cardiff) p. 645.
[6] Palæont. Abhandl. vol. iv (1888) p. 143.
[7] Trans. Leicester Lit. & Phil. Soc. n. s. vol. i, pt. xi (1889) p. 20, and Catal. Foss. Fishes Brit. Mus. pt. ii (1891) p. 510.

Series. A Bone-Bed occupies this position in the Sodbury section, at Patchway, Redland, Sedbury Cliff, Watchet, Penarth, and Emborough. At Gold Cliff, near Newport, a Bone-Bed underlies 3 feet of Tea-Green Marls. In several other well-known sections it lies a short distance above the base. Thus at Aust it lies 9 inches, at Wainlode Cliff 2 feet, and at Coombe Hill $3\frac{1}{2}$ feet, above the base of the Black-Shale Series.

Although more or less isolated vertebrate remains may be met with, no true Bone-Bed has been recorded at the Rhætic sections of Wells, Shepton Mallet, Uphill, Pylle Hill, Saltford, Knowle, and Stoke Gifford. At most of these sections, however, a band of hard sandstone or tough limestone, with a smaller or greater number of vertebrate remains, occurs at or near the base of the Black-Shale Series, and is regarded as the equivalent of the Bone-Bed. Thus, at Pylle Hill, a very thin and irregular seam of pyritic grit, containing scales, teeth, and coprolites of fishes, occurs at the base; and at Wells there is a tough bluish-brown limestone in the same position. Similar bands occur at other horizons in the northern part of the district. Thus, at Chaxhill, a micaceous sandstone, regarded by Mr. L. Richardson as the equivalent of the Bone-Bed, overlies 7 feet of alternating shales and micaceous sandstones; and at Puriton, a somewhat similar bed of sandstone, passing into impure limestone, is recorded in the vertical section of the Geological Survey, at a height of $20\frac{1}{2}$ feet above the base of the Black-Shale Series.

In various sections more than one Bone-Bed is met with. Thus, in the Penarth (Lavernock) section, while a typical but very irregularly-developed Bone-Bed occurs at the base of the Black Shales, a second and thinner Bone-Bed is found at a height of 4 feet from the base. At Aust, in addition to the well-known basal Bone-Bed, there are indications of a second some 3 feet above the base of the Black Shales. At Emborough the principal Bone-Bed is at the base of the Black Shales, while a second and thinner one occurs at the top; and a band of conglomerate with scales and teeth underlies some 3 feet of sand and sandstone which intervene between the Black Shales and the Tea-Green Marls.

In the coast-section to the east of Watchet, in addition to the principal Bone-Bed at the base of the Black Shales, Prof. Boyd Dawkins describes two thinner Bone-Beds, consisting of hard sandstone with many fish-teeth, and occurring at a height of about 10 feet from the base. At Sedbury Cliff, in addition to the Bone-Bed at the base of the section, Mr. Richardson records a band with coprolites, fish-teeth, and an ichthyodorulite, which lies at about the middle of the Black Shales. At Garden Cliff the principal Bone-Bed occurs at a height of about $6\frac{1}{2}$ feet from the base of the Black-Shale Series. Lower down are the upper and lower bands of *Pullastra*-sandstone, each of which contains numerous vertebrate remains. At Wainlode Cliff, too, in addition to the main Bone-Bed 2 feet from the base of the Black Shales, a second band 10 feet higher up was noted by Brodie; in Mr. Richardson's recent account of the section,

P 2

a limestone-band with vertebrate remains is recorded, but hardly such a deposit as could strictly be termed a Bone-Bed.

A consideration of the geographical position of the above localities, shows that throughout Somerset, with the exception of Emborough and Watchet, no true Bone-Bed has been recorded. In the district to the immediate north of Bristol—Redland, Aust, Patchway, Sodbury, but not Stoke Gifford—there is a single, well-marked Bone-Bed at, or very slightly above, the base of the Black-Shale Series; while farther north, in the Gloucester district, the principal Bone-Bed tends to lie at a greater distance from the base of the Black Shales.

The facts summarized above seem to render it clear that the principal Bone-Beds of the various sections in the Bristol district cannot be regarded as the homotaxial equivalents of one another; a conclusion to which, as already stated (p. 200), we have been led by a comparison of the Sodbury section with that at Garden Cliff.

The following is a list of the principal localities in the Bristol district where a section showing the base of the Rhætic Series occurs, with some references to the most recent, complete, or accessible descriptions of the sections:—

Aust.—Vert. Sect., Geol. Surv. sheet 46, no. 6; W. J. Sollas, Proc. Geol. Assoc. vol. vi (1880) pp. 385–86; Brit. Assoc. 1898 (Bristol), 'Excursion to Aust & Overcourt,' p. 5; & A. Rendle Short, Quart. Journ. Geol. Soc. vol. lx (1904) p. 178.

Chaxhill.—L. Richardson, Proc. Cottesw. Nat. Field-Club, vol. xiv, pt. ii (1903) p. 175.

Coombe Hill.—Vert. Sect., Geol. Surv. sheet 47, no. 7; & L. Richardson, *op. cit.* p. 143.

Cotham Road.—A. Rendle Short, Quart. Journ. Geol. Soc. vol. lx (1904) p. 177.

Emborough.—C. Lloyd Morgan & S. H. Reynolds, Proc. Bristol Nat. Soc. vol. ix, pt. ii (1901, issued for 1899) p. 109.

Garden Cliff, Westbury.—Vert. Sect., Geol. Surv. sheet 46, no. 7; & L. Richardson, *op. cit.* p. 154.

Gold Cliff, near Newport.—J. E. Lee, Rep. Brit. Assoc. 1872 (Brighton) Trans. Sect. p. 116; & H. B. Woodward, Proc. Geol. Assoc. vol. x (1888) p. 538.

Knowle.—Vert. Sect., Geol. Surv. sheet 46, no. 4.

New Clifton.—See Redland.

Patchway.—Vert. Sect., Geol. Surv. sheet 46, no. 8.

Penarth and Lavernock.—Vert. Sect., Geol. Surv. sheet 47, nos. 1 & 3; R. Etheridge, Trans. Cardiff Nat. Soc. vol. iii (1872) p. 39; & H. B. Woodward, Proc. Geol. Assoc. vol. x (1888) p. 529.

Puriton.—Vert. Sect., Geol. Surv. sheet 46, no. 1.

Pylle Hill.—E. Wilson, Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 545.

Radstock (Clan Down).—W. Buckland & W. D. Conybeare, Trans. Geol. Soc. 2nd ser. vol. i, pt. ii (1824) p. 278.

Redland.—W. H. Wickes, Proc. Bristol Nat. Soc. vol. ix, pt. ii (1901, issued for 1899) p. 99; J. Parsons, *ibid.* p. 104; & A. Rendle Short, Quart. Journ. Geol. Soc. vol. lx (1904) p. 170.

Saltford.—Vert. Sect., Geol. Surv. sheet 46, no. 9.

Fig 1.

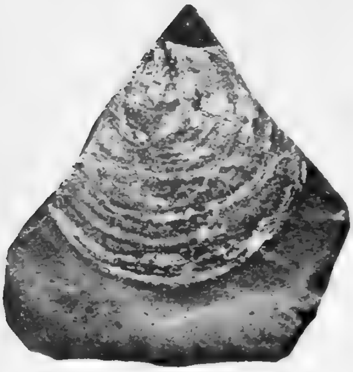


Fig. 4.

Fig. 2.

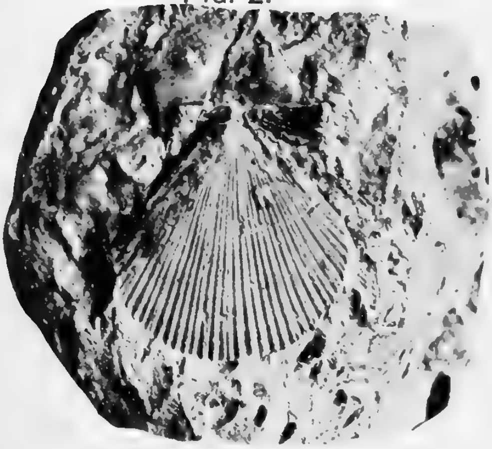


Fig. 2a.

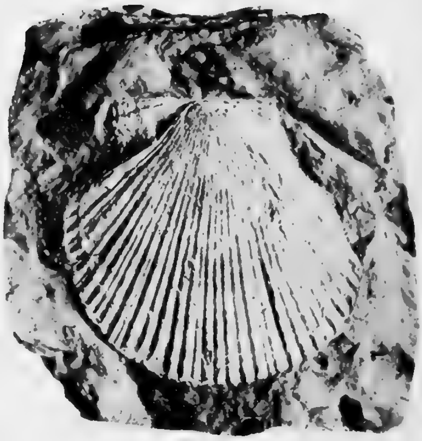


Fig. 3.

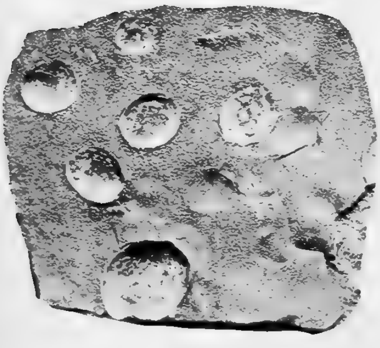


Fig. 3a.

Fig. 5.

*J. W. Tutcher, Photogr.*

*Bemrose, Collo.*

RHÆTIC LAMELLIBRANCHIATA.

Sedbury Cliff.—L. Richardson, Quart. Journ. Geol. Soc. vol. lix (1903) p. 390 & pl. xxiv.
Shepton Mallet.—Vert. Sect. Geol. Surv. sheet 46, no. 15.
Uphill.—Vert. Sect., Geol. Surv. sheet 46, no. 3.
Wainlode Cliff.—L. Richardson, Proc. Cottesw. Nat. Field-Club, vol. xiv, pt. ii (1903) p. 128.
Watchet.—W. Boyd Dawkins, Quart. Journ. Geol. Soc. vol. xx (1864) p. 396.
Wells.—Vert. Sect., Geol. Surv. sheet 46, no. 14.

## EXPLANATION OF PLATE XVIII.

Rhætic Lamellibranchiata.—All the figures are of the natural size.

Fig. 1. *Anomia* sp. (See p. 201.)
Figs. 2 & 2 *a*. *Pecten valoniensis*, Defr. (See p. 202.)
3 & 3 *a*. *Modiola sodburiensis*, sp. nov. (See p. 203.)
Fig. 4. *Cardinia concinna*, Sow. aff. *regularis*, Terq. (See p. 204.)
5. Fragment of *Plicatula cloacina*, sp. nov. (See p. 202.)

[We are greatly indebted to Mr. J. W. Tutcher for the excellent photographs from which the figures in this plate are reproduced.]

## Discussion.

Mr. Strahan testified to the great value of the observations made by the Authors on the sections that had been opened up on the new line of railway. He had had an opportunity of visiting the Chipping-Sodbury cutting, and had been particularly struck with the form of the Palæozoic floor under the Rhætic shales. In one place a small crag, formed by a hard quartz-grit interbedded in the Carboniferous Limestone, projected above the generally-even level of that floor and had yielded great blocks which lay at its foot embedded in the shales. Another projecting mass, formed by the upper beds of the Old Red Sandstone, had formed an island and subsequently a shoal in the earliest Rhætic sediments. Its surface, recently cleared of the shales, showed the rounding and smoothing by the Rhætic waves in extraordinary freshness. In strong contrast to this was the base of the Keuper Marl on the other side of Lilliput Bridge, where the old cliff showed no such wave-action, but had been littered up with a talus of rough blocks.

The earliest Rhætic sediments thinned out on the flanks of the Old-Red-Sandstone crag to which he had referred, but the later beds overspread it, curving gently upward and thinning as they did so. The Authors showed the Bone-Bed as extending continuously over the surface of the old rock, which suggested that it might be not strictly contemporaneous, but a littoral representative of any part of the Lower Rhætic shales. It indicated merely a sudden change of physical conditions.

The Rev. H. H. Winwood referred to the great interest attaching to these Rhætic beds, at least among West-of-England geologists, and regretted the absence of the Authors, who had done such good work in these sections. He wished to ask a few questions by way of explanation, not of criticism. What was their definition of the 'true Bone-Bed'? If fish-scales and teeth were any guide, he had found both in a thin band of limestone in the Black Shales, on the south side of Stoke-Gifford cutting. Again, it was stated that no true Bone-Bed had been recorded in Somerset, except at Emborough and Watchet; but he had found a fish (*Pholidophorus*) at the base of the Black Shales, at Newbridge-Hill cutting, near Bath. What evidence, moreover, was there for their division of the strata into Upper, Middle, and Lower Rhætic? In conclusion, he drew attention to the surface of the Palæozoic floor, smoothed and planed down by the sea which deposited these Rhætic beds.

## 16. *The* Derby Earthquakes *of* March 24th *and* May 3rd, 1903. By Charles Davison, Sc.D., F.G.S. (Read February 24th, 1904.)

[Plate XIX—Map.]

As a seismic region, Derbyshire is marked by few earthquakes, though parts, and even the whole, of the county are occasionally disturbed by shocks from other British centres. To find one that will compare in strength with the principal subject of this paper, we must go back more than a century, to November 18th, 1795, when a shock was felt over a district reaching in one direction from Leeds to Bristol, and in the other from Norwich to Liverpool. The dimensions of the disturbed area are given by Dr. E. W. Gray, F.R.S.,[1] as about 165 miles from north to south, and about 175 miles from east to west. 'In this latter direction, or rather from north-east to south-west,' he remarks, 'it may be said to have reached nearly across the island.' The area disturbed cannot have been less, and may have been much more, than 23,000 square miles; while, if we may judge from the places where chimneys were wholly or partly destroyed (Derby, Chesterfield, and Ashover), the epicentre may have coincided approximately with that of the principal earthquake of 1903.

In another respect there seems to have been a close resemblance between the two shocks. It is probable from Dr. Gray's account (*op. cit.* p. 365), that the earthquake of 1795 was what I have termed a 'twin'-earthquake, that it consisted of two distinct parts separated by a very short interval of rest and quiet. That this was a characteristic feature of the earthquake of 1903 was evident from the earliest reports; and, on this account, and also since the district is a favourable one for such investigations, I endeavoured to make an unusually-detailed study of the shock.[2] If, in so doing, I have met with any measure of success, it is almost entirely owing to the kindness of the very large number of correspondents who have sent me reports, to the courtesy of many newspaper-editors who have given a wide circulation to my inquiries, and not least to the invaluable help which I have received from Sir John G. N. Alleyne, Bart., Mr. H. H. Arnold-Bemrose, F.G.S., Mr. J. E. Bolton of Eckington, Mr. J. Darby, Hon. Secretary of the Wolverhampton Naturalists' Field-Club, Mr. T. Gledhill of Dronfield, Mr. E. O. Powell, headmaster of the Grammar-School, Stafford, the Rev. C. Price of Denstone College, Mr. A. H. Stokes, F.G.S., H.M. Inspector of Mines, Mr. P. K. Tollit, headmaster of the Grammar-School, Derby, Dr. G. S. Turpin, headmaster of the High School, Nottingham, and Mr. F. W. Webb, manager of the London & North-Western

[1] Phil. Trans. Roy. Soc. vol. lxxxvi (1796) pp. 353–81.

[2] The expenses of the investigation were defrayed from a grant received from the Government Research Fund.

Railway locomotive-department at Crewe. My debt to Mr. Arnold-Bemrose may to some extent be realized by the statement that I have to thank him for more than 170 records, many of them the results of personal interviews with observers, for a classified series of newspaper-reports, for the enlargement of the seismographic record which appears in fig. 1 (p. 220), and for information on the geological structure of the epicentral district. Without this timely aid, the gaps in our knowledge of the Derby earthquake would have been more serious, as well as more numerous, than those which at present exist.

The undoubted earthquakes were four in number, namely:

*a.* March 24th, 1.30 P.M. (Principal earthquake.)
*b.* March 24th, about 1.45 P.M.
*c.* March 24th, about 5 P.M.
*d.* May 3rd, 9.22 P.M.

Besides these, eight other disturbances are reported, three before and five after the principal earthquake, but the evidence is insufficient to decide their seismic origin. They are as follows:—

March 23rd, about 1.45 P.M.: Abbotshulme (near Rocester). Two persons felt a shock.
March 24th, about 5 A.M.: Kirk Langley. Two persons felt a shock similar to the principal shock.
March 24th, about 10.55 A.M.: Abbotshulme. One person felt a shock.
March 24th, about 1.50 P.M.: Tissington. A very slight shock.
March 25th, 0.30 A.M.: Fenny Bentley. A vibration without noise.
March 25th, about 6 A.M.: Draycott. A slight shock.
April 2nd, 2.30 A.M.: Duffield. A slight rumbling noise.
April 3rd, 1.17 A.M.: Duffield. A slight rumbling noise.

## The Principal Earthquake.

### *a.* March 24th, 1.30 P.M.

Intensity, 7 (nearly 8); centre of isoseismal 7, lat. 53° 3·1′ N., long. 1° 41·5′ W. Number of records 1136, from 528 places; and 63 negative records from 56 places.

### Time of Occurrence.

The total number of records of the time is 565. Of these, 71 are considered by their observers to be accurate to the nearest minute. Though two of them are as low as 1.25 and one as high as 1.36 P.M., the majority lie between closer limits, 36 records giving the time as 1.30, 10 as 1.31, and 8 as 1.32. The mean of 40 records from places within the isoseismal 6 is $1^h\ 30^m\ 15^s$. Three estimates are probably of greater value than the rest, namely, $1^h\ 30^m\ 6^s$ for Derby (12 miles from the centre), $1^h\ 31^m$ for Alsager (26 miles), and $1^h\ 31^m\ 5^s$ for Handforth, near Stockport (30 miles).

In these three records no reference is made to the particular epoch timed—an element of some importance, considering the long duration of the movement. As will be seen in a later section, the first tremors reached Birmingham (41 miles from the centre) at $1^h\ 30^m\ 19^s$, and Bidston (65 miles) at $1^h\ 30^m\ 44^s$. Taking the velocity afterwards calculated (p. 223) into account, it is clear that the time of the first vibrations at the epicentre must be within a very few seconds of $1^h 30^m 0^s$ P.M., an estimate that agrees closely with the mean recorded time within the isoseismal 6.

## Isoseismal Lines and Disturbed Area.

On the map of the earthquake (Pl. XIX) are shown five isoseismal lines. The innermost, corresponding to an intensity of less than 8 according to the Rossi-Forel scale, includes all the places but one in which slight damage is known to have occurred to buildings. In none was the injury more serious than the cracking of a poorly-built wall, or the overthrow of a few chimney-pots accompanied by the fall of some of the surrounding bricks. The bounding curve is elliptical in form, 16½ miles long, 8½ miles wide, and 112 square miles in area, the longer axis being directed N. 32½° E. and S. 32½° W. The centre of the curve coincides with the village of Kniveton, which lies about 3 miles north-east of Ashbourne, in lat. 53° 3·1′ N., and long. 1° 41·5′ W.[1]

The next isoseismal, of intensity 7, is 23½ miles long, 17½ miles wide, and 272 square miles in area, with its longer axis running N. 33° E. and S. 33° W. Its distance from the innermost isoseismal is a little more than 3½ miles on both sides of the axis. The isoseismal 6 is 48 miles in length, 36 miles in width, and 1348 square miles in area. Its longer axis is parallel to that of the isoseismal 7, the distance between the curves being 12 miles on the north-west side and 8 miles on the south-east. The isoseismal 5 is 76 miles long, 69 miles wide, and contains 4060 square miles, its distance from the isoseismal 6 being 17 miles towards the north-west and 16 miles towards the south-east.

Still more nearly circular is the outermost isoseismal, that of intensity 4, which, as drawn, is 129 miles long from north-west to south-east, 126 miles from north-east to south-west, and 12,000 square miles in area: its distance from the isoseismal 5 being 35 miles on the north-west side, and 25 miles on the south-east. Owing, however, to the difficulty always experienced in obtaining observations from outlying regions, it is possible that the path of this curve is inaccurately laid down, and that the divergence of the curve towards the north-west is largely, if not entirely, due to a defective series of records from other quarters.

Records have also been received from a few places beyond this isoseismal line—from Settle, Aysgarth, Richmond, and Easby (1 mile east of Richmond), which are respectively 7½, 21, 27, and 27 miles north of the isoseismal, and from Boston, 12 miles farther to the east. If the disturbed area were bounded by a circle concentric with the isoseismal 4, it would contain 16,000 square miles if the circle passed through Settle, 18,000 if through Boston,

[1] In a cottage at Alfreton (which is nearly 7 miles from the bounding curve) a chimney-pot was thrown down, and some bricks in the chimney were displaced.

22,000 if through Aysgarth, and 25,000 if it traversed Easby and Richmond. Nothing, either in the time of occurrence or the description given, throws the least doubt on the observations made at these places. But, considering that at such distances they could only have been furnished by exceptionally-keen observers, I think that the disturbed area should be regarded as bounded by the isoseismal 4, and therefore as containing about 12,000 square miles.

## Nature of the Shock.

The following accounts are given to illustrate the twin-character of the earthquake and its variation throughout the disturbed area. Of the places referred to, Ashbourne and Darley Dale are close to the longer axis of the inner isoseismals, the former being very near the epicentre; Duffield lies on the continuation of the shorter axis of the same curves, while Quarndon and Derby are respectively $1\frac{1}{2}$ and 3 miles from it.

At Ashbourne, two distinct shocks were felt, the first twice as long as the second and also rather stronger: the impression produced by both shock and sound being that a heavy article of furniture was rapidly rolled in the room upstairs from east to west, and then, after a pause of a second or two, was rolled a short way back again. At Darley Dale there were also two parts, each of which began with a low distant rumbling like the rushing of a strong wind, and culminated in a violent shock as it passed underneath the house. The second and stronger part was accompanied by an undulation crossing the floor from the north-west; and, immediately after its last vibrations had died away, another slight shock was felt.

From Derby the accounts are very numerous, but in most respects they agree closely. There were again two distinct shocks, each lasting 3 seconds with an interval of half a second between them, and consisting of vibrations having a period of about half a second. At Quarndon, a rumbling sound was first heard; then came a violent shock, as if a steam-roller had crashed into the foundations of the house on the north-west side; the rumbling continued for about 2 seconds, and, before it ceased, a second shock was felt, but not so violent as the first, the rumbling gradually dying away on the south-east. At Duffield only a single shock was observed, a quivering motion during the loudest part of the rumbling sound, which resembled that made by a muffled peal of thunder or by a sudden gust of wind.

With some exceptions, such as that last mentioned, the double shock was observed in every part of the disturbed area. Towards the north, it was clearly perceptible at Preston, Lytham, Aysgarth, Settle, Richmond, and Doncaster; towards the east, at Grantham, Eagle, and Boston; towards the south, at Barnt Green, Mere Hall, and Hagley; towards the west, at Shrewsbury and Vicar's Cross (near Chester). There is no evidence of the usual tendency of one part to become evanescent at a considerable distance from the epicentre.

Throughout the whole disturbed area, the double shock is distinctly recorded by 68 per cent. of the observers. In some parts this percentage rises to more than 80, especially in an elongated district about 30 miles in length, lying along the continuation towards the south-west of the major axis of the innermost isoseismal. In no large area does it fall below 48.

If, however, we plot the places where the double shock was felt, and also those where only a single series of vibrations was observed, a definite law of variation is rendered evident. The single shock was felt chiefly within a narrow rectilinear band, about 5 miles wide, running centrally across the inner isoseismals in a direction from W. 34° N. to E. 34° S., that is, at right angles to the longer axes of the isoseismals.[1] In the map (Pl. XIX) the boundaries of this band are represented by broken lines. Outside the band, the interval between the two parts of the shock was one of rest and quiet, its average length over the whole disturbed area being exactly 3 seconds.[2] Close to the band (as at Derby) the interval was much shorter, though still distinct; while, within the band, the shock generally appeared continuous, the ends of the two parts overlapping, although near the epicentral area, and close to the boundaries of the band elsewhere (as at Quarndon), two maxima of intensity were frequently perceived.

From the mere fact that the double shock was noticed at places near the boundary of the disturbed area, it is evident that the two parts were of nearly equal strength. If there had been any marked difference, it would have been possible, with so large a number of observations, to draw isoseismal lines for each part of the shock, and thus to determine the positions of the two epicentres. As it is, there is often considerable doubt as to which part was the stronger. At Derby, for instance, the first part of the shock was regarded as the stronger by 19 observers, and the second by 16; while 5 considered the two parts as of approximately-equal intensity. In the whole disturbed area, 61 per cent. of the observers state that the first part was the stronger, and 39 per cent. the second. Dividing the area into two portions by the axis of the rectilinear band, 60 per cent. of the observers on the north-east side, and 63 per cent. of those on the south-west side, regarded the first part as the more intense.[3]

## Origin of the Double Shock.

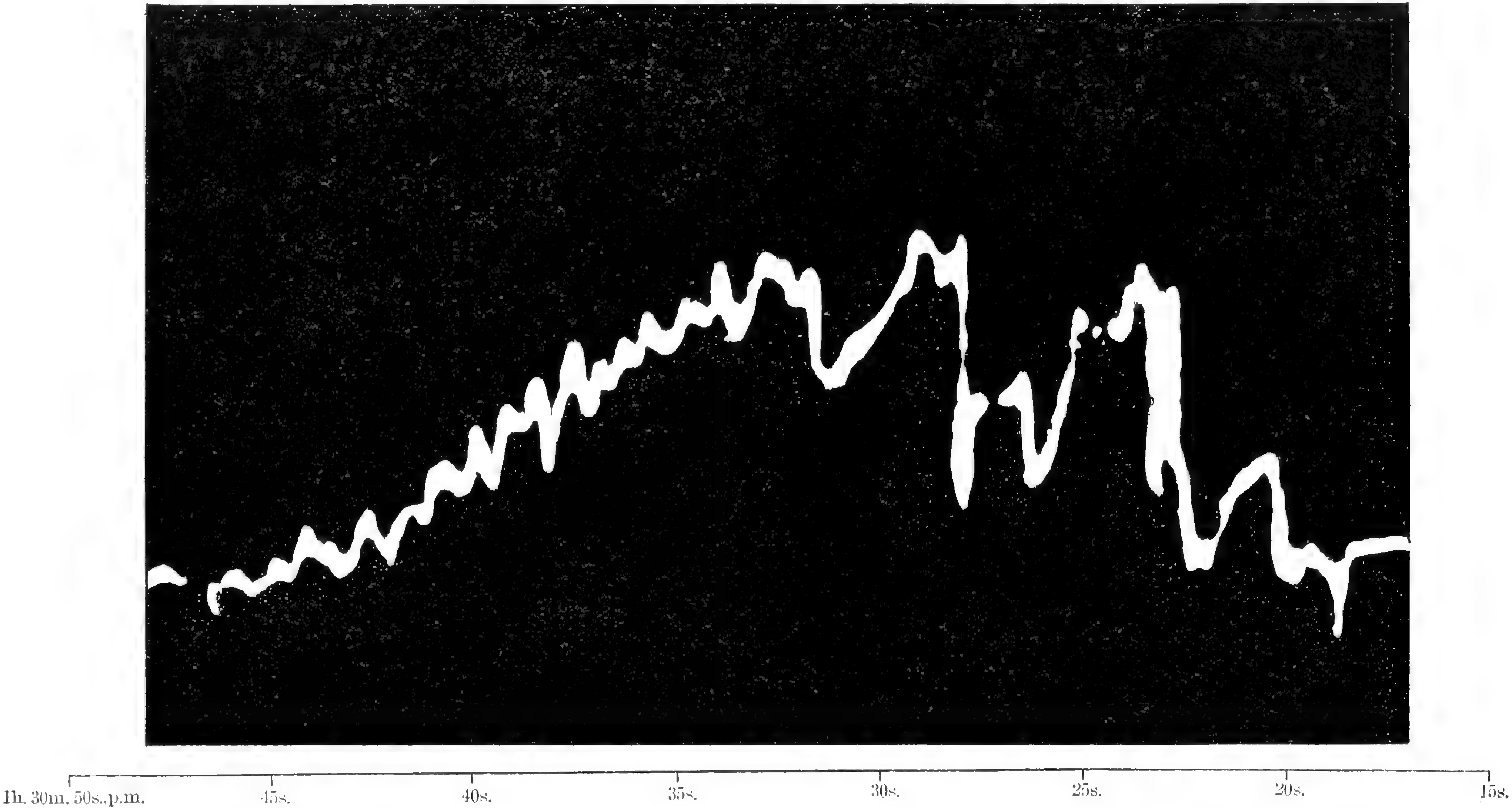
It is evident, from these accounts, that the double shock owed its origin to two distinct impulses of nearly-equal strength;

[1] It should perhaps be mentioned that the boundaries of this band were laid down without any reference to the previously-drawn isoseismal lines, and before the approximate positions of the two epicentres were known.

[2] This is the average of 125 observations, estimates of 10 or more seconds being omitted.

[3] This result, as will be seen from the following paragraphs, is due: (1) to the approximate equality of the two impulses; and (2) to their occurrence at the same instant. In each half of the disturbed area, the vibrations which formed the first part of the shock were those which came from the nearer focus.

Fig. 1.—*The record of the earthquake of March 24th, 1903, registered at Birmingham by an Omori horizontal pendulum.*



and the next point to be determined is whether they occurred within the same focus at different times, within two foci at the same time, or within two foci at different times. The theory of two successive impulses within the same focus is negatived by the existence of the rectilinear band within which the two parts of the shock were superposed, and by the fact that the first part of the shock was not everywhere the stronger. For the same reasons, the double shock cannot be referred to the duplication of a single initial impulse by reflection or refraction at the bounding surfaces of different rocks, or by the separation of its direct and transverse waves. There must, therefore, have been two distinct foci arranged along a line parallel, or nearly so, to the longer axes of the isoseismal curves; and that the foci were practically detached is evident from the cessation of all sound and movement during the interval between the two parts of the shock.

One of the most interesting features of twin-earthquakes is the occurrence of the second impulse before the vibrations from the focus first in action have time to reach the other. In other words, the second impulse is not a consequence of the first. In the Hereford earthquake of 1896, the two impulses were separated by a brief interval of time, and the two corresponding parts of the shock coalesced within a hyperbolic band, the convexity of which faced the focus first in action. In the Derby earthquake, however, this band is rectilinear, showing that the two impulses must have occurred at the same instant. They were therefore due to a single generative effort, and it is on this account that I have given the name of 'twins' to this class of earthquakes.

## Position of the Two Foci.

In the absence of isoseismal lines for each part of the shock, the exact positions of the two epicentres cannot be determined. From the form of the curves in Pl. XIX, however, it is probable that one epicentre was situated near Ashbourne, and the other about 3 miles west of Wirksworth: their centres being, therefore, about 8 or 9 miles apart.

## Seismographic Records.

Records of the Derby earthquake were given by an Omori horizontal pendulum at Birmingham, by a Milne seismograph at Bidston (near Birkenhead), and by an astatic pendulum designed by Dr. E. Wiechert at Göttingen. The first of these, which is the most interesting ever obtained of a British earthquake, is reproduced in fig. 1 (p. 220) from a photographic enlargement of the original record, for which I am indebted to the kindness of Mr. Arnold-Bemrose.

The Omori pendulum belongs to the type first devised by Mr. Gerard, of Aberdeen, in 1853, and afterwards re-discovered and employed by Prof. Milne in his well-known seismograph. It differs from the latter instrument in its mechanical form of registration, the record being made by a fine point on a rotating surface of smoked paper travelling at the rate of 10·8 millimetres per minute. Owing to the short period of the vibrations at Birmingham, the heavy bob of the pendulum acted almost as a steady point, the slight swinging of the pendulum being evident in the large curve on which the seismic waves are superposed. The movements of the ground in such a case are magnified 13·7 times by the pendulum; and, as the original record is also magnified 28·1 times by the enlargement in fig. 1, it follows that the latter represents the actual movements multiplied by 385.

An examination of the record under the microscope shows not the slightest trace of movement before the first abrupt disturbance to the east, which took place at $1^h\ 30^m\ 19^s$ P.M., G.M.T. The diagram is chiefly remarkable for the two prominent displacements to the west, which occurred at $1^h\ 30^m\ 23^s$ and $1^h\ 30^m\ 28^s$, and which no doubt correspond to the two parts of the shock so widely observed. It is difficult to determine accurately the periods of these two large waves, owing to the width of the trace made by the recording pointer, but in each case it seems to have been about 0·8 sec. At $1^h\ 30^m\ 31^s$, another oscillation of some importance took place, followed by a series of 13 ripples with an average period of 0·84 sec. These are all that are shown in fig. 1, but the original record continues with a series of 79 still smaller ripples, with a slightly longer average period of 1·03 secs., the last visible under the microscope occurring at $1^h\ 32^m\ 3^s$. The total duration of the disturbance as registered in Birmingham was $1^m\ 44^s$.

Making allowance for the width of the trace and the swinging of the pendulum, the range of motion of the ground from east to west was ·078 millimetre during the first prominent displacement, and ·075 mm. during the second. Birmingham, however, lies S. 11° W. from the epicentre, and therefore, if we may assume that the resultant movement was directed from that point, the total displacements registered by the pendulum must have been ·41 and ·39 millimetre respectively. These, with periods of ·8 sec., would correspond to maximum accelerations of 12·6 and 12·0 millimetres per sec. per sec., showing how nearly equal in strength were the two principal parts of the shock. The values given seem to be too small to produce a shock sensible in the centre of a busy city; and it is therefore probable that the recorded range of motion is less than the actual movement of the ground, owing to the unavoidable friction between the pointer and the smoked paper and between the different parts of the apparatus.

Bidston lies 65 miles west-north-west of the epicentre, and 8½ miles south-west of the rectilinear band. The method of registration in the Milne seismograph being photographic, the paper is made to travel much more slowly than in the Omori pendulum, and consequently the diagrams are less detailed and the times of different epochs are ascertainable with less accuracy. I am informed by Mr. W. E. Plummer that

'The record of the Derby earthquake is small, both in amplitude and duration.

The time of the first disturbance is 13.30.44 [that is, $1^h\ 30^m\ 44^s$ P.M.], as nearly as it can be read off the diagram. The record gives evidence of but one impulse which has moved the pendulum towards the west: the subsequent oscillations of the pendulum, which are carried on for about 55 seconds, being due to the original disturbance. The greatest amplitude of oscillation is about 0·7 millimetre, and, as the movement dies away, there is no trace of the ordinary period of the pendulum, which is about 16 seconds. The vibrations appear to have accomplished themselves in a shorter time, so that the successive vibrations have run into each other.'

One of the most interesting features of this record is the fact that only one impulse was detected. Bidston being so close to the rectilinear band, the interval between the two prominent vibrations was too short to allow of their separate registration.

At the time of the earthquake, as Dr. Wiechert kindly informs me, rather strong pulsations were being registered by his pendulums at Göttingen; and, on this account, all measurements are to some extent uncertain. The determinations of the epochs, for instance, may err by as much as 5 seconds on either side of the times given. The preliminary tremors, though very small, were distinctly recognized with the aid of a lens, beginning at $1^h\ 33^m\ 32^s$ P.M. (G.M.T.); their period was about 1 second, and their amplitude about ·0001 millimetre. They were succeeded by a series of larger waves, beginning at $1^h\ 34^m\ 20^s$, and attaining their maximum at $1^h\ 34^m\ 40^s$, with a period of between 2 and 3 seconds and an amplitude of about ·0007 millimetre. The total duration of the movement was about $1\frac{3}{4}$ minutes.

## Velocity of the Earth-Waves.

The most accurate determinations of the time are probably those given by the pendulums at Birmingham and Göttingen, the distances of which places from the epicentre are 66 and 808 kilometres respectively, or 41 and 502 miles. The interval between the arrival of the first vibrations at these places being 193 seconds, and of the maximum of the principal waves 257 seconds, it follows that the preliminary tremors travelled with a velocity of 3·8 kilometres (or 2·4 miles) per second, and the larger waves at the rate of 2·9 kilometres (or 1·8 miles) per second. The former of these values many be inaccurate, for we cannot be certain that the first tremors recorded in Birmingham corresponded with those registered in Göttingen; the latter value agrees closely with the estimates made for many other earthquakes.

## Sound-Phenomena.

### Isacoustic Lines and Sound-Area.

As persons differ considerably in their powers of hearing very deep sounds, the short-period vibrations, in spreading outwards from the origin, tend to become inaudible to a continually increasing number of observers; and the rate of decline in audibility may be represented by a series of isacoustic lines, or curves drawn through places in which the percentage of observers who heard the sound is the same. If, from any cause, such as the superposition of sound-waves from two foci, the amplitude of the vibrations be locally increased without a corresponding increase in their period, the percentage of audibility will rise, and there will be an expansion outwards of the isacoustic lines in the neighbourhood of the region in question.

In the Derby earthquake, the smallness of the sound-area and the scarcity of observations from places near its boundary, render impossible the construction of a complete series of isacoustic lines. On the map of the earthquake (Pl. XIX), only two such curves (indicated by dotted lines) are shown, namely, those corresponding to percentages of 95 and 90. In order to draw them, the whole disturbed area was divided into squares by north-to-south and east-to-west lines 10 miles apart; the percentage of observers within each square who heard the sound was supposed to correspond to the centre of the square, and the curves were then drawn through points dividing the lines that join adjacent centres in the proper ratios. The meaning of the curve marked 95, then, is that, if with any point on it as a centre, a small circle be described, 95 per cent. of all the observers within the included district heard the earthquake-sound.

The inner line (that marked 95) is 33 miles in length and 16 miles in greatest width, and the outer line (marked 90) 49 miles in length and 19 miles in width. The greatest of these dimensions being not more than five times a side of one of the squares, it follows that details in the form of the curves are smoothed away by the process of construction, and that the only important feature that possesses a physical meaning is the general trend of the curves in the direction of the rectilinear band within which the single shock was observed. At places inside this band, the vibrations from the two foci coalesced; and so the earthquake-sound was reinforced, and was consequently heard by a greater proportion of observers. Thus, the evidence of the sound-phenomena supports the conclusion to which we were led by the nature of the shock, namely, that the earthquake was caused by simultaneous fault-slips within two detached foci.[1]

Excluding a few records from very distant places, the sound was observed within the area bounded by the outer dotted line in Pl. XIX —an area 101 miles long in the direction of the major axis of the isoseismals, 98 miles wide, and containing about 7800 square miles, or nearly two-thirds of the whole disturbed area. The exceptional records come from Ashton-in-Ribble, Lytham, and Southport in Lancashire, and from Aysgarth and Settle in Yorkshire.

Within the isoseismal 7, no fewer than 97 per cent. of the

[1] The insensible distortion of the isoseismal lines and the marked expansion of the isacoustic lines in the direction of the rectilinear band, is due to the brevity of the two principal vibrations of the shock and the long duration of the two parts of the sound. Within the rectilinear band, there must have been a still narrower band within which the two principal vibrations absolutely coalesced; but the area of the latter band was so small that the observations from places within it seem to be entirely wanting.

observers heard the earthquake-sound; in the surrounding zone (that between the isoseismals 7 and 6) the percentage of audibility was 89; in the next (bounded by the isoseismals 6 and 5) 80; while, between the isoseismal 5 and the boundary of the sound-area, it fell to 65. In other words, within a radius of about 40 miles from the epicentre, nine out of every ten persons heard the sound; but, outside a surrounding zone 10 miles in width, the sound became inaudible to all but the most acute observers.

## Nature of the Sound.

The sound was generally a heavy rumble, deeper than any thunder, a quick succession of reports, though sometimes apparently continuous. The low grating character of the sound is illustrated in many descriptions, such as its comparison with a number of steam-rollers passing over a very uneven road, a very large barrel rolling over cobble-stones, a peal of thunder in a hilly country, a great fall of rock in underground workings, a confusion of knockings or the trampling of many feet; the rapid rush of the sound is shown by frequent reference to runaway traction-engines, a number of big vans galloping up a road, or the moving of heavy furniture in a great hurry; the approach to continuity by comparisons with a steam threshing-machine at a distance, or the rush of a strong wind.

The total number of descriptions in the whole sound-area amounts to 745. In 53 per cent. of these, the sound is compared to passing traction-engines, etc., in 21 per cent. to thunder, in 5 to wind, in 8 to the tipping of a load of stones, in 4 to the fall of a heavy body, in 7 to explosions, and in 3 per cent. to miscellaneous sounds.

In any one place, many different types of comparison are employed, certain vibrations of the series being audible to some persons and not to others. Thus, at Derby, 61 per cent. of the observers compared the sound to passing traction-engines, etc., 11 per cent. to thunder, 6 to wind, 11 to loads of stone falling, 5 to the fall of a heavy body, 3 to explosions, and 2 per cent. to miscellaneous sounds. These proportions also vary in different parts of the sound-area, though (except as regards distance) the law of variation cannot be determined with certainty. The percentage of comparisons to passing traction-engines, etc., is 46 within the isoseismal 7, 53 between the isoseismals 7 and 6, 56 between the isoseismals 6 and 5, and 59 between the isoseismal 5 and the boundary of the sound-area; for thunder, the corresponding percentages are 32, 21, 16, and 14. Thus, with increasing distance from the origin, the sound tends to become smoother and more monotonous, owing to the gradual extinction of the limiting sound-vibrations, and especially those of longest period.

## Relation of the Sound to the Double Series of Vibrations.

In many of the detailed accounts, reference is made to two distinct sounds, accompanying each part of the shock, and separated by a brief interval of rest and quiet. Few observers, however, noted the relative intensity of both parts of the sound and shock. The first part of both sound and shock was the more intense according to 7 observers, the second part according to 9, while 1 considered them to be approximately equal in intensity. Again, 8 observers state that the first part of the shock was the stronger and that no sound was heard with the second part; and 1 that the second part of the shock was the stronger, while no sound accompanied the first. Thus, all observers agree in connecting the louder part of the sound with the stronger part of the shock.

## 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 the beginning or end of the sound preceded, coincided with, or followed, the corresponding epoch of the shock; the letters *g*, *e*, and *l* indicate the number of records per cent. in which the duration of the sound was greater than, equal to, or less than, that of the shock.[1] The last line of the table contains the average percentages for four strong earthquakes, namely, the Pembroke earthquakes of 1892 and 1893, the Hereford earthquake of 1896, and the Inverness earthquake of 1901.

| | Beginning. | | | End. | | | Relative Duration. | | |
|---|---|---|---|---|---|---|---|---|---|
| | *p* | *c* | *f* | *p* | *c* | *f* | *g* | *e* | *l* |
| Within isoseismal 7 | 63 | 34 | 3 | 20 | 53 | 27 | 59 | 37 | 5 |
| Between isoseismals 7 and 6 | 53 | 40 | 7 | 17 | 52 | 31 | 48 | 45 | 7 |
| " " 6 and 5 | 55 | 37 | 8 | 23 | 62 | 15 | 39 | 49 | 12 |
| " " 5 and the boundary of the sound-area | 70 | 27 | 3 | 24 | 71 | 6 | 31 | 69 | ... |
| Whole sound-area | 57 | 37 | 7 | 21 | 55 | 24 | 46 | 46 | 9 |
| Average for strong earthquakes. | 76 | 15 | 8 | 19 | 26 | 56 | 73 | 21 | 6 |

A comparison of the last two lines of the table shows that, in the Derby earthquake, there was a closer approach than usual to coincidence in both terminal epochs and therefore to equality in duration. Moreover, this tendency was almost as marked in the central region as in the outer zones, from which we may infer: (1) that the sound-waves travelled with the same, or very nearly the same, velocity as those of larger amplitude and longer period, and (2) that the marginal regions of the foci were of comparatively-small dimensions in a horizontal direction.

[1] The number of records from the outer zone (that between the isoseismal 5 and the boundary of the sound-area) is much less than from the others, and the corresponding percentages are therefore of inferior value.

## Observations in Mines.

As observations in mines have hitherto been few in number, I endeavoured to obtain accounts from many of those surrounding the epicentral region. For some of the most valuable records, I am indebted to Mr. H. H. Arnold-Bemrose, F.G.S., and Mr. A. H. Stokes, F.G.S., H.M. Inspector of Mines. The total number received is 48 from 32 mines, most of which are situated between two lines running east and north-east from the centre of the isoseismal 7.

From the south-western quarter observations are entirely wanting, the earthquake having passed unnoticed in the pits of Cannock Chase. Towards the west, it was perceived as far as Bucknall near Stoke-on-Trent (19 miles from the centre); towards the north-west, at Monsal Wale near Buxton (18 miles, 117 yards deep); towards the north-east, at Eckington (22 miles); towards the east, at Hucknall Torkard (20 miles, 500 yards deep) and Bulwell (20 miles, 300 yards deep); and towards the south at Swadlincote, near Burton-on-Trent (20 miles, 470 yards deep).

The general impression produced by the earthquake was that an explosion or fall of rock had taken place in some distant part of the mine. In the pits at Clay Cross and Morton (situated between Alfreton and Chesterfield), both parts of the shock were felt, the first part being the stronger and, at Clay Cross, accompanied by the louder noise. In three pits, at Glapwell, Pilsley, and Swancote (all in the Alfreton district), the shock was strong enough to detach small pieces of shale from the roof. At Tibshelf (4 miles from Alfreton), the shock caused the air in the mine to vibrate, as if from an explosion.

The sound seems to have differed slightly from that observed on the surface, in being less intermittent and more monotonous, closely resembling that made by a railway-train passing over iron girders or a wooden bridge, and in a few cases not unlike that of an explosion of firedamp or a heavy fall of rock.

The distribution of intensity of the shock and sound presents several features of interest, which seem worthy of record:—

(1) The shock, as a rule, was not felt in the more distant mines. The sound only was observed in the pits at Eckington, Teversall (18 miles from the centre), Sutton-in-Ashfield (18 miles), Hucknall Torkard, Ilkeston (16 miles, about 400 yards deep), Swadlincote, and Bucknall; but in two others, Monsal Wale and Bulwell, the movement was also perceived. It would seem, then, that at a distance the sound was a much more prominent feature than the shock; and this relative prominence was probably not accidental, for men lying down to work would be in a favourable position for feeling a slight tremor. Similar observations were made during the Hereford earthquake of 1896, the shock being noticed at a distance of at least 20 miles, and the sound as far as Chasetown near Walsall, 54 miles from the centre.

(2) In the Great Rake lead-mine at Brassington, at a depth of 160 yards, and only $2\frac{3}{4}$ miles from the centre, no shock was felt by

any of the men, although a 'dreadful roaring noise' was heard. As the mine must be in the immediate neighbourhood of the north-eastern focus, and especially of its marginal regions, it is probable that the sound overpowered all other sensations.

(3) In several cases, the sound appeared to be more overhead than below. At Clay Cross, according to one observer, the sound was noticed 'more as in the roof than on the floor'; according to another, there was 'a rumbling noise above, as though a train was passing over.' In the Manners Colliery, near Ilkeston, at a depth of about 400 yards, the sound is described as like that of a train passing close overhead, while some of the men thought that it was caused by a break in the overlying strata. At Pilsley, near Clay Cross, the rumbling resembled that of a train of trucks passing over the workings. Lastly, at Swadlincote, near Burton-on-Trent, men working in the Eureka seam at a depth of 400 yards were alarmed by a rumbling noise 'passing overhead, like a railway-train passing over a wooden bridge'; others in the Kilburn seam, 470 yards below the surface, heard a heavy rumbling noise, 'as though the stone-head was falling in,' which seemed to pass over their heads and die away in the distance.[1]

(4) Mr. G. S. Bragge, who kindly communicated the last account, informs me that the rumbling noise was also heard in some cases in the Woodfield seam, 350 yards from the surface, but no notice was taken of it. In the workings of the Little Coal, at a depth of about 220 yards, he was unable to find that any unusual noise was heard at all. It would seem, then, that the intensity of the sound increased with the depth of the workings.

## Effect on Underground Water.

The only observation under this heading that I possess is one communicated to me by Mr. Arnold-Bemrose, from Mr. T. Webster at Hognaston, a village which lies about a mile east of the centre, and probably not far from the line of the earthquake-fault. Shortly after the earthquake, the water of the village-well was found to be of a milky colour. Mr. Webster then emptied the well three times, and saw the water bubbling out of the springs at the bottom quite thick, as if with powdered lime. It remained so for two or three days before it returned to its normal clearness, after which a white sediment remained at the bottom for a few weeks. Mr. Webster adds that he has known the well for 35 years, and that neither he nor the oldest inhabitant can remember a similar occurrence. Whether the sediment was a result of the fault-slip that caused the earthquake, or merely a secondary effect of the shock itself, is doubtful, though

[1] A similar observation was made in a mine at Ashover, near Matlock, during the earthquake of November 18th, 1795. The men at work heard 'a rushing rumbling kind of noise, which appeared to be at a distance, and to come nearer and nearer, until it seemed to pass over them, and die away.' The position of the epicentre is unknown, but it was probably not very distant, for several chimneys were thrown down at Ashover, Phil. Trans. Roy. Soc. vol. lxxxvi (1796) p. 359.

the former is not an improbable origin. In any case, owing to the proximity of Hognaston to the earthquake-fault, the observation is one of considerable interest.

### After-Shocks.

#### *b.* March 24th, about 1.45 P.M.

The only records of this after-shock come from Abbotshulme (near Rocester), Bakewell, and Tissington. There was a slight tremor at all three places, and at Abbotshulme a rumbling sound was heard.

#### *c.* March 24th, about 5 P.M.

A slight shock was felt at Brailsford, Fenny Bentley, and Onecote (near Leek). There is no record of any accompanying sound.

#### *d.* May 3rd, 9.22 P.M.

Intensity, 5; centre of isoseismal 4, lat. 23° 2·4′ N., long. 1° 39·9′ W. Number of records, 62, from 42 places in Derbyshire, and 11 from 10 places in Staffordshire; and 35 negative records from 30 places.

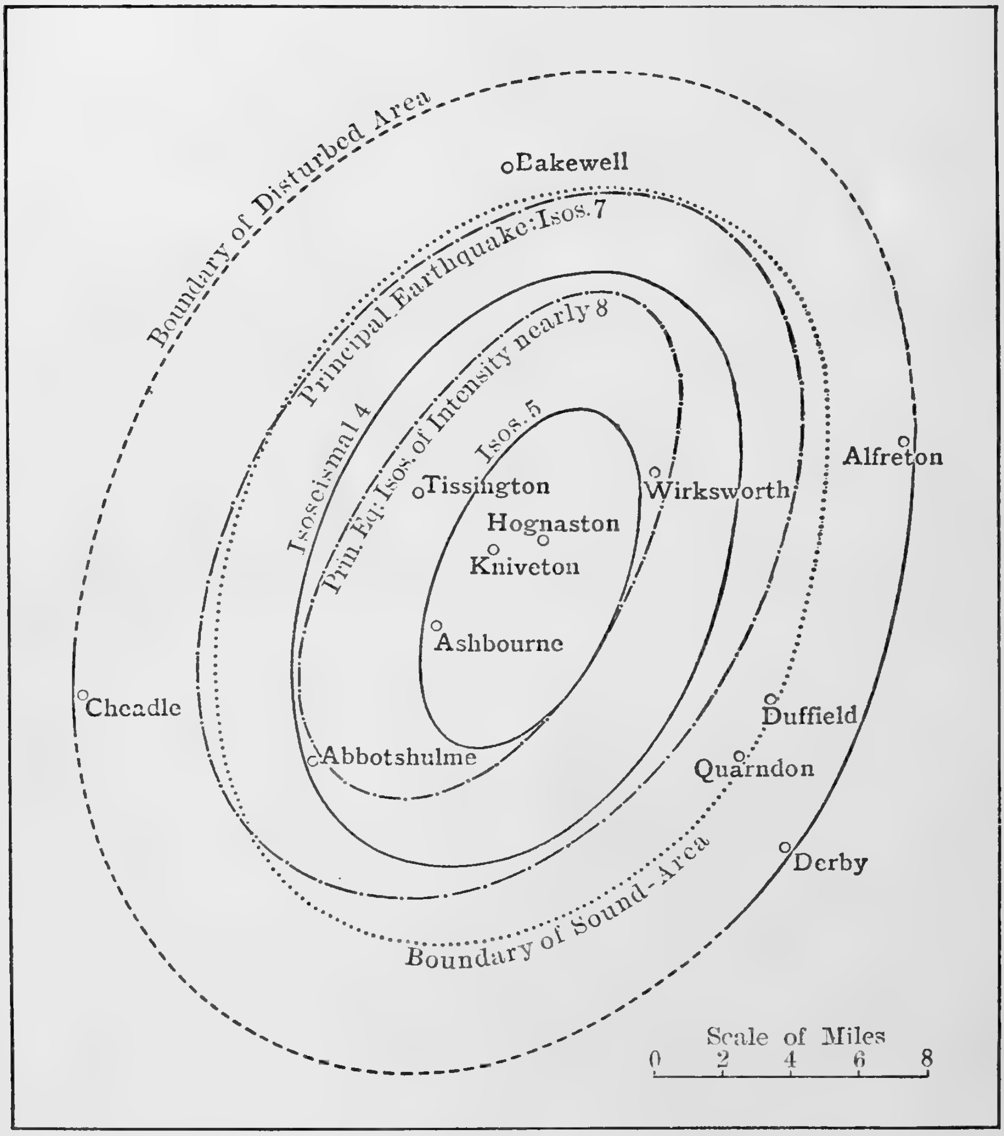
##### Time of Occurrence.

As the earthquake was not recorded by any seismograph, we have to rely on local observations of the time of occurrence. The time given above was that determined by two signalmen in different boxes on the railway-line between Derby and Duffield. It agrees closely, moreover, with the mean of all the more careful observations, namely, $9.21\frac{1}{2}$ P.M.

##### Isoseismal Lines and Disturbed Area.

On the map of this after-shock (fig. 2, p. 230) are shown six curves, the isoseismals 5 and 4 being indicated by continuous lines, the boundary of the disturbed area by the outer line continuous in part but mostly broken, the boundary of the sound-area by the dotted line, while the two inner isoseismal lines of the principal earthquake are indicated by broken-and-dotted lines. The isoseismal 5 is $10\frac{3}{4}$ miles long, $5\frac{1}{4}$ miles wide, and about 44 square miles in area. The isoseismal 4 (the most accurately drawn of the series) is 19 miles long and 12 miles wide, and contains about 179 square miles. Its centre is about one mile south-west of Hognaston, and the direction of its longer axis is N. 25° E. and S. 25° W. The course of the boundary of the disturbed area is doubtful, except in the neighbourhood of Derby, Ripley, and Cheadle. As drawn, it is 31 miles long, 24 miles wide, and about 585 square miles in area. The distances between the isoseismals 5, 4, and that which forms the boundary of the disturbed area, are respectively 3·7 and 6·4 miles on the north-west side, and 3·0 and 5·0 miles on the south-east side. Taking account of possible error in the tracing of these curves, it follows that the originating fault must, in the neighbourhood of the focus, run about N. 25° E. and S. 25° W., hade towards the north-west, and intersect the surface along a line passing near, or a short distance to the south-east of Hognaston. The epicentre, or the chief part of it, evidently lies between the two epicentres of the principal earthquake (of March 24th); while the displacement towards the east or south-east of the isoseismal lines with respect to those of the principal shock shows that, if connected with the same fault, the focus must have been situated much nearer to the surface. The latter inference is also supported by the closeness of the isoseismals, which is indicative of a rapid decline in intensity from the epicentre outwards.

Fig. 2.—*Map of the Derby earthquake of May 3rd, 1903.*




## Nature of the Shock.

In most places, the shock is described as a sudden shiver or short tremor, its average duration being about $3\frac{1}{2}$ seconds. Of the 36 observers who refer to the nature of the shock, 29 distinctly state that it consisted of only one part, and the remainder do not enter into details. The shock was, therefore, not a twin, but due to a disturbance within a single continuous focus.

### Sound-Phenomena.

The boundary of the sound-area is shown by the dotted curve in fig. 2. Towards the south, its course is somewhat uncertain, but it probably does not deviate by more than a fraction of a mile from the position there laid down. The boundary, as drawn, is 24 miles long, 17 miles wide, and contains about 320 square miles. The sound was heard by 92 per cent. of all the observers. It was compared to passing traction-engines, etc., in 45 per cent. of the records, to thunder in 39 per cent., wind in 6, loads of stones falling in 3, explosions in 3, and to miscellaneous sounds in 3 per cent. The beginning of the sound is said to have preceded that of the shock in 47 per cent. of the records, and to have coincided with it in 53 per cent.; while the end of the sound is said to have coincided with that of the shock in 58 per cent. of the records, and followed it in 42 per cent. Twelve observers noted the time-relations of both terminal epochs; according to six of them, the duration of the sound was greater than, and according to the other six equal to, that of the shock. Thus, in its nature, and in its time-relations with the shock, the sound of this after-shock resembled that which accompanies the typical slight earthquake.

## Origin of the Earthquakes.

According to the seismic evidence, the mean direction of the earthquake-fault must be N. 33° E. and S. 33° W., its hade must be to the north-west, and the fault must either traverse the village of Hognaston or pass a short distance to the south-east of it. On the Geological Survey-map (sheet 72), no faults are marked in the immediate neighbourhood of this place. The surface-rocks belong to the Yoredale Series, except for an inlier of Carboniferous Limestone between Kniveton and Bradbourne, which terminates towards the west in two masses of toadstone. The faults that border these masses, according to the Survey-map, were for the most part inserted to account for the presence of the toadstone. About a mile west of Hognaston, a few small faults, half a mile or less in length, occur; but none agrees, either in direction or position, with the fault assigned by the seismic conditions. This fault, however, is roughly parallel to the strike of the neighbouring rocks, and either dies out before reaching the surface or, more probably, is obscured by the superficial covering of Drift.

From the phenomena described in the foregoing pages, the succession of events during the recent disturbances may be clearly realized. For many years, possibly for more than a century, there had been no movement of any consequence along the earthquake-fault. During the previous twenty-four hours, there may have been a few small creeps, but the evidence on this point is indecisive; and the principal slips took place at 1.30 P.M. on March 24th, practically without any sensible preparation. It is perhaps worthy of notice that the Hereford earthquake of 1896 was preceded by several shocks, originating chiefly in the south-eastern focus; and that the two slips of the twin-earthquake were not simultaneous, the earlier and stronger impulse taking place in the north-western focus. In the Derby earthquake, there was little, if any, preparatory movement: the two impulses occurred simultaneously, and were approximately equal in strength. The foci, the centres of which were about 8 or 9 miles apart, were completely detached, so far as any sensible movement in the intermediate region was concerned, and they were probably small in their horizontal dimensions, the amount of slip becoming rapidly evanescent towards both lateral margins. On the same day, two other small slips took place, but their localities are unknown.

An important result of the double slip was a sudden increase of stress in the regions of the fault-surface within and surrounding the margins of both foci. The portion of the fault between the foci, being affected by movements at each end, received the greatest accession of effective stress, and consequently, on May 3rd, forty days after the principal disturbance, a minor slip took place chiefly or entirely within this region, partly perhaps intruding on the nearer lateral margins of the two foci, and extending upwards to within a short distance from the surface.

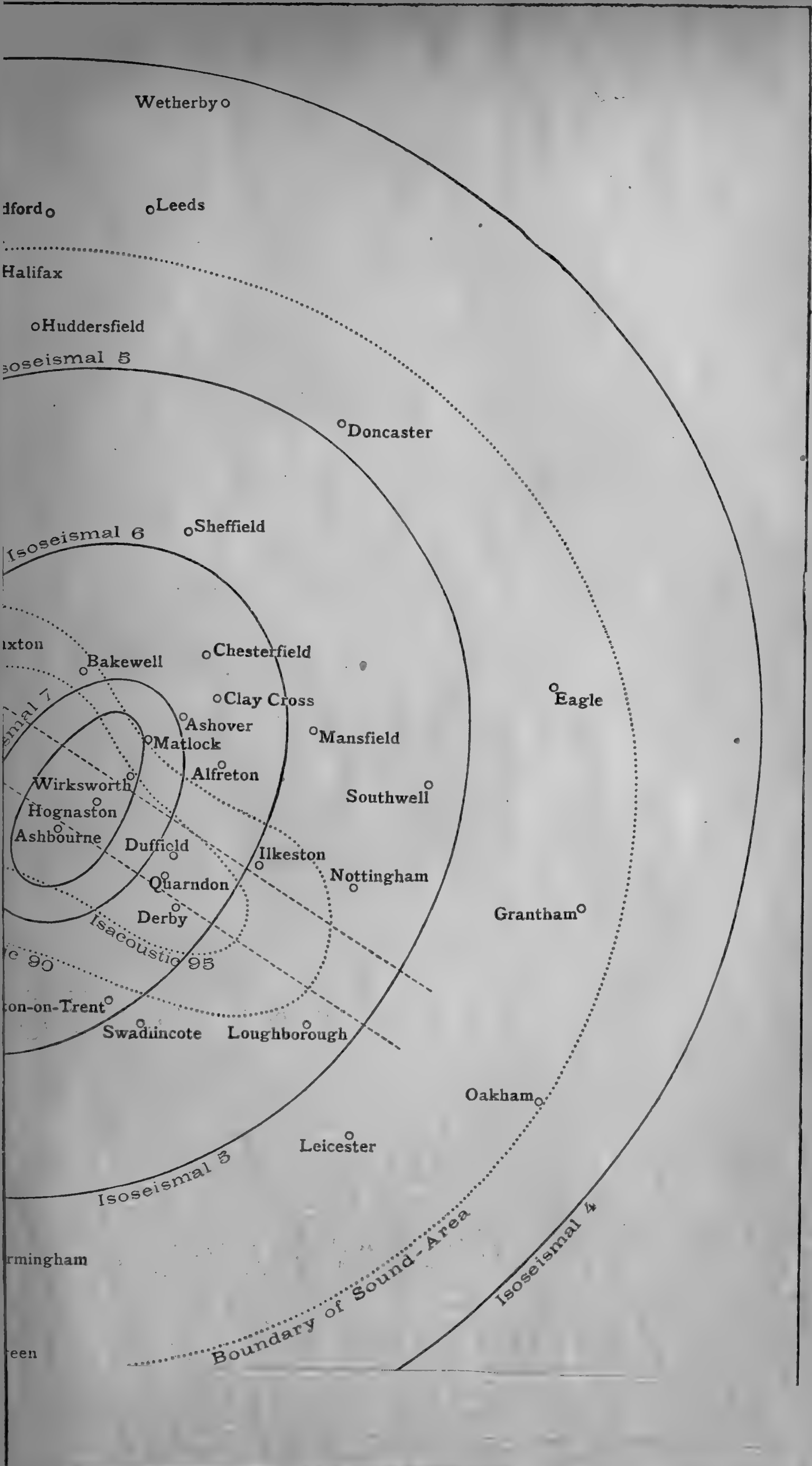
It may be useful, in conclusion, to compare the succession of movements along the Derbyshire fault with those which have been the parents of other recent earthquake-series. The first Carlisle earthquake of July 9th, 1901, was the result of slips in two principal foci, the centres of which were about 23 miles apart, and of a continuous, though less, displacement throughout the whole intermediate region. About 20 minutes later, there followed a slip which resembled that of May 3rd, 1903, in being complementary to the principal displacement and affecting the fault-surface between the two foci.[1] Again, the Inverness earthquake of September 18th, 1901, was succeeded by several after-shocks, the foci of the more important of which gradually approached the surface.[2] A similar decrease in depth characterized most of the numerous after-shocks of the great Japanese earthquake of 1891; and, as we have seen, the focus of the Derby earthquake of May 3rd, 1903, was much closer to the surface than those of the principal shock. The materials at our disposal are still too scanty to allow of general conclusions being drawn. Future shocks may render manifest other modes of displacement; but I trust that I am not too sanguine in thinking that the careful study of earthquakes such as we experience in this country may, in time, reveal to us the laws according to which faults grow.

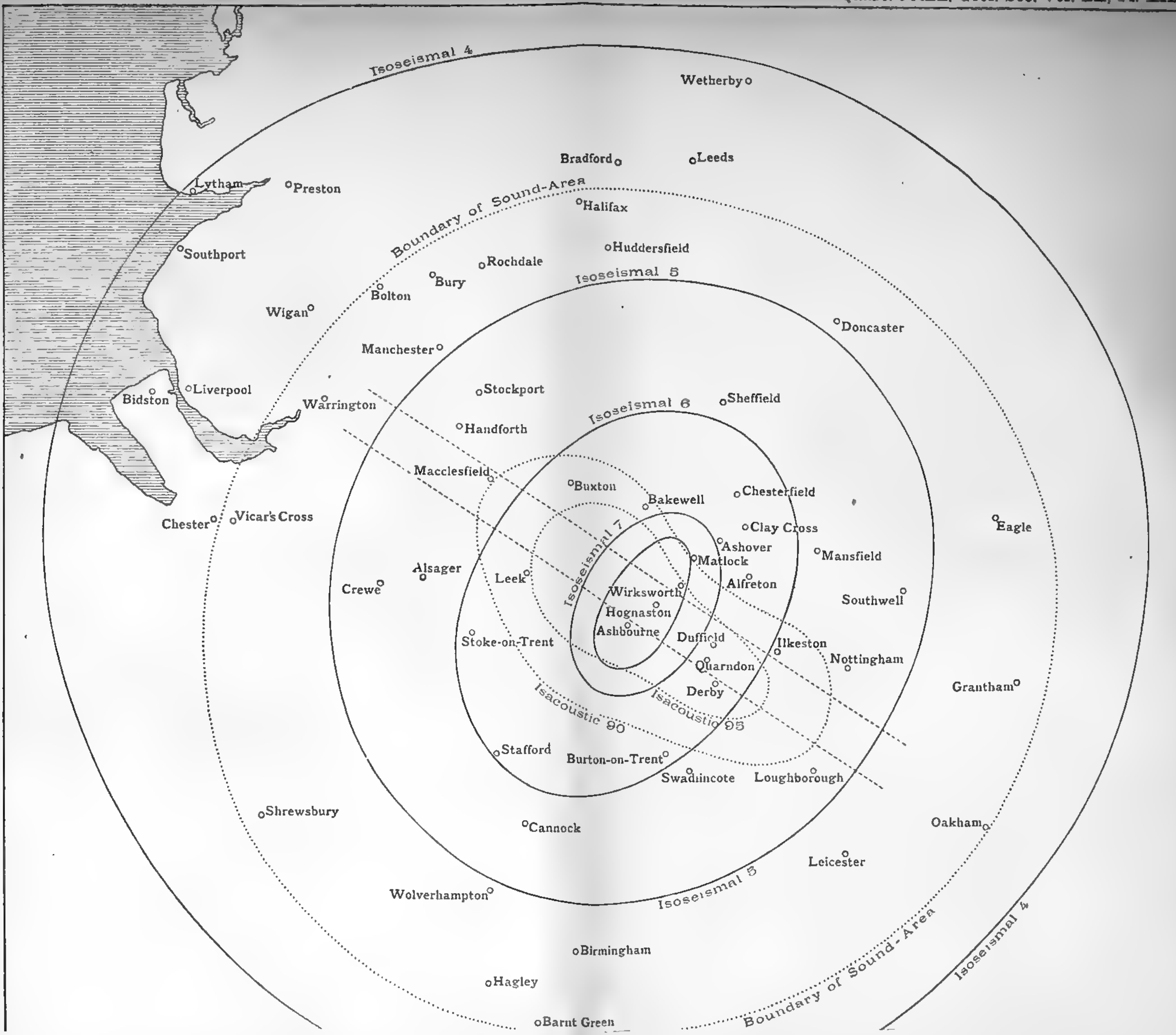
## EXPLANATION OF PLATE XIX.

Map of the Derby earthquake of March 24th, 1903, on the scale of about 15 miles to the inch.

---

[1] Quart. Journ. Geol. Soc. vol. lviii (1902) pp. 371–76.
[2] *Ibid.* pp. 377–79.


Wetherby
dford
Leeds
Halifax
Huddersfield
soseismal 5
Doncaster
Sheffield
Isoseismal 6
ixton
Bakewell
Chesterfield
Clay Cross
Eagle
smal 7
Ashover
Matlock
Mansfield
Alfreton
Southwell
Wirksworth
Hognaston
Ashbourne
Duffield
Ilkeston
Nottingham
Quarndon
Derby
Grantham
Isacoustic 95
c 90
ton-on-Trent
Swadiincote
Loughborough
Oakham
Leicester
Isoseismal 5
rmingham
Boundary of Sound-Area
Isoseismal 4
een


Isoseismal 4
Wetherby
Bradford
Leeds
Lytham
Preston
Boundary of Sound-Area
Halifax
Huddersfield
Southport
Rochdale
Bury
Bolton
Isoseismal 5
Wigan
Doncaster
Manchester
Liverpool
Bidston
Stockport
Sheffield
Warrington
Isoseismal 6
Handforth
Macclesfield
Buxton
Bakewell
Chesterfield
Clay Cross
Ashover
Matlock
Mansfield
Eagle
Chester
Vicar's Cross
Isoseismal 7
Alsager
Leek
Crewe
Wirksworth
Alfreton
Southwell
Hognaston
Ashbourne
Duffield
Stoke-on-Trent
Ilkeston
Nottingham
Quarndon
Derby
Grantham
Isacoustic 90
Isacoustic 95
Stafford
Burton-on-Trent
Swadlincote
Loughborough
Shrewsbury
Cannock
Oakham
Leicester
Wolverhampton
Isoseismal 5
Birmingham
Hagley
Barnt Green
Boundary of Sound-Area
Isoseismal 4

# 17. *The* Caernarvon Earthquake *of* June 19th, 1903, *and its* Accessory Shocks. By Charles Davison, Sc.D., F.G.S. (Read June 22nd, 1904.)

[Plate XX—Map.]

## I. Introduction.

During the nineteenth century, the county of Caernarvon was visited by at least fourteen earthquakes. Seven, if not more, of these disturbances arrived from distant centres, situated near Pembroke, Hereford, etc.: but three or four were probably of local origin, their epicentres being either within or not far from the boundaries of Caernarvonshire. All of these local shocks, however, were of slight intensity; and, indeed, within the last five centuries, there does not seem to have been a single indigenous earthquake that can be compared either in intensity or in extent of disturbed area with that which, on June 19th, 1903, was felt over nearly the whole of Wales, the North-West of England, the Isle of Man, and several of the eastern counties of Ireland.

In the investigation of this earthquake, I have, as usual, been assisted by a large number of correspondents, to whom my best thanks are due. In various ways, I have also received timely aid from Mr. Edward Greenly, F.G.S., Mr. J. D. Macdonogh of Bettws-y-Coed, Mr. W. T. Davies of Nantlle, and Mr. W. A. Thomas of Llanfair-pwllgwyngyll. For lists of after-shocks, the value of which it would be difficult to overestimate, I am indebted to Mr. F. C. Carey of Bethesda, Mr. E. Davies of Bodfeirig, Mr. W. T. Davies of Nantlle, Mr. W. Hughes of Gaerwen, Mr. W. W. Hughes of Penygroes, and Mr. R. R. Jones of Clynnog.[1]

The total number of earthquakes belonging to the recent series may amount to 15 or more, the first occurring on June 19th and the last on June 23rd. Seven of these depend on the evidence of more than one observer, and are distinguished below by letters and detailed descriptions. The remainder are recorded on the authority of one person only; and, although I have been careful to include no disturbance which did not appear to me to be of seismic origin, it is advisable, I think, to follow the usual rule, and to regard their character as earthquakes as not fully established.

## II. Fore-Shock.

### *a*. June 19th, about 4.25 a.m.

Number of records, 2, from 1 place.

A rumbling noise like thunder was heard at Griffiths Crossing, near Caernarvon.

[1] The cost of the investigation was defrayed from a grant received from the Government Research Fund.

## III. Principal Earthquake.

### b. June 19th, 10.4 A.M.

Intensity, 7; centre of isoseismal 7, lat. 53° 3′·0 N., long. 4° 22·9′ W. Number of records, 388, from 206 places; and 56 negative records from 44 places.

### Time of Occurrence.

The total number of time-records (excluding those which are confessedly approximate) is 176. Of these, 38 estimates are regarded by their observers as accurate to the nearest minute: the average of 18 such estimates from places within the isoseismal 7 being $10^h$ $8^m$ $3^s$ A.M. As, however, the earthquake was registered by seismographs at $10^h$ $5^m$ $5^s$ at Bidston, and $10^h$ $5^m$ $56^s$ at Birmingham, it would seem that the majority of railway-clocks, and of others dependent on them, must have been kept about 4 minutes fast, and I have therefore deducted this amount from the times given for all the shocks.

### Isoseismal Lines and Disturbed Area.

The continuous lines in Pl. XX, broken in parts where their course is doubtful, represent the isoseismals 7 and 6, the boundary of the disturbed area, and those portions of the isesoismals 5 and 4 which traverse the land. In one or two places, buildings were slightly damaged. At Clynnog, a slab of slate, weighing more than a hundredweight, was dislodged from the top of a chimney; and, at Penygroes, two chimneys were thrown down. Both places are close to the epicentre of the earthquake.

The isoseismal 7 is an elongated ellipse, 33½ miles long, 15 miles wide, and 420 square miles in area. The centre is situated in lat. 53° 3′·0 N., long. 4° 22·9′ W., that is, 4 miles west of Penygroes church, and the longer axis runs from N. 40° E. to S. 40° W. Of the next isoseismal (6), little more than half can be drawn with any approach to accuracy; though the completed curve probably does not deviate greatly from the path marked by the broken line. The width of the curve is 38 miles, and its distance from the isoseismal 7 is 11·8 miles on the north-west side, and 10·6 miles on the south-east. The isoseismal 5 is interrupted by the sea to the north of Flintshire and in Caerdigan Bay. Its distance from the isoseismal 6 towards the south-east is 20 miles. Of the isoseismal 4, nearly half can be drawn. It traverses the Isle of Man, and the eastern counties of Ireland; but its course in the latter district is doubtful. Its distance from the isoseismal 5 towards the south-east is 27 miles.

The outermost isoseismal drawn corresponds to an intensity between 4 and 3. It is 185 miles in length from north-east to south-west, 173 miles wide, and contains 25,000 square miles. The shock was also felt at four places outside this line—at Dunmore

East in County Waterford, Ravensdale in County Louth, Kendal, and Didsbury (near Manchester). The distances of these places from the outermost isoseismal are, respectively, 22, 8, 25, and 13 miles. If we regard the boundary of the disturbed area as passing through Kendal and as concentric with the isoseismal, the disturbed area would include about 40,000 square miles. The observations at the four places mentioned were, however, made in upstair rooms, and, with one exception, by invalids in bed. It seems desirable, therefore, to regard the disturbed area as bounded by the outermost isoseismal, and as containing 25,000 square miles.

## Nature of the Shock.

In its general features, the nature of the shock was practically uniform throughout the disturbed area; and the following account from Meyllteyrn (near Nevin) may be regarded as typical for a very large portion of the area. The shock began with a series of tremors, lasting 4 or 5 seconds, which merged gradually into a single series of principal vibrations of about 3 or 4 seconds' duration, these in turn being succeeded by a brief series of tremors, lasting only 1 or 2 seconds. The movement was thus continuous, increased gradually in intensity, and then rather more rapidly died away. At a few places not far from the central area, two maxima of intensity in the principal vibrations were detected by careful observers; and their evidence, as will be seen, is confirmed by the seismographic record at Birmingham. At a great distance, at Liverpool and Southport and in some parts of Ireland, for instance, the vibrations between these maxima were imperceptible, and the shock seemed to consist of two detached parts. The period of the vibrations also increased with the distance, so that, in Lancashire, Ireland, and elsewhere, the motion was a gentle swaying several times to and fro. The average of 88 estimates of the duration of the shock is $6\frac{3}{4}$ seconds.

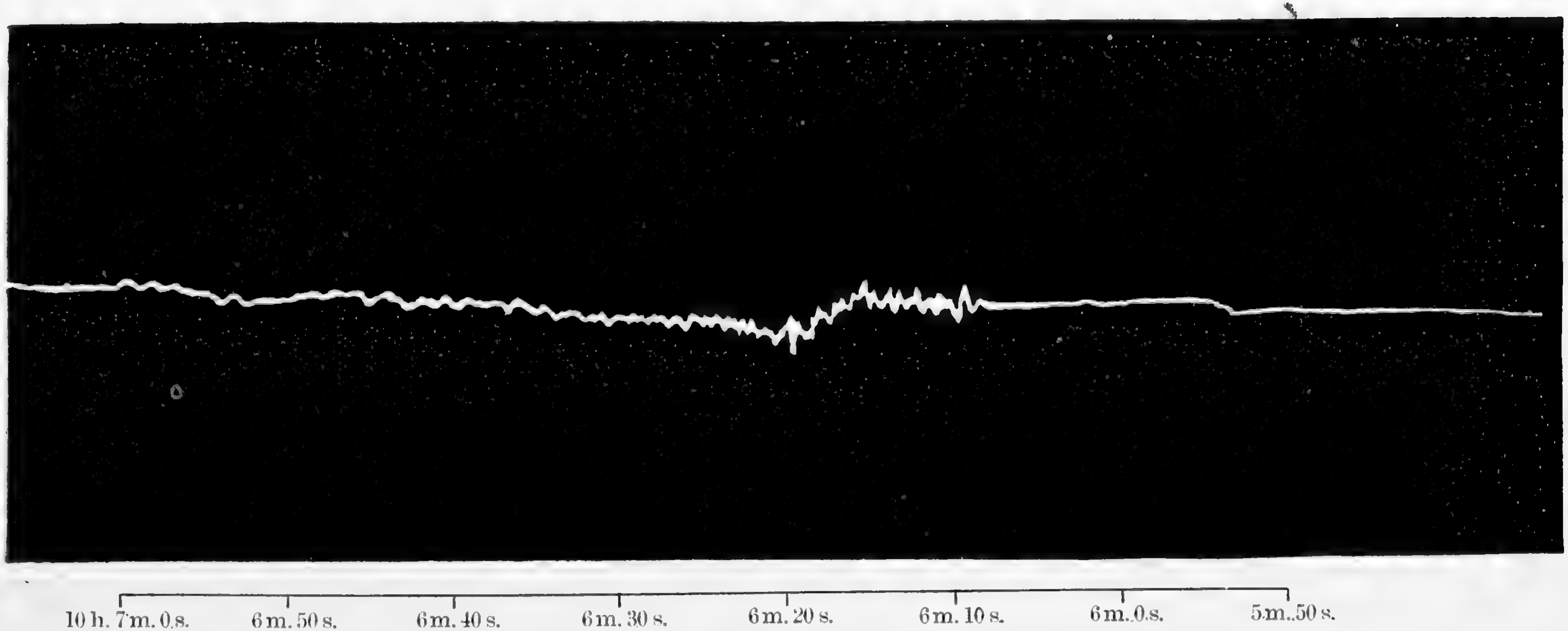
## Seismographic Records.

The Caernarvon earthquake was recorded by a Milne seismograph at Bidston, near Birkenhead, and by an Omori horizontal pendulum at Birmingham.

Bidston is 60 miles from the centre in the direction E. 24° N. Mr. W. E. Plummer, the director of the observatory, kindly informs me that the first movements took place at $10^h\ 5^m\ 5^s$ A.M. The separate oscillations of the pendulum are not shown on the diagram, but there seem, he says, to have been two distinct impulses, the second taking place at $10^h\ 7^m\ 30^s$. The amplitude of the disturbance was even less than in the case of the Derby earthquake of March 24th, 1903.

Birmingham lies 111 miles E. 20° S. from the centre. The record, which is enlarged 9·75 times in fig. 1 (p. 236), gives the component of the motion in the east-and-west direction; and, as the movement

Fig. 1. *The record of the earthquake of June 19th, 1903, registered at Birmingham by an Omori horizontal pendulum.*



of the ground is magnified 13·7 times by the pendulum, it follows that the enlarged diagram represents the actual motion multiplied by 134. The whole movement is divisible, as usual, into three parts—the preliminary tremors, the principal vibrations, and the concluding undulations. The preliminary tremors are first perceptible at $10^h\ 5^m\ 56^s$ A.M. (Greenwich mean time), and lasted for 13 seconds. The enlarged diagram shows hardly any trace of them ; but when the original record is examined under the microscope, they appear as minute notches, 51 in number, on the tracé. The average period of the tremors was, therefore, a quarter of a second. The principal vibrations began at $10^h\ 6^m\ 9^s$, and lasted 26 seconds. The total number of vibrations is 40 ; but the first 19 are, as a rule, of much greater amplitude than the rest. They have an average period of ·63 second, while that of the remaining 21 vibrations is ·67 second. In the 2nd and 19th vibrations, which are the largest of the series, the range (or double amplitude) was ·023 millimetre in the east-and-west direction, or ·024 millimetre (that is, about one-thousandth of an inch) in the direction of the epicentre. Taking the period of these vibrations as ·63 second, the maximum acceleration would be 1·3 mm. per sec. per. sec., or about one-tenth of that of the Derby earthquake of 1903 at Birmingham. The concluding undulations began at $10^h\ 6^m\ 35^s$. On the enlarged diagram (fig. 1, p. 236), twenty-seven may be seen, with an average period of 1 second; but, with the aid of the microscope, they can be detected until $10^h\ 7^m\ 40^s$, though so obscurely in some parts of the tracé that their exact number cannot be ascertained. The total duration of the disturbance was thus $1^m\ 44^s$.[1]

## Sound-Phenomena.

The boundary of the sound-area is indicated by the dotted line in Pl. XX. It is 147 miles long from north-east to south-west, 136 miles wide, and contains about 15,700 square miles, or, say, three-fifths of the disturbed area. In the whole of the latter area, 88 per cent. of the observers heard the earthquake-sound. In the central district, the sound was unnoticed by very few persons, the percentage of audibility being 100 within the isoseismal 7 ; 99 between the isoseismals 7 and 6 ; 98 between the isoseismals 6 and 5 ; and falling to 48 in the surrounding zone. The rapid decline in audibility near the boundary of the sound-area is thus as marked as it was in the case of the Derby earthquake of 1903.

The number of observers who describe the sound is 291. Of these, 45 per cent. compare it to passing traction-engines, motor-cars, etc. ; 29 per cent. to thunder ; 7 to wind ; 8 to loads of stones falling ; 1 to the fall of heavy bodies ; 7 to explosions ; and 3 per cent.

[1] There is no trace of the second impulse registered at Bidston at $10^h\ 7^m\ 30^s$. At the beginning of the diagram in fig. 1, there is a slight disturbance, which was, I believe, caused by some particle of dust or roughness of the paper. It will be noticed that the second half of the more prominent vibrations are superposed on a larger curve, which is due to a slight swinging of the pendulum.

to miscellaneous types. These approximate closely to the proportions prevalent in strong earthquakes, the average percentages for the different types in ten recent earthquakes being 46, 22, 10, 4, 3, 8, and 6, respectively. The percentage of comparisons to passing traction-engines is 42 within the isoseismal 7; 49 between the isoseismals 7 and 6; and 50 between the isoseismals 6 and 5. For thunder, the corresponding percentages are 30, 30, and 24; and, for wind, 3, 6, and 8: showing how the sound tends to become smoother and more monotonous with increasing distance from the epicentre.

The beginning of the sound preceded that of the shock in 62 per cent. of the records, coincided with it in 36, and followed it in 2, per cent. The end of the sound preceded that of the shock in 8 per cent., coincided with it in 49, and followed it in 43 per cent., of the records. The duration of the sound was greater than that of the shock in 65 per cent., equal to it in 35, and less than it in 1 per cent., of the records.

## Miscellaneous Phenomena.

A few observations were made in slate-quarries in which the workings are continued underground. At Nantlle, the shock was felt at a depth of from 50 to 70 yards, the workmen thinking that a large fall of rock had taken place. It was also noticed in underground workings at Blaenau Ffestiniog, 19 miles from the centre.

Among the most interesting observations on the earthquake were those made on the movement of the loose material of screes. Owing to the very gradual creeping downwards with every change of temperature of all stones free to move, a large part of the material is almost in unstable equilibrium, and a very slight force is necessary to set it in motion.[1] At the time of the earthquake, Mr. W. G. Fearnsides, F.G.S., was sitting on a slope of screes 150 yards south of Lleyn dur Arddu and 1 mile north-west of the summit of Snowdon. There were, he says, three chief shocks within about 1½ minutes. The second and strongest so affected the screes that, on turning round, he saw numbers of stones shuffling and rolling down the surface. Stones of all sizes were involved, blocks of felsite up to 2 feet in diameter among them, the larger moving more quickly than the others, and the noise caused during their motion was so great that it finally drowned the rumbling of the earthquake. The screes continued unstable for five minutes, and, at the end of that time, hundreds of newly-fallen blocks were to be seen lying at the base.[2]

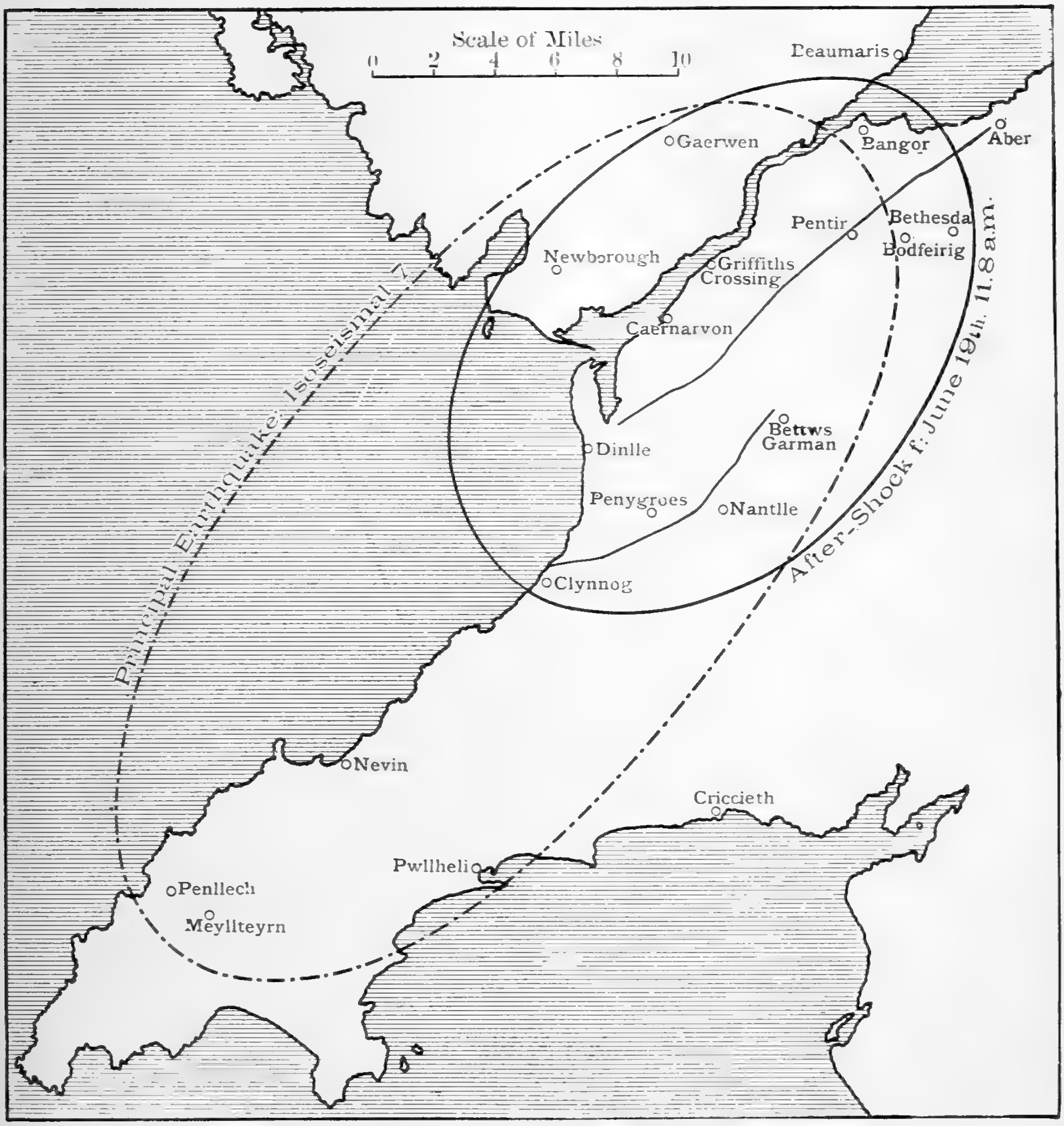
[1] Quart. Journ. Geol. Soc. vol. xliv (1888) pp. 232–37, 825–26.

[2] A somewhat similar observation was made at Blaenau Ffestiniog, where fragments of slate were seen rolling down the 'tips' of waste slate from the quarry-workings.

## IV. After-Shocks.

June 19th, 10.7 A.M.: Meyllteyrn.—A very slight tremor, of intensity 3, accompanied by a sound like that of distant thunder.

Fig. 2.—*Map illustrating the area affected by after-shock* f *of June 19th, 1903.* *(See p. 240.)*




[*For* 'Bettws Garman' *read* 'Bettws Garmon'.]

### *c.* June 19th, 10.9 A.M.

Intensity, 3. Number of records, 4, from 4 places.

A slight tremor was felt at Penygroes and at Gaerwen, while a rumbling sound was heard at the latter place and also at Bethesda and Bodfeirig. The boundary of the disturbed area and the position of the epicentre must have coincided nearly with those of the after-shocks of June 19th, 11.8 A.M. (*f*) and June 21st, 8.6 A.M. (*g*).

### *d.* June 19th, 10.12 A.M.

Intensity, 3. Number of records, 2, from 2 places.

A slight tremor was felt at Penygroes, and a tremulous sound was heard at Bethesda. The epicentre probably coincided with, or was not far distant from, that of the preceding after-shock (*c*).

### *e.* June 19th, 10.16 A.M.

Intensity, 3. Number of records, 2, from 2 places.

A tremulous sound was again heard at Bethesda. At Bettws Garmon, a slight tremor was felt, lasting about 2 seconds, accompanied by a sound like very faint distant thunder.

June 19th, 10.23 A.M.: Bethesda.—A tremulous sound.
June 19th, 10.48 A.M.: Penygroes.—A slight tremor.

### *f.* June 19th, 11.8 A.M.

Intensity, 3; epicentre, lat. 53° 7·6′ N., long. 4° 14·3′ W. Number of records, 7, from 7 places (fig. 2, p. 239).

The seven places of observation lie within an elliptical area, 20 miles long, 13 miles wide, and 219 square miles in area. The centre of the area is 8 miles north-east of that of the principal shock, and the direction of its principal axis N. 47° E. and S. 47° W. A slight tremor was felt at every place, accompanied at Clynnog, Nantlle, Penygroes, and Gaerwen by a faint rumbling sound.

June 19th, 12.5 P.M.: Bodfeirig.—A slight shock.
June 21st, 5.26 A.M.: Upper Clynnog.—A shock, accompanied by a sound like that of the tipping of quarry-rubbish.

### *g.* June 21st, 8.6 A.M.

Intensity, 3. Number of records, 5, from 5 places.

The boundary of the disturbed area and the position of the epicentre were nearly the same as those of the after-shock on June 19th, 11.8 A.M. (*f*, fig. 2, p. 239). A slight shock was felt at Nantlle and Penygroes, and a rumbling sound was heard at Bodfeirig, Clynnog, and Newborough.

June 21st, about 9.6 A.M: Clynnog.—Sound heard.
June 22nd, 4.26 A.M.: Penygroes.—A slight shock, accompanied by a rumbling noise. A slight shock was also felt at Penllech during the same morning, but the time is not given.
June 23rd, about 5.31 A.M.: Nantlle.—A very slight shock.

## V. Origin of the Earthquakes.

From the seismic evidence, we obtain the following elements for determining the position of the originating fault:—(1) the mean direction of the fault must be parallel, or nearly so, to the longer axis of the isoseismal 7, that is, it must be from N. 40° E. to S. 40° W.; (2) the hade of the fault must be towards the side on which the isoseismals are farthest apart, or towards the north-west; (3) the fault-line must pass a short distance, a few miles at the most, on the south-east side of the centre of the isoseismal 7: so that, in the epicentral district, its course may be submarine, or it may pass through or near Clynnog or even a mile or two farther to the south-east; and (4) the fault must be of some magnitude, extending about 8 miles both to the north-east and south-west of Clynnog.

On the map of the epicentral district (fig. 2, p. 239), are shown two faults reduced from the Geological-Survey map (sheets 75 & 78): one traced for a distance of 14 miles from Aber to Dinlle on the coast of Caernarvon Bay, the other for 8 or 9 miles from Bettws Garmon to Clynnog. Of the two, the former satisfies the seismic conditions more closely. Its average direction is N. 52° E. and S. 52° W., it hades to the north-west, and, according to Ramsay, the downthrow of the Silurian beds on that side is between 4000 and 5000 feet at Pentir (3 miles south of Bangor), and between 2000 and 3000 feet at Dinas (4 miles farther to the south-west). If the fault, after leaving Dinlle, is continued under the sea as far as Nevin, trending rather more to the south, it would occupy approximately the position assigned to the originating fault. As no other large fault is known to exist in the epicentral district, it seems probable that the Caernarvon earthquake was caused by a slip along the Aber-Dinlle Fault.

The region of the fault-surface occupied by the seismic focus was about 16 miles in length, extending from near Nevin to near Caernarvon; and the amount of displacement was almost uniform throughout, dying away somewhat rapidly towards both ends. Though two maxima of intensity were observed at some places, and were indicated on the seismographic record at Birmingham, there is no evidence that the focus was discontinuous. The displacement appears to have been of that simple type to which the great majority of slight earthquakes owe their origin, and to have been distinguished only by its great length.

The accessory shocks fall naturally into two classes. The first includes those, six in number, that were strong enough to attract the attention of several or many persons; the second includes six tremors (three of them accompanied by sound) and two earth-sounds, but all so weak that their occurrence in each case rests on the evidence of only one observer.

The fault-slips corresponding to the former class were confined to the north-eastern margin of the principal focus, or to its immediate neighbourhood. One of them occurred between five and six hours before the great displacement, the next four within little more than an hour afterwards, and the sixth two days later. The last two, if they were connected with the Aber-Dinlle Fault, originated in foci quite close to the surface.

If we may assume the disturbances of the second class to have been of seismic origin, then small sudden creeps, rather than slips, affected other portions of the fault, one of them occurring at the south-western end of the principal focus, two at the north-eastern end, and five in the central region. If, however, the originating fault were submarine, the weakness of the tremors resulting from the central and southern slips may be partly due to the greater distance of the foci.

Denoting slips at the north-eastern end, centre, and south-western end, by the letters *n*, *c*, and *s*, and using capital letters for those perceived by several or many observers, the distribution of the different slips in time may be represented as follows :—

| June 19th | | | | | | | | | | 21st | | 22nd | 23rd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *N*, principal focus, | *s*, | *N*, | *N*, | *N*, | *n*, | *c*, | *N*, | *n*, | *c*, | *N*, | *c*, | *c*, | *c*. |

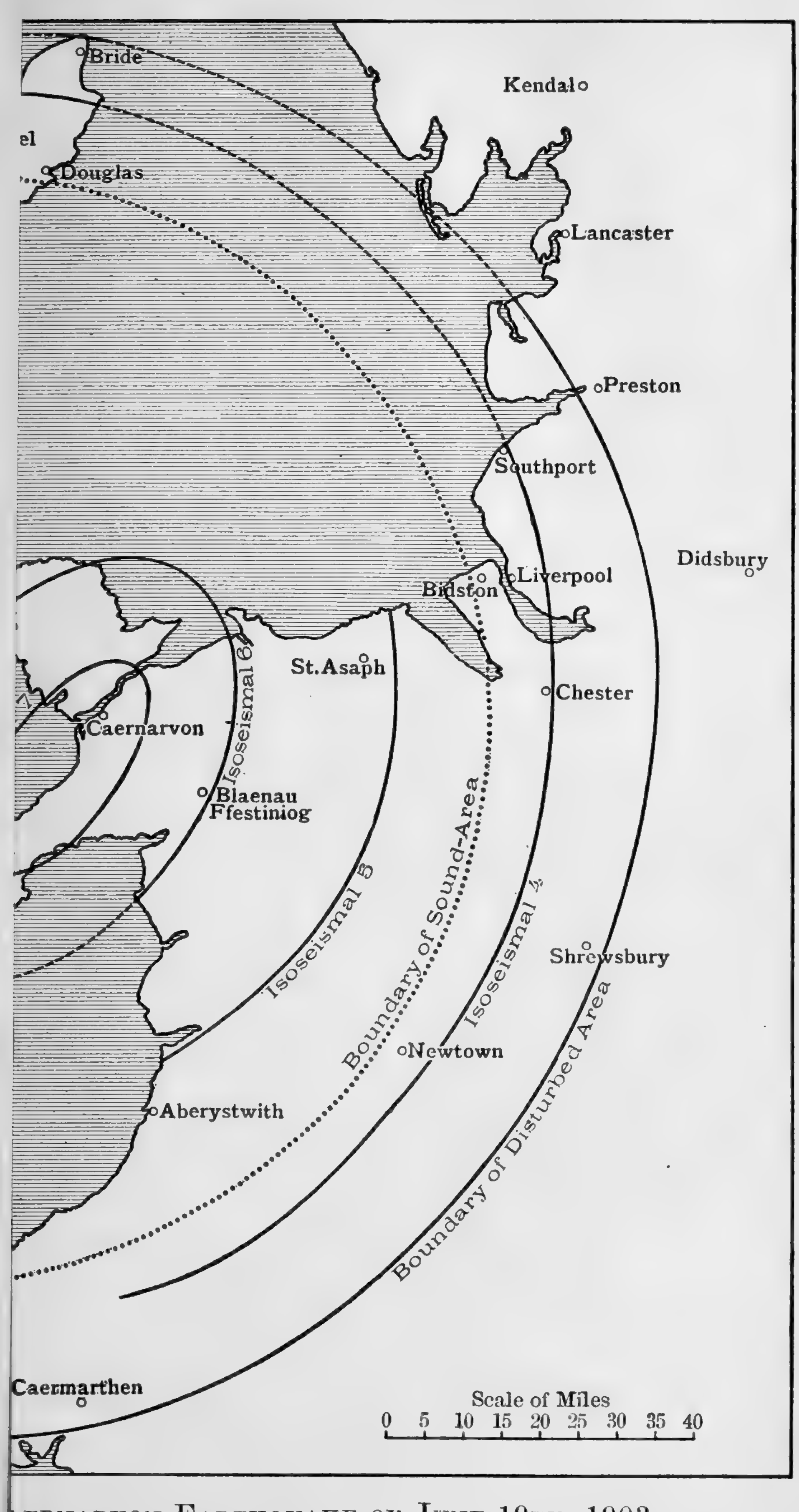
Thus, as in the Japanese earthquake of 1891 and the Inverness earthquake of 1901, seismic action towards the close of the series was withdrawn from the lateral margins of the principal focus and was ultimately confined to its central region.

## EXPLANATION OF PLATE XX.

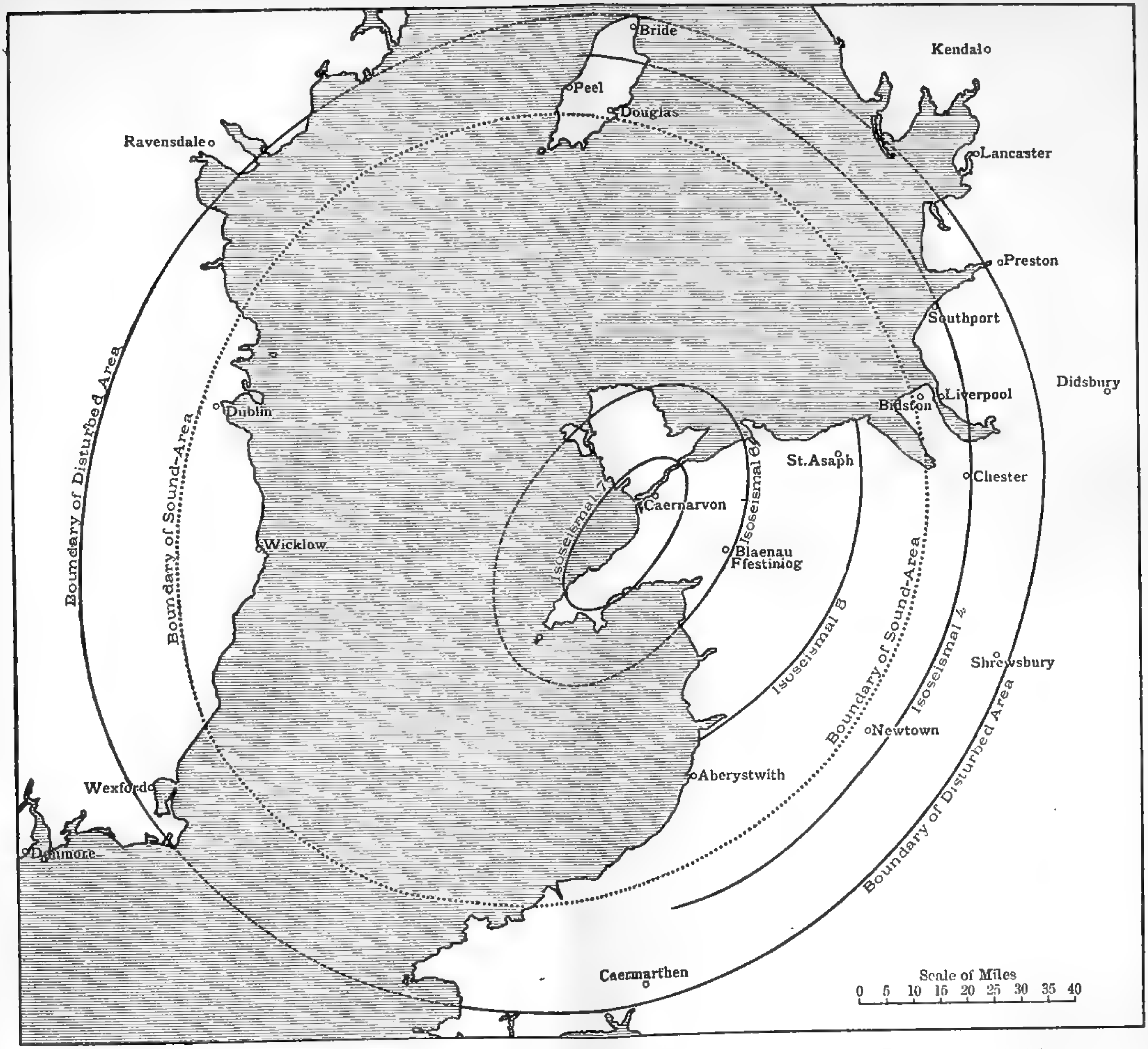
Map of the area affected by the principal Caernarvon earthquake of June 19th, 1903, on the scale of 30 miles to the inch.

## Discussion.

The President observed that the Author's first paper read before the Society discussed the movements of scree-material. Subsequently the Society had welcomed several papers on earthquakes from his pen ; and it was interesting to find that these very different subjects were both dealt with in the present paper. The Aber-Dinlle Fault, so far as he recollected, brought rocks of very different degrees of hardness into apposition along some parts of its course.




ÆRNARVON EARTHQUAKE OF JUNE 19TH, 1903.




MAP OF THE AREA AFFECTED BY THE PRINCIPAL CAERNARVON EARTHQUAKE OF JUNE 19TH, 1903.

## 18. Eocene *and* Later Formations surrounding the Dardanelles.

By Lieut.-Col. Thomas English, late R.E., F.G.S. (Read February 24th, 1904.)

[Plates XXI–XXIII.]

Contents.



### I. Pre-Eocene Formations.

A description of the Tertiary and post-Tertiary deposits surrounding the Dardanelles can hardly be made clear without some reference to the older rocks upon which they rest, but our knowledge of the conditions under which the pre-Eocene strata in Thrace and Anatolia were deposited and broken up is as yet very limited.

The pre-Eocene sedimentary formations are, as a rule, so highly metamorphosed that no fossils are visible; and they are so much dislocated that the general appearance is that of an archipelago of old rocks in the Eocene Sea. A succession of mica- and hornblende-schists, crystalline limestones, and marble, with occasional gneiss or granite and serpentine, upon which the Tertiary deposits rest unconformably, can be traced from Olympus and Athos, along the Thracian coast, including the island of Thasos, into the Sea of Marmora. The Eocene shore-lines and fringing coral-reefs can be identified in some instances, but an inspection of the map (Pl. XXI) will show the probable islands of the pre-Eocene archipelago more clearly than any description. I shall, therefore, only refer to a few localities hitherto unnoticed, or where some correction to previous accounts appears to be necessary.

At Tenedos Island I found the south-eastern face for about 2 miles in length, from Cape Marmora to Oinos Point, to be formed of white marble.

Along the southern shore of the Sea of Marmora, a stretch of about 35 miles, from Boz Burnu to Kara Burnu, and thence halfway up the Gulf of Artaki, shows, from west to east, granite, schist, diorite, marble, and granite.

At Pasha Liman Island, 13 miles east of Kara Burnu, the lowest rock visible at the south-western point is marble, and there is an exposure of schists for a mile in length along the western shore, with a steep northerly dip. Spratt (1,[1] p. 218) terms this island 'volcanic,' but near the sea-level I could find no trace of volcanic action.

The neighbouring islands of Kutali and Afizia show schists, granite, and syenite.

In the adjacent Artaki Peninsula marble appears near the sea-level, covered by epidote-hornblende-schists, and diorite with hornblende, with a steep northerly dip at the north-western extremity, Palios Point. At Murad Bair (near Artaki town), on the south side of the peninsula, schists and marbles are exposed with a varying dip.

Marmora Island, separated from the Artaki Peninsula by a channel 5 miles wide and 30 fathoms deep, is similarly formed of alternating marble, schist, syenite, and marble, dipping steeply northwestward.

The Devonian rocks of the Bosphorus, 120 nautical miles east-north-east from the Dardanelles, have long been known. Their south-western limit is usually, following F. von Hochstetter, stated to be the Golden Horn, and Stambul is supposed to be built on Miocene deposits (2, p. 373); but there is an outcrop, in the railway-cutting at Old Seraglio Point, of steeply-inclined brown schistose rocks, which are, to all appearance, older than Miocene, and may probably be Devonian: they dip about 60° southward.

The southernmost visible extension of Devonian rocks is at the Deserters' Islands, off Tuzla Burnu.

For the reasons already assigned, I do not propose to enter into any discussion of pre-Eocene foldings, and I have selected the Eocene deposits as the starting-point of a more detailed description of the tectonic phenomena, because they can be traced throughout the whole district, and are perhaps more readily to be identified than any other of the formations which are exposed therein.

## II. Eocene (Lutetian).

The Eocene deposits surrounding the older rocks begin with sandstones, conglomerates, and clays, which become calcareous and nummulitic upwards, and then change again to unfossiliferous sandstones and shales, with subordinate lacustrine beds. These strata are much disturbed and faulted, and are often vertical.

I have seen a section between Yenikeui and Sarkeui, on the northern shore of the Sea of Marmora, in which hard coralline limestone, highly metamorphosed, lies conformably upon bands of rough conglomerate, containing pebbles of old rocks, and sandstones. These, again, overlie purple and grey clays, the whole dipping 70° north-westward. Similar sections exist west of Demotika and at Bektashli in Thrace (3, pp. 344, 351); also at Kara Deré on the southern shore of the Sea of Marmora (4, p. 18).

[1] Numerals in parentheses throughout this paper refer to the Bibliographical List on p. 274.

In other places, however, Nummulitic Limestones lie directly upon the older rocks without the intervention of any sandstones, conglomerates, or clay. Prof. R. Hœrnes says that in Samothrake they rest immediately upon old clay-slates (5, p. 9); and F. von Hochstetter remarks that at Sarai, Wisa, and Kirk-kilissé in the north, they lie directly upon the gneiss, also that there is most clearly a similar sequence in the Tundscha defile (2, pp. 383, 390, 392).

Viquesnel gives a section at Balouk-keui, near Feredjik in Thrace, of red and green clays, with bones, and of greenish sandstone resting unconformably on 'terrains de transition'; then sandy limestones with freshwater shells, *Viquesnelia lenticularis* and *Paludina*; and at the top, calcareous, possibly Nummulitic sandstone (grès calcarifère à nummulites?), with *Nerinæa*, *Pecten*, large *Turritella*, and club-like corals (3, p. 331). A. d'Archiac, in his identification of the bones from this section as those of a *Rhinoceros* of indeterminate species, classifies them as belonging to the Middle or Upper Tertiary fauna, but is evidently at a loss to explain the occurrence of Nummulitic deposits above them (3, p. 470). I examined the beds at Balouk-keui, but unfortunately without knowledge (at the time) of Viquesnel's description, so that I cannot be sure whether it was the same exposure which I saw; the upper beds appeared to me to be distinctly Miocene, and they certainly include naphtha-sands.

F. von Hochstetter, relying principally upon Viquesnel's description of this section, has concluded that there is a lower division of the Eocene in this region, with a partly-lacustrine facies, under the purely-marine Nummulitic Limestone-Series. He goes on to say that he can scarcely find another place for the coal-seams known in Thrace, at the time at which he wrote, than this lower lacustrine division of the Eocene (2, p. 450). This, in my opinion, is certainly erroneous, and the mistake probably arose from his classification of the Oligocene strata, in which the coals really occur, as Primary rocks (phyllit).

There is a section, found by Mr. White (the engineer to the Keshan Collieries), running north and south along the Gorgona Valley near Sarkeui, on the northern shore of the Sea of Marmora, in which the outcropping edges of vertical and steeply-inclined Nummulitic strata are exposed for more than half a mile, nearly at right angles to the strike. The section continues southward for about the same distance across the edges of the lacustrine sandstones, clays, and shales, which are interbedded with the upper portion of, and then overlie, the Nummulitic Series. The measured details of this exposure are given in Table II (p. 273), but the conditions of the ground leave it uncertain whether the section represents only the actual thickness of the Nummulitic Series, or whether the beds are repeated by folding or faulting. If, as I believe, they are not so repeated, the Nummulitic Series here cannot be less than 2000 feet thick.

Nummulitic deposits have been found in Samothrake (5, p. 9), along the whole length of the Eocene coast-line in Thrace (3, *passim*), at Vernitza, and at Teke, near Keshan (on the north side of the Gulf of Xeros), and from Bournar Oren to Mount Elias, along the northern shore of the Sea of Marmora. They appear also on the southern shore of that sea at Kara Deré, west of Gueredjé, and nearly opposite to Gallipoli (4, p. 18), and at Korou, south of Lampsaki.[1] The foraminifera and other fossils collected from the Nummulitic (Lutetian) Limestones of Vernitza and Mount Elias are described in Appendices II & III (pp. 288, 292).

Coralline limestones, generally harder than the Nummulitic deposits, are frequently interstratified with them, as at Vernitza; and also occur separately at Saraiyik, about 4 miles east of Chanak in the Dardanelles, and at numerous localities in Thrace.

Prof. L. de Launay (6, p. 244 & map), following Tchihatcheff (7, vol. iii, pp. 172 *et seqq.*), but with some reserve, shows in his geological map, as unfossiliferous Eocene, a great belt of country some 50 miles wide, bounded on the north by the Marmora shore from the Gulf of Artaki to Guemlek, and sweeping round to the south-west until it meets the sea, from Adramyti nearly to Smyrna.

### III. Uppermost Eocene and Oligocene.

Immediately overlying the Nummulitic rocks is a succession, about 3000 feet thick, of lacustrine sandstones, clays, and shales, interstratified with volcanic rocks and containing coal-seams. These strata represent the uppermost Eocene and the Oligocene, and the coal-seams belong to the latter formation. They are widespread in Southern Thrace, and are cut off to the eastward by the falling-in of the Marmora sea-bed. They extend along the Gallipoli Peninsula to the islands of Imbros and Lemnos, and possibly farther southward to Psara and Eubœa.

In the paper which I had the honour of reading before this Society in December 1901 (9, pp. 153–55), I described the coal-basin near Keshan, the only one the limits of which had then been partly traced. Since that time, the existence of the same principal seam has been proved at a number of points, notably at Masatly and Harmanly, about 17 miles north of Keshan. The Keshan coal-basin has also been traced eastward for about 12 miles to a point south of Malgara, and there is every reason to believe that it extends yet farther eastward in the direction of Rodosto, and westward across the Maritza River.

The evidence of its age is as follows:—A lower jaw and teeth, included in the coal itself, and now at the British Museum, were discovered at Masatly, and have been identified as *Anthracotherium*, nearly related to *A. minus*.

There are innumerable impressions of leaves distributed through the sandstones and clays, yet in only one case have they been found in a recognizable condition. Prof. Toula, in 1895, found plant-

[1] Communication to the Author from Mr. F. Calvert.

remains on the southern shore of the Sea of Marmora, between Lampsaki and Gueredjé (4, pp. 19–20), which were pronounced by Dr. Fritz Kerner von Marilaun to be ferns, agreeing well with *Chrysodium (Fortisia) Lanzæanum* from Monte Promina, and from the Lower Bagshot of Studland, the Middle Bagshot of Bournemouth, and the Upper Eocene of Hordwell; also nearly identical with Oligocene forms from the gypsum of Aix and from the Aquitanian of Manosque (8, p. 26 & pls. i–ii). He moreover identified *Sterculia Labrusca*, fan-palm, oak, and laurel-leaves, and considered the beds to be not older than Middle Eocene, but not younger than Oligocene. These plant-remains occur between Kara Deré and Boz Burnu, in two marl-beds, in a series of sandstones with layers of conglomerate and slaty marl, dipping 45° north-north-westward.

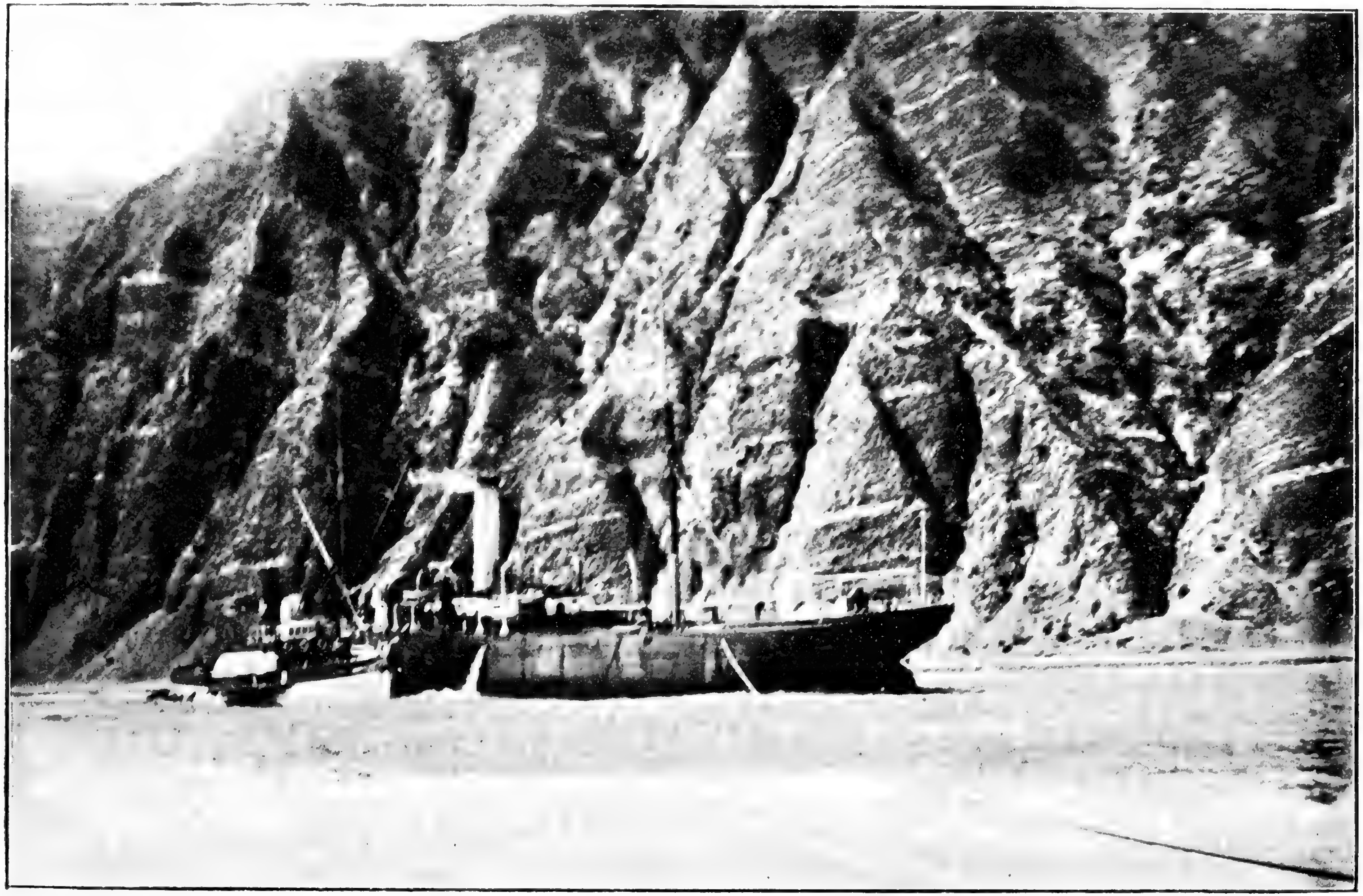
At Keshan, about 40 feet above the coal, and immediately under the band of brecciated andesite which covers it, there is a thin fossiliferous seam in the sandstones, traceable for about a mile and a half, containing abundant casts of *Corbicula (Cyrena) semistriata* and *Melanopsis* aff. *M. fusiformis*, accompanied by indeterminable plant-impressions. At Lalakeui, 8 miles north of Keshan, the sandstones contain leaf-impressions and *Corbicula semistriata*, which has also been found in the coal at Masatly. Samples of soft shelly limestone, found at Harmanly, 3 miles east of Masatly, contain *Corbicula semistriata* and *Melanopsis*, with small fragments of lignite.

Three miles inland from Hora, on the northern shore of the Sea of Marmora, a boring, started in the naphtha-bearing Miocene deposits at 400 feet above sea-level, struck the fault which cuts off the Lower Tertiary sandstones here (9, p. 152), at about 270 feet from the surface. The boring was continued in hard sandstones and shales, with a very steep dip, to a depth of 1149 feet, and specimens of (probably) *Corbicula semistriata* were brought up from between 1043 and 1066 feet.

Mr. White has measured a section through the Keshan sandstones, of which the details are set forth in Table III (p. 274), with the result that there are at least 1230 feet of blue shales and sandstones above the coal, and 1350 feet of brown and grey sandstones (with occasional shales) below the coal, before any Nummulitic rocks appear. This section agrees very fairly with the upward continuation of the section at Gorgona Deré and Sarkeui, distant 25 miles south-east by east (see Table II, p. 273), where, for a horizontal distance of 3600 feet to the southward of the highest Nummulitic stratum yet recognized, there are vertical and steeply-inclined brown sandstones and shales, overlain by green sandstones and clays, containing seams of lignite and leaf-impressions.

On the northern shore of the Sea of Marmora, with possible exceptions in small outcrops between Buyuk Tchekmedjé and Silivri, these lacustrine sandstones and clays only reach the sea between Ganos and Combos, where they form the high coast-cliffs of the Tekfur Dagh, and have been cut off to the eastward by the fault

Fig. 1. *Coast-cliffs of the Tekfur Dagh, northern shore of the Sea of Marmora.* (*See pp. 247, 249.*)



bordering the falling-in of the Marmora sea-bed. The general appearance of the strata is shown in fig. 1 (p. 248), reproduced from a photograph taken at a point near to which the soundings show an average gradient of 1 in 3 from the foot of the cliffs down to a depth of 580 fathoms.

On the south of the Sea of Marmora, coal-seams, clays, and shales interstratified with andesite, occur near Tchatal Tepé, south of Kamir. The principal seam consists of bright, bituminous coal, similar in quality to that found at Keshan, 18 inches thick, with a clay-floor and roof.

Since writing my previous paper, I have had an opportunity of tracing these lacustrine deposits westward from the neighbourhood of Examil, on the isthmus between the Gulf of Xeros and the Sea of Marmora, where they are overlain by Miocene strata. They appear again between Bulair and Yeni-keui, on the northern coast of the Gallipoli Peninsula, and form the whole of this coast as far as Cape Suvla, a distance of 25 miles, considerably disturbed in places, and with a generally-steep south-south-easterly dip. The coast-cliffs are apparently cut off all the way by a fault with a north-north-westerly downthrow, and plunge immediately into the deep water of the Gulf of Xeros. These strata form the backbone of the Gallipoli Peninsula, and the harder rocks rise in places to an altitude of 1300 feet. South-eastward they are overlain unconformably by the generally-horizontal Miocene sands and clays which enclose the Dardanelles, the line of demarcation following approximately the centre-line of the peninsula. Seams of coal occur at several places in the sandstones, between Buyuk and Kutchuk Hanafart, at Taifur-keui and Kavakly.

Similar sandstones, also with thin seams of coal, reappear in the north-eastern quarter of Imbros, which is separated from Cape Suvla by a channel 13 miles wide and 50 fathoms deep. They continue to show along its northern coast, until they are hidden by the volcanic rocks which make up the main bulk of the island. The sandstones, with subordinate shales and clays, come into contact with andesite about a mile south of the village of Panagia, where they dip 30° eastward. A thin lignite-parting shows in the sandstones about half a mile south of Panagia. At a mile and a half north-east of the village, some small excavations have been made, in order to ascertain the development of a coal-seam about 6 inches thick, which crops out here between clay-beds. There are some old coal-workings about 4 miles north-east of this locality, and coal is said to crop out some miles to the west. The sandstones are indistinguishable from those of Keshan, and the appearance of the coals is also very similar.

In Lemnos, according to Prof. L. de Launay's description, the sedimentary rocks are composed exclusively of sandstones, grauwackés, conglomerates, and shales, without limestones, and occupy more than two-thirds of the island, often showing traces of metamorphism. These deposits are generally dark in colour, from brown to green, and of very compact, fine-grained texture, with no traces of organic life except indistinguishable plant-remains, generally with very steep dips, and occasionally with reversed beds (6, p. 201). This description might be applied, word for word, to the bulk of the coal-bearing strata on the mainland and in Imbros.

Prof. de Launay supposes that the Lemnos rocks represent a sort of 'flysch,' either supra-Cretaceous or Eocene, and that the solution of the question of their age may be furnished by an examination of Imbros (6, p. 208). He evidently inclines to a supra-Cretaceous date (6, p. 198), but perhaps the Eocene or Oligocene alternative would have had more weight with him, had he been in possession of the information from Imbros and the Gallipoli Peninsula which I have had the opportunity of obtaining.

Prof. Hœrnes describes, in Samothrake, above black Nummulitic and echinoidal limestones, a series of alternate layers of sand, sandstone, and conglomerate, between which more or less thick strata of greenish-blue and red to blackish-brown volcanic tuffs are intercalated. This series includes a great part of the island, and is surmounted by trachytes (5, p. 9).

From the abundance of *Corbicula semistriata* it is certain that the coal-seams in the Dardanelles district are Oligocene. All the available evidence points to the conclusion that the strata of Lemnos, north-eastern Imbros, the southern shore of the Gulf of Xeros, the Kuru Dagh and Tekfur Dagh in Thrace, a great part of Samothrake, and the beds described by Prof. Toula at Gueredjé and by myself at Tchatal Tepé (on the south side of the Sea of Marmora), belong to the same lacustrine formation above the Nummulitic (Lutetian) Limestones. As in the Carpathian Sandstones in Western Rumania, this formation appears to represent both the uppermost Eocene and the Oligocene (10, p. 79).

Farther south in the Archipelago, the evidence is more conflicting, but, according to Prof. de Lapparent, the flora of the basin of Kumi, in Eubœa, belongs to the Aquitanian division of the Oligocene (11, p. 1509). In the island of Skyro, and in Chelidromia, one of the Magnesian group, Prof. Philippson notices lignite-deposits, which he considers to be equivalent to those of Kumi. He also remarks black and yellowish clay-slates, sandstones, and limestones above the Cretaceous, in the islands of Skiatho, Skopelo, and Chelidromia (12, pp. 117, 127, 130, 136). The eastern coast of Psara, 35 miles south-south-west from the western point of Mitylene, consists of a series of dark-blue and grey shales, interstratified with occasional beds of yellow and reddish sandstones, all showing a general dip of 30° to 40° south-eastward. These beds apparently extend nearly, if not quite, to the highest point of the island. I could see no appearance of volcanic rocks from the sea.

## IV. Lower Tertiary Foldings.

Throughout the whole district surrounding the Dardanelles, the general folding of the Lower Tertiary strata, both Nummulitic and lacustrine, is very plainly developed, and follows a north-east-by-easterly direction through the Eocene channel between the old rocks of Thrace and those of the Troad. The central fold can be traced, in nearly a straight line north 60° east, for 200 miles from the islands of Skiatho and Skopelo in the Magnesian group, through Lemnos, Imbros, and the north-western coast of the Gallipoli Peninsula, until abreast of Ibridji, in the Gulf of Xeros. This direction of folding of the Lower Tertiary strata accords with that shown by Prof. Philippson (14, map) for the 'flysch' of Thessaly, which is described by Hilber as Oligocene and as containing coal-seams (13, p. 621).

F. von Hochstetter considered that the higher ridges of the Gallipoli Peninsula consist probably of clay-slate (phyllit), and that the Nummulitic Limestone in Thrace lies generally horizontal, showing only local disturbances (2, pp. 389, 409). These conclusions are not borne out by the facts which I have observed: the Nummulitic and Oligocene rocks are dislocated and folded on a large scale, and form basins in which the Helvetian and later deposits were laid down.

The Lower Tertiary lake had a coast-line in Thrace little differing from that of the Nummulitic sea, but probably transgressing somewhat more in places over the older rocks; as, for example, in the south-eastern part of Samothrake, where the sandstones and volcanic tuffs lie directly upon old clay-slates (5, p. 11). Its waters reached certainly to Lemnos in the west, and to Rodosto in the east, possibly even farther eastward, as Viquesnel mentions sandstones with carbonized plant-impressions from Buyuk Tchekmedjé to Silivri, on the northern shore of the Sea of Marmora (3, p. 310).

A reference to Pls. XXI & XXII will show that the strikes and dips of the Lower Tertiary strata surrounding the Dardanelles result from three main foldings, of which the northernmost intersects the island of Samothrake, where the Nummulitic strata dip north-westward and westward in the western portion of the island, and eastward in the south-eastern corner. This fold forms the eastern portion of the northern boundary of the North Ægean depression; thence, passing inland, it shows in the anticlinal ridge of the Kuru Dagh. It is continued, through the Tekfur-Dagh ridge, nearly to Rodosto, and thence eastward forms the northern boundary of the Marmora depression. Fig. 2 (p. 252) shows the appearance of the vertical Oligocene strata at Combos near Rodosto, with the horizontal Miocene terraces overlying them unconformably.

The folding which follows the southern shore-line of the Eocene channel between Thrace and the Troad enters the district in a nearly north-and-south line at Mitylene (16, p. 428), passes through the Troad in a north-north-easterly direction, curving north-eastward, and skirts the old rocks at Gueredjé, where the Lower Tertiary lacustrine deposits dip 45° north-north-westward. From this place it runs as a fault with a north-north-westerly downthrow along the southern shore of the Sea of Marmora, past

Kara Burnu, skirts Marmora Island, and, turning eastward, forms the southern border of the Marmora depression.

Along the central fold the beds dip north-north-westward at Skopelo Island (12, p. 130): in Lemnos they dip north-north-westward towards the North Ægean depression, and south-south-eastward towards Mitylene; in north-eastern Imbros they dip eastward; and along the coast of the Gallipoli Peninsula, from Cape Suvla to opposite Gallipoli, they dip south-south-eastward. A much later development of this fold (Pl. XXII, fig. 2) has given

Fig. 2.—*Vertical Oligocene strata at Combos, unconformably overlain by horizontal Miocene terraces.* (*See p. 251.*)

rise to the ridge of Dohan Aslan and Serian Tepé, and has dislocated the Sarmatic Beds to the eastward as far as Ganos, by a fault with a south-easterly downthrow.

There is not, as yet, sufficient information available to determine the positions of the subsidiary foldings dependent on the changes of direction of the main folds, but there are indications of one running about north 30° west through the islands of Tenedos, Imbros, and Samothrake, and of another in a nearly due northerly direction through Ibridji, passing west of Keshan.

## V. Tertiary Volcanic Rocks.

The volcanic eruptions in this district were prolonged, apparently without much interruption, from Cretaceous times into the Miocene Period, but a more detailed study than has yet been made will be required to determine the periods of action of the respective volcanic foci. In Imbros, however, a date later than Oligocene and earlier than Sarmatic can be assigned to the andesite-flows in the south-eastern portion of the island.

At Keshan, the interstratification of Lower Tertiary sandstones with andesite is distinctly visible. A section on the south side of the Keshan ridge, which rises about 1000 feet from the plain, shows, from below upward: shale and sandstone, about 40 feet of andesite, 300 feet of sandstone, 30 feet of volcanic rock (probably andesite), 200 feet of sandstone, and a coping of volcanic rock. This section is exposed in a small ravine at Tekekeui, where there are unaltered sandstones overlying the andesite, and within 2 feet of the solid rock; while under the andesite, similar sandstones and fine shales are equally unaltered, even close to the contact-surface. The andesites and sandstones have the normal dip of the surrounding strata, that is, about 10° north-north-eastward.

In Lemnos, Prof. L. de Launay has observed quartz-andesites, dacites, trachyandesites, and augitic andesites; he considers them to be perhaps Miocene, certainly later than the sandstones which they have dislocated and intersected (6. pp. 209, 219).

At Hagio-Strati Island, 20 miles south-south-west of Lemnos, I found nothing but hornblende-andesite at the sea-level. This island is about 1000 feet high, rugged and trackless: it seemed to me to be a uniform mass of volcanic rock, without any appearance of Tertiary sedimentaries (see Appendix I, p. 277).

On Imbros I found that the whole south-eastern face of the island, exclusive of the promontory of Megalai Kephalai, which is virtually separated from it by a salt-lagoon enclosed by sand-ridges, consists of grey and dark-red andesite, weathering into rounded lumps, and forming a red soil between them. Following the valley of Melano Potamo north-westward to the watershed, I found an exposure of biotite-augite-andesite, differing considerably in external appearance from the surrounding rocks, and splitting into rectangular vertical prisms which resist weathering; its petrological character is also peculiar (see Appendix I, p. 277). The track passes for 3 or 4 miles over andesite, with occasional obsidian-dykes, and well-defined flows of what must have been semi-fluid material, which have curled over and now form large caves. At the watershed, the track skirts a breccia with a matrix of hardened volcanic mud. Fragments of porcellanite are abundant, but the main mass, on both sides of the watershed, is andesite, shown in fig. 3 (p. 254). The higher hills to the south-west are apparently volcanic, and include several isolated domes.

At the head of the Gulf of Xeros are several small outcrops of volcanic rock, generally hornblende-andesite, on the synclinal fold of the lacustrine sandstone-strata, and in one of these, at Xero Mikro Island, I found schists lying horizontally under volcanic rock.

At Enos there is a large volcanic mass, forming a detached boss about 1300 feet high, and roughly 6 miles in diameter: Viquesnel describes it as formed of trachyte and domite (3, p. 326); and he characterizes the volcanic rocks in the Maritza and Arda Valleys generally as trachytes and tuffs.

There are numerous volcanic outcrops in the near neighbourhood of Keshan, including brecciated rhyolite and andesite, olivine-basalt, hornblende- and biotite-andesite (see Appendix I, p. 277).

A small outcrop of basalt is exposed 3 miles north of Rodosto, and another about 12 miles north-east of this (3, p. 312); a detailed survey of the country would no doubt reveal many similar exposures.

In Asia Minor are very many outcrops, sporadic and in belts, in the country east of the Troad, which Tchihatcheff generally classes as trachyte and basalt (7, *passim*).

Fig. 3.—*The andesitic hills of Imbros, with a distant view of Megalai Kephalai (Sarmatic). (See pp. 254, 259.)*

South of Kamir, on the southern shore of the Sea of Marmora, decomposed andesite or rhyolite and volcanic mudstone appear at Arsali, silicified andesitic or rhyolitic tuffs at Pekmeslu, and hornblende-andesites at Tchatal Tepé, interstratified with Oligocene rocks.

In the Southern Troad, Mr Diller has given particulars of liparites, mica- and hornblende-andesites, augite-andesite, and basalt, and considers that the eruptions have continued from Eocene to Pliocene times. He also notices a well-marked eruptive centre at Assos (Behram Keui), not older than Middle Tertiary (17, Prelim. Report, p. 179).

In Mitylene, Prof. de Launay reports a more varied series than at Lemnos, and considers that the following is the most probable order of succession:—felspathic trachyte, rhyolitic trachyte, dacite, trachyandesite, hornblende- and augite-andesite, labradorite, and basalt (6, pp. 184–85).

In Tenedos, Spratt describes the north-eastern point of the island as 'trachyte' (1, p. 214). I found that there is also an exposure of volcanic rock along more than half of the eastern coast, extending farther south than Tar Point.

In the valleys of the Scamander (Men Deré) and of the Thymbrius (Kemer Deré), Mr. Calvert found basalts between Bali Dagh and Akché Keui, in the form of coulées flowing from the crystalline marble and serpentine-hills, and covering and indurating the débris at their feet. At the White Cliffs, below Chanak in the Dardanelles, he also found the red clays and calcareous beds much disturbed and altered by an outburst of volcanic rock.[1] A specimen of this rock has been identified as an unusual variety of biotite-andesite (see Appendix I, p. 276).

The Tertiary volcanic rocks show a marked tendency to appear along the coasts of the Eocene Sea, and in long belts following the strikes of the foldings of the Lower Tertiary strata.

The widespread late Eocene and Oligocene volcanic rocks would certainly seem to imply considerable differences in the relief of the land, at the time at which they were ejected; and it is difficult to reconcile this with the equally widespread coal-seams, presumably requiring shallow lakes or marshy country with only slight differences of level.

## VI. Miocene.

I propose to demonstrate the existence of Helvetian-Tortonian deposits, probably vestiges of a Lower Miocene sea-connection between the Ponto-Caspian and the Mediterranean. These are overlain by fresh-water Sarmatic strata with lignites and naphtha, succeeded by marine (*Mactra*-) limestones, which occupy nearly the whole of the northern shore of the Sea of Marmora, to the exclusion of the Levantine Beds, suggested by F. von Hochstetter (2, map) as filling up this area. These *Mactra*-limestones are in direct continuation of those already known in the Southern Troad and in the Dardanelles. There is also evidence of the occurrence of Sarmatic strata in Imbros and in Tenedos.

At Eregli, on the northern shore of the Gulf of Xeros, and thence several miles inland to Fakirma, occurs an exposure of sands and sandy limestones, with a slight southerly dip. These beds, close to the present sea-level at Eregli, contain typical Helvetian-Tortonian fossils—*Pecten aduncus*, *Alectryonia Virleti*, and *Anadara diluvii*, also *Ostrea lamellosa*, of which specimens are now in the British Museum (Natural History): see Appendix II, p. 285. Prof. Suess says that, from a large number of measurements, he has arrived at the conclusion that the shore-line at this epoch was 440 to 450 metres above the existing level of the sea (15, pp. 412–13); and the Eregli beds probably owe their preservation to the fact of

[1] Communication to the Author.

their having been deposited at a point where a further development of synclinal folding subsequently took place.

Near Myriophyto, on the northern shore of the Sea of Marmora, a band, full of *Ostrea crassissima* (Appendix II, p. 285), occurs under soft yellow sand, dipping about 45° south-south-eastward, at a height of 700 feet above the sea. Below the oyster-band are soft shales, resting upon quartz-conglomerate. The whole of this series has been thrown down by the fault which extends from Mount Elias to Ganos, and abuts on the nearly-vertical Lower Tertiary shales and sandstones (9, p. 152).

Strata of similar age have been found to the north at Varna and at Cape Tchokrak in the Kertch Peninsula (18, p. 190, and 24, Table of Beds below the Sarmatic, p. 7), and to the south at Savakly in the Troad (Fischer, 7, pp. 259 *et seqq.*); and at Kasos Island (19, map), and in Thessaly and Macedonia (16, p. 431).

The Eregli and Myriophyto Lower Miocene marine shell-beds thus form links in a chain of deposits of the same age, extending from the Crimea to the Mediterranean, and the most obvious explanation is that they are detached fragments of what was a continuous sea-bed.

Between the deposition of these beds and that of the lacustrine and marine Sarmatic strata which succeeded them, the folding must have developed considerably, perhaps to the extent shown in fig. 1, Pl. XXII, which indicates the main anticlines of the Eocene and Oligocene Series, and a possible coast-line of the Sarmatic and Pontian basins.

The connection with the Sarmatic sea probably developed from the outflow of a lake, with a narrow opening to the north-east between the Eocene deposits near Derkos on the Black-Sea coast (see Pl. XXI). From here the shore-line swept round the southern portion of the Sea of Marmora, skirting Marmora Island, and the serpentines and schists, volcanic and Eocene strata in the Troad, against which Mr. Calvert has noticed the Sarmatic strata to thin out at Dumbrek in the Kemer Deré, and at Belenkeui.[1]

A deep gulf, directed north-east and south-west, included the Dardanelles and part of Tenedos, and terminated near Mitylene. Its north-western shore skirted the south-east of Imbros and the Oligocene lacustrine sandstones of the Thracian Chersonese, which then formed a long peninsula in the opposite direction to the present one, terminating between Yenikeui and Bulair, where the Sarmatic Beds cross the present isthmus between this point and the Oligocene sandstones near Examil, in what was a channel about 8 miles wide. The waterway was subsequently blocked by the elevation, due to further folding, of the Dohan-Aslan ridge, which is thrown up diagonally across it, and has tilted the bituminous Sarmatic Beds on its southern slope, where they can be seen dipping 50° south-eastward.

This channel formed a connection with an internal Sarmatic

[1] Communication to the Author.

basin, traces of which can be found stretching across the Chalkidike Peninsula to Kassandra (20).

As, however, nearly the whole possible area of this basin is now covered by water, its limits cannot be defined farther than that it did not extend beyond the northern coasts of Lemnos and Athos, and the southern coasts of Thasos and Samothrake. The last-mentioned island was probably then connected with the mainland, as it stands on a broad bank of soundings, on which the depths do not exceed 30 fathoms.

Eastward of this, the Oligocene rocks of the Kuru Dagh and the Tekfur Dagh formed a large tract of land, into which a Sarmatic gulf extended for some miles beyond the head of the present Gulf of Xeros. The ridge of Serian Tepé, though not so markedly developed as now, formed the southern shore of this gulf, and stretched to the south-westward as a narrow peninsula in the same line as the Thracian Chersonese. It terminated in a point near Examil, which formed the eastern limit of the channel leading into the interior basin.

From this point the coast-line of the Sarmatic land stretched nearly in a straight line for about 32 miles north-east by east to Ganos. The Sarmatic Beds now disappear under the sea-level at Ganos, apparently cut off by the fault which bounds the deep Marmora depression terminating at that place. They appear again about 12 miles north-eastward at Combos, and from here the coast-line, of steeply-dipping Oligocene rocks (fig. 2, p. 252), turned westward, past Malgara and Keshan to Enos. From Balouk-keui, near Feredjik, the coast, principally of volcanic and Eocene rocks, followed the right bank of the Maritza upward nearly to Adrianople, where another interior basin in all likelihood commenced, as A. d'Archiac indicates Sarmatic fossils, *Mactra podolica*, etc., at Gheuldjik and at Nebilkeui,[1] in the Arda basin (3, pp. 473, 477). From Adrianople eastward to Derkos, the northern portion of the Sarmatic basin had a coast-line very little different from that of the Eocene sea, since, according to Viquesnel (3, Atlas), the old rocks to the northward are separated from the Miocene deposits by a continuous narrow belt of Eocene strata.

In the outer basin Sarmatic fossils have been obtained as follows:—

At San Stefano I found *Melanopsis costata* and fragments of *Unio*, in a thin seam close to the sea-level, under the *Mactra*-limestone, which latter extends 7 miles farther east, to Constantinople.

Along nearly the whole distance from Ganos to Examil the Sarmatic freshwater beds, conglomerates, sands, and clays, with lignite and petroleum, which underlie the *Mactra*-limestone, can be traced as a belt from 2 to 4 miles broad, very much dislocated by later disturbances, but generally thinning out against the harder Oligocene sandstones. These freshwater beds, and the marine Sarmatic which overlies them, are well developed in the Dardanelles section, where they have been described by Calvert & Neumayr (29,

[1] F. von Hochstetter (2, p. 376) misquotes Naip-kioi, near Rodosto, for the locality of these fossils.

p. 357), Prof. Hœrnes (21, p. 7), and Prof. Toula (4, p. 8), and contain fossils similar to those which I have found in the districts of Myriophyto and Hora. These include *Melanopsis* aff. *costata, Unio, Anodonta, Bithynia, Limnæa, Neritina, Planorbis* cf. *cornu*, and *Melania* cf. *Escheri*.

At Demotika and Tomletchi (between Tchampkeui and Feredjik), Viquesnel collected several varieties of *Mactra podolica* (3, p. 477). I have found *Cardium protractum* in limestone near the potteries, about a mile north-west of Keshan, and also in thin beds of soft limestone and clays at Ghermé Tepé, halfway along the road from Keshan to Boz Tepé.

Harder limestone-beds, with *Mactra podolica* and *Cardium protractum*, occur about 8 miles north of Keshan, in the area between Beyendik, Lalakeui, Mal Tepé, and Basait. At Yailah, 8 miles east-south-east of this locality, in the direction of Malgara, the same fossils occur. At Malgara itself, *Mactra podolica* is very abundant in a soft grey limestone-bed. Near Sarkeui I have found *Limnocardium* in soft shales at the southern end of the Gorgona Deré. *Mactra podolica* occurs in semicrystalline limestone near Heraklitza, and also in limestone 1 mile south-west of Dohan Aslan.

At Saraijelli, about 4 miles south-east of Chanak, in the Dardanelles, Mr. Calvert has noticed an unconformity in the Miocene formation, the lower strata, close to the Nummulitic rocks, dipping 20° south-westward, while the superposed beds are nearly horizontal.[1]

I do not consider that there is any adequate foundation, on the present evidence, for F. von Hochstetter's determination of his Levantine formation in this neighbourhood. The authority for this is his statement that the uppermost strata, from Stambul to Kutchuk Tchekmedjé, contain numerous casts and impressions of freshwater shells (*Melanopsis, Paludina, Planorbis*, and *Neritina*), and therefore must be acknowledged as freshwater Levantine deposits (2, p. 381 & map). The only fossil-locality quoted in support of this statement is the section in the railway-cutting at Jedikule, near Constantinople, which consists of:—

1 to 2 feet of humus;
4 to 5 feet of yellowish shelly limestone, with numerous casts of *Melanopsis* cf. *inconstans, Neritina Grateloupana (semiplicata), Planorbis cornu, Pl. pseudammonius, Paludina (Bithynia)* sp.;
2-inch clay-parting; 6 inches of white calcareous marl; 4 inches of clay;
1 foot calcareous sandy bed, with countless casts of *Mactra podolica*;
2 feet of white marly limestone, with conchoidal fracture;
3 inches of clay and 1 foot calcareous sandy bed (21, pp. 31–32).

This cutting is now grass-grown, wherefore no fossils are visible; but Prof. Hœrnes examined those obtained by F. von Hochstetter, and came to the conclusion that the *Melanopsis*-casts belonged to *M. trojana* (=*costata*), which he had found in the Sarmatic deposits at Erenkeui, in the Dardanelles, and that the fauna generally from this section appears to bear a great resemblance to that of the lower lacustrine (Erenkeui) beds.

[1] Communication to the Author.

Prof. de Launay remarks, with respect to these Sarmatic and Levantine deposits, that there is so much confusion between successive palæontologists, as to make him think that they have mixed up Pontian formations, like those of Mitylene, with the Sarmatic horizons (6, p. 240). It must be allowed that there is some cause for this opinion, but the recent discovery, or rather re-discovery, for they are mentioned by Strabo (22, § 58), of bituminous and naphtha-bearing beds, tends to confirm the assignment of Sarmatic age to nearly all the strata along the northern shore of the Sea of Marmora, marked as Levantine in F. von Hochstetter's map.

Naphtha has been found in the following localities:—On the north-western slope of the Tekfur Dagh, near Rodosto; on the south-eastern slope of the Tekfur Dagh, along the Marmora shore from Ganos to Sarkeui; and at Balouk-keui, near Feredjik in Thrace, where there is a thickness of about 20 feet of naphtha-sand, dipping 25° south-eastward. A bed of hard limestone-breccia, 3 feet thick, cemented by bitumen and dipping 50° south-eastward, has lately been discovered on the northern shore of the Sea of Marmora, near Dohan Aslan. All the beds of naphtha and bitumen as yet traced in this neighbourhood bear a strong resemblance to those of the Sarmatic petroleum-district of Bustenar and Cosmina, in Rumania, and the harder portions of the sandstones form similar globular concretions, often 3 feet in diameter, in both localities.

The naphtha-sands along the northern shore of the Sea of Marmora are directly overlain by the marine Sarmatic (*Mactra*-) limestones and marls, which stretch as a coastal belt about 2 miles wide and 30 miles long, from Kalamitza on the east, nearly to the Dardanelles, and form a fringing border to the freshwater sands and clays. These beds have a general slight south-easterly dip, and disappear beneath the sea-level between Kalamitza and Myriophyto, while towards the south-west they are overlain near Gallipoli by Upper Pliocene deposits. They reappear in Kalo Nero Bay, forming the upper beds which border the Dardanelles there.

In my previous paper I suggested that the naphtha-bearing beds near Milos were probably Pliocene (9, p. 156); but, since I have found *Mactra*-limestone at Heraklitza overlying similar beds, I see no reason for dissociating the strata at the two localities, as, although the individual beds are too broken up to trace, yet the series as a whole is continuous, and I am therefore now of opinion that the naphtha-bearing strata at Milos and Hora are Sarmatic.

At the south-eastern corner of Imbros, I found that the promontory of Megalai Kephalai consists of a projection about 2 miles long and half a mile wide, averaging 100 feet in height (fig. 4, p. 260), convex to the south-east, and united to the main portion of the island by sand-ridges $1\frac{1}{4}$ miles long, enclosing the large salt-lagoon already mentioned (p. 253). The formation consists of soft horizontal sands, clays, and marls, with a harder sandstone-bed at the summit, and is generally light in colour. I could find no fossils, but the appearance of the beds is identical with that of the

Sarmatic strata of the Gallipoli Peninsula, which they directly face. The width of the channel here is 10 miles, and its greatest depth is 50 fathoms.

These beds have evidently been eroded by recent sea-action over the space now occupied by the lagoon and sand-ridges, in which some small knolls, remnants of a clay-bed just above the sea-level, are still visible. At their junction with the main mass of the island, the Sarmatic strata apparently rest unconformably upon the sloping profile of the volcanic rock, though the actual junction is hidden by a talus of volcanic débris. The lower portion, more especially the above-mentioned clay-bed, contains rounded andesite-pebbles, and the whole appearance is that of a Sarmatic coast-line near the present sea-level. The water-line, however, at the time of the deposition of the highest Sarmatic beds, must have stood

Fig. 4.—*Promontory of Megalai Kephalai, island of Imbros.* *(See p. 259.)*

more than 700 feet above the present shore, as the nearly-horizontal strata on both sides of the Dardanelles are at fully that height where they thin out against the older rocks.

Spratt's collection of fossils from Tenedos, in the Geological Society's Museum, includes unmistakable specimens of *Mactra podolica*, and the Sarmatic waters must have covered the larger part of this island and of the adjacent islets, as well as the western coast of the Troad and the site of Hamaxitos, nearly as far south as Cape Baba (17, p. 630); but, according to Prof. de Launay (6, p. 282), no Sarmatic deposits can be traced in Lemnos or in Mitylene.

Brackish and freshwater Pontian deposits have been described as occurring in Chios (25, p. 350), Mitylene (6, pp. 167 *et seqq.*), the Troad (17, p. 630), the Dardanelles (11, p. 1546), Kassandra (20, p. 323), the northern shore of the Sea of Marmora, and the Ergene valley in Thrace (3, pp. 472, 480). In addition to these localities there are, I believe, some small fragments remaining about a mile south of Keshan, at Karakaya Deré, where the Oligocene sandstones are overlain by a thin series of soft limestones, in which I have found *Prosodacna*, *Dreissensia*, and *Neritina*. At Hafus Hassan Tchiflik, 3 miles west of Keshan, *Prosodacna*, *Anodonta*, *Planorbis*, and *Melania* occur in shelly sand. Near Boz Tepé, 6 miles west of Keshan, *Melanopsis Martiniana* occurs; and near Tekekeui, 3 miles south of Keshan, I have obtained *Lyrcæa Bonelli* from sandy beds overlying the Oligocene sandstones.

At Myriophyto, *Bithynia* and *Melania* were found in soft clay taken out of a shallow well.

## VII. Pliocene.

Prof. Andrussov has come to the conclusion that the Pontus existed as a large, perhaps also deep, brackish lake, enclosed on all sides, from the Pontian until the beginning of the Diluvial Epoch (26, p. 73), and that the Bosphorus is the bottom of a fluvial valley lowered beneath the sea-level (24, xxix, p. 9).

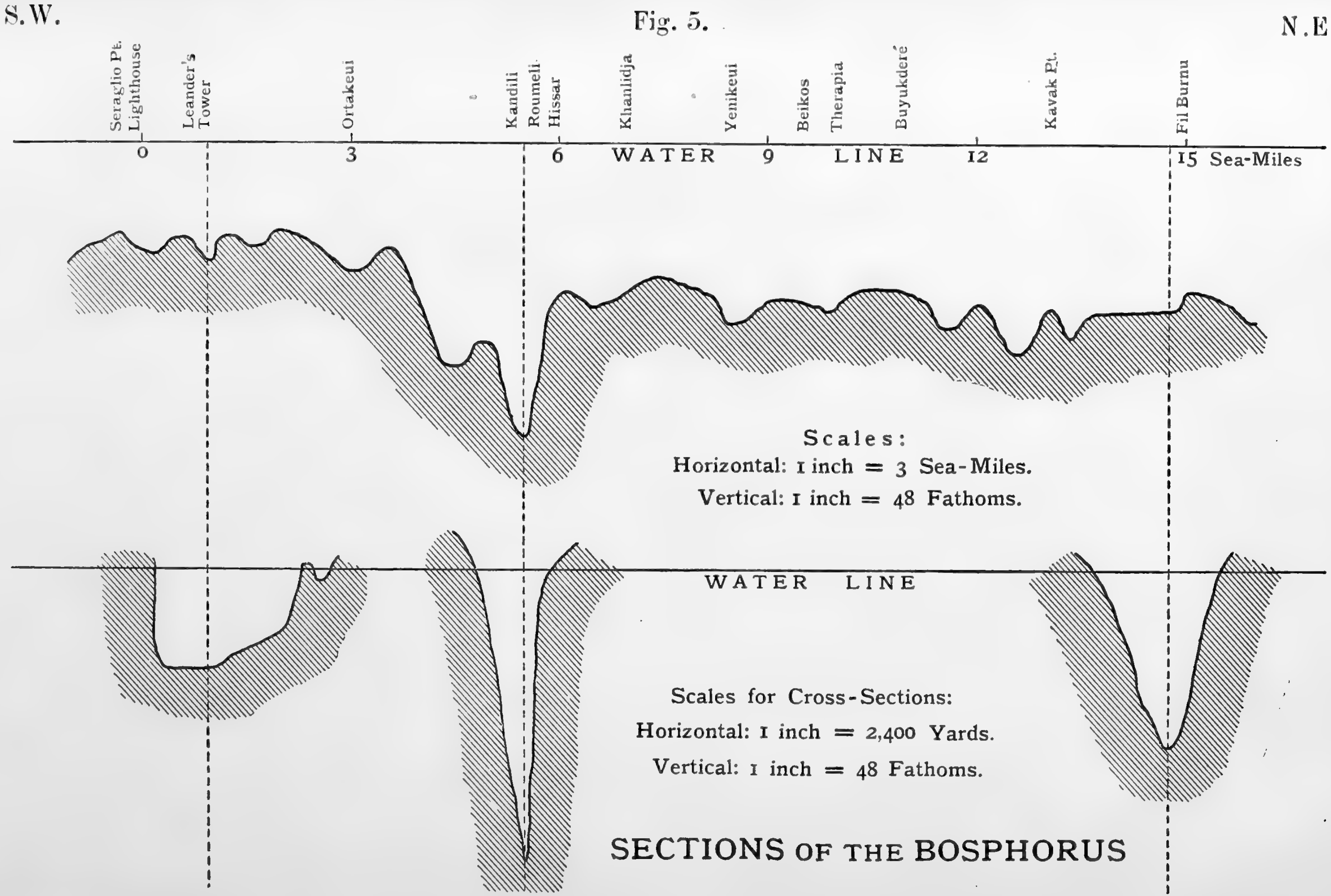
The details of several facts bearing on this question, which I have observed, may now be given to confirm this view; and I would call special attention to the post-Sarmatic eastward extension of the central fold of Tertiary rocks, resulting in the upheaval of the Dohan-Aslan and Serian-Tepé ridge. This upheaval closed the connection between the Marmora basin and the Gulf of Xeros (Pl. XXII, fig. 2) by the formation of a dam which, though much weathered down, is still 180 feet above the present water-level.

This upheaval, moreover, has led to the exposure of some of the older rocks near the axis of folding. Epidote-quartz-rock, calcite or dolomite, and chlorite, with calcareous tuffs and andesite, appear at Dohan Aslan, while a large expanse of foliated and sheared serpentine, with calcite, dolomite, and hornblende-schist extends, in an east-north-easterly direction, from Bournar Oren through Serian Tepé to Yolzdik. That this ridge is post-Sarmatic is proved beyond question by the steep inclination away from it, on either side, with a continuous east-north-easterly strike, of the Tertiary sedimentaries, up to and including the Sarmatic.

The dam thus formed, confining the Marmora water from any outlet to the westward, was the proximate cause of the cutting of the Bosphorus, and of the drainage of the Marmora into the Black Sea, during Pliocene times. Later on, as will be shown, it similarly resulted in the cutting of the Dardanelles and the drainage of the combined Black-Sea and Marmora water into the Mediterranean.

Since no traces of Tertiary deposits have been found as yet along the Bosphorus, to my knowledge, it is useless to speculate as to how or when the valley, which now forms the channel, first took a connected shape in the old rocks. To all appearance it was developed on the recession of the Sarmatic sea, as that of a river running to the north-eastward, and confined within a narrow rocky gorge

Fig. 5.




SECTIONS OF THE BOSPHORUS

between Roumili Hissar and Kandili, where the general water-parting between the present drainage to the Black Sea and that to the Sea of Marmora crosses the channel (23). At Beikos *Ostrea edulis*, of which a specimen is now in the British Museum (Natural History), has been found in grey clay, about 80 feet below the present water-level, and therefore the Devonian rock-bottom of the lateral valley, which joins the Bosphorus at this place, must be lower still. The Buyuk-Deré valley is also partly filled up with brick-earth; and if these and other lateral valleys were cleared of their post-Tertiary accumulations, the Bosphorus channel would take the shape of an ordinary river-valley, with numerous small affluents.

The slope of the longitudinal section along the deepest part of the channel, with the exception of a remarkable hole of 66 fathoms abreast of Kandili, to which I shall refer later, is fairly uniform, the depths increasing from 20 fathoms at the south-western end, between Old Seraglio Point and Leander's Tower, to 36 fathoms at the north-eastern entrance, abreast of Fil Burnu, in a distance of 14 sea-miles (see fig. 5, p. 262).

The existence, already mentioned (p. 244), of strata apparently older than Miocene at Old Seraglio Point, and the occurrence of soundings with rocky bottom outside this point, make it probable that a hard rock-barrier crosses the channel here to the Devonian rocks at Scutari. This bar gives the shallowest water in the whole distance, 167 sea-miles, between the Mediterranean and the Black Sea; it thus fixed a lower limit to the water-level of the Sea of Marmora before the Dardanelles were cut, and now determines the level at which the Black Sea would again become a closed basin.

At the time of the completion of the cutting of the Bosphorus valley, the water in the Ponto-Caspian lake described by Prof. Andrussov must evidently have stood at a level nearly 200 feet lower than at present.

I do not believe that any trustworthy evidence is available, or likely to be obtained, to show whether the formation of the deep depression (660 fathoms) of the Sea of Marmora preceded or followed the cutting of the Bosphorus valley; but the numerous earthquakes, some of the isoseismals of which are evidently in connection with the faults bordering this collapsed area (27, p. 151), render it probable that the falling-in of the Marmora sea-bed is still in progress. In either case, however, the result of the recession of the Sarmatic sea would be to leave one or more lakes draining north-eastward through the Bosphorus river, and the water in these would be freshened and lowered as the Bosphorus valley gradually attained its present general profile at some time during the Pliocene Period.

Then the level of the Ponto-Caspian lake commenced again to rise, so that, in correspondence with this, the Sea of Marmora gradually extended its limits westward to Gallipoli, and the brackish-water bed of Caspian shells, that now forms the conglomerate upon which the town is built, was deposited. The rise of water gradually reached the height indicated by the beach at Hora,

Fig. 6.—*Raised beach, 130 feet above sea-level, at Hora lighthouse, north-western coast of the Sea of Marmora.* *(See pp. 263, 265.)*

Fig. 7.—*Ancient river-channel at Maitos, Dardanelles.* *(See p. 265.)*

130 feet above sea-level, containing *Neritina fluviatilis* (=*danubialis*), *Didacna crassa, Dreissensia polymorpha,* and *Mytilus edulis.* This beach commemorates the last high-water mark of the Ponto-Caspian closed basin, and probably followed a portion of the contour of the Marmora lake at the time when the Gallipoli shell-bank accumulated (fig. 6, p. 264).

The conglomerate-rock, upon which Gallipoli is built, consists in great part of shells of *Didacna crassa, Dreissensia Tschaudæ,* and *Dr. polymorpha.* The deposit is not, in my opinion, a raised beach, and it is about double the height generally stated. It is spread out over at least 2 square miles, with a fairly-uniform surface about 80 feet above the water. At Bas-Chesmé Bay (Gallipoli), the conglomerate is partly replaced by a local bed of sandy loam, in which is a seam, about a foot thick, of the same Caspian shells (*Didacna crassa* and *Dreissensia polymorpha*), evidently in or close to their original location, as many of the shells have both valves connected.

Prof. Andrussov considers the Gallipoli Conglomerate to be the equivalent of the Tschauda Beds at Kertch, containing *Dreissensia polymorpha, Dr. Tschaudæ, Cardium crassum, C. Cazecæ,* and *C. Tschaudæ,* which he shows to be an Upper Pliocene fauna of Caspian type, deposited in an enclosed brackish lake before the Dardanelles were in existence (24, xxx, Table of Beds above the Sarmatic, facing p. 4; and 26).

## VIII. Pleistocene.

According to Prof. Philippson's researches (14, p. 138), the deep depressions in the Ægean district, due to tectonic collapses, began to take shape between the Lower and the Upper Pliocene. I propose to show that the consequent reversal of the drainage of the Dardanelles area resulted in the formation of a river, the watershed of which lay south-west of Gallipoli, and that when this was worn down by subaërial agencies to the level of the dammed-in Pontic water, the following rapid outflow caused the formation of the Dardanelles channel.

The first result of the tectonic changes referred to by Prof. Philippson would be to convert the North Ægean area into a large closed basin, bounded on the south by the chain of the Northern Cyclades, Andros, Tinos, Mykoni, Nikaria, and Samos. The dip of the Sarmatic strata from the Dardanelles south-westward shows that there was considerable relative subsidence in this direction, as the level of the Upper Sarmatic of Imbros is now some 600 feet lower than that of the corresponding beds east of Chanak in the Dardanelles, in a horizontal distance of about 25 miles. The Sarmatic deposits of Tenedos show a similar dip. This settlement, on the verge of the Ægean depression, is further indicated by an ancient river-channel, discovered by Mr. Calvert, which has cut through the neck of land at Maitos (fig. 7, p. 264) opposite Chanak, to within 100 feet of the present water-level.

Fig. 8.—*Cliffs of soft Miocene deposits along the Dardanelles.* (*See p. 267.*)

The river then apparently deserted its course for a more southerly one, included in the present excavation of the Dardanelles below Chanak, and conveyed the drainage both of the Dardanelles and of the Rhodius valleys into the closed basin of the North Ægean. The watershed dividing this new drainage from that which continued to follow the old course through the Sea of Marmora, must have been to the south-west of Gallipoli, as no traces of the Ponto-Caspian lake occur beyond this place, and its position was probably determined by the subsidiary north-to-south fold of the Lower Tertiary strata, which passes through Ibridji (see Pl. XXII, fig. 2).

The branch of this river-valley occupying the Upper Dardanelles would be of less width than the existing waterway, which has an average breadth of about $2\frac{3}{4}$ miles, and therefore no traces of it are now visible above Abydos. When its watershed was worn down to the level (130 feet or less above the present sea) at which the Sea of Marmora stood at that time, the valley would be rapidly widened and deepened into the present section by the outflow of the Ponto-Caspian.

A violent outflow of this description would account for the scooping-out of the remarkable cavity previously mentioned as existing in the bed of the Bosphorus opposite Kandili (p. 263), in which, going southward, the depth increases from 33 to 66 fathoms in half a mile (see fig. 5, p. 262). This is immediately below the Roumili-Hissar gorge, in which the sectional area of the present channel is reduced to about 430,000 square feet, or three-quarters of its normal waterway. The sectional areas of the northern end of the channel abreast of Fil Burnu, and of the southern end, between Old Seraglio Point and Leander's Tower, are each about the same, that is, 560,000 square feet (28, sections).

The high cliffs of soft material, which now bound the Dardanelles and form so remarkable a feature (fig. 8, p. 266), would readily be shaped by the carrying away of the material protecting their bases, without the whole section between them being necessarily occupied by water at any one time.

Prof. Philippson concludes that the North Ægean basins were not occupied by the Mediterranean until Quaternary times; that the lowering of the collapsed regions is still going on; and that, in addition, a general subsidence of the Ægean land has taken place since the beginning of the Quaternary Period (14, pp. 135, 139, 141). It is not possible, therefore, to ascertain what the water-level in this district was when equilibrium took place between the Ponto-Caspian and the Mediterranean, as all traces of this event have been since submerged. So far as the Sea of Marmora is concerned, the profile of the south-western entrance of the Bosphorus shows that its level did not differ materially from the present one.

There have been, as will now be shown, various considerable oscillations of water-level since the opening of the Straits; but, so far as I am aware, there is no evidence to show that they have not been quietly effected, in every case, by a gradual rise or fall of the water.

Fig. 9.—*Mediterranean shell-beach at Hora, 405 feet above sea-level.* (*See p. 269.*)

After the completion of the discharge of the Ponto-Caspian water, and the formation of a sea-connection through the Dardanelles, the water in the Sea of Marmora became again sufficiently salt to allow of the entry of the existing Mediterranean fauna in early Pleistocene times. Traces of this invasion occur at many points in the Sea of Marmora. Vestiges of a beach-conglomerate, about 330 feet above the present sea-level, occur, as stated in my previous paper, near Myriophyto, on the northern shore (9, p. 159).

Quite recently, Mr. Claude Warner has traced for me the remains of a Mediterranean shell-beach *in situ* at Hora, 405 feet above the sea (fig. 9, p. 268), and about 1000 yards farther inland than the lacustrine beach at the 130-foot level, which I had previously seen at that place. There are numerous scattered blocks of conglomerate at Hora, both above and below the 130-foot level, containing Mediterranean shells, such as *Mytilus edulis*, *Ostrea edulis*, *Callista Chione*, and *Osilinus articulatus*.

The Caspian shells (*Mytilus edulis*, *Didacna crassa*, *Dreissensia polymorpha*, and *Neritina fluviatilis*) were found by me in the 130-foot beach, and in detached conglomerate-fragments. Admiral Spratt collected *Melania*, *Nerita*, *Dreissensia*, and *Cardium* from the same locality (1, pp. 216, 217); and the list given by A. d'Archiac includes *Congeria (Mytilus) rostriformis*, *Cardium ovatum*, *C. protractum*, *Paludestrina*, *Neritina danubialis*, *Mytilus spathulatus*, and *Melanopsis* (3, pp. 480, 481), without specifying the positions of the beds from which they were obtained. This mixture of fossils rendered it very difficult to draw any conclusion as to what formations they really represented; but since *Cardium*, *Ostrea edulis*, and *Mytilus edulis* have now been collected from the 400-foot beach itself, it becomes fairly certain that the Mediterranean marine fossils found below are derived from it, and that the remainder are partly from the 130-foot lacustrine beach, and partly from the Miocene strata upon which both beaches rest.

In several places along the shore-line of the Sea of Marmora, I have found sandy and loamy clay surface-deposits, containing scattered shells of Mediterranean species, at heights varying from 10 to 100 feet above the water.

On the top of a low coast-cliff about three-quarters of a mile west of Gallipoli, there is a deposit of sand, hardened sufficiently in some parts to be worked for building, in which I collected *Ostrea edulis*, *Osilinus turbinatus*, *Gibbula adriatica*, and *G. Biasolleti*, at about 40 feet above sea-level.

About a mile farther west, on the top of a cliff 90 to 100 feet high, formed of Sarmatic clay and marly limestone, I found a scattered surface-deposit of *Cerastoderma edule*, *Pullastra pullastra*, *Tapes* cf. *Dianæ*, *Murex trunculus*, *M. Brandaris*, *Cerithium vulgatum*, *Loripes lacteus*, and *Petricola lithophaga*. *Didacna crassa* and *Dreissensia polymorpha* were also found, but are probably derived from the Gallipoli Conglomerate.

Half a mile inland from Tchardak, on the Asiatic coast opposite

Gallipoli, I observed a surface-deposit, varying from 40 to 50 feet above sea-level, which yielded the following section:—The lowest bed visible is a soft yellow sand, in which I found no fossils. This is covered by a hard concretionary shell-bed, 1 foot thick, containing *Tapes* cf. *Dianæ* and *Cerastoderma edule*. Above this come 3 feet of loam, with Mediterranean marine shells scattered through it, the quantity of shells being greatest in the upper part. The following species were collected from the loam:—*Ostrea edulis*, *Tapes* cf. *Dianæ*, *Gibbula adriatica*, *Cerastoderma edule*, *Mytilus edulis*, *Chlamys varia*, *Chl. opercularis*, *Tritia reticulata*, *Loripes lacteus*, *Gastrana fragilis*; also *Dreissensia polymorpha*, probably from Gallipoli. The surface-soil above these marine shell-beds is a sandy loam, about 3 feet thick, with scattered rounded pebbles of quartz, rhyolite, and mica-schist, fragments of pottery, and the following land-shells:—*Buliminus Lœwii*, *Helix pomatia*, *H. cincta*, and *Pomatias (Cyclostoma) elegans*.

At Mavris Island, 12 miles east of Constantinople, a clay-bed resting on the Devonian rocks, at about 10 feet above sea-level, yielded the following scattered shells:—*Chlamys unicolor*, *Cardium rusticum*, and *Chione gallina*. On the mainland at Paulo Liman, close to Mavris Island, I found *Murex Brandaris*, *Cerithium vulgatum*, *Cerastoderma edule*, and *Cardium rusticum* in a similar bed, 10 to 20 feet above sea-level.

About a mile north-east of Gallipoli, on the road to Bulair, is a loamy clay-bed, containing a seam about 20 feet above the sea-level, and between 1 and 2 feet thick, full of *Ostrea Cyrnusii (lamellosa)*. This is presumably the oyster-bed of Gallipoli, which Prof. Andrussov (24, xxx, Table of Beds above the Sarmatic, facing p. 4) correlates with the Pleistocene marine shell-deposits of the Kertch Peninsula, containing *Ostrea adriatica*, *Mytilus latus*, *Venus gallina*, and *Nassa reticulata*: it is capped by a thickness of about 6 feet of red clay.

From beds, none of which are more than 40 feet above the water, at Abydos and Chanak in the Dardanelles, Calvert & Neumayr collected 33 species, 28 of which are still living in the Mediterranean, and generally widespread (29, p. 366).

Having had the advantage of discussing the question with Mr. Calvert, I have his authority for saying that the section of the Gallipoli Conglomerate, in Calvert & Neumayr's paper (29, sections), has no reference to these Mediterranean shells; also that the Palæolithic knife, quoted by Prof. Suess (15, p. 441) as having been found in the Gallipoli Conglomerate, was really found in the Mediterranean shell-beds at Abydos, 18 miles lower down the Dardanelles. Prof. Toula's collection from a terrace at Yapuldak (4, pp. 14, 15), 13 miles below Gallipoli, is evidently from the same horizon. Mr. Calvert informs me that similar beds occur at Ak Bashi, Maitos, Morto Bay, and In Tepé in the Dardanelles, and in the plain of the Scamander. He has also found a raised beach with *Ostrea* and *Cardium*, 80 to 90 feet above the present sea-level at Five Pines and Usbeg, about 3 miles south-east of Abydos.

Prof. Hœrnes describes late marine shell-beds in Samothrake, about 650 feet above sea-level according to his section, with *Cerastoderma edule*, *Ostrea lamellosa*, *O. cochlear*, *Cerithium vulgatum*, *Spondylus*, and *Pecten* (5, p. 10).

The red loamy or sandy clay, which is the latest general deposit, and occupies a very large area in the aggregate, throughout the district, is a feature that cannot be ignored in any discussion of the present developments.

Burgerstein (20, p. 325) has fully described its appearance in the Chalkidike Peninsula, and, as shown in my previous paper (9, p. 157), it may be said to have left its traces in every direction, up to a height of 1000 feet above the sea. It contains scratched and facetted boulders (9, p. 158) in some of the higher localities, and is scarcely ever free from fragments of stone. As a rule, these are small, angular, scattered lumps of the rock which forms the subsoil, and they correspond exactly with the fragments into which the fissile rocks are being split up at the present time by tree-roots, especially by those of *Pinus maritima.* No organic remains have been found in it to my knowledge, except recent land-shells, such as *Pupa*, *Clausilia*, and *Cyclostoma.*

This clay occurs in the most unlikely places for any fluviatile deposit: for example, there is a well-marked patch about 8 feet thick, and full of small angular stones derived from the underlying rocks, which is exposed by quarrying at Roumili Hissar on the Bosphorus. It occupies a surface-depression in the Devonian strata, at a height of about 180 feet, on the steep rocky slope facing the waterway.

No doubt, in many localities, this red clay has been redistributed and locally thickened by the surface-drainage (ruissellement) which Prof. de Lapparent (11, p. 1612) considers to be the cause of the deposition of lœss, but I think that the angular nature of the small stones contained in it is a serious obstacle to looking in this direction for the general origin of the formation.

In order to show the widespread nature of this deposit, I have indicated on the key-map (Pl. XXIII) some few of the localities where it occurs, with approximate heights (where known); but a detailed survey would be required to give any adequate representation of the innumerable small patches, as well as large areas, which are met with in all parts.

This red clay bears, in many respects, a strong resemblance to the Rubble-Drift described by Sir Joseph Prestwich, and the limiting height agrees with his observations (30). In my opinion, the formation in the Dardanelles district results from a short submergence of the land to a uniform height of about 1000 feet above the present sea-level, probably during (or shortly after) the Glacial Period. It is obvious, however, that no rise of water could, unaided, scratch boulders such as occur in the higher portions of the red clay. Perhaps an explanation of this effect, and of the peculiar characteristics of the clay itself, may be found in the work of shore-ice and tides, in sweeping up the surface-soil and its contents during a submergence which allowed insufficient time for ordinary sedimentation.

Mr. Calvert has found boulders and clay in the Dardanelles Valley, apparently distributed along an old beach from the foot of Kemel to the Five Pines, also large blocks of quartz, some of them striated, in the ancient river-gravels of the Rhodius, 50 to 60 feet above the present sea-level. These quartz-blocks must have come from the auriferous reef at Astyra, about 12 miles distant to the east-south-east.

## IX. Summary of Observations.

A list of the publications to which I have referred is annexed to this paper; and the following is a summary of geological facts not hitherto recorded, which I have had the opportunity of observing in the region surrounding the Dardanelles:—

1. The Pasha-Liman group of islands and the Artaki Peninsula in the Sea of Marmora are not volcanic, but consist of stratified rocks which formed part of a pre-Eocene archipelago.
2. The Kuru-Dagh and Tekfur-Dagh ranges are not composed of Primary rocks (phyllit), but of Lower Tertiary lacustrine sandstones, clays, and schists, overlying the Nummulitic Series. They are 3000 feet thick, interstratified with volcanic rocks, and contain Oligocene coal-seams. The Gallipoli Peninsula and the island of Imbros are partly composed of strata of the same age, which also occur at Tchatal Tepé, south of the Sea of Marmora.
3. The Eocene and Oligocene strata are folded on a large scale. The central fold can be traced for 200 miles through Lemnos in a direction of S. 60° W., according with that shown by Prof. Philippson for the 'Flysch' of Thessaly.
4. Strati Island is entirely volcanic, as is the south-east of Imbros also.
5. Helvetian-Tortonian marine deposits occur north of the Gulf of Xeros, and on the northern shore of the Sea of Marmora.
6. Sarmatic strata, freshwater and marine, form the northern shore of the Sea of Marmora from Ganos to the Dardanelles, and no Levantine Beds are to be found here. Sarmatic strata also occur near Keshan and Malgara in Thrace, at the south-eastern corner of Imbros, and in Tenedos.
7. Pontian Beds occur near Keshan.
8. There is a post-Sarmatic extension of the central fold of the Lower Tertiary strata, from Dohan Aslan through Serian Tepé and Mount Elias to Ganos, which has thrown up a ridge blocking the Sarmatic connection between the Sea of Marmora and the Gulf of Xeros.
9. The Ponto-Caspian water rose to 130 feet above the present sea-level in Upper Pliocene times, and left a beach of brackish lacustrine shells at Hora.

TABLE

| *Estimated approx^te thickness.* | | rdanelles. | Marmora. | Bosphorus. | Ponto-Caspian. |
|---|---|---|---|---|---|
| | | *pared with the present water-level.* | | | |
| *Feet.* | | | | | |
| 3 | Tcha | 0 → | → | → | → |
| Various. | Ch / Gu / Bo | + 1000 → | → | → | → |
| 4 to 10 | Ga / Isl | o + 100 → | → | | |
| | Sam | → | → | → | ? + 650 → |
| 12 | Hor | → | + 405 → | → | → |
| | | 0 → | → | 0 → | → |
| | | 0 → | → | 0 → | → |
| | Mor | Land Barrier. | | | |
| 80 | Ga | Land Barrier. | ← | + 130 → | → |
| 15 | | Land Barrier. | ← | 0 → | → |
| | Mait | Land Barrier. | ← | − 120 → | → |
| 20 | Boz | Land Barrier. | ← − 120 → | Land Barrier. | ← − 200 → |
| 80 | Mity | Land Barrier. | ← 0 → | Land Barrier. | ← 0 → |
| | Doh | Land Barrier. | | | |
| 500 | Sa / Te | + 800 → | → | → | → |
| (?) 200 | Hor | | | | |
| (?) 100 | Kert | 1500 → | → | → | → |
| 3000 | Ga / Te / Ke / Sa / Le | Marshes → | → | | (?) |
| 2000 | M / V / Sa / Tr | hipelago → | → | | (?) |
| | Seri / Den | | | | |

TABLE I.—EOCENE AND LATER FORMATIONS SURROUNDING THE DARDANELLES.

| *Series.* | *Stage.* | *Nature of Beds.* | *Estimated approx<sup></sup>te thickness.* | *Localities.* | *Fossils.* | *Relative heights in feet, compared with the present water-level.* Eastern Mediterranean. | Northern Cyclades. | Ægean. | Dardanelles. | Marmora | Bosphorus. | Ponto-Caspian. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RECENT and PLEISTOCENE. | Glacial. | Surface-loam. | *Feet.* 3 | Tchardak. | Land-shells. | ←------- | ------- | ------- | 0 | ------- | ------- | -------→ |
| | | Red clay. | Various. | Chalkidike; Maritza Basin; Gulf of Xeros; Marmora; Bosphorus; Lemnos. | Land-shells. | ←------- | ------- | ------- | + 1000 | ------- | ------- | -------→ |
| | | Marine shell-beds and terraces. | 4 to 10 | Gallipoli; Tchardak; Mavris Island; Dardanelles; Kertch. | Mediterranean shells. | | | ←--- + | 10 to + 100 | -------→ | | |
| | | Marine shell-bed. | | Samothrake. (?) Trebizond. | *Ostrea Cyrnusi (lamellosa).* | | | ← + 650 | ------- | ------- | ------- | ? + 650 → |
| | | Conglomerate: marine terrace. | 12 | Hora. | *Ostrea edulis. Mytilus edulis. Callista Chione.* | | | ←-------<br>← -0-<br>← −600- | -------<br>0<br>0 | + 405<br>-------<br>------- | -------<br>0<br>0 | -------→<br>-------→<br>-------→ |
| PLIOCENE. | Sicilian. | Conglomerate: marine terrace, and shell-beds. | | Morea; Kos; Rhodes. | Mediterranean shells. | + 1166<br>+ 540 ---→<br>+ 600 to 800 | Land Barrier. | (?) | Land Barrier. | | | |
| | | Shell-beds. | 80 | Gallipoli; Hora; Cape Tschauda. | *Neritina danubialis. Dreissensia polymorpha. Didacna crassa.* | | | | | ←------- | + 130 | -------→ |
| | | Lacustrine terrace. | 15 | | | | | | | ←------- | 0 | -------→ |
| | | River-channel. | | Maitos. | | | | | | ←------- | − 120 | -------→ |
| MIOCENE. | Pontian. | Sandy beds. | 20 | Boz Tepé. | *Lyrcæa Bonelli. Vivipara megarensis. Bithynia. Planorbis.* | | | | | ← − 120 → | Land Barrier. | ← −200 → |
| | | Freshwater limestones and clays. | 80 | Mitylene; Dardanelles. | | | | | | ← 0 → | | ← 0 → |
| | | Ridge of old rocks. | | Dohan Aslan. | | | | | | | | |
| | Sarmatic. | Marine limestones and clays. | 500 | San Stefano; Heraklitza; Erenkeui; Tenedos; Hamaxitos; Demotika. | *Mactra podolica.* | | | ←------- | + 800 | ------- | ------- | -------→ |
| | | Freshwater sands. | (?) 200 | Hora; Erenkeui; Feredjik. | *Anodonta. Melanopsis costata. Rhinoceros.* Naphtha. Lignite. | | | | | | | |
| | Tortonian and Helvetian. | Sands and sandy limestone. | (?) 100 | Kertch; Eregli; Myriophyto; Kasos. | *Pecten aduncus. Ostrea Alectryonia Virleti. crassissima* | ←------- | ------- | + 1466 | to 1500 | ------- | ------- | -------→ |
| OLIGOCENE. | Aquitanian. Stampian. ? | Lacustrine sandstones, schists, clays, and volcanic beds. | 3000 | Ganos; Gorgona Deré; Tchatal Tepé; Gueredjé; Keshan; Gallipoli Peninsula; Samothrake; Imbros; Lemnos. | *Corbicula semistriata. Anthracotherium.* Coal. *Chrysodium Lanzæanum.* | (?) | | ←------- | Marshes | -------→ | | (?) |
| EOCENE. | Lutetian. | Limestones, sandstones, and conglomerates. | 2000 | Mount Elias; Gorgona Deré; Vernitza; Feredjik; Samothrake; Demotika; Troad. | *Fimbria subpectunculus. Nummulites Dufrenoyi. Cladocora cf. articulata. Cycloseris Perezi.* | (?) | | ←------- | Archipelago | -------→ | | (?) |
| | ? | Conglomerates, sandstones, and clays. | | Serian Tepé; Gorgona Deré; Demotika. | | | | | | | | |

10. There have been considerable oscillations of the water-level in the Sea of Marmora since the advance of the Mediterranean through the Dardanelles. A beach with recent Mediterranean shells occurs at Hora, at 405 feet above sea-level, and there are numerous shell-beds along the shore-lines of the Dardanelles and the Sea of Marmora, up to 100 feet.
11. Glacial or post-Glacial red clay, formed at the expense of the surface-soil of a land-area, has been widely spread to a height of 1000 feet, and contains scratched and striated boulders.

Dr. J. S. Flett has furnished a description, in Appendix I (p. 276), of the more important rock-specimens; and Appendices II & III (pp. 277, 292) contain detailed accounts, by Mr. R. Bullen Newton and Mr. R. Holland respectively, of the fossils which I have collected. To each of these gentlemen I desire to tender my most sincere thanks.

TABLE II.

MEASURED SECTION OF STRATA AT GORGONA DERÉ, NEAR SARKEUI.

| Southern end of section (beds in descending order). | *Measured horizontal distances in feet.* |
|---|---|
| Greenish sands and clays | 180 |
| Green sandstones and clays with earthy coal-outcrops, brown sandstones with leaf-impressions, greenish-brown sandstones, dark leafy clays, nodular coaly shales, thinly-bedded sandstones and clays | 491 |
| Shales | 516 |
| Brownish-grey sandstones with leaf-impressions, in vertical beds | 45 |
| Shales | 156 |
| Sandstones in vertical beds | 18 |
| Brown calcareous sandstones, interbedded with shales | 375 |
| Thickly-bedded brownish-grey sandstones and shales | 23 |
| Shales, dip from 70° to vertical | 1380 |
| Brown sandstones, clays, and shales, dip 80° northward | 240 |
| Brown sandstones, thin shales, and conglomerates | 12 |
| Sandstones and conglomerates, Nummulitic sandstones, grit, and Nummulitic beds, vertical and dipping southward | 465 |
| Conglomerates, brown and green sandstones with coaly leaf-impressions | 420 |
| Brown and blue sandstones and shales | 255 |
| Beds covered by gravel, etc. | 525 |
| Brownish-blue sandstones, green sandstones with pebbles, dark-coloured sand and grey sandstones | 116 |
| Pebbly green sand, dip 45° north-westward | 81 |
| Shales, green and dark sand | 114 |
| Dark clay, blue and brown sandstones and shales | 90 |
| Green sandstones and green clays, vertical beds | 78 |
| Thin limestones, Nummulitic, dip 45° northward | 192 |
| Thin sandstones and shales, vertical and inclined to south | 120 |
| Nummulitic sandstones and conglomerates, vertical and inclined to north | 180 |
| Limestones, sandstones with green and purple pebbles, and dark clay | 190 |
| Sandstones, limestones, and conglomerates, Nummulitic and coralline, gritty sandstones, shales and conglomerates, dipping northward | 234 |
| Northern end of section. | |

## Table III.

### Measured Section of Strata near Keshan, above and below the Coal.

| North-eastern end of section (beds in descending order). | Approximate dip | *Thickness of each formation in feet.* |
|---|---|---|
| Blue shales. | | |
| Soft blue shales in thin layers | 45° | 240 |
| Nodular sandstones | 45° | 6 |
| Soft blue shales in thin layers | 45° | 350 |
| Greenish sandstones, with thin layers of shale | 45° | 40 |
| Sandstones and shales in thin layers | 45° | 66 |
| Soft blue shales in thin layers | 45° | 132 |
| Sandstones, with thin layers of shale | 45° | 106 |
| Grey, thickly-bedded, nodular sandstone | 45° | 73 |
| Soft blue shales, with thin layers of sandstone | 45° | 180 |
| Blue shales and rhyolite | 45° | 28 |
| Thickly-bedded sandstone | 45° | 15 |
| Coal | 45° | 3 |
| Thickly-bedded greenish sandstone | 45° | 40 |
| Blue shale, with layers of sandstone | 45° | 44 |
| Sandstones | 45° | 40 |
| Brownish-grey nodular sandstone, layers of shale | 45° | 250 |
| Thickly and thinly-bedded sandstones, layers of shale | 45° | 120 |
| Thinly-bedded nodular sandstones | 45° | 90 |
| Grey sandstones and shales | 30° | 70 |
| Grey nodular sandstones | 30° | 90 |
| Thin sandstones and shales | 30° | 240 |
| Grey nodular sandstones | 30° | 390 |
| Thinly-bedded shales and sandstones | 30° | 180 |
| Nummulitic limestone. | | |
| South-western end of section. | | |

## X. Bibliographical List.


(1) Spratt, T. 'On the Freshwater Deposits of the Levant' Quart. Journ. Geol. Soc. vol. xiv (1858) p. 212.

(2) Hochstetter, F. von. 'Die geologischen Verhältnisse des östlichen Theiles der europäischen Türkei' Jahrb. d. k.-k. Geol. Reichsanst. vol. xx (1870) p. 365.

(3) Viquesnel, A. 'Voyage dans la Turquie d'Europe' vol. ii (1868).

(4) Toula, F. 'Eine geologische Reise nach Kleinasien' Beitr. z. Paläont. u. Geol. Œsterreich-Ungarns u. des Orients, vol. xii (1900) p. 1.

(5) Hœrnes, R. 'Geologischer Bau der Insel Samothrake' Denkschr. d. k. Akad. d. Wissensch. Wien, vol. xxxiii (1874) pt. ii, p. 1.

(6) Launay, L. de. 'Études géologiques sur la Mer Égée' Ann. des Mines, ser. 9, vol. xiii (1898) p. 157.

(7) Tchihatcheff, P. de. 'Asie Mineure—4ème Partie: Géologie' vols. i–iii (1867–69); & 'Paléontologie' (A. d'Archiac, P. Fischer, & E. de Verneuil) 1866.

(8) Gardner, J. S., & Ettingshausen, Baron C. 'Monograph of the British Eocene Flora' Palæont. Soc. vol. i (1879–82).

(9) English, T. 'Coal & Petroleum-Deposits in European Turkey' Quart. Journ. Geol. Soc. vol. lviii (1902) p. 150.

(10) Stefanescu, S. 'Étude sur les Terrains tertiaires de Roumanie' Thèse présentée à la Faculté des Sciences de Paris pour obtenir le grade de D. ès Sci. Nat. (Lille, 1897).

(11) Lapparent, A. de. 'Traité de Géologie' 4th ed. vol. iii (1900).

(12) Philippson, A. 'Beiträge zur Kenntniss der griechischen Inselwelt' Peterm. Mitth. Ergänzungsheft 134 (vol. xxix, 1901).


Bemrose, Collo.

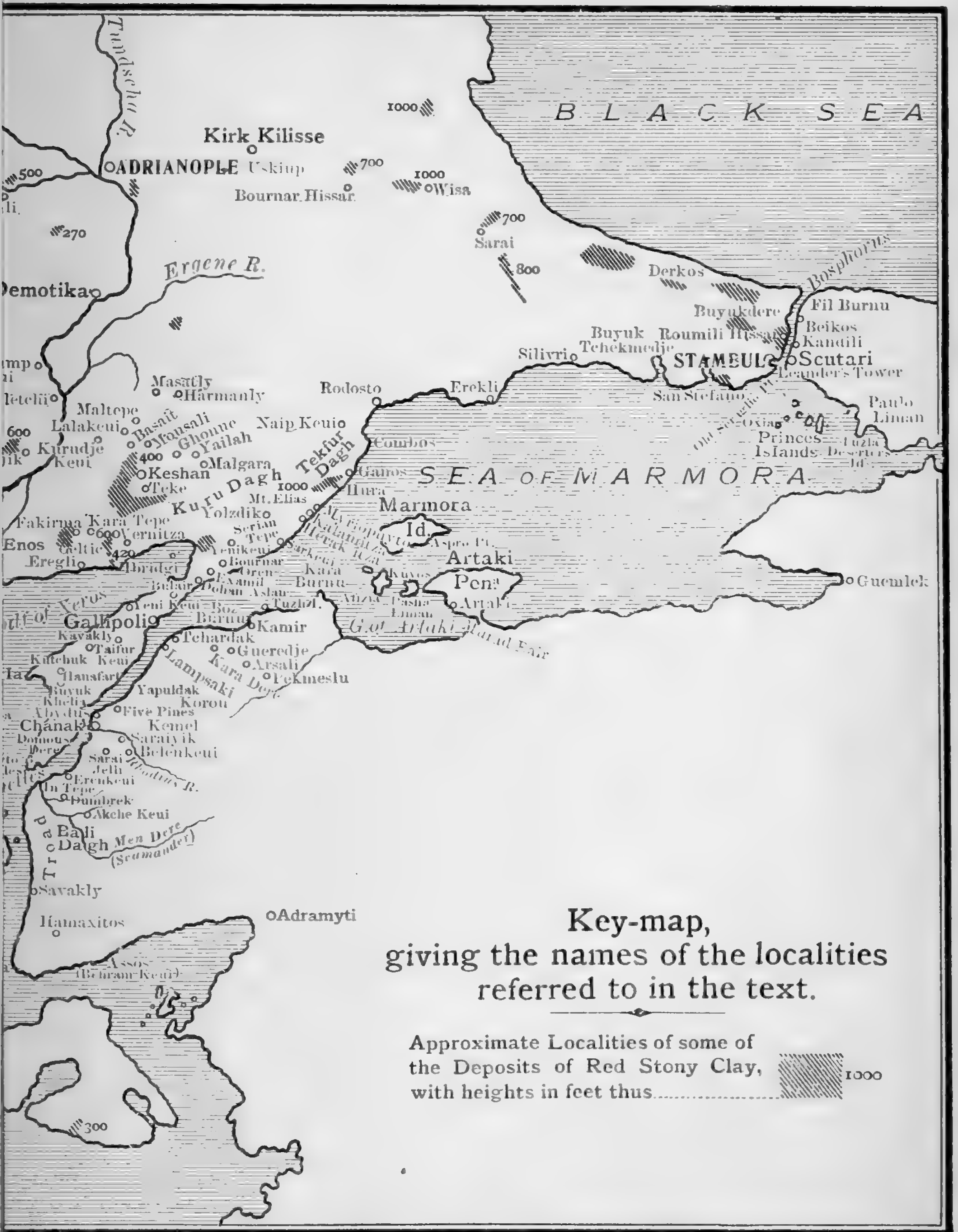
GEOLOGICAL SKETCH-MAP OF THE COUNTRY SURROUNDING THE DARDANELLES.

Fig. 1.—Sarmatic and Pontian.

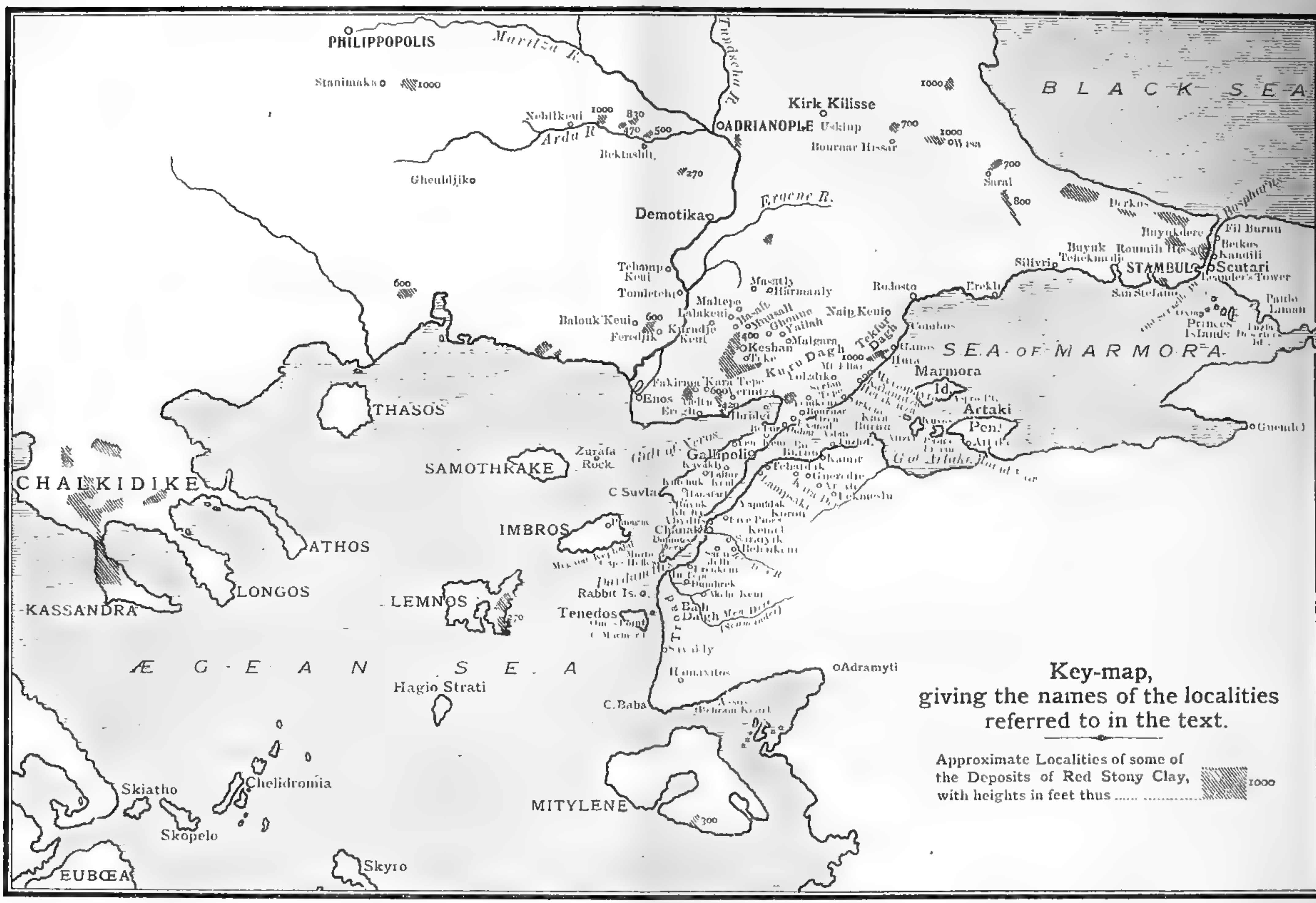
Bemrose, Collo.

Fig. 2.—Upper Pliocene.

Probable Foldings of Lower Tertiary, and Coast-Lines of Upper Tertiary Formations surrounding the Dardanelles.




...a' *read* 'Heraklitza'; *and for* 'Hura' *read* 'Hora'.]




[*For* 'Abydus' *read* 'Abydos'; *for* 'Herak . . itza' *read* 'Heraklitza'; *and for* 'Hura' *read* 'Hora'.]

(13) HILBER, V. 'Geologische Reise in Nordgriechenland & Makedonien' (1893 & 1894) Sitzungsberichte d. k. Akad. d. Wissensch. Wien, vol. ciii, pt. i (1894) pp. 575, 616.
(14) PHILIPPSON, A. 'La Tectonique de l'Egéide' Ann. Géograph. vol. vii (1898) p. 112.
(15) SUESS, E. 'La Face de la Terre' [transl. E. de MARGERIE] vol. i (1897).
(16) SUESS, E. 'La Face de la Terre' [transl. E. de MARGERIE] vol. iii (1902).
(17) DILLER, J. S. 'Notes on the Geology of the Troad' Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 627; & Preliminary Report.
(18) ANDRUSSOV, N. 'Ueber das Auftreten der marin-mediterranen Schichten in der Krim' Verhandl. d. k.-k. Geol. Reichsanst. (1884) p. 190.
(19) BUKOWSKI, G. 'Der geologische Bau der Insel Kasos' Sitzungsberichte d. k. Akad. d. Wissensch. Wien, vol. xcviii, pt. i (1889) p. 653.
(20) BURGERSTEIN, L. 'Geologische Untersuchungen im südwestlichen Theile der Halbinsel Chalkidike' Denkschr. d. k. Akad. d. Wissensch. Wien, vol. xl (1880) p. 321.
(21) HŒRNES, R. 'Ein Beitrag zur Kenntniss fossiler Binnenfaunen' Sitzungsberichte d. k. Akad. d. Wissensch. Wien, vol. lxxiv, pt. i (1876–77) p. 7.
(22) STRABO. 'Geography' [transl. Tardieu] Paris, 2nd ed. (1894). Fragments of Lib. VII.
(23) GOLTZ, — VON DER. Karte der Umgegend von Constantinopel. Berlin, 1897.
(24) ANDRUSSOV, N. 'La Mer Noire' no. xxix; & 'Environs de Kertch' no. xxx, Guide des Excursions du VII$^{ème}$ Congrès Géologique International (St. Petersburg) 1897.
(25) TELLER, FR. 'Geologische Beobachtungen auf der Insel Chios' Denkschr. d. k. Akad. d. Wissensch. Wien, vol. xl (1880) p. 340.
(26) ANDRUSSOV, N. 'Die Schichten von Cap Tschauda' Ann. d. k.-k. Naturhist. Hofmuseums, vol. v (1890) p. 66.
(27) EGINITIS, D. 'Le Tremblement de Terre de Constantinople' Ann. Géograph. vol. iv (1895) p. 151.
(28) WHARTON, SIR WILLIAM. 'Report on the Currents of the Dardanelles & Bosphorus' Admiralty, London, 1886.
(29) CALVERT, FR., & NEUMAYR, M. 'Die jungen Ablagerungen am Hellespont' Denkschr. d. k. Akad. d. Wissensch. Wien, vol. xl (1880) p. 357.
(30) PRESTWICH, SIR JOSEPH. 'On the Evidences of a Submergence of Western Europe & of the Mediterranean Coasts, &c.' Phil. Trans. Roy. Soc. ser. A, vol. clxxxiv (1893–94) p. 903.

## EXPLANATION OF PLATES XXI–XXIII.

### PLATE XXI.

Geological sketch-map of the country surrounding the Dardanelles.

### PLATE XXII.

Probable foldings of Lower Tertiary, and coast-lines of Upper Tertiary formations surrounding the Dardanelles.

Fig. 1. Sarmatic and Pontian.
2. Upper Pliocene.

### PLATE XXIII.

Key-map of the Ægean & Marmoran area, giving the names of the localities referred to in the text, and showing the approximate localities of some of the deposits of red stony clay. Approximate scale: 45 miles = 1 inch.

[For the Discussion, see p. 295.]

## Appendix I.

### Notes *on the* Collection *of* Rock-specimens *made by* Col. English *in* European Turkey *and* Asia Minor. By John Smith Flett, M.A., D.Sc., F.G.S.

The collection of specimens submitted to me by Col. English, though not very large, included representatives of many different kinds of rocks—sedimentary, igneous, and metamorphic. The most numerous, however, were the recent lavas, which ranged from rhyolites and trachytes to very basic augitites. Many of the specimens, having been collected in the course of hurried traverses through difficult regions, were not so fresh as might have been desired. Yet it was possible, in nearly all cases, to form a definite opinion regarding the nature of the rock and the group to which it was to be assigned.

The clastic sediments and organic limestones of the Tertiary Series require no special description, but mention may be made of the occurrence of red, baked, and hardened, nodular shales, which had been contact-altered apparently by lava-flows that covered or enveloped them. None of the advanced stages of thermal alteration were found in any of the rocks sliced. Trachytic (?), andesitic, and basaltic tuffs were numerous, but call for no detailed treatment.

The assemblage of crystalline, igneous, and metamorphic rocks was on the whole very similar to that which has been described by J. S. Diller from the adjacent district of the Troad.[1] With the exception of the nepheline-basalts, practically all the rocks described by him were present also in Col. English's series; and there were only one or two classes the occurrence of which was not already known from Mr. Diller's paper.

Rhyolites were certainly few, although they are reported as abundant in the Troad; only one good specimen was collected, at Boz Tepé, west of Keshan. It may be remarked, however, that many of the more felspathic 'andesites' were both decomposed and much silicified, so that often it was uncertain whether originally they might not have had the characters of rhyolites. Trachytes were equally rare, in fact it was doubtful whether they were represented at all.

Most of the lavas were andesitic, and hornblende-andesites preponderated, though biotite-andesites were also common. A pale-green pyroxene was practically always present in these latter rocks, and in some of them the biotite was so intensely corroded and so inconspicuous, that a peculiar type of pyroxene-andesite was developed, in which the essential constituents were a pale-green (sometimes pleochroic) augite and highly-zonal plagioclase-felspar. Its abnormal character raised suspicions as to its true nature; and, on further examination, it became clear that these felspathic augite-

[1] Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 627.

andesites were merely unusual varieties of biotite-andesite. The groundmass is commonly pilotaxitic, less frequently hyalopilitic. The best example of these came from the White Cliffs (Dardanelles). An excellent biotite-andesite was collected on the south-eastern slope of the watershed above Panagia (Imbros); it contained, in addition to large hexagonal plates of biotite, a little much-corroded hornblende and porphyritic green augite.

Five specimens from the island of Strati were all hornblende-andesites (containing a little dark-brown biotite), and were exceptionally fresh and good examples of this class of rocks. Typical hypersthene-andesites, much decomposed, occur at Korou.

Olivine-basalts were found on the Kuru Dagh and near Keshan: from the latter locality some peculiar rocks were obtained. One of these resembled an augitite; another consisted of olivine, brownish augite, biotite, plagioclase, and orthoclase-felspar, with an abundant clear glassy base.

In the Serian-Tepé district, examples of serpentine, amphibolite, epidote-amphibolite, and serpentine-schist occur. The serpentines include weathered dunites and harzburgites.

## Appendix II.

## Notes *on the* post-Tertiary *and* Tertiary Fossils *obtained by* Col. English *from the* District *surrounding the* Dardanelles. By Richard Bullen Newton, Esq., F.G.S.

[Plate XXIV.]

Considerable interest may be attached to the fossils collected by Col. English in a number of localities surrounding the Dardanelles, since many of the specimens rank as fresh records for this part of South-Eastern Europe. One of the most important results accruing from an examination of the collection has been the fixing of the age of the coal-deposits at Masatly, which can now be referred to the Stampian or Middle division of the Oligocene System, on account of the discovery of *Corbicula semistriata* in those beds at that locality, in association with *Anthracotherium*-remains.

The specimens are scheduled under the following formations:—

| | |
|---|---|
| Post-Pliocene. | |
| Pliocene (Sicilian). | |
| Miocene | Pontian. |
| | Sarmatian. |
| | Vindobonian (Helvetian—Tortonian). |
| Oligocene | Aquitanian. |
| | Stampian. |
| Eocene ... | Lutetian. |

The whole of the collection has been generously presented to the British Museum (Natural History) by Col. English.

## Post-Pliocene.

Marine mollusca found in the region of the Dardanelles have been identified with existing Mediterranean species. Hence, the deposits containing them may be recognized as of post-Pliocene age, and probably of contemporaneous origin with those found in Cyprus (as known to us through the researches of Prof. Gaudry), and in the Hellespont by Calvert & Neumayr.

(A) List of marine shells from the coast-cliffs west of Gallipoli, 40 to 100 feet above sea-level.

| Gastropoda. | Lamellibranchia. |
|---|---|
| *Murex Brandaris*, Linnæus. | *Ostrea edulis*, Linnæus. |
| *Murex trunculus*, Linnæus. | *Cerastoderma edule* (Linnæus). |
| *Cerithium vulgatum*, Bruguière. | *Pullastra pullastra*. |
| *Gibbula adriatica* (Philippi). | *Petricola lithophaga* (Retzius). |
| *Gibbula* cf. *Biasoletti* (Philippi). | *Loripes lacteus* (Poli). |
| *Osilinus turbinatus* (Born). | *Tapes Calverti*, sp. nov. (= *Tapes* cf. *Dianæ*, Locard). |

(B) A marine shell from Gallipoli Ovassi, about one mile north-east of Gallipoli, in a loamy clay-bed 20 feet above the sea.

*Ostrea Cyrnusii*, Payraudeau.[1]

(C) List of marine shells from the other side of the Dardanelles opposite Gallipoli, about 1 mile inland from Tchardak. The beds containing this fauna are of a sandy character, and nearly 50 feet above sea-level. The exact section measures about 10 feet in thickness, and is capped by a loamy soil full of recent terrestrial shells.

| Gastropoda. | Lamellibranchia. |
|---|---|
| *Tritia reticulata* (Linnæus). | *Ostrea edulis*, Linnæus. |
| *Gibbula adriatica* (Philippi). | *Chlamys opercularis* (Linnæus). |
| | *Chlamys varia* (Linnæus). |
| | *Cerastoderma edule* (Linnæus). |
| | *Mytilus edulis*, Linnæus. |
| | *Gastrana fragilis* (Linnæus). |
| | *Loripes lacteus* (Poli). |
| | *Tapes Calverti*, sp. nov. (= *Tapes* cf. *Dianæ*, Locard). |

The specimens of *Tapes* cf. *Dianæ*, which occur both at Tchardak and Gallipoli, agree with Calvert & Neumayr's shells from the Quaternary deposits of the Hellespont which are similarly identified.[2]

[1] *Ostrea Cyrnusii* was originally described by Payraudeau ('Catalogue des Annélides & des Mollusques de l'Ile de Corse' 1826, p. 79, pl. iii, figs. 1 & 2) as living off Corsica. It is narrowly-elongate in form, and furnished with an extensive ligamental area. The more modern figure, published by Reeve in his 'Conchologia Iconica' vol. xviii (1873) pl. xvii, fig. 37, of the lower valve of this shell agrees in every way with the specimen collected by Col. English. It may be mentioned that this species is generally united to *O. lamellosa*, as one of its synonyms.

[2] Denkschr. d. k. Akad. d. Wissensch. Wien, vol. xl (1880) p. 366 & pl. ii, figs. 7–8.

This form of *Tapes* is not only extinct, but it differs sufficiently in proportions and contour from Locard's original *T. Dianæ*, which was obtained from the Miocene of Corsica,[1] as to necessitate another name: that of *Tapes Calverti* is therefore proposed for it.

(D) List of shells from Paulo Liman, occurring in a surface-clay about 20 feet above the sea.

| Gastropoda. | Lamellibranchia. |
|---|---|
| *Cerithium vulgatum*, Linnæus. | *Cerastoderma edule* (Linnæus). |
| *Murex Brandaris*, Bruguière. | *Cardium rusticum* (=*tuberculatum*) Linnæus. |

(E) List of shells from a disintegrated beach of clay and stones about 10 feet above sea-level, occurring at Mavris Island (Sea of Marmora).

Lamellibranchia.

*Chione gallina* (Linnæus).
*Cardium rusticum* (=*tuberculatum*) Linnæus.
*Chlamys unicolor* (Lamarck).

This deposit and the preceding (D) are of a later post-Pliocene age than those of Gallipoli and Tchardak.

(F) List of terrestrial shells found in a loamy soil capping the marine beds at Tchardak. They were associated with fragments of pottery, and are of very recent age.

Gastropoda.

*Helix pomatia*, Linnæus.
*Helix cincta*, var., Müller.
*Buliminus Lœwii* (Philippi).
*Pomatias elegans* (Draparnaud).

(G) Marine shells found in a conglomerate at Hora, about 400 feet above sea-level and 1000 yards inland from the lighthouse at this locality.

| Gastropoda. | Lamellibranchia. |
|---|---|
| *Osilinus articulatus* (Born). | *Ostrea edulis*, Linnæus. |
| | *Mytilus edulis*, Linnæus. |
| | *Callista Chione* (Linnæus). |

(H) A sandy conglomerate forming a raised beach, containing recent Mediterranean shells, from near Kavak Deré.

Lamellibranchia.

*Ostrea edulis*, Linnæus.
*Anomia ephippium*, Linnæus.
*Chlamys opercularis* (Linnæus).
*Amussium cristatum* (Bronn).

In connection with the determinations of the recent mollusca

[1] 'Description de la Faune des Terrains tertiaires moyens de la Corse' 1877, p. 190 & pl. vii, figs. 1–3.

in the foregoing lists, the writer desires gratefully to acknowledge the assistance given to him by his colleague at the British Museum, Mr. Edgar Smith, I.S.O.

## Pliocene (Sicilian).

The Pliocene shells of this collection, chiefly obtained from the Gallipoli Conglomerate, are of lacustrine habit and bear the Caspian facies. Admiral Spratt[1] was one of the earliest geologists to call attention to the lacustrine or freshwater deposits skirting the margins of the Grecian Archipelago, the Sea of Marmora, and the Black Sea, all of which he thought were indications of the former existence of an 'Oriental Lake' extending over those areas to the Sea of Azov. Two of the more frequent shells found in the Marmora beds resembled a *Mytilus* and a *Cardium*, and were long recognized as marine forms; but, on examining the fauna of Lakes Kattabug and Yalpuk, Spratt ascertained that the so-called *Cardium* (= *Didacna*) was living there in fresh water, and differed from the marine genus in having two syphons. He had also recognized the same shell in the Kertch deposits and in the Gallipoli Conglomerate, where it was associated with the *Mytilus*-like shell, or *Dreissensia* of modern conchologists; hence he concluded that these freshwater mollusca belonged to his great 'Oriental Lake-Period.'

In the British Museum (Natural History) are some excellent examples of this *Cardium*-like shell, now determined as *Didacna crassa*, a species originally described by Eichwald from the Caspian Sea. These specimens, forming part of Admiral Spratt's collection, were obtained from sandy marls underlying red, earthy drift-deposits at Babel, on the eastern coast of Yalpuk Lake (Bessarabia), and were presented by Col. F. T. N. Spratt-Bowring, R.E., in 1892.

Prof. Andrussov,[2] who has studied the fauna of the Gallipoli Conglomerate, regards it as of Upper Pliocene age, and synchronizes it with the Tschauda Beds of the Kertch Peninsula, since both deposits contain *Didacna crassa*, Eichwald[3] (Pl. XXIV, figs. 1 & 2), *Dreissensia polymorpha*, Pallas (Pl. XXIV, fig. 3), and *Dr. Tschaudæ*, Andrussov (Pl. XXIV, fig. 4).

Besides these shells from the Gallipoli Conglomerate, the present collection contains examples of a nearly-identical conglomerate from Hora, 130 feet above sea-level, exhibiting lacustrine conditions. Although *Dreissensia Tschaudæ* is not identifiable in this rock, the other two lamellibranchs are recognized, besides *Neritina fluviatilis*

[1] Quart. Journ. Geol. Soc. vol. xiii (1857) pp. 72–83; *ibid.* vol. xiv (1858) pp. 203–19; & *ibid.* vol. xvi (1860) pp. 281–92.

[2] See 'Environs de Kertch' Guide des Excursions du VII$^{ème}$ Congrès Géol. Intern. (St. Petersburg, 1897) no. xxx.

[3] *Didacna crassa* is recorded as occurring still farther eastward, in the district of the Caucasus between Cape Bailov and Baku, by Prof. N. I. Lebedev, in Dr. Gustav Radde's 'Die Sammlungen des Kaukasischen Museums' vol. iii (1901) p. 160 & pl. iv, figs. 713 *a–b*.

and fragments of *Mytilus edulis*. The appearance of the last-named among lacustrine species need not be wondered at, as it has been recorded as living in the Caspian and Black Seas by S. P. Woodward[1] and other authorities.

(A) List of lacustrine shells from the Gallipoli Conglomerate.

LAMELLIBRANCHIA.

*Dreissensia polymorpha* (Pallas).
*Dreissensia Tschaudæ*, Andrussov.
*Didacna crassa*, Eichwald.

(B) List of lacustrine shells from the Hora Conglomerate (130 feet).

| GASTROPODA. | LAMELLIBRANCHIA. |
|---|---|
| *Neritina fluviatilis* (Linnæus). | *Dreissensia polymorpha* (Pallas).<br>*Didacna crassa*, Eichwald.<br>*Mytilus edulis*, Linnæus. |

## Miocene (Pontian).

The collection contains a few lacustrine mollusca, which prove the presence of Pontian deposits in the region of the Dardanelles. Prof. S. Stefanescu[2] appears to be the principal authority on the Pontian and the succeeding Sarmatian groups of rocks, especially in connection with Rumania, his latest researches being summarized in a 'Thesis' containing valuable faunistic lists, comparative tables, and a comprehensive bibliography.

By this it is evident that *Dreissensia rimestiensis* and *Prosodacna* cf. *stenopleura* (both collected by Col. English) are characteristic Pontian shells; while an equally-typical shell of this stage of the uppermost Miocene is the gastropod, *Lyrcæa Bonelli*, which Dr. Brusina[3] has recorded from Hungary and Servia.

Species of Pontian age:—

*Lyrcæa Bonelli*, Brusina. (Pl. XXIV, figs. 5 & 6.)
*Dreissensia rimestiensis*, Fontannes. (Pl. XXIV, figs. 7 & 8.)
*Prosodacna* cf. *stenopleura*, S. Stefanescu. (Pl. XXIV, figs. 9 & 10.)

Locality.—Found in beds occurring above the Nummulitic Limestone, at a brook north of Teke-keui.

| | |
|---|---|
| *Neritina.*<br>*Prosodacna.* | *Dreissensia.* |

Locality.—Keshan (Kara Kaya Deré).

| | |
|---|---|
| *Planorbis.*<br>*Melania.* | *Anodonta.*<br>*Prosodacna.* |

Locality.—Near Keshan (Hafus Hassan Tchiflik).

[1] 'A Manual of the Mollusca' 3rd ed. (1875) p. 69.
[2] Thèse présentée à la Faculté des Sciences de Paris: 'Étude sur les Terrains tertiaires de Roumanie' (Lille, 1897) pp. 124–26. See also Fontannes, 'Faune malacologique des Terrains Néogènes de Roumanie' Arch. Mus. Hist. Nat. Lyon, vol. iv (1887) pp. 322–61 & pls. xxvi–xxvii.
[3] 'Iconogr. Moll. Foss. Tert. Hungariæ, &c.' 1902, p. 7 & pl. v, figs. 29–32.

## Miocene (marine Sarmatian).

Marine Sarmatian shells have been obtained from the limestones, etc., of San Stefano, Heraklitza, Dohan Aslan (near Keshan), Malgara, etc., the most important being *Mactra podolica* and *Cardium protractum*. *M. podolica* is a typical Sarmatian species, while the *Cardium* is found in the Crimea in beds of similar age.

MACTRA PODOLICA, Eichwald. (Pl. XXIV, figs. 16–18.)

*Mactra podolica*, Eichwald, 'Naturhistorische Skizze von Lithauen, &c.' 1830, p. 207.
*Mactra deltoides* & *M. biangulata*, Abich, 'Geologie d. Kaukasus' Mem. Acad. Imp. Sci. St. Petersb. ser. 6, vol. ix (1859) pp. 531, 532, figs. 1–4 (p. 514) & pl. viii, figs. 4 *a* & 4 *b*.
*Mactra podolica*, Hœrnes, 'Foss. Moll. Tert.-Beck. Wien' Abhandl. d. k.-k. Geol. Reichsanst. vol. iv (1859) pt. i, p. 62 & pl. vii, figs. 1–8.

Good specimens of this shell occur in a reddish siliceo-calcareous rock at Heraklitza, showing external and internal features in every way agreeing with the figures published by A. d'Archiac in Viquesnel's 'Voyage dans la Turquie d'Europe' (1868) pl. xxiv, figs. 1 & 2.

Further examples of the species are observed in another reddish rock from Charkeui, in the same neighbourhood, and obscure casts are present on a white limestone from San Stefano, near Constantinople. Beside these, matrix-casts, of various sizes and of somewhat rounder form, occur abundantly in a reddish rock accompanied by an indeterminable *Cardium*, at Yailah. Similar natural casts are frequent in a grey formation of marly character at Malgara, while a very different rock from this also comes from near Malgara, which is full of a small, globulose, thick-tested shell, probably representing the younger stage of the species (Pl. XXIV, figs. 17 & 18). Abich has figured some very rounded forms of *Mactra podolica* (under the names of *M. deltoides* of Lamarck and *M. biangulata* of Pusch), from the Middle Tertiary deposits of Russian Armenia, which, although of larger size than the present specimens, may bear a relationship to them. These globulose specimens from Malgara have highly-crystalline tests, which prevent any development of internal characters, so that the dentition is not exposed. A moderate-sized example has the following dimensions:—Height = 12 millimetres; length = 13; maximum depth with closed valves = 11.

One of the samples of this rock shows indistinct traces of a *Cardium*.

Horizon.—Miocene (Sarmatian).

Localities.—Heraklitza; Charkeui; San Stefano; Yailah; near Malgara; and Dohan Aslan.

CARDIUM PROTRACTUM, Eichwald. (Pl. XXIV, fig. 19.)

*Cardium protractum*, Eichwald, 'Zoologia Specialis,' vol. i (1829) p. 283, pl. v, fig. 9; W. H. Baily, Quart. Journ. Geol. Soc. vol. xiv (1858) p. 144; A. d'Archiac, in Viquesnel's 'Voyage dans la Turquie d'Europe' vol. ii (1868) p. 480; P. Fischer, 'Faune Tertiaire Moyenne' in Tchihatcheff's 'Asie Mineure: Paléontologie' (1866) p. 356 & pl. vii, fig. 3.

This species is represented by a few well-preserved casts having a variability of contour, some being more transverse than others. It is of frequent occurrence in the marly rocks of Ghermé Tepé, Yailah, etc. Originally it was described from Podolia, but since then the species has been identified by Baily from the Crimea (specimens in the British Museum), by A. d'Archiac from Turkey, and by Fischer from the neighbourhood of the Bosphorus (between Yerlukeui and the fort of Kilia).

Horizon.—Miocene (Sarmatian).

Localities.—Yailah; north-west of Keshan (the Potteries); Ghermé Tepé, near Keshan; Yailah-Ghonué; and from a brook east of Teke-keui.

## Miocene (lacustrine Sarmatian).

Sarmatian freshwater deposits occur in the neighbourhood of Kerassia, and have yielded the following fossils:—

*Planorbis* cf. *cornu*, Brongniart.
*Limnæa*.
*Melania* cf. *Escheri*, Merian.
*Bithynia*, in association with a large flattened *Anodonta* (indet.).
*Neritina*, accompanied by the casts of a small trigonal *Unio* (= *Unio* cf. *Spratti*, Calvert & Neumayr).
*Anodonta*, a large, somewhat crushed form, in a grey marly matrix, which appears to be intermediate between the *A. cygnæa* of modern European rivers and the *A. hellespontica*[1] from the Sarmatian deposits of the Dardanelles.

The other species of Sarmatian age are as follows:—

*Planorbis cornu*, Brongniart.
*Melanopsis incerta*, Férussac. (Pl. XXIV, figs. 12 & 13.)
*Melanopsis buccinoidea*, var., Férussac.
*Melania* cf. *Escheri*, Merian. (Pl. XXIV, fig. 11.)
*Unio Delesserti*, Bourguignat. (Pl. XXIV, fig. 14.)
*Unio* sp.
Locality.—In a drab-coloured marly clay, Potamina Deré.

*Planorbis cornu*, Brongniart.
*Unio* cf. *Spratti*, Calvert & Neumayr.
*Limnocardium*.
*Corbicula*.
*Cypris*.
Locality.—In drab-coloured marly clays, from near Arabli.

*Halitherium*? (a lumbar vertebra, determined by Dr. C. W. Andrews).
*Diplomystus marmorensis*, sp. nov., A. S. Woodward (see p. 284).
*Unio* cf. *Delesserti* (impression of valve).
*Limnocardium* associated with *Cypris* (ostracoda).
Locality.—Gorgona Deré (southern end) near Sarkeui (Sea of Marmora).

The fauna here tabulated contains certain species which have been already noticed by Calvert & Neumayr,[2] Prof. R. Hœrnes,[3] etc.,

[1] P. Fischer in Tchihatcheff's 'Asie Mineure: Paléontologie' (1866) p. 349 & pl. vi, fig. 2.
[2] Denkschr. d. k. Akad. d. Wissensch. Wien, vol. xl (1880) p. 374.
[3] Sitzungsberichte d. k. Akad. d. Wissensch. Wien, vol. lxxiv (1876–77) pt. i, pp. 7–34.

as occurring in the Sarmatian deposits of the Dardanelles or of its immediate neighbourhood. Among these may be mentioned:—*Planorbis cornu*, *Melania* cf. *Escheri*, *Melanopsis buccinoidea*, var., *M. incerta*, *Unio Delesserti*, *U.* cf. *Spratti*, etc.

A freshwater deposit occurs beneath the marine *Mactra*-limestone at San Stefano, from which Col. English has obtained some excellent specimens of *Melanopsis costata* (Pl. XXIV, fig. 15), associated with fragments of an *Unio*. This alternation of marine and non-marine conditions in the Sarmatian Series has already been alluded to by Prof. Hœrnes [1] in connection with the same locality. Prof. Gaudry [2] has recorded the occurrence of *Melanopsis costata* in the lacustrine Miocene of Attica, which would suggest the contemporary deposition of these two sets of beds.

## Pisces.

Diplomystus marmorensis, sp. nov. (Pl. XXIV, fig. 28.)

The type- and only-known specimen of this new species is preserved for the most part in impression, but exhibits many of its essential features. Its total length to the extremity of the caudal fin must have been originally about 58 millimetres, while its maximum depth in the abdominal region would be 12 mm. The length of the head with the opercular apparatus is about 15 mm. The jaws are not observable; and the large orbit is the only distinct feature in the head. The slender, constricted vertebral centra are shown in longitudinal section, and seem to have been pierced by a persistent remnant of the notochord. There are about twenty-four vertebræ in the abdominal region, and fourteen in the caudal region. The ribs are moderately stout, and clearly meet the large ridge-scutes at the ventral border. There are also indications of numerous inter-muscular bones. The small pectoral fins are exhibited; and one of the pelvic fin-supports shows that the pelvic fins were inserted immediately behind a point opposite the origin of the dorsal fin. The dorsal fin is comparatively small, but comprises at least twelve rays: the distance between its termination and the caudal fin is slightly less than that between its origin and the occiput. The anal fin arises slightly behind the posterior end of the dorsal, and is not more extensive than the latter fin: its rays probably number 12. The ventral ridge-scutes, about 20 in the series, are uniform in size, and each is produced behind into a slender point. The dorsal ridge-scutes immediately behind the occiput are only seen in imperfect impressions, which appear to indicate that each was longer than broad. There are no traces of ordinary scales.

Among known species, *Diplomystus marmorensis* agrees most closely with *D. humilis*, from the Eocene Green-River Shales of Wyoming (U.S.A.), and with *D. vectensis*, from the Lower Oligocene Osborne Beds of the Isle of Wight. It is essentially identical with

[1] Verhandl. d. k.-k. Geol. Reichsanst. 1875, p. 174.
[2] 'Animaux fossils & Géologie de l'Attique' 1862, p. 406 & pl. lxii, figs. 7–15.

both these species in the number of vertebræ; and it also agrees with *D. humilis* in the characters of the ridge-scutes and the extent of its median fins. In these species, however, the head is smaller, and the dorsal fin farther forward than in the new form; while *D. vectensis* is also easily distinguished by the greater extent of its anal fin, which comprises sixteen or seventeen rays.

[A. Smith Woodward.]

Formation.—Miocene (lacustrine Sarmatian). The matrix is a light-coloured calcareous sandstone.

Locality.—Found on the surface of the ground at the southern end of Gorgona Deré, near Sarkeui (Sea of Marmora.)

## Miocene (Vindobonian = Helvetian-Tortonian).

The oldest marine Miocene shells that have been determined belong to the Helvetian-Tortonian Period, or Vindobonian (of Depéret), and were obtained from Eregli and Fakirma in the Gulf of Xeros; from near Myriophyto Deré, about 700 feet above sea-level; and from Tzenguerli Deré.

Those from Eregli include:—*Alectryonia Virleti*, Deshayes; *Ostrea lamellosa*, Brocchi; *Pecten aduncus*, Eichwald; *Anadara diluvii*, Lamarck, which is also found at Fakirma.

From Myriophyto Deré, 700 feet above sea-level:—*Ostrea crassissima.*

From Tzenguerli Deré:—*Ostrea gingensis* (Schlotheim).

These are species characteristic of the Vindobonian (= Helvetian-Tortonian) rocks of countries skirting or near the Mediterranean, such as Egypt and Northern Africa, Greece, Persia, etc. The specimens of *Pecten aduncus*, Eichwald, are well interpreted by Fuchs's figures of examples from Egypt.[1]

## Oligocene (Aquitanian & Stampian).

Some light-brown to drab-coloured sandstones have been obtained from north-west of Beyendi-keui and south-east of Lala-keui, showing dicotyledonous leaf-impressions, one of which appears to resemble *Myrica lignitum*, as identified in the British Museum (Natural History), a form common to the Parschlug Beds of Styria, and of Aquitanian age. It is, therefore, probable that these plant-remains belong to the same horizon.

The presence of Stampian Beds (or Tongrian of older authors) at Masatly and north-west of Keshan, etc., is much more certain, however, as the characteristic shell *Corbicula semistriata* (= *Cyrena subarata*, Bronn) has been determined, associated with *Melanopsis* cf. *fusiformis* and *Anthracotherium*-teeth (of small size, and possibly related to *A.* cf. *minus*, a form characteristic of the Hempstead or Stampian Beds of the Isle of Wight). The *Anthracotherium*-remains

[1] 'Beiträge zur Kenntniss der Miocänfauna Ægyptens, &c.' in 'Palæontographica' vol. xxx (1883) p. 54 & pl. xix, figs. 1–5.

are found actually in the coal-beds at Masatly accompanied by *Corbicula semistriata*, thus fixing the age of the coal as Middle Oligocene, or the Stampian stage of that Period.[1]

A single imperfect specimen of what is considered to be *Corbicula semistriata* was obtained by Mr. Claude Warner, when boring for petroleum 3 miles inland from Hora, at a depth of rather more than 1000 feet from the surface.

## Mammalia.

### Anthracotherium cf. minus, Cuvier. (Pl. XXIV, fig. 20.)

*Anthracotherium minus*, Cuvier, 'Recherches sur les Ossemens Fossiles' 2nd ed. vol. iii (1822) p. 403, & vol. v (1824) pt. ii, p. 528.
*Anthracotherium* cf. *minus*, Lydekker, 'Catal. Foss. Mammalia Brit. Mus.' pt. ii (1885) p. 242.

Remains of *Anthracotherium* associated with *Corbicula semistriata* have been found embedded in a sample of coal from Masatly. These consist of anterior molars and premolars belonging to both sides of a mandible, which are of much smaller size than those characterizing either *A. magnum* or *A. alsaticum*, being probably related to *A.* cf. *minus* occurring in the Hempstead Beds of the Isle of Wight, and provisionally identified as such by Mr. R. Lydekker from material in the British Museum (Natural History). It may be stated that Dr. C. W. Andrews agrees with this determination, and, like myself, experiences some difficulty in analysing any differences that may exist between the teeth from Hempstead and those from the Turkish locality.

Horizon.—Oligocene (Stampian).

Locality.—Masatly.

## Mollusca—Gastropoda.

### Melanopsis cf. fusiformis, J. Sowerby.

*Melanopsis fusiformis*, J. Sowerby, 'Mineral Conchology' vol. iv (1822) p. 35 & pl. cccxxxii, figs. 1–7; J. Morris, in Forbes's 'Isle of Wight' Mem. Geol. Surv. (1856) p. 156 & pl. vi, fig. 7.

The specimens referred to this form of *Melanopsis* agree remarkably well with Morris's figures published in Forbes's 'Isle of Wight.' The narrower and more elongate aperture appears to separate the

[1] *Anthracotherium* is essentially a genus of the Oligocene Period, not having been found, so far as can be ascertained, either below the Sannoisian or above the Aquitanian stages of that group of rocks. It occurs, among other European localities, in lignites of Lower Tongrian age near Gran in Hungary, as recorded by Hébert & Munier-Chalmas, associated with *Corbicula semistriata*, C. R. Acad. Sci. Paris, vol. lxxxv (1877) p. 184; and Prof. Hœrnes reports it, without however the shell, in the coal-formation of Transylvania, Verhandl. d. k.-k. Geol. Reichsanst. 1878, p. 146; while the present discovery at Masatly forms the most south-easterly point in Europe for this genus.

As the Hempstead Beds of England are correlated by Prof. Renevier, Prof. A. de Lapparent, and others with the Middle or Stampian (=Rupelian) stage of the Oligocene, it is considered that the palæontological evidence is in favour of the Masatly beds belonging to the same horizon.

species from those figured by A. d'Archiac in Viquesnel's work [1] as *M. incerta*, Férussac, var. *Melanopsis fusiformis* is characteristic of the Headon Beds of England.

Locality.—Keshan Colliery, associated with *Corbula* and indeterminable plant-remains.

Horizon.—Oligocene (Stampian) greenish marls.

### Mollusca—Lamellibranchia.

Corbicula semistriata, Deshayes. (Pl. XXIV, figs. 21–23.)

*Cytherea (?) convexa*, Brongniart, in Cuvier's 'Recherches sur les Ossemens Fossiles' 2nd ed. vol. ii (1822) pt. ii, pp. 282, 284, 458, 462, 612 & pl. viii, figs. 7 *a*–7 *b* (insufficiently defined for adoption).
*Cyrena semistriata*, Deshayes, 'Encycl. Méthod.' vol. ii (1830) pt. ii, p. 52.
*Cyrena subarata*, Bronn, 'Lethæa Geognostica' 2nd ed. vol. ii (1838) p. 958 & pl. xxxviii, fig. 2.
*Cyrena semistriata*, J. Morris, in Edw. Forbes's 'Tert. Fluv. Marine Formations of the Isle of Wight' Mem. Geol. Surv. (1856) p. 148 & pl. iii, fig. 2.

The specimens representing this species exhibit the variations of contour referred to by John Morris in 1856. Some of the valves are more equilateral, others being more obliquely produced on the posterior side; the dentition is solid, strong, and prominent, and the concentric sulcate structure is rather more pronounced on the anterior than on the posterior side of the shell.

This is a very characteristic species of the Oligocene Period, having been collected in England and in many Continental countries, such as France, Germany, Hungary, Galicia, etc. At Fontainebleau, nearly 40 miles south-east of Paris, it is abundantly found in beds which Prof. A. de Lapparent and others recognize as Middle Oligocene, or the so-called Stampian part of that system. Vacek [2] records its occurrence in the Menilit-Schiefer (= Stampian of A. de Lapparent) near Alsó-Vereczke, on the confines of Galicia, in association with *Meletta sardinites*, and considers that the beds should be synchronized with the Lower Oligocene of Schilag, in Transylvania, as described by Dr. K. Hofmann.[3] Hébert & Munier-Chalmas [4] recognized the shell in the Hungarian lignites of Gran, and Dr. E. Fournier [5] records it from the Central Caucasus. Lastly, it is well represented in the Hempstead Beds of England. As a fossil from the region of the Dardanelles, it is now known for the first time.

Horizon.—Oligocene (Stampian).

Localities.—Masatly; Harmanly; north-west of Keshan; and 3 miles inland from Hora.

Corbula sp.

A small trigonal form of *Corbula* makes up very largely the green marly rock found at Keshan. The specimens are difficult to diagnose,

[1] 'Voyage dans la Turquie d'Europe' vol. ii (1868) pl. xxiv *b*, figs. 4 & 5.
[2] Jahrb. d. k.-k. geol. Reichsanst. vol. xxxi (1881) pp. 200–202.
[3] Verhandl. d. k.-k. Geol. Reichsanst. 1881, p. 16.
[4] C. R. Acad. Sci. Paris, vol. lxxxv (1877) p. 184.
[5] Thèse présentée à la Faculté des Sciences de Paris: 'Descr. Géol. Caucase Central' (Marseille, 1896) pp. 184, 186.

as they are embedded in the matrix, and there are no clean isolated examples for examination. A large anterior tooth can be seen in one of the right valves, followed by a triangular cardinal cavity; and the external sculpture is certainly of an unequal concentric character. A. d'Archiac described *C. Saulcyi*[1] from Mal Tepé, which is larger than the present species, but in contour shows a resemblance that would suggest the possibility of the new specimens being young examples of the same.

Locality.—Keshan.

Horizon.—Oligocene (Stampian), associated with *Melanopsis* cf. *fusiformis* and indeterminable plant-remains.

### Plant-remains.

Plant-remains, in the shape of dicotyledonous leaf-impressions, have been collected in a brook lying north-west of Beyendi-keui and south-east of Lala-keui. The matrix is a sandstone varying in colour from light-brown to drab, but the specimens themselves are not determinable, and consequently they are of little use for horizonal purposes. One of them resembles *Myrica lignitum*, Heer, as represented by specimens in the British Museum (Natural History), from Parschlug in Styria: consequently, it is probable that these plant-deposits belong to the Aquitanian stage of the Oligocene.

Horizon.—Oligocene (Aquitanian?).

Indeterminable plant-remains are found associated with *Melanopsis* cf. *fusiformis* and *Corbula* sp. in the green marly rock. They are merely impressions, one having a stem-like character. These specimens bear no affinity with the sandstone plant-impressions containing the supposed *Myrica lignitum*.

Locality.—Keshan.

Horizon.—Oligocene (Stampian?).

## Eocene (Lutetian).

The following fossils, belonging to the Middle or Lutetian stage of the Eocene Period, have been determined as occurring at Tzenguerli Deré, Gorgona Deré, Vernitza, and Teke-keui.

#### Mollusca.

*Spondylus subspinosus*, D'Archiac.
*Fimbria subpectunculus* (D'Orbigny).
Locality.—Tzenguerli Deré.

#### Actinozoa.

*Cladocora* cf. *articulata*, Abich.
Locality.—Gorgona Deré.

*Trochocyathus* sp.
*Cycloseris* cf. *Perezi*, Haime.
Locality.—Vernitza.

#### Foraminifera.

*Nummulites Dufrenoyi*, D'Archiac.
*Nummulites* cf. *distans*, Deshayes.
*Nummulites* (probably) *variolaria* (Lamarck).
*Nummulites* (probably) *Heberti*, D'Archiac.
*Discocyclina* (probably) *papyracea* (Boubée).
*Discocyclina* (probably) *dispansa* (J. de C. Sowerby).
Locality.—Vernitza.

[1] See Viquesnel's 'Voyage dans la Turquie d'Europe' vol. ii (1868) p. 478 & pl. xxv *b*, fig. 13.

FORAMINIFERA (*continued*).

*Nummulites* (probably) like those from Vernitza.
*Discocyclina.*
*Orbitolites* (probably) *complanata*, Lamarck.
*Alveolina* (near to) *oblonga*, D'Orbigny.
*Textilaria.*
*Biloculina.*
*Polymorphina.*
*Miliolina.*

FORAMINIFERA (*continued*).

*Globigerina.*
Rotaline forms.

Locality.—Mount Elias.

Rock-specimen containing *Nummulites.*

Locality.—Teke-keui.

For fuller information respecting the Foraminifera, see Mr. R. Holland's Report, Appendix III, p. 292.

MOLLUSCA—LAMELLIBRANCHIA.

SPONDYLUS SUBSPINOSUS, D'Archiac. (Pl. XXIV, figs. 24 & 25.)

*Spondylus subspinosus*, D'Archiac, 'Descr. des Foss. du Groupe Nummulitique, &c.' Mém. Soc. Géol. France, ser. 2, vol. iii (1850) pt. ii, p. 437 & pl. xiii, fig. 1.

Represented by a single valve showing a regular convexity. The surface is ornamented with rounded ribs of considerable strength, separated by deep and prominent grooves, the sides of which, as well as the ribs, are covered with extremely-fine transverse striations. The specimen is imperfect on the right side, so that the exact number of ribs cannot be ascertained, but about nineteen can be counted; in all probability, therefore, the original number was about 23, that for the type-specimen being from 21 to 23. No auricles are preserved, and the ribs have been subjected to some eroding influence, as their summits are frequently smooth and not striated. Occasionally, short and thick spines are observable on the ribs, especially near the sides of the valve. The dimensions exceed those of the type, as the following comparison will illustrate:—

| | *Col. English's specimen.* | *Type.* |
|---|---|---|
| Height ............... | 60 millimetres. | 45 mm. |
| Length ............... | 52 mm. | 39 mm. |

Except in size, therefore, the specimen from Turkey appears to correspond with the type described and figured by A. d'Archiac from the Nummulitic rocks of Biarritz.

Dr. E. Fournier reports its occurrence in the Middle Eocene deposits of the Central Caucasus.[1]

Horizon.—Middle Eocene (Lutetian): matrix containing nummulites.

Locality.—Tzenguerli Deré.

FIMBRIA SUBPECTUNCULUS, d'Orbigny.

*Corbis pectunculus*, Lamarck, 'Hist. Nat. Anim. sans Vert.' vol. v (1818) p. 537; Deshayes, 'Descr. Coq. Foss. des Environs de Paris' vol. i (1824–35) p. 87 & pl. xiii, figs. 3–6.
*Corbis subpectunculus*, D'Orbigny, 'Prodrome Paléont. Strat. Univ.' vol. ii (1850) p. 387.
*Fimbria subpectunculus*, Deshayes, 'Descr. Anim. sans Vert.' vol. i (1860) p. 607.
*Corbis subpectunculus*, D'Archiac, in Viquesnel's 'Voyage dans la Turquie d'Europe' vol. ii (1868) p. 459.

Represented by a fragmentary right valve, showing the

[1] Thèse présentée à la Faculté des Sciences de Paris: 'Descr. Géol. Caucase Central' (Marseille, 1896) p. 182.

characteristic sculpture of this robust shell. The species was originally described from the Middle Eocene of France, and it was recognized by A. d'Archiac as occurring in the Eocene deposits of Sarikaia (Rumelia) and in the Crimea.[1]

Horizon.—Middle Eocene (Lutetian).

Locality.—Tzenguerli Deré.

## ACTINOZOA (CORALS).

CLADOCORA cf. ARTICULATA, Abich.

*Cladocora articulata*, Abich, 'Ueber das Steinsalz & seine geologische Stellung im russischen Armenien' Mem. Acad. Imp. Sci. St. Petersb. ser. 6, vol. ix (1859) p. 96 & pl. viii, figs. 1 *a*–1 *b*.

Specimens showing cylindrical tubes measuring 5 millimetres in diameter, which are externally covered with granulose longitudinal costæ; in these and their septal characters, so far as can be ascertained, they appear to be related to the *Cl. articulata*, as described by Abich, from the Nummulitic rocks of Russian Armenia.

Horizon.—Middle Eocene (Lutetian).

Locality.—Gorgona Deré, near Sarkeui.

TROCHOCYATHUS sp.

Small turbinate coral resembling the genus *Trochocyathus*. Diameter =15 millimetres; height =30 mm.

Horizon.—Middle Eocene (Lutetian).

Locality.—Vernitza.

CYCLOSERIS cf. PEREZI, Haime. (Pl. XXIV, figs. 26 & 27.)

*Cyclolites Borsonis*, Michelin, 'Iconographie Zoophytologique' 1840–47, p. 266 & pl. lxi, fig. 2 (*non* Michelin, pl. viii, fig. 4).

*Cycloseris Perezi*, Haime, in D'Archiac, 'Histoire des Progrès de la Géologie' vol. iii (1850) p. 229.

*Cycloseris Perezi*, Bellardi, 'Catal. raisonné des Foss. nummulitiques du Comté de Nice' Mém. Soc. Géol. France, ser. 2, vol. iv (1852) pt. ii, p. 288.

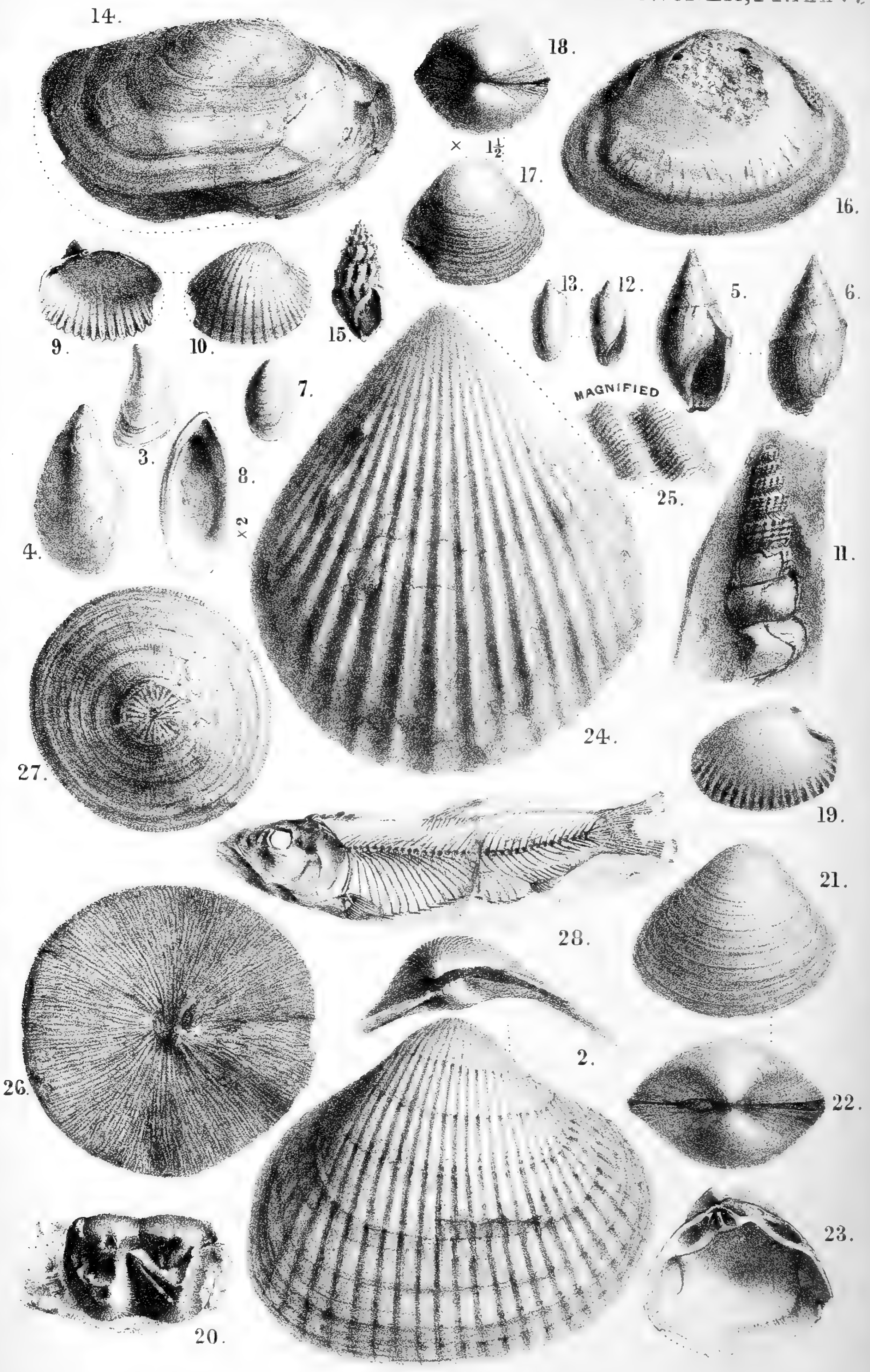
*Cycloseris Peresi*, Haime, in D'Archiac & Haime's 'Description des Animaux foss. du Groupe Nummulitique de l'Inde' vol. i (1853) p. 193.

There are three specimens belonging to the genus *Cycloseris* which are related to *C. Perezi*, a Lutetian species recognized from France and India (Scind). The calyx is subcircular, with a diameter ranging from 30 to 40 millimetres, the height of the coral being about 10 mm. The specimens are nummiform above but turbinate below, and the septa are probably more tortuous than straight (as originally described), although they are equally thin and numerous, being well exposed marginally, finely dentated, and minutely granulated on the lateral surfaces. The slightly-turbinate basal region is covered with a thin concentric epitheca, through which the costations are seen; while its central area forms a rounded horizontal section of about 9 millimetres in diameter, exhibiting a series of thickened septa, the chief of which extend to a papilla-like columella.

Horizon.—Middle Eocene (Lutetian).

Locality.—Vernitza.

[1] 'Histoire des Progrès de la Géologie' vol. iii (1850) p. 259.




F. H. Michael del. et lith.

Mintern Bros. imp.

TERTIARY FOSSILS FROM DISTRICT SURROUNDING THE DARDANELLES.

*(Nat. size, except where otherwise marked)*

## EXPLANATION OF PLATE XXIV.

[All the figures are drawn of the natural size, except where otherwise stated. The specimens are preserved in the British Museum (Natural History).]

*Didacna crassa*, Eichwald. (See p. 280.)
Pliocene (Sicilian): Baschesmé Bay, Gallipoli.

Fig. 1. External view of right valve.
2. View showing umbonal summit and dentition of the same valve. [L. 13661.]

*Dreissensia polymorpha*, Pallas. (See p. 280.)
Pliocene (Sicilian): Gallipoli.

3. External aspect of a left valve—the specimen is attached to a conglomeratic matrix filling the interior of a valve of *Didacna crassa*. [L. 13661.]

*Dreissensia Tschaudæ*, Andrussov. (See p. 280.)
Pliocene (Sicilian): Gallipoli.

4. Outer view of a right valve. [L. 13662.]

*Lyrcæa Bonelli* (Sismonda), Brusina. (See p. 281.)
Miocene (Pontian): from above the Nummulitic Limestone at a brook north of Teke-keui.

5. Front aspect, showing aperture.
6. Dorsal view of the same shell.

*Dreissensia rimestiensis*, Fontannes. (See p. 281.)
Miocene (Pontian): from above the Nummulitic Limestone at a brook north of Teke-keui.

7. External view of a right valve.
8. Inner view of a left valve, belonging to another specimen. ×2.

*Prosodacna* cf. *stenopleura*, S. Stefanescu. (See p. 281.)
Miocene (Pontian): from above the Nummulitic Limestone at a brook north of Teke-keui.

9. Interior of a right valve.
10. External view of the same specimen.

*Melania* cf. *Escheri*, Merian. (See p. 283.)
Miocene (Sarmatian): Potamina Deré.

11. Fragmentary specimen, exhibiting sculpture-characters closely resembling this species.

*Melanopsis incerta*, Férussac. (See p. 283.)
Miocene (Sarmatian): Potamina Deré.

12. Apertural view.
13. Dorsal view of the same specimen.

*Unio Delesserti*, Bourguignat. (See p. 283.)
Miocene (Sarmatian): Potamina Deré.

14. External view of a right valve.
This determination is according to D'Archiac's interpretation of Bourguignat's species from Palestine: see Viquesnel's 'Voyage dans la Turquie d'Europe' vol. ii (1868) p. 479 & Atlas, pl. xxiv, fig. 1 *a*.

*Melanopsis costata*, Olivier. (See p. 284.)
Miocene (Sarmatian): found beneath the *Mactra*-Limestone at San Stefano.

15. Front view of a specimen showing the characteristic sculpture of this species.

*Mactra podolica*, Eichwald. (See p. 282.)
Miocene (Sarmatian): Heraklitza, and near Malgara.

Fig. 16. Limestone-cast of a right valve, showing pallial and muscular scar-impressions (Heraklitza).
17. } Two views of an example of the small globose form which may re-
18. } present the young condition of this species (near Malgara). ×1½.

*Cardium protractum*, Eichwald. (See pp. 282–83.)
Miocene (Sarmatian): Ghermé Tepe.

19. Natural cast of right valve.

*Anthracotherium* cf. *minus*, Cuvier. (See p. 286.)
Oligocene (Stampian): Masatly.

20. Coronal aspect of what is probably a 2nd molar tooth belonging to the left ramus of a mandible. [M. 8246.]

*Corbicula semistriata*, Deshayes. (See p. 287.)
Oligocene (Stampian): Masatly.

21. External aspect of the right valve of a specimen with closed valves.
22. Dorsal view of the same, showing the summits, ligament-area, &c.
23. Interior of a right valve of another specimen, exhibiting dentition, lateral sockets, etc.

*Spondylus subspinosus*, D'Archiac. (See p. 289.)
Eocene (Lutetian): Tzenguerli Deré.
(The matrix of this specimen contains nummulites.)

24. External aspect of valve, showing the strong longitudinal ribs with occasional short thick spines.
25. Magnification of sculpture-striations observed on the ribs of the left lateral region, which has been less subjected to eroding influences than other parts of the specimen.

*Cycloseris* cf. *Perezi*, Haime. (See p. 290.)
Eocene (Lutetian): Vernitza.

26. Upper surface of calyx, showing the crowded and dentated character of the septa.
27. Basal view of another specimen, exhibiting the fine costations through the thin epitheca; the dentated margin; and the central area with the thickened septa,

*Diplomystus marmorensis*, sp. nov. (See p. 284.)
Miocene (Sarmatian): Gorgona Deré (southern end).

28. Left lateral aspect.

## Appendix III.

## Notes *on* Nummulites *in the* Turkish Rocks *described by* Col. English. By Richard Holland, Esq.

[Plate XXV.]

There appear to be at least three species of nummulites (giving six forms) in the rocks from Vernitza. These are:—

1. (Pl. XXV, figs. 1–3.) A large nummulite having a width of from 45 to 50 millimetres, and a thickness of from 5 to 10 mm. It is microspheric, and there are eleven to twelve turns of the spiral

in a radius of 3 mm. The filets cloisonnaires are sinuo-striate and delicate. The chamber-ratio is irregular: $\frac{\text{Height}}{\text{Width}} = \frac{2}{1}, \frac{4}{3}$. The septal angle is about 45°. The spire is irregular after the first few turns, and the line of the spiral duplicates and coalesces occasionally.

This nummulite is identified as *Nummulites Dufrenoyi*, D'Archiac, form B.[1] De la Harpe refers *N. Dufrenoyi* to the *N. complanata* of Lamarck. It undoubtedly belongs to the *complanata*-group; but it is quite sufficiently distinct, as D'Archiac has shown, and the true *N. complanata* nowhere occurs in these rock-specimens. Moreover, the 'companion'-form of the species differs from *N. Tchihatcheffi*, D'Archiac, which is the 'companion' of *N. complanata*.

2. (Pl. XXV, fig. 4.) A moderate-sized nummulite varying in width from 8 to 10 millimetres, and having a thickness of about 5 mm. Megalospheric, with six turns of the spiral in a radius of 3 mm. Filets cloisonnaires sinuo-striate and rather coarse. Spire fairly regular. The chamber-ratio is rather irregular: $\frac{\text{Height}}{\text{Width}} = \frac{4}{5}, \frac{3}{5}$. Surface non-tuberculate, but the 'pillars' are visible as white specks on a varnished surface. Septal angle = about 50°. This nummulite occurs in great abundance in the main Nummulitic rock at Vernitza. It agrees fairly in dimensions with *N. Tchihatcheffi*, D'Archiac, but differs considerably in the general appearance of its horizontal section. It is identified as *N. Dufrenoyi*, D'Archiac, form A.

3. (Pl. XXV, fig. 5.) A microspheric nummulite, measuring about 15 mm. in width, and rather thin. Filets cloisonnaires sinuo-radiate. Delicate in its characters. The dimensions are not given, because very few specimens have been secured sufficiently well preserved for accurate measurement, and no specimen from which the thickness could be properly measured. On the other hand, a varnished specimen has furnished a fairly-good photograph of the spire, except the first few turns. This nummulite is provisionally identified as a variety of *N. distans*, Deshayes, form B.[2]

4. (Pl. XXV, fig. 6.) A megalospheric nummulite, rather smaller than No. 2, varying in width from 5 to 8 mm. and in thickness from 3 to 4 mm. The spire is regular at first, and gives seven or eight turns in a radius of 3 mm.; it then frequently becomes more or less irregular. The filets cloisonnaires are sinuo-striate, and more delicate than in No. 2. The chamber-ratio is regular: $\frac{\text{Height}}{\text{Width}} = \frac{2}{1}$; septal angle = about 75°. Although in external appearance this nummulite and No. 2 are somewhat similar, the spiral characters are strikingly different. This No. 4 is provisionally identified as a variety of *N. distans*, Deshayes, form A. A goodly number of

[1] D'Archiac & Haime, 'Description des Animaux fossiles du Groupe Nummulitique de l'Inde' 1853, p. 89 & pl. i, figs. 4*a*–4*e*.

[2] Deshayes, 'Descr. Foss. rec. en Crimée, &c.' Mém. Soc. Géol. France, vol. iii (1838) p. 68 & pl. v, figs. 20–22; D'Archiac & Haime, 'Descr. Anim. foss. Groupe Nummulitique de l'Inde' 1853, p. 91 & pl. ii, figs. 1*a–c*, 2*a*, 3*a*, 4*a*, 5*a*, & 5*b*.

specimens have been examined, but it does not occur in profusion in the rock.

5 & 6. Two very small nummulites, about 3 or 4 mm. in width. These occur in the rocks in great profusion, but they are very difficult to deal with, because of their minute size and crystalline condition. It has not been found possible hitherto to obtain good split specimens. Several have been ground down and then varnished, but they have not furnished results such as to justify the identification of the species. It is thought that there are two forms—one microspheric and one megalospheric; and roughly they resemble *N. variolaria*, Sowerby,[1] and *N. Heberti*, D'Archiac.[2]

All these nummulites are highly crystalline. Nos. 2 & 4 split readily under the usual treatment, though the process spoils nearly 50 per cent. of the specimens operated upon. When they are split the crystalline condition entirely masks the internal structure, but this is fairly well brought out by the use of a varnish of Canada balsam dissolved in benzol. Nos. 1 & 3 split with very great difficulty, and, in fact, to obtain the spiral characters of No. 3 it has been necessary to grind a specimen down to the median plane and then use varnish. In spite of the intractable nature of the specimens, Mr. H. W. Burrows, F.G.S., has kindly attempted to get some micro-photographs; and he has succeeded (by the use of the acetylene-light) in securing from opaque varnished specimens results which are highly satisfactory in the circumstances.

Associated with the nummulites in the rocks are numerous Orbitoides. It has not yet been found possible to separate out any good specimens, but a transparent section of the 'black' rock shows a few of the chambers of the median plane in one of the Orbitoides. These chambers are clearly rectangular, and the Orbitoides are Discocyclines. It is probable that the species *Orbitoides (Discocyclina) papyracea* and *O. (D.) dispansa* both occur.

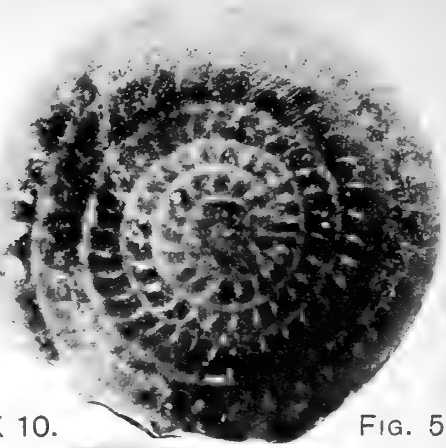
Other Nummulitic rocks from the neighbourhood of Mount Elias have also been examined. Some of them contain nummulites and Orbitoides in outward appearance not unlike those from Vernitza, but it has not been found practicable to isolate specimens good enough and numerous enough to examine them properly for purposes of identification.

Three transparent slides cut from the rocks of Mount Elias have been examined. These contain, in addition to *Nummulites* and *Orbitoides*, *Orbitolites* (probably *O. complanata*), *Alveolina* (near *A. oblonga*), numerous *Textilariæ*, *Biloculina*, *Polymorphina*, *Miliolina*, and several Globigerine and Rotaline forms.

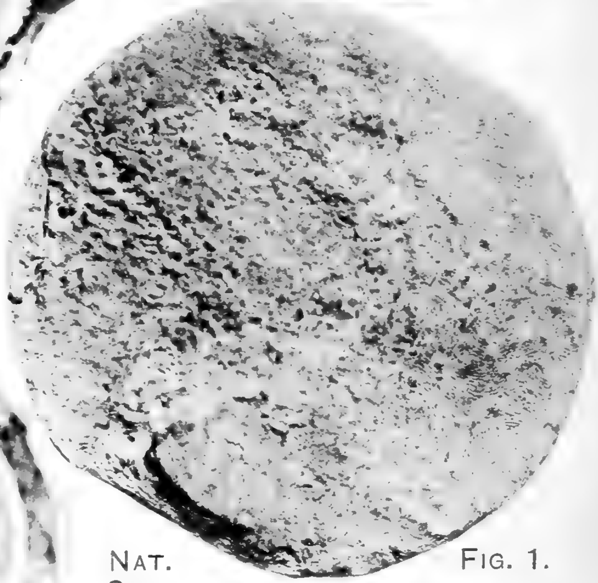
[1] Thomas Brown, 'Illustrations of the Fossil Conchology of Great Britain' 1849, p. 37 & pl. xxvi, figs. 3–5; and D'Archiac & Haime, 'Description des Animaux fossiles du Groupe Nummulitique de l'Inde' 1853, p. 146 & pl. ix, figs. 13 *a*–13 *g*.

[2] D'Archiac & Haime, *op. cit.* p. 147 & pl. ix, figs. 14 *a*–14 *g*, 15, & 15 *a*.

Fig 6. X 10.



X 10. Fig. 5.



Nat. Size. Fig. 1.

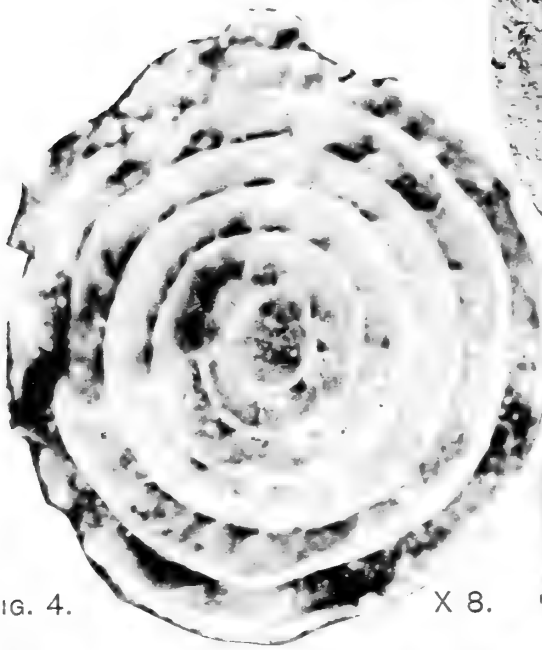


Fig. 4. X 8.

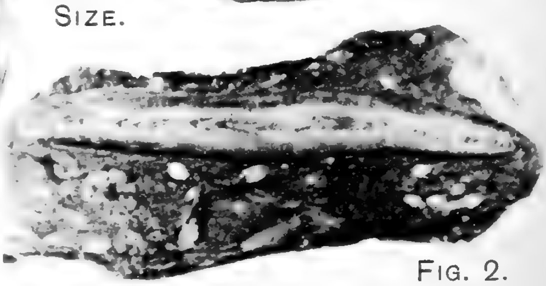
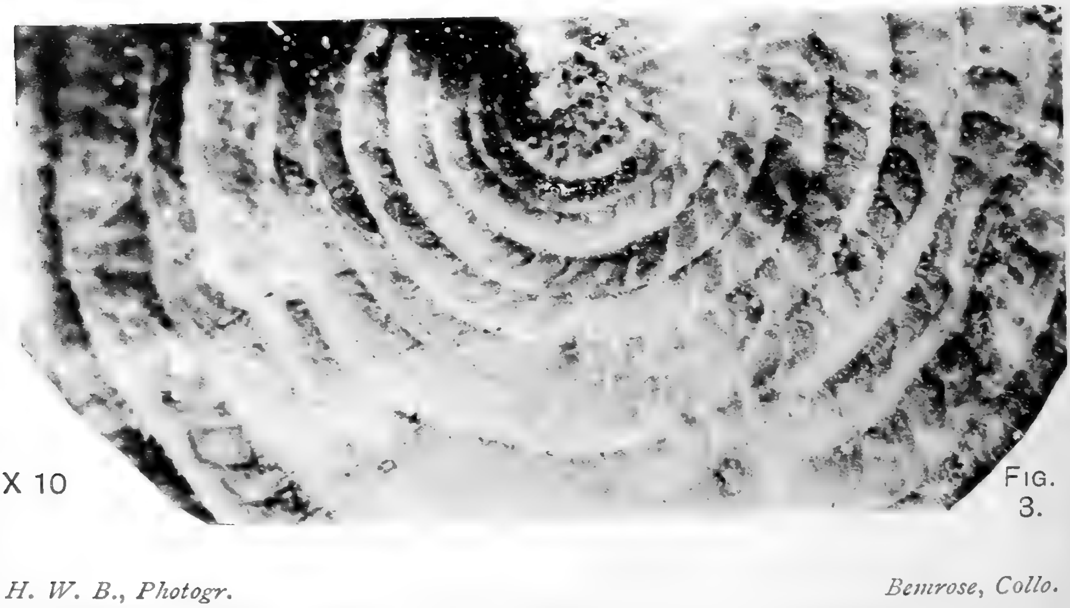


Fig. 2. Nat. Size.



X 10 Fig. 3.

*H. W. B., Photogr.* *Bemrose, Collo.*

NUMMULITES FROM THE COUNTRY SURROUNDING THE DARDANELLES.

It is deduced from other palæontological evidence that these beds are of Lutetian age. There appears to be nothing in the foraminiferal evidence to conflict with this view.

## EXPLANATION OF PLATE XXV.

Fig. 1. *Nummulites Dufrenoyi*, D'Archiac, form B. External view, showing the delicate sinuo-striate filets cloisonnaires. Natural size.
2. *N. Dufrenoyi*, D'Archiac, form B. Transverse section in matrix. Natural size.
3. *N. Dufrenoyi*, D'Archiac, form B. Segment of central whorls on the median plane of a split section. × 10.
4. *N. Dufrenoyi*, D'Archiac, form A. Central whorls on the median plane of a split section. × 8.
5. *N. distans*, var., Deshayes, form B. Central whorls on the median plane of a ground section—the first few turns wanting. × 10.
6. *N. distans*, var., Deshayes, form A. Central whorls on the median plane of a split section. × 10.

## Discussion.

The President said he considered that the paper was an excellent illustration of the value of geology in throwing light upon the origin of the present superficial features of the earth.

Dr. C. W. Andrews thought that remains of *Anthracotherium* were not of very great value for the determination of horizons, as that genus had a considerable range, and closely-allied forms occurred in the Upper Eocene and Miocene of Egypt. Nevertheless, its occurrence in the Dardanelles area was of extreme interest, and further finds might well throw considerable light on the distribution of the early Ungulates.

Mr. R. B. Newton pointed out that there could be no question as to the Oligocene age of the *Anthracotherium*-remains obtained from the coal-deposits at Masatly, since they were found associated with *Corbicula semistriata*, a very characteristic shell of that period.

Mr. A. P. Young said that it seemed likely that some of the igneous rocks exhibited would, on analysis, yield interesting results. The green pyroxene observed in one of the slides might prove to be wholly or in part a soda-iron silicate, such as frequently crystallized out from magmas in which the alumina-constituent was deficient in respect of alkalies.

The Author thanked the Fellows present for the reception accorded to his paper.

# 19. *The* History *of* Volcanic Action *in the* Phlegræan Fields.

By Prof. Giuseppe de Lorenzo, of the Royal University of Naples.[1] (Communicated by Sir Archibald Geikie, Sc.D., Sec.R.S., V.P.G.S. Read April 13th, 1904.)

[Plates XXVI–XXVIII: Maps & Sections.]

Contents.



## I. Introduction.

The scene that discloses itself to the observer who enters the Bay of Naples by the so-called Bocca Grande, presents three parts, each characterized by distinct features. On the right, masses of calcareous pink and white rock rise up into the Island of Capri from the foam-flecked waters of the Mediterranean, and stretch through Sorrento and Amalfi to the cloud-capped Apennine. On the left, a vast succession of undulating ridges of tawny-coloured tuff begins, first at the Island of Ischia, and then, extending through Vivara and Procida, spreads out into the gentle declivities upon which Naples is built. In the central background looms grand and solemn the smoking peak of Vesuvius.

Just as these three components of the landscape are diverse in aspect, so too are they diverse in geological origin and constitution. The island of Capri and the peninsula of Sorrento are made up of a gigantic pile of dolomitic and calcareous deposits of Upper Triassic (Hauptdolomit) and of Cretaceous (Urgonian - Turonian) age. Upon these rest in places a few insignificant patches of Eocene-Miocene Flysch. Vesuvius is a typical volcano of concentric accumulation (vulcano a recinto), almost entirely built up of leucotephritic, fragmental, and lava-form materials. Between Naples and Ischia lies a vast and complex assemblage of extinct craters, which have erupted much fragmental material but little lava, generally of a trachy-andesitic character, though exceptionally the crater of Vivara has disgorged a basaltic magma.[2]

This region, more especially that portion of it lying between Naples, Cuma, and Miseno, received from the early Greek colonists the name of the Phlegræan Fields. These men, as they beheld the titanic warfare between the subterranean volcanic forces and the calmer agencies of the atmosphere, pictured it as a great battle

[1] Translated by the Assistant-Secretary.

[2] G. de Lorenzo & C. Riva 'Il Cratere di Vivara nelle Isole Flegree' Atti R. Accad. Sci. Napoli, ser. 2, vol. x (1901) no. 8.

between the giants and the gods, terminating in the ultimate victory of the latter.

In the month of March 1903, I made some memorable excursions in this region with Sir Archibald Geikie, who urged me to give a summary of the results of my researches into its volcanic history, which might be submitted to the Geological Society of London. In now complying with this request, I am not unmindful of the many errors and omissions to which the student of so complicated an eruptive area is liable, an area wherein every new excursion propounds fresh problems and suggests unsuspected mysteries.

In order to trace this volcanic history with most satisfaction, it is desirable, first of all, to understand the geological structure of the great basin of the Bay of Naples, in which the eruptions have taken place.

## II. Origin of the Bay of Naples.

The same rocks as those which form the backbone of the Apennines constitute also the fundamental skeleton of the Neapolitan area: that is, Upper Triassic dolomites, Cretaceous dolomites and limestones, Flysch (Eocene-Miocene) sandstones and marls. These strata, the combined thickness of which is some 3300 feet, have been dislocated and fissured by the post-Eocene orogenic uplift of the Apennines.[1] While this upheaval contorted the softer deposits of the Flysch into innumerable narrow folds, or left patches of them imprisoned within and pinched into the fissures opened up in the underlying Mesozoic formations, the rigidity of these last-named rocks formed a sufficient obstacle to their plication into tightly-packed folds. Consequently they were slightly curved into broad domes and large basins, which in their turn were fractured by dynamic agencies, and the dismembered masses slipped along the fracture-planes, step-faults, etc. being thus originated.

One of these fractured basins is precisely the great calcareous hollow which, sweeping round from the Island of Capri and the Peninsula of Sorrento past the hills of Nola, Caserta, and Capua, and projecting again into the sea at Massico, embraces, as within one colossal amphitheatre, the entire Campania Felice. In Capri and Sorrento the strata dip north-westward, at Caserta westward, and at the Monte Massico south-westward. Thus they form a synclinal depression, the major axis of which, trending north-west and south-east, is some $43\frac{1}{2}$ miles long. The entire rim of this great basin is broken by huge longitudinal fractures, striking sensibly parallel with the Apennines (from north-west to south-east); and by transverse fractures perpendicular to the first-mentioned, and therefore trending south-west and north-east.

But the present configuration of the Apennine country is no longer such as it was broadly outlined by the post-Eocene uplift.

[1] For this and the subsequent observations, see G. de Lorenzo 'Studii di Geologia nell' Appennino meridionale' Atti R. Accad. Sci. Napoli, ser. 2, vol. viii (1897) no. 7.

That uplift, towards the end of the Miocene Period, raised our mountains to a level probably higher than the present one, and thus exposed them to long-continued denudation. In this way there gradually disappeared from the summits of the great broken calcareous massifs every trace of the softer Eocene and Miocene sediments, which nevertheless remained sheltered in the wide and deep synclines, and were mantled over by later deposits.

After the great uplift, this region was subjected in Pliocene times to another depression, and the sea flowed in again over the mountains. Thus it is that we find the great Pleistocene terraces carved out on Aspromonte up to an altitude of 4265 feet above the present sea-level, and in the remainder of the Apennines up to 3280 feet and more.

But when the Pliocene age came to an end, a fresh uplift marked the beginning of the Pleistocene, an uplift which is still in progress, and has been and is accompanied by seismic phenomena and by the active vulcanicity of the Southern Apennines. To such vicissitudes also the fundamental structure of the Bay of Naples has been subjected.

Confining ourselves to that portion of the area which lies nearest the volcanic formations, that is, to the Peninsula of Sorrento and the Island of Capri, we find there (as before stated) dolomites and limestones of Triassic and Cretaceous age. The Tertiary deposits have been all but completely swept away by the long-continued post-Eocene denudation, a mere patch of Eocene-Miocene Flysch now surviving on the highlands between Amalfi and Castellamare di Stabia; while another, rather larger patch, lies amid the lowlands of Sorrento and Massa, in the hollows formed by depression. Not a remnant is now left among these hills of the Upper Pliocene or the marine Pleistocene; but the blocks thrown up from the old crater of Vesuvius [1] and the artesian wells dug in Naples (at the Royal Palace and on Piazza Vittoria) prove that such deposits, containing shells nearly all of which are identical with species now living in the Bay, occur at the very bottom of the basin, beneath the deposits of volcanic material, at little more than 650 feet below the present level of the sea. We may, then, conclude that the volcanic eruptions of the Neapolitan area began somewhere between the end of the Pliocene and the beginning of the Pleistocene Period, upon the bottom of a great synclinal basin, resembling those to be seen elsewhere in the Apennines, but in part drowned by the sea.

The southern rim of this basin now projects above the waters, in the shape of the Island of Capri and the Peninsula of Sorrento. But, just as the various elevations and depressions of both island and peninsula are primarily due to the transverse and longitudinal fractures, which have broken up the calcareous massif into so

[1] H. J. Johnston-Lavis 'The Ejected Blocks of Monte Somma' Trans. Edin. Geol. Soc. vol. vi (1893) p. 314.

many fault-blocks, subsequently sculptured by atmospheric agencies: so do the Island of Capri and the Peninsula of Sorrento themselves in reality form part of a single great calcareous mass limited by the submarine contour of 3280 feet, and measuring at least 7870 feet from top to bottom, of which thickness only about 4590 feet now emerges from the waves (see Pl. XXVI).

This great mass is followed on the north-west by a second, which rises from the 3280-foot submarine contour to about 650 feet below sea-level (see Pl. XXVI & Pl. XXVII, section); and this is divided from the first by an embayment, which in all probability corresponds to a valley of transverse fracture, analogous to all the others known elsewhere in the Apennines. The character of the contours, more precipitous on the south and more gentle on the north, suggests the inference that in this submarine massif, just as in the Peninsula of Sorrento, the strata dip from south-east to north-west, and are cut off by a great fracture on the south-east. In this second mass the marine Tertiary and Quaternary sediments have been naturally better preserved, because they were more protected from erosive agencies. The blocks ejected from Monte Somma have furnished abundant evidence in favour of this conclusion.

To sum up then, the bottom of the Bay of Naples, originally moulded by the orogenic post-Eocene folding and by the post-Pliocene uplift, is chiefly composed of two great masses of limestone and dolomite, intensely fractured and dislocated, the constituent strata of which dip *en masse* towards the foci of eruption. This synclinal dip of the strata towards the volcanic centre, observable also in the Monte Vulture,[1] and at other localities, is doubtless favourable to eruptive phenomena, perhaps for the reason that it carries deeper down the dislocated material, which then becomes subject to powerful thermal agencies with the consequent production of an igneous magma. This hypothesis is, to some extent, confirmed by the fact that in the neighbouring Gulf of Salerno, where dislocations are both more considerable and more numerous than in the Bay of Naples, but in which the arrangement of the strata is anticlinal, there is not the faintest trace of eruptive phenomena. Whatever may be the origin of the deep-seated magma, certain it is that the Pleistocene submarine eruptions emerged above the sedimentary masses, dislocated and folded into a basin, in the Bay of Naples. First came those of Ischia and of other crateriform vents, which built up the whole Campanian plain with sanidine-bearing materials, which are also found heaped up at Sorrento and Capri, and along the range of the Southern Apennines. These discharges were followed by a less widespread phase of vulcanicity, represented by the trachy-andesitic rocks of the Phlegræan Fields and the leucotephritic material of Vesuvius. While, however, at the Vesuvian vent the eruptions have discharged fragmental and lavaform materials from one single

[1] G. de Lorenzo 'Studio geologico del Monte Vulture' Atti R. Accad. Sci. Napoli, ser. 2, vol. x (1901) no. 1.

persistent chimney, in the Phlegræan Fields, on the other hand, a long series of outpourings and explosions took place from many different funnels and vents. It is the object of the present paper to show that in the latter case these phenomena followed a definite order of succession, both in space and in time.

## III. The Eruptions in the Phlegræan Fields.

Taking account of its aspect and its lithological characters, as also of its stratigraphical succession, the eruptive material of the Phlegræan Fields may be divided into three principal categories, which in their turn include evidence of several secondary eruptive phases. The middle division of the three, and the most easily distinguishable, is represented by the well-known characteristic yellow tuff of Posillipo, which forms the main framework of the entire Phlegræan area. The lower division consists of all the various materials which underlie the yellow tuff, and are visible only to a very small extent. Lastly, the upper division comprises all the deposits of later formation than the yellow tuff. This threefold distinction, of petrographical and stratigraphical relations in the series of volcanic rocks in the Phlegræan Fields, points to three main epochs of volcanic activity. It is needless to add that at no single point is the series to be found complete and in the exact order of superposition. Just as the eruptive vents varied in their output, and the subsequent activity of denuding agencies varied also: so too, both in quality and quantity, the representative products of each particular period are seen to be diverse. We may consider, however, that a nearly complete type-section is available in the artesian well of the Royal Garden at Naples, sunk in 1847 at an altitude of 79 feet above sea-level, and going down to a depth of 701½ feet below sea-level, traversing therefore a thickness of 780½ feet of deposits. The section, neglecting minor details, is, in descending order, as follows:—

| | *Feet.* |
|---|---|
| 1. Humus, drift-material, pozzolana, and grey lapilli ... | 64 |
| 2. Compact yellow and greenish tuff .......................... | 264 |
| 3. Pozzolana, sands, sandy tuffs, pumice, volcanic breccias and conglomerates, intermingled with clays and marls made up also of volcanic constituents of a trachytic facies .......... | 319 |
| 4. Pipernoid grey tuff, similar to that of Sorrento and Caserta .......... | 88 |
| 5. Pleistocene clayey sands, with marine shells similar to species now living in the Bay of Naples .................. | 45½ |
| | 780½ |

Of the formations enumerated in the foregoing section, those included in No. 5 most probably represent the sedimentary platform upon which rest all the eruptive deposits of Campania. The various and complex constituents of 3 and 4 are records of the First eruptive Period, anterior to the yellow tuff. This last, included under 2, is the representative of the Second Period; and those eruptive materials which are *in situ*, included under 1, mark the Third Period.

We will now examine how the materials belonging to these three successive periods are visibly represented in the Phlegræan Fields.

## (1) First Period.

The products of this period may be divided into two great categories, corresponding to two different eruptive phases: the one, more ancient, represented by the well-known piperno and the grey pipernoid tuffs of Campania; the other, made up of alternating beds of pumice, lapilli, sands, breccias, and other volcanic accumulations. It will be well to bear in mind the distinction between these two categories.

### (*a*) Phase of the Piperno and Pipernoid Tuff.

All the broad plain of Campania and all the valleys of the neighbouring calcareous massif of the Apeninnes, from those of Capri and Sorrento to the far-off vales of Salerno, Avellino, Caserta, and Capua, are filled, to a greater or less thickness, with a grey trachytic tuff, in which are scattered small black scoriæ, resembling in appearance the well-known piperno, and consequently termed 'pipernoid tuff.' In its present situation this pipernoid tuff is the outcome of the heaping-up and consolidation, not only of detrital eruptive material, transported by aërial, and perhaps also marine, currents far from the original vents and laid down where it now lies, but likewise of such material as was, both contemporaneously and subsequently, washed down from the mountain-tops by running waters and accumulated in the valleys.

The detrital constituents of which these tuffs are made up (capable of being carried by high winds 30 miles or more away from their original source), must have been so rich in hydrofluoric, hydrochloric, and sulphuric acids, that, helped by the action of percolating waters, they acted upon the limestones against which they rested, and upon such limestone-blocks as were embedded in the tuffs, inducing extreme metamorphism therein, and thus originating the famous fluor-bearing blocks which have been studied by A. Scacchi.[1]

These tuffs, as the well-sections and the natural exposures demonstrate, rest almost directly upon the sedimentary rocks of the Campanian basin, and consequently represent the first products of eruption of that part of Campania. They were ejected from volcanoes and craters, which have been completely obliterated by later geological vicissitudes, but must have been at one time concentrated especially in the area of the Phlegræan Fields.

[1] See, in this connexion, Report of the Committee appointed for the Investigation of the Volcanic Phenomena of Vesuvius & its Neighbourhood, drawn up by H. J. Johnston-Lavis, Rep. Brit. Assoc. Adv. Sci. 1890 (Leeds) p. 397. Also W. Deecke 'Zur Geologie von Unteritalien: § 3. Der sogenannte Campanische Tuff' Neues Jahrb. vol. ii (1891) p. 286.

In that area, the work, both destructive and constructive, accomplished by later vulcanicity has been so manifold and extensive, that it is no easy task to trace the equivalent of the pipernoid tuffs. Nevertheless, a great mass of them has been found, as before described, in the artesian well sunk in the Royal Garden at Naples; and less considerable remnants are traceable in the depression that lies between the hills of Vomero and Posillipo. Also at Monte di Cuma, immediately above the great dome of trachyte which forms the base of the historic acropolis, and is perhaps contemporary with the piperno presently to be described.

Instead of the pipernoïd tuffs, we find exposed in the Phlegræan Fields as their representative the celebrated piperno. This forms the base of the Hill of the Camaldoli, and, interrupted here and there, by later deposits of yellow tuff and grey pozzolana, may be traced from the spurs of that hill for about a mile and a quarter eastward into the basin of Soccavo, and for other two-thirds of a mile northward into the basin of Pianura, divided into two beds or layers by an intervening band of breccia.

The controversy has been a lengthy one, as to whether the piperno should be regarded as a metamorphosed tuff or as a lava, and even now geologists are by no means unanimous on the point. It appears to the present writer, however, that both the geological conditions and the petrographical characters of the piperno are in favour of the conclusion that it is a trachytic schlieren-lava, the dark stripes of which are made up of such minerals as augite, ægyrine, and magnetite, while the lighter groundmass is of felspathic nature (anorthose), with a spherulitic structure and tiny microliths of ægyrine and augite. It is not claimed, however, that a sharp dividing-line can be drawn between the dark schlieren and the light groundmass.

The occurrence of the piperno at the base of the Hill of the Camaldoli leads to the supposition that this locality, which is practically in the very centre of the Phlegræan Fields, is also the site of one of the principal vents from which was ejected the pipernoid tuff of Campania. This supposition is strengthened by the fact that at that very same spot great explosive eruptions took place at a later period, to which the superposed bands of breccia bear emphatic witness, not to speak of a considerable ejection of yellow tuff. So abundant indeed was the accumulation of eruptive material, that it served to build up the present Hill of the Camaldoli, which, despite successive demolitions and degradations, still forms the most conspicuous elevation in the Phlegræan Fields.

### (*b*) Phase of the Conglomerates and Breccias.

Above the piperno and the pipernoid tuffs comes a succession of strata diverse in character, it is true, but predominantly conglomeratic, and bearing visible traces of the flow of sea-currents and of marine deposition. Whence it may be inferred that, equally perhaps with the piperno and the pipernoid tuffs, they are the products of submarine eruptions.

The series consists of ashes, sands, lapilli, and trachytic pumice, often intermingled with shell-bearing clays and marls, while intercalated among them and overlying them are conglomerates and coarse breccias of a thickness which varies with their proximity to, or distance from, the vents whence they were erupted. These breccias, to which Dr. Johnston-Lavis has applied the name of Museum Breccias, are made up of blocks of all sizes, torn indiscriminately from the underlying rocks, and therefore of extremely diverse character. Among them may be noticed, as especially abundant, blocks of obsidian, pumice, and scoriaceous trachyte: hardly less numerous are the fragments of leucitic and of metamorphosed calcareous rocks. Taken as a whole, they bear a remarkable resemblance to the breccias of the islands of Procida and Vivara,[1] and date probably from the same period as these.

In fact, we find these deposits of sandy and clayey tuff, of conglomerates and breccias, sometimes intercalated with deposits of rusty-black cinders or scoriæ, most typically developed in that part of the Phlegræan Fields which is nearest the above-mentioned islands—that is, along the entire western base of the Monte di Procida, and on the north-western flanks of the Monte di Cuma. Another remarkable deposit is that which occurs below the Camaldoli, in the shape of picturesque, precipitous, ruddy crags, seen from afar off to be clearly based on the piperno and capped by the yellow tuff. Noteworthy also is the great mass of these strata, about 330 feet of which were pierced through in the artesian boring of the Royal Garden at Naples. Finally, traces of them have been met with below the Vomero Hill, in the course of excavations made for the cable-railway from Montesanto to Vomero.

It need scarcely be added that exactly-similar deposits, overlying the pipernoid tuff, are found in the valleys of Capri, Sorrento, and other localities in Campania. But in this paper we are concerned only with those which lie near their source of origin, in the Phlegræan Fields. Here, indeed, they are exposed only at a few points, being elsewhere mantled over by the eruptive masses of the Second and Third Periods.

### (2) Second Period.

Overlying the breccias and conglomerates of the Camaldoli, of Monte di Cuma, and of Monte di Procida, are the masses of the most widespread and most characteristic geological formation to be seen in the Phlegræan Fields—the yellow tuff. This tuff, characterized by a fine cream-coloured or straw-coloured yellow tint, is a well-compacted aggregate of ashes, lapilli, and small pumice-fragments of trachytic nature. Scattered through this uniform matrix are

[1] G. de Lorenzo & C. Riva 'Il Cratere di Vivara nelle Isole Flegree' Atti R. Accad. Sci. Napoli, ser. 2, vol. x (1901) no. 8.

fairly-numerous fragments of other tufaceous rocks and lavas, with a few infrequent fragments of felspar and pyroxene-crystals. Among the rock-fragments, the most prevalent is a greenish tuff, very similar to the Epomeo tuff, which has also been met with, in place, below the yellow tuff in the artesian well of the Royal Garden. Trachytic black scoriæ, too, are scattered abundantly through the yellow tuff, diminishing in size as the distance of the exposure from the vents whence they were erupted increases, and being therefore smallest at the outermost periphery of the volcanoes.

The yellow tuff, like similar volcanic deposits, is invariably stratified in very well-marked thin bands, coinciding with the tectonic structure of the volcanic mass of which they form part. This coincidence often helps the observer to reconstruct hypothetically more than one volcanic edifice, which later cataclysms have in part destroyed, or perhaps swept entirely away. The layers, uniformly yellow, are sometimes intercalated with paler grey bands, or, where they have been exposed to surface-alteration, are sometimes covered with a sort of grey film. As a rule, however, the picturesque masses of yellow tuff stand out from afar off, and being fissured by vertical joints, form rugged and precipitous crags, such as may be seen, for instance, below the Camaldoli and at the headland of Posillipo.

The eruptions of ash, lapilli, and pumice whence these masses of yellow tuff, of an average thickness exceeding 300 feet, were derived, were generally of an explosive character. But it seems probable that lava-eruptions, though of rare occurrence, were not entirely wanting; and the products of such outbursts may well be represented by the trachytic masses, met with in the tunnels of the Cuman Railway and of the great Cloaca, which run beneath the Vomero Hill.

These eruptions, like those of the First Period (pipernoid tuff and piperno), must also have taken place under the sea. This may be inferred from the extreme and uniform compactness of the tuff, and from the non-remanié or unaltered shells of *Ostrea*, *Pecten*, and other marine organisms which occur sporadically buried in the tuff,

On account of the great uniformity of this deposit, it does not seem possible to map out any order of succession for the different eruptive vents whence the materials of which it is built up were derived. Geologically speaking, we may regard these eruptions as contemporaneous manifestations of one great phase of vulcanicity which affected the entire area of the Phlegræan Fields.

It is true that some of the volcanoes built up of yellow tuff are better preserved than others, some of which are barely recognizable. But this greater or less degree of preservation is not due so much to difference of age, as to diversity of the accidents to which the volcanoes have been subjected since their formation. Some of them were sooner upheaved above the sea and to a higher altitude, and were consequently exposed to longer and more destructive atmospheric erosion. Several were broken up, or eviscerated, or overwhelmed by later eruptions, while their neighbours escaped.

For these reasons, in the following rapid enumeration of the various volcanoes built up of yellow tuff, it is thought best to adopt a topographical arrangement.

### The Volcanoes of Yellow Tuff.

The ashes, lapilli, and pumice of which this tuff is composed, as they were erupted from various orifices scattered about the Phlegræan area, were heaped up around these vents in obedience to the laws of projective energy and gravity, forming therefore so many cones, rather broad and flat than otherwise, with wide and deep craters. In these cones, the material, being uniform in character, accumulated in layers, the major portion of which coincided in inclination with the external slope of the cone; while the remainder was stratified conformably with the internal crater-slope. This structure is in accordance with the law of the formation of detritic volcanoes, whereof Monte Nuovo is a notable example.

After their formation, these cones of yellow tuff, together with the underlying rock-platform, were upheaved above the waves of the sea, and each in turn fell a prey to the destructive agencies of the atmosphere, which proved to be more relentless in their attack at some points than at others. Moreover, within the area of the Phlegræan Fields later vents of eruption opened, (with which I shall deal when describing the Third Period), and by their explosive energy rent and dislocated such of the cones of yellow tuff as lay in their way, and overwhelmed and covered them with fresh erupted material. Thus it is that what we now behold are the mere fragmentary ruins of the volcanoes of yellow tuff, and yet they form the most important and conspicuous feature in the scenery of the Phlegræan Fields.

The southernmost, perhaps, of these volcanoes of yellow tuff still submerged beneath the sea are represented by the two shoals of Mezzogiorno and Penta Palummo, which, at distances of $1\frac{1}{4}$ and $2\frac{1}{2}$ miles respectively from Cape Miseno, rise from a depth of some 300 feet to within 164 and 98 feet respectively from the surface of the sea, and betray by their conical form their volcanic origin. But we may pass on from these to the consideration of those unmistakable volcanoes which rise above the waves.

First among them is the little Islet of Nisida, which attains a height of 330 feet or so above the sea, while the roots of the volcano certainly go down to at least an equivalent depth below sea-level. The crater, into which the waves flow by a narrow breach open to the south-west, is 360 feet deep, measures 1312 feet round its upper rim, and 490 feet round its lower orifice. These dimensions are almost identical with those of the crater of Monte Nuovo, which it also resembles most strikingly in shape. The typical yellow tuff of which it is built, is unmistakably stratified with a quaquaversal dip along the external slope of the cone and along the inner declivity of the crater. The tuff is crowded with big black scoriæ, as is always the case in the neighbourhood of the eruptive vents, and is mantled with a thin covering of pozzolana and grey tuff, the products of the later eruptions of the Third Period. The volcano of Nisida, being the smallest and the best preserved of all those that were built up of the yellow tuff, may be regarded as a type and a model for pursuing the study of the remainder.

Practically joined to Nisida by small skerries of yellow tuff, the fine hill of Posillipo towers above the sea with its perpendicular walls some 500 feet high, and its long picturesque summit-ridge stretching inward to Naples. This hill, as has been shown elsewhere,[1] represents the lateral remnants of two contiguous volcanoes, the craters of which opened on the flats of Bagnoli and Fuorigrotta. The western flanks of these volcanoes were demolished by later eruptions (probably from Agnano), while their eastern slopes have survived to form the ridge of Posillipo. In this ridge, the strata of yellow tuff dip outward or towards the south-east. Its crest, like that of every other Phlegræan hill, is crowned with soft grey tuffs and pozzolana, the varyingly-conformable and unconformable superposition of which upon the yellow tuff may be well observed in the great cuttings, and in the caves situated at Piedigrotta and at the outermost extremity of Posillipo, at Coroglio.

Separated from that ridge by a gentle syncline, the hills of the Vomero, Capodimonte, and Poggioreale rise on the north-east: they, too, are fundamentally built up of yellow tuff. The original forms of these volcanoes, however, are not easily made out in this case, as they have been masked by later eruptions and demolitions. It may be that their craters corresponded more or less to the existing curved shores of La Marinella and the Riviera di Chiaja, and that they were divided one from the other by the crest which even now (though in part demolished) projects from the Vomero into the promontory of Ecchia or Pizzofalcone, and thence into the rock-shelves and skerries of Castel dell' Ovo, which likewise consist of yellow tuff. Amid the yellow tuff of the Vomero, the excavations made for the tunnels of the Cuman Railway and for the great storm-water drain, have revealed a considerable mass of trachyte, which bears witness to the probability of lava-eruptions, if not during that period, at least during the immediately-preceding age.

The neighbouring Hill of the Camaldoli (1502 feet high), forming the most elevated summit of the Phlegræan Fields, is manifestly made up, for the greater part, of yellow tuff. This is seen on every hand below the loose grey tuffs and the pozzolana, where these rocks have been laid open in the gullies and channels which seam the northern flanks of the hill. The eruptive vents of this yellow tuff were evidently situated in the two basins of Soccavo and Pianura, which preserve to this day an unmistakable crateriform aspect.

[1] G. de Lorenzo & C. Riva 'Il Cratere di Astroni nei Campi Flegrei' Atti R. Accad. Sci. Napoli, ser. 2, vol. xi (1902) no. 8, p. 72 & fig. 5.

On the other hand, it is no easy matter to trace the original vents or apertures whence were derived the outcrops of yellow tuff which are to be observed around the Piano di Quarto up to its extreme northern boundary (where this is cut by the Via Campana); or those which crop up here and there along the beach from Bagnoli to Pozzuoli. Subsequent geological changes have obliterated every vestige of the original craters.

Between the shore and the Piano di Quarto, however, the volcano of the Gauro, the finest in the Phlegræan Fields, and one of the best-preserved of those built up of the yellow tuff, towers to a height of 1082 feet above the sea. The cone, unbroken on the north, was torn open on the east and west by two subsequent outbursts, and has been worn down on the south by the rains, the winds, and the waves of the sea, which beat against it at the time of its emergence. If we ascend the slopes of this great cone, we see on reaching the summit a vast crater yawning below us (hence the epithet, which Juvenal applied to the mountain, of *Gaurus inanis*), nearly 5000 feet wide and more than 650 feet deep. In dimensions and majesty it challenges comparison with the later, neighbouring crater of Astroni.

Of uncertain origin, again, are the outcrops of yellow tuff which occur along the western portion of the Phlegræan Fields, at Arco Felice, Bacoli, etc. up to the Monte di Cuma, near the so-called Temple of Apollo, and to the Monte di Procida, the eastern shoulder of which is capped by them.

On the other hand, the crateriform character of the Porto di Miseno and Cape Miseno is sufficiently obvious: they are both made up of yellow tuff, overlain by pozzolana and scoriæ of later eruption. The crater of Porto Miseno is all but drowned by the sea, its upper rim only emerging in part. Cape Miseno, long famous for its internal structure, laid bare on its broken-down south-western flank, emerges to the height of 544 feet above the waves, while its roots plunge down to 330 feet below them. Thus, both in dimensions and in form, it is strikingly similar to the crater of Nisida, which may be regarded as the other southern outpost of the Phlegræan Fields.

Moreover, the form of Miseno and Nisida is paralleled by that of Monte Gauro and the other yellow-tuff volcanoes, and this parallelism of form is associated with similarity of structure and petrographic composition. All of which fits in to a certain extent with their common mode of origin, namely, submarine eruptions taking place almost simultaneously over the entire Phlegræan area.

A much greater, though not perhaps an extreme, diversity is found among the later volcanoes, which arose at different points and at different times, and almost all on land in the open air.

### (3) Third Period.

It would seem that the eruptions of yellow tuff which had fashioned almost the entire framework of the Phlegræan Fields were immediately succeeded by an uplift of the whole region, and this by a somewhat lengthy period of erosion; for the later materials are everywhere, not only deposited (sometimes conformably, sometimes unconformably) upon the eroded surface of the yellow tuff, but are evidently derived on the whole from subaërial eruptions.

Thus, we no longer find in these later deposits that uniformity of composition which characterizes the yellow tuff, although they also consist predominantly of fragmental materials of a trachy-andesitic character. They show, however, both macroscopically and microscopically, a certain diversity, according to the particular eruptive vent from which any given material was derived.

Moreover, we are no longer dealing with contemporaneous eruptive vents, scattered, with some approach to regularity, over a vast area, as was the case with the vents whence issued the materials of the yellow tuff; but we can trace a distinct succession, both in time and space, with a progressive limitation and a slow diminution of vulcanicity, all preluding the moribund stage or perhaps final extinction of volcanic activity in the entire Phlegræan area.

In the succession of eruptive vents here, as is the general rule with volcanoes, a primary big vent is followed by one or more of progressively-diminishing size, a diminution accompanied by a slight shifting of the axis of eruptivity. This shifting has been sometimes confined within the circumference of the original crater-rim, and we get as a result a system of concentric craters, or crateri a recinto, as, for example: Agnano—Astroni—and the internal craters of Astroni. At other times, the shifting has been excentric, instead of concentric; and this has resulted in a series of parasitic cones on the outside of the first, as, for example, Astroni—craters of Campana; or Astroni—Cigliano. In other cases, finally, the shifting of the axis of eruptivity has been so considerable, as to leave no point of contact between the new and the old volcano, and to give rise to entirely-different systems, as, for example, Astroni and Monte Nuovo. I propose to enumerate these different volcanic systems of the Third Period, beginning with the oldest and ending with the most recent; and, wherever possible, to show an order of succession between widely-distant and often mutually-independent eruptive vents.

Around each such vent the generally-fragmental material was heaped up in the same manner as that described in connection with the yellow-tuff volcanoes. That is, crateriform girdles were built up, wherein the layers dipped centrifugally outward, and in part centripetally inward. The materials of these cones have a generally greyish tinge, and are much looser in texture than those which constitute the yellow tuff, from which they are therefore easily distinguishable. On the other hand, it is not easy to distinguish, one from the other, the products of the various volcanoes of the Third Period. Consequently, at those localities which are at some distance from the eruptive vents, and where the material has been spread out and distributed uniformly by the winds and the dynamic force of the outbursts, it is only possible to speak of ashes, lapilli, pumice, and tuffs as promiscuously derived from the central volcanoes. In a few instances only, as, for example, in the case of a small layer of manganiferous purplish ash, which occurs on the summit of the Hill of the Camaldoli and at some other localities in the Phlegræan Fields, can it be said that this particular deposit has been derived from the Astroni eruptions: the evidence for this identification being the existence, in the walls of the Astroni crater, of a thicker band of the same ash.[1] In the same manner, we may conclude that the loosely-textured grey material which almost everywhere caps the hills of yellow tuff (and is known to the quarrymen as mappamonte) is no product of disintegration or aqueous erosion, but is on the whole directly derived from the central grey-tuff volcanoes of the Phlegræan Fields.

Not always, however, did the eruptive vents of the Third Period discharge a quantity of material sufficient to build up true crateriform cones, on the type of Agnano, Astroni, Cigliano, Monte Nuovo, etc. Sometimes the outbursts merely rent asunder the ancient deposits of yellow tuff, forming in them 'craters of explosion,' round the rims of which the scanty products of the outburst accumulated. Such are the circular or semicircular cavities which occur dispersedly in the Phlegræan Fields. Thus, from the colossal example of the Piano di Quarto, with a maximum diameter of $2\frac{1}{2}$ miles, we may pass to the Piano di Torre Poerio (north of Astroni and east of the Craters of Campana), to the Piano di Teano (south-west of Monte Gauro), and thence to yet others, until we reach Avernus, the most typical of all these craters of explosion. This too, almost alone among those of the Phlegræan Fields, has furnished, besides the authigenous material erupted from it, scoriæ and blocks of leucotephrite which now form a small band among the layers of fragmental material on its northern flank.

Of course, *pari passu* with the shifting of the axis of eruptivity the craters of accumulation have occasionally alternated with those of explosion. Consequently, if we endeavour to establish a chronological sequence among the central volcanoes of the Phlegræan Fields, we must take account of both categories. A sequence of this kind, as I have said before, can only be determined with a comparative amount of relative certainty. One series, for instance, is exemplified by the contemporaneous craters of Posillipo, Soccavo, or Pianura, with which are successively and concentrically associated the craters of Agnano and Astroni, and the internal cone of the latter.

Another sequence, concentric also, may well be represented by the crater of Pianura, the explosion-crater of Torre Poerio, the

[1] G. de Lorenzo & C. Riva 'Il Cratere di Astroni nei Campi Flegrei' Atti R. Accad. Sci. Napoli, ser. 2, vol. xi (1902) no. 8, pp. 22–23.

crater of accumulation of Astroni and its internal cones. A third sequence, in part excentric and in part concentric, is furnished by Monte Gauro, the explosion-crater of Teano, and those of Avernus and Monte Nuovo. Excentric sequences, on the other hand, are exemplified in the crater of Astroni, as well as in the volcanoes of Cigliano and Campana which have arisen on its shoulder; and similarly in the volcano of Monte Gauro, with the subsidiary cones of Concola and Fondo Riccio, which are placed parasitically on its western flanks.

All these concordant sequences demonstrate, not only that eruptive activity was gradually diminishing, but that it was in general contracting towards the centre of the volcanic area; or rather, that it was shifting southward and seaward, receiving from the waters of the ocean the kinetic factor, steam.

But, leaving aside these theoretical considerations, it may be well to describe as briefly as possible the chief among the latest volcanoes of the Phlegræan Fields.

## The Volcanoes of Grey Tuff.

The greatest and most ancient of the third series of the volcanoes of the Phlegræan Fields is that of Agnano. Its broad and deep crater, about 1¼ miles across, is all but intact on the east, but is partly demolished and partly masked on the west by later outbursts, such as those which have originated the successive volcanoes of Astroni and the Solfatara. The materials of which Agnano is built up, like those of the later volcanoes, consist mainly of layers of pumice, ashes, lapilli, and soft grey tuffs, among which, on the eastern and southern flanks (Monte Spina), are also intercalated beds of scoriæ. With this volcano we may too, in all probability, associate the great mass of trachy-andesitic lava of Caprara, which, torn asunder and then mantled over by the later eruptions of Astroni, is now involved in the eastern flank of the last-named volcano. From the internal eastern flanks of Agnano thermal mineral springs well forth in great abundance. These are now canalized, and debouch by artificial channels into the sea. But about fifty years ago they united to form at the bottom of the crater a broad and shallow lake, wherein was deposited the detritus carried down from the slopes by rainwash. It was in consequence of the occurrence of these thermal springs, and of the exhalations of steam and gas associated with them, that the ancient Romans created here great baths, which might be successfully restored.

West of Agnano arise the volcanoes of Astroni and the Solfatara, the relative antiquity of which it is at present impossible to determine. The materials of the Solfatara have been completely altered by copious gaseous exhalations. Now, as such altered materials are seen underlying those of Astroni, it may be reasonably argued that the earlier eruptions of the Solfatara were perhaps anterior in date to those of Astroni. Whereas, however, the great cone of Astroni was thrown up, as it were, with one spurt and finished off in a single gigantic though brief spasm of eruptivity, followed by a few ejections of ashes and scoriæ, and by one scanty outflow of lava in the central portion of the crater: the volcano of Solfatara, on the other hand, remained active throughout a long period, giving rise to small outbursts of lava within the crater itself, and to great trachytic flows which coursed down its southern flanks as far as the sea, there forming the Monte Olibano. In the Middle Ages incandescent lava was still to be seen in the crater of Solfatara, and even at the present day its temperature is higher than that of any other eruptive vent in the Phlegræan Fields. To this long continuance is due the intense alteration, which the gases customarily occurring in fumaroles have induced in the materials of which the volcano is built up, in such wise that it forms an unique instance in the Phlegræan area. The very persistence of this activity, primarily eruptive and subsequently solfataric, leads to the inference that a local magmatic basin, larger than those of the neighbouring vents, exists beneath the Solfatara. This supposition is confirmed by the relatively-greater quantity of lava ejected from this vent than that poured out from the other volcanoes of the Phlegræan Fields, which are, indeed, predominantly built up of fragmental materials. Generally speaking, *volcanoes of detritic or of tufaceous type represent the outcome of rapid and violent explosive action*, and hence they have a much shorter life than volcanoes of the type which is mainly lavaform or mixed.

On the external north-western slopes of the great crater of Astroni two small adventitious or parasitic volcanoes are to be seen: *Cigliano* and *Campana*. The first-named is a simple cone, with a crater eroded on the south by the action of winds and rains upon the friable material of which the cone is wholly built up (ashes and small pumice). The volcano of Campana, on the other hand, belongs to the concentric type (*vulcano a recinto*), being made up of three practically-concentric rings, within the innermost of which is a small but most beautiful crater, rent on the east by a deep and narrow fissure known as *La Senga*. These three 'girdle-craters' of Campana consist of but little ash and lapilli, with a vast mass of scoriæ and bombs, red and black, of trachy-andesitic character, and increasing in quantity inwards in such wise that the latest crater, called the *Fossa Lupara*, may be said to be entirely composed of blocks of lava. It seems probable that the rending-open of the fissure of La Senga was brought about by the settling-down and cooling of these blocks.

Of practically the same type as Cigliano, that is, almost wholly built up of ashes and pumice, with a few infrequent scoriæ, is a tiny, barely perceptible *vulcanetto*, known as *Santa Teresa*, which lies on the plain of Bagnoli, south-east of the outer slopes of Agnano. Here, too, as on Cigliano, the rain-laden southerly winds have broken down and swept away the southern wall of the crater, only the northern part remaining as a crescent-shaped ridge. Little tufaceous hillocks, like that of Santa Teresa, occur at other localities in the Phlegræan Fields, as, for example, the Hill of the Crisci, between Cigliano and Campana. But they have been so greatly denuded that it is no longer possible to determine whether they are the outcome of single eruptive outbursts, or represent remnants left from the erosion of neighbouring craters.

Volcanic deposits of the same type as those of the Campana craters, that is, made up chiefly of red and black scoriæ and bombs, intermingled with fragments of pinkish-yellow tuff, are found dispersedly in the Phlegræan Fields. They invariably overlie the yellow tuff, and underlie the series of grey ashes, lapilli, and tuffs. These deposits are typically massed on the western and northern slopes of the Gauro volcano, forming the so-called Concola and the little volcano of Fondo Riccio. They constitute also the great fan of red and black scoriæ which occurs on the Cleft Mountain or Montagna Spaccata, where the ancient Via Campana runs through a deep cutting into the Piano di Quarto. Again, they are found north-east of the city of Naples, on the eastern slopes of Capodimonte, and at Santa Maria del Pianto and the Ponti Rossi. Yet although, as I have already pointed out, these deposits are lithologically very similar indeed to those of the Campana craters, they must be of much greater age, as is indicated by their structure and by their invariable infraposition below the grey tuff. At La Concola and the Fondo Riccio, the form of the crater from which they were derived may still be traced; on the other hand, not a vestige of it remains among the scoriaceous masses of Santa Maria del Pianto and the Ponti Rossi. The scoriæ of the Montagna Spaccata must have been either contemporaneous with, or of but little later date than, the explosions which gave rise to the great basin that lies east of Monte Gauro, which was possibly anterior to the crater of Astroni and to that of Agnano.

It is no easy matter, however, to determine the precise stratigraphical and chronological relations either of these scoriaceous volcanoes, or of the tuff-volcanoes which range in a direct north-and-south line, west of Monte Gauro and Monte Nuovo, from Monte Ruscello to Bacoli.

The northernmost eminence along this line, Monte Ruscello, is followed southward by a crater-ring known as Monte Grillo, which encircles the later explosive crater of Avernus, this again engirdling Monte Nuovo, the latest volcano of the series and of the entire Phlegræan Fields. South of Baia is yet another little crater of grey tuff, known as Fondi di Baia.

Naturally, the most important of the whole of this series is the crater-lake of Avernus, not only because of its dimensions and depth, but because, alone among the volcanoes of the Phlegræan area, it erupted, besides the customary ashes, lapilli, pumice, scoriæ, and blocks of the underlying yellow tuff, small scoriæ of leucotephrite, with fine crystals of leucite, which now form a thin stratum in the upper part of the northern flank of the crater. Up to a height of about 130 feet the crater of Avernus is filled with fresh water, which one day perchance percolating below ground fed the thermal springs of Tripergola, and there in September 1538 initiated the outburst of Monte Nuovo. This eruption, with its ejectamenta of ash, lapilli, pumice, and lastly phonolitic scoriæ, forms for the present the closing chapter in the history of vulcanicity in the Phlegræan Fields. With a certain amount of hesitation and uncertainty I may, perhaps, venture to summarize that history in the following table:—

Schematic Synopsis of Vulcanicity in the Phlegræan Fields.

<table>
<tr><th>Type of Eruption.</th><th>Phases.</th><th colspan="4">Eruptions of ash, lapilli, pumice, and other detritic materials.</th><th colspan="2">Eruptions of lava and scoriæ.</th></tr>
<tr><td rowspan="8">Subaërial Eruptions.</td><td rowspan="8">Third Period.</td><td colspan="4">Monte Nuovo.</td><td colspan="2">Phonolitic scoriæ of Monte Nuovo.</td></tr>
<tr><td colspan="2">Fondi di Baia.</td><td></td><td rowspan="5">Detritic eruptions of Solfatara.</td><td colspan="2" rowspan="2">Leucotephrite of Avernus.</td></tr>
<tr><td>Avernus.</td><td rowspan="3">Detritic eruptions of Cigliano, of the craters of Campana, Santa Teresa, the Crisci, etc.</td><td rowspan="3">Detritic eruptions of the internal craters of Astroni.</td></tr>
<tr><td>Monte Grillo.</td><td colspan="2" rowspan="2">Lavas and scoriæ of Monte Olibano, of the internal cones of Astroni, and of the craters of Campana.</td></tr>
<tr><td>Monte Ruscello</td></tr>
<tr><td colspan="3">Formation of the external girdle of Astroni.</td><td>Ancient lavas of the Solfatara.</td><td rowspan="3">Montagna Spaccata, Fondo Riccio, and La Concola.</td></tr>
<tr><td colspan="4">Detritic eruptions of Agnano.</td><td>Scoriæ of Monte Spina and trachytic mass of Caprara.</td></tr>
<tr><td colspan="4">Outbursts of Fuorigrotta, Soccavo, Pianura, Quarto, Teano, etc.</td><td>Scoriaceous eruptions of Santa Maria del Pianto, Ponti Rossi.</td></tr>
<tr><td rowspan="3">Submarine Eruptions.</td><td>Second Period.</td><td colspan="4">Yellow tuff of Nisida, Posillipo, Vomero, Capodimonte, the Camaldoli, Gauro, Pozzuoli, Quarto, Monte di Cuma, Procida, Porto Miseno, Capo Miseno, etc.</td><td colspan="2">(?) Trachytic masses met with in the various tunnels under the Vomero Hill.</td></tr>
<tr><td rowspan="2">First Period.</td><td colspan="4">Breccias and conglomerates of the Camaldoli, Cuma, Monte di Procida, Monte Santo, etc.</td><td colspan="2">Scoriaceous lavas and scoriæ of Monte di Procida, Monte di Cuma, etc.</td></tr>
<tr><td colspan="4">Pipernoid tuffs of the Campania.</td><td colspan="2">Piperno. Trachyte of Cuma.</td></tr>
</table>

## IV. Conclusions.

We have seen that, in the Bay of Naples, towards the end of the Pliocene and the beginning of the Pleistocene Period, while the Apennine chain was in process of uplift, eruptive phenomena which were then happening beneath the waves of the sea, over an area of local dislocation, laid the foundation of the volcanic districts that now encircle the city of Naples.

In that part of the region which is known as the Phlegræan Fields, we now behold a continuous succession of volcanic formations, the lowermost of which bear unmistakable signs of a submarine origin, while the upper deposits are just as undoubtedly of subaërial origin. The earlier deposits bear witness to phenomena of a more widespread character and of more grandiose dimensions; the later testify to a gradual diminution, both in extent and intensity, of volcanic activity.

The lowermost of these deposits of the Phlegræan Fields are the lavas and pipernoid tuffs which may be correlated with the grey tuffs that constitute the entire platform of Campania. These are followed by a series of breccias, conglomerates, and layers of scoriæ; and the whole of this earlier submarine series is overlain by the great masses of yellow tuff, which form the framework of all the hills between Naples and Cuma.

The eruption of yellow tuff was followed by an uplift, and by prolonged denudation. Later began a series of subaërial eruptions, the products of which were chiefly ashes, lapilli, and pumice (more or less loosely compacted to form grey tuffs), and also a few lavas of trachy-andesitic character.

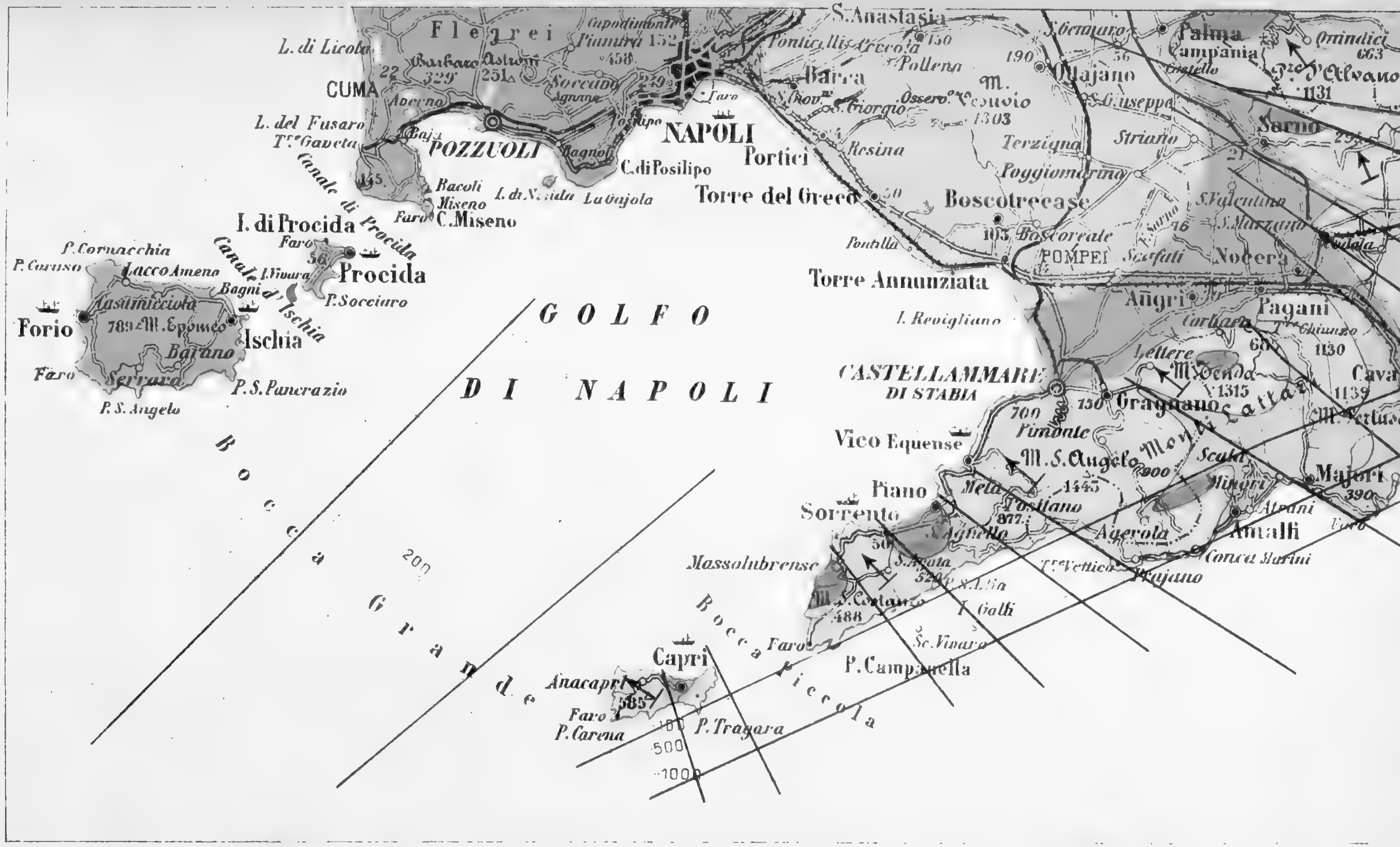
These subaërial eruptions took place over a more limited area, internal to, and shifted more southward and seaward than, the earlier eruptions. Not only was there this distinction, but the several volcanoes of the second series diminished gradually in intensity and extension, although this diminution was fitful rather than regular. They began with the great outbursts of the enormous ancient crater of Agnano, and died out in the paroxysm of Monte Nuovo.

In this manner the volcanic fires which, towards the beginning of the Pleistocene Period, glowed with such intensity over the entire Phlegræan area, are now confined to a few localities on its southern shore-line; and eruptive energy has shifted its centre a little farther southward, to Vesuvius. Volcanic action, which is always associated with orogenic movements, has in this case also followed upon the uplift of the Apennines: an uplift which, beginning in the north, has been subsequently prolonged and slackened off southward. Thus the subterranean fires which first kindled the volcanoes of the Tuscan Maremma and the Agro Romano, passing on by the Islands to the Phlegræan Fields and Vesuvius, have now travelled farther south, to the flaming Æolian Isles, and snowy Ætna, the pillar of heaven.

# GEOLOGICAL SKETCH OF THE BAY OF NAPLES

Scale of 1 : 500 000.

Quart. Journ. Geol. Soc. Pl. XXVI

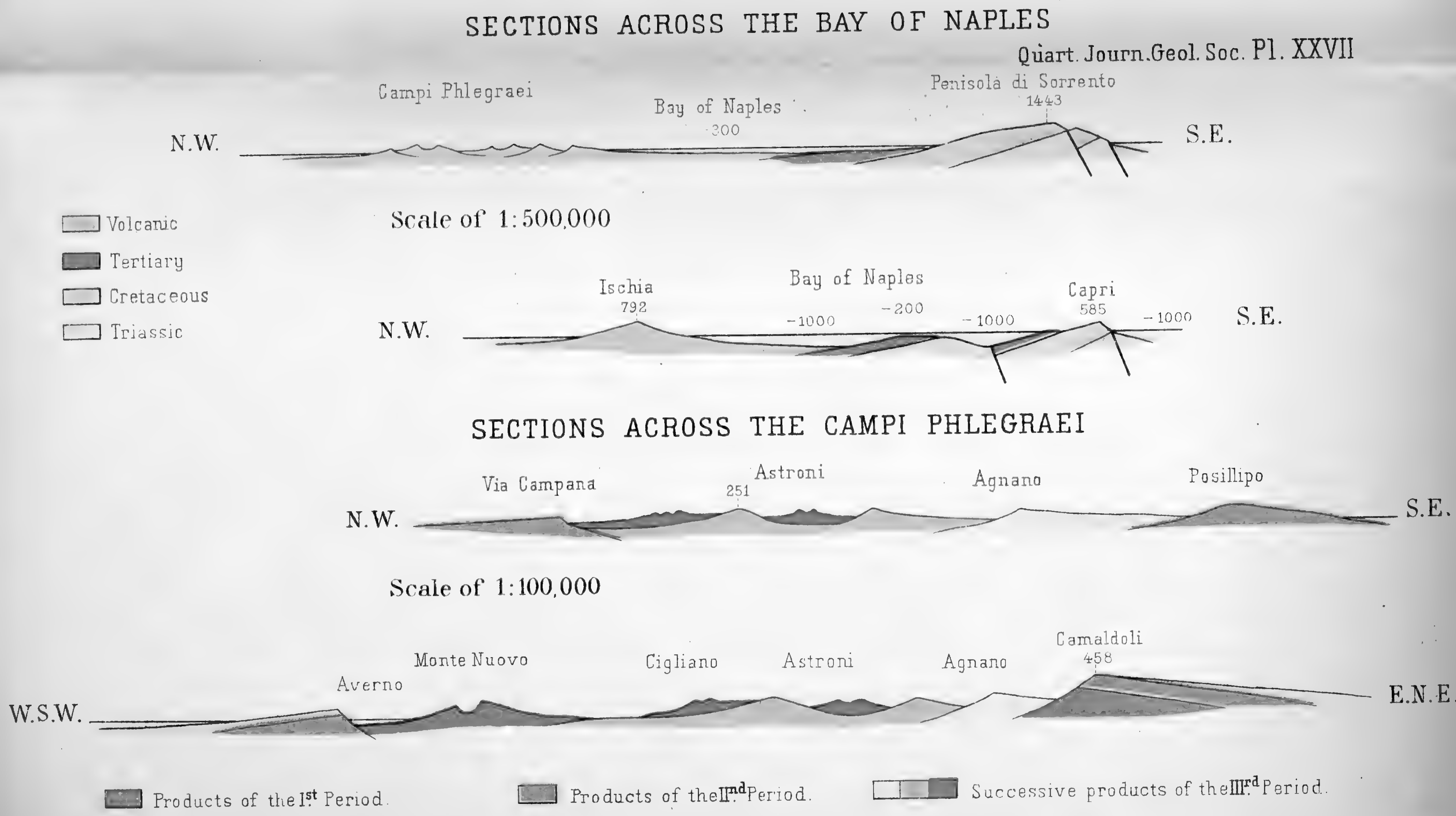



**Sedimentary Plateau**
- Tertiary Flysch.
- Cretaceous Limestones.
- Hauptdolomit (Trias).

**Volcanic Products**
- Chiefly basaltic.
- Chiefly leucotephritic.
- Chiefly trachytic.

Inclination of rocks.

Lines of the principal faults.


SECTIONS ACROSS THE BAY OF NAPLES
Campi Phlegraei
Bay of Naples
300
Penisola di Sorrento
1443
N.W.
S.E.
Scale of 1:500,000
Volcanic
Tertiary
Cretaceous
Triassic
Ischia
792
Bay of Naples
-1000
-200
-1000
Capri
585
-1000
N.W.
S.E.
SECTIONS ACROSS THE CAMPI PHLEGRAEI
Via Campana
251
Astroni
Agnano
Posillipo
N.W.
S.E.
Scale of 1:100,000
Averno
Monte Nuovo
Cigliano
Astroni
Agnano
Camaldoli
458
W.S.W.
E.N.E.
Products of the Ist Period.
Products of the IInd Period.
Successive products of the IIIrd Period.

# GEOLOGICAL SKETCH OF THE CAMPI PHLEGRAEI

Scale of 1 : 100 000.




Products of the I.st Period (Piperno, pipernoid tuffs, breccia, etc.)

Products of the II.nd Period (Yellow tuff).

Lavas and scoriae of the III.rd Period.

Ashes, lapilli, pumices and tuffs of the III.rd Period, round their vents.

Detritic products of the III.rd Period, scattered far from their vents.

Subvolcanic deposits (Dunes-, beach-, lake- and alluvium-deposits).

## EXPLANATION OF PLATES XXVI–XXVIII.

[Altitudes and soundings are expressed in metres.]

### Plate XXVI.

Geological sketch-map of the Bay of Naples, on the scale of 1 : 500,000.

### Plate XXVII.

Sections across the Bay of Naples, on the scale of 1 : 500,000; and sections across the Phlegræan Fields, on the scale of 1 : 100,000.

### Plate XXVIII.

Geological sketch-map of the Phlegræan Fields, on the scale of 1 : 100,000.

## Discussion.

The President said that he was glad to find that, owing to the application of modern methods of research, as carried out in this paper, and notwithstanding the increase of our knowledge of vulcanicity derived from such eruptions as those of Krakatoa and Tarawera, these only supplemented and did not supersede the teachings of the classical areas of the Mediterranean, including the Phlegræan Fields. It was a graceful act of the Author to send his paper to the Geological Society of a country, the geologists of which—notably Sir William Hamilton and Sir Charles Lyell—had contributed so much to our knowledge of the Phlegræan Fields.

Sir Archibald Geikie stated that, during the spring of last year, he had had an opportunity of making a number of traverses of the Phlegræan Fields with the Author, and had been so much impressed with the minuteness and breadth of his knowledge of the volcanic history of the district, that he urged him to prepare a succinct statement of this history which could be communicated to the Geological Society. The paper read this evening was the result of this request. It was a grievous loss to science when Prof. Carlo Riva, who had been associated with the Author in the preparation of two admirable detailed memoirs on portions of the Phlegræan Fields, met his tragic death two years ago. But it was hoped that Prof. De Lorenzo would himself continue the work which had been so auspiciously begun. The speaker pointed out the interesting similarity, between the sequence of volcanic events in the Neapolitan, and that in the Roman Campagna. In the latter area, the earliest eruptions, as shown by the remarkable sections laid open by the side of the Tiber to the north of Rome, took place in the Pliocene sea, probably from many submarine vents; while the latest were all subaërial, and piled up the huge cones of the Alban Hill and Bracciano. While rambling over the Roman Campagna, he (the speaker) had not been able to trace out three periods of volcanic activity, and had not found any satisfactory equivalent of the yellow tuff which makes so conspicuous a feature in the Neapolitan region. Two periods of eruption, however, submarine and subaërial, were well-developed, and possibly more detailed investigation and comparison might show the parallelism between the two areas to be even closer than it appeared.

## 20. PHENOMENA *bearing upon the* AGE *of the* LAKE *of* GENEVA.

By C. 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 11th, 1904.)

[Abstract.]

FOLLOWING up his investigations concerning the age of the principal Alpine lake-basins, the Author has, during a recent prolonged stay on the Lake of Geneva, examined the low-level gravel-beds and other alluvia in the Rhone Valley, from Geneva to the Jura-bar near Fort de l'Écluse, as well as the high-level gravel-beds of La Côte above Rolle and of the Jorat district above Lausanne, and, further, the rock-formations on both sides of the lake, in view of evidence of flexures as the primary cause of the formation of the present deep lake-basin.

After describing the phenomena around the Lake of Geneva, and comparing them with those around the Lake of Zurich, he is led to the following conclusions:—

(1) The low-level gravel-beds of the Rhone Valley near Geneva, overlying the Molasse and underlying the glacial alluvia, are, like the deep-level gravel-beds of the Limmat Valley near Zurich, fluviatile deposits of the second Interglacial Period, and were formed before the present deep lake-basin came into existence.

(2) The high-level gravel-beds of La Côte above Rolle and of the Jorat district above Lausanne are, like the corresponding deposits of the Uetliberg near Zurich, and of the Dombes and of Lyons, true Deckenschotter. Hence the term alluvion ancienne should, in its proper acceptation, only apply to the high-level deposits.

(3) The formation of the present deep lake-basin of Geneva was, like that of Zurich, primarily due to the lowering of the valley-floor by flexures of the Molasse and its contact-zones, posterior to the maximum glaciation, as evidenced more especially by the reverse dip of the old erosion-terraces between Lausanne, Vevey, and Clarens.

The Author holds that the concord of evidence in the two cases strengthens the conclusion, already arrived at by analogy in his previous paper,[1] that the Lake of Geneva, together with the other principal zonal lakes between the Alps and the Jura, was formed under similar conditions and at the same time as the Lake of Zurich, that is, towards the close of the Glacial Period; indeed, the

[1] Quart. Journ. Geol. Soc. vol. lx (1904) p. 65.

phenomena in support of that view are, in the case of the Lake of Geneva, on a grander scale, more striking, and, if anything, even more conclusive.

## Discussion.

Prof. Carl Schmidt remarked that the parallelism claimed by the Author as existing between the Lakes of Zurich and Geneva was not very clear to him: the formation of the first-named lake, at right angles to the strike of the Molasse-country, was easier to explain than that of the last-named lake. In his opinion, the structure of the Lake of Geneva might be more nearly compared with that of Lucerne: the development of the glacial formations was very similar in the two cases. He pointed out the increasing difficulty experienced in distinguishing the three formations of Schotter as one approached the Alps, and he agreed with Lugeon, Schardt, and other observers in regard to the uncertainty which attended this question. He commented on the fluctuation of opinion concerning the flexures of the Molasse, and observed that there seemed to be nowadays a tendency to revert to the older theories.

Prof. Bonney thought that the comparison of the lakes in the same Alpine zone could not fail to bring about valuable results. He had examined, in August 1891, the section below Geneva, to which the Author referred, and now read some extracts from notes written on the spot. At that time he was thinking more about the hypothesis of glacial excavation for the lake, than of the date of its formation. What he then saw, as these extracts showed, had convinced him that the gravels on either side of the Rhone must have been formed by that river and not by the Arve alone; that ice had subsequently passed over them, without any appreciable disturbance; and that the pebbles were too much rounded to have been formed by torrents flowing from the end of a glacier near at hand,—they must have travelled at least several miles. Since that date he had examined, sometimes under the Author's guidance, the gravels and morainic deposits in the Limmat Valley and elsewhere, with the result that the late date of the Alpine lakes had been gradually forced upon his mind. He realized, as plainly as any one could do, that this was a startling conclusion, but we must remember that the North American lakes showed that there had been considerable movements in comparatively-recent times, and this was not the only instance which might be quoted.

## Postcript to the Discussion.

[The Author, not having been present at the discussion, wishes to point out that Prof. Schmidt's opinion that the structure of the Lake of Geneva may be more nearly compared with that of Lucerne than with that of Zurich, is invalidated by the physiographical fact that the Lakes of Zurich and Geneva each lie in one continuous, previously-eroded river-valley; whereas the Lake of Lucerne lies in two transverse valleys composed of four different troughs, and therefore exhibits, not unlike the Lake of Lugano, a far more complicated structure than other lake-basins within the same zone. The Author fully agrees with Prof. Bonney that the bulk of the low-level gravel-beds underlying the post-Glacial and Glacial alluvia near and below Geneva is derived from the drainage-area of the Rhone Valley: apart from the pebbles of crystalline and sedimentary rocks, as well as of Nagelfluh, of that watershed, this is evidenced more especially by the striking abundance of the Valais gabbro and serpentine (from the Bagne and Saas Valleys), as well as of the green (Tavayanaz) sandstone of Diablerets; that is, of material transported and deposited, not by the Arve, but by the Rhone.—*May 21st, 1904.*]

## 21. *The* VALLEY *of the* TEIGN. By ALFRED JOHN JUKES-BROWNE, Esq., B.A., F.G.S. (Read March 9th, 1904.)

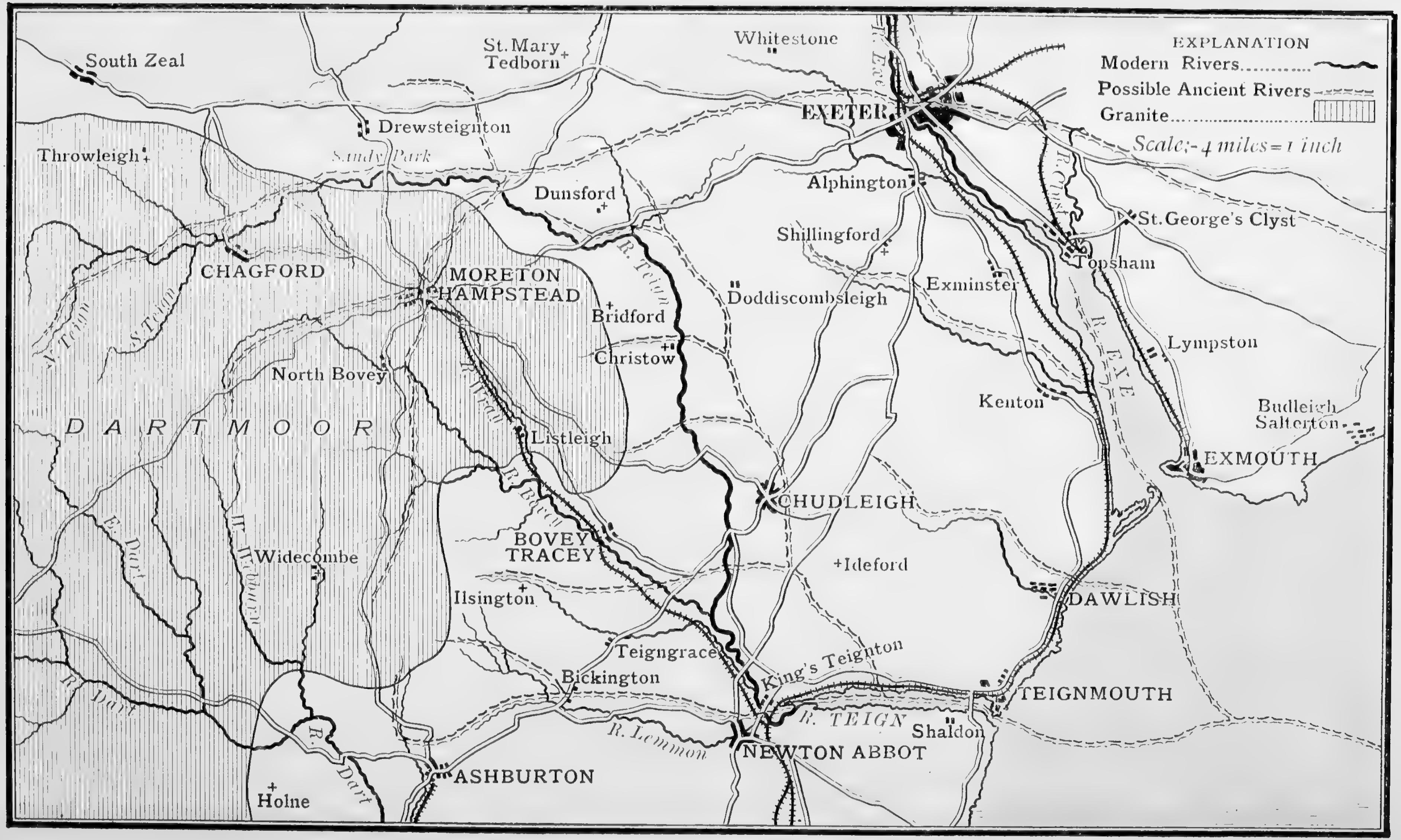
THE problem of the Teign Valley attracted my attention soon after I came to live in Devonshire; and I have lost no opportunity of considering it from different points of view, both in the study and in the field. The following pages are the outcome of this consideration, and constitute an attempt to explain the peculiar course which the river takes in passing from its sources on Dartmoor to the sea at Teignmouth.

The Teign Valley is, in fact, one of the most remarkable in the British Islands, because it is not a simple transverse valley, nor a longitudinal one between more or less parallel ridges, nor does it take such a course as the general slope or gradient of the country below its sources would suggest. On the contrary, although the earlier part of its course is in accordance with this general gradient, it afterwards takes a curve which leads it to run at right angles to its primary direction, and to traverse a depression which has the aspect of a longitudinal valley. From this it debouches into a plain; and in this plain it again turns at right angles, to pass through a gap which is clearly a transverse valley excavated out of the ridge that borders the seaward side of the longitudinal valley. This gap is now occupied by the estuary of the Teign.

As might be imagined, a valley which exhibits so curious a succession of changes presents also a variety of physical features, different parts of its course contrasting strongly with one another in this respect. The head-waters of the river are called the North Teign, and have their sources in the north-eastern part of Dartmoor, among the characteristic scenery of that district. From the high level of this area (above 1200 feet), it descends through a gorge into what has been called the Chagford Basin. Though not exactly a basin, the valley here widens out in a peculiar manner. In its eastern part, the contour-line of 600 feet recedes for some distance on both sides of the river, along a depression which crosses the valley from north-west to south-east; while the rim of the area is from 800 to 1000 feet above the sea, except at one place. The river, however, does not escape from this depression at the point where the rim is lowest, but through one of the highest parts of the rim and opposite the point where it enters. Here, also, the river leaves the granite, and has cut a deep gorge through the band of indurated Culm-Measures which borders the northern side of Dartmoor.

The gorge of the Teign runs in an easterly direction for about $3\frac{1}{2}$ miles, and the river descends about 160 feet in this distance, that is, from about 430 to 270 feet. The gorge then bends to the south-east and continues for another 2 miles, the stream falling another 64 feet in that distance. Emerging from this deep and picturesque ravine, the river takes another short turn to the east,

Fig. 1.—*Drainage-area of the River Teign.*



and then bends southward to pursue a course which brings it between the outermost granitic ridge on the one hand, and the Haldon Hills on the other hand. Its valley here is broad and open.

Near Chudleigh Knighton the Teign enters the plain of the Bovey Eocene deposits, and flows over this to Newton Abbot, where it receives the waters of the Bovey and the Lemmon; but, instead of continuing to run southward into Tor Bay, as the present features of the country would lead everyone to expect that it would have done, it turns abruptly to the east, and enters the gap in which its estuary now lies.

Such are the facts which have to be explained; and the problem is certainly not to be solved from a mere study of maps, nor from a cursory examination of the physical features of the district. It does not take long to perceive that the gap of the Teign estuary is very probably part of an ancient river-valley, excavated before the present physical features of the surrounding country had been developed. It may also be surmised that such a transverse cut is not likely to have been made by the Teign, if that river has always pursued its present course; but it is not so easy to determine what river or rivers can have made the valley of the Teign estuary, or how the modern Teign came to take the erratic course above described. The problem is also complicated by the local crust-movement which produced the Bovey Basin, although, as will be seen in the sequel, I do not think that the synclinal trough of this basin is so local as it appears to be.

This problem of the Teign Valley has interested many local geologists and observers, but has not yet received what appears to me a satisfactory explanation.

In 1867 G. W. Ormerod noticed some of the peculiarities of the Teign Valley in the pages of this Journal[1]; he recorded the presence of ancient gravels with granite-pebbles along the upper valley, and for a short distance within the gorge of the Teign (as far as Wootton Castle above Clifford Bridge), and he commented on the absence of any such 'old gravels' along the further course of the river. His explanation of the facts was that the whole gorge of the Teign was of comparatively-recent formation, and that the original course of the river was through the gap in the rim of the Chagford Basin, which I have already mentioned. His theory was, therefore, that the present valley of the Wray Brook (see fig. 1, p. 320) is the ancient valley of the Teign, and that the gorge of the Teign was opened subsequently by some 'disruption of the Carboniferous rocks since the gravels were deposited.' The idea of such a disruption is not in accord with modern methods of interpretation; and Ormerod's theory can hardly be adopted now, because if the river ever followed such a course as he suggested, one cannot see any reason why it should

[1] Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 418.

have abandoned it, and consequently the hypothesis fails to account for the deeply-cut gorge of the Teign.

A theory exists that the Teign once flowed southward by Kingskerswell into Tor Bay, and it has been attributed to Mr. J. H. Key; but this appears to be a mistake, for Mr. Key only pointed out[1] that, if the Bovey deposits were formed in a lake on the site of the present basin (as he supposed they were), the overflow of this lake must have been in the direction of Torquay. William Pengelly made a similar statement in 1863[2]; but thought it far more likely that the overflow was through the present valley towards Teignmouth. Neither of the writers just quoted said anything about the River Teign ever having run into Tor Bay, and I think that the idea of its having done so is in the highest degree improbable.

In the years 1901 and 1902, Mr. A. Somervail published several short notes on the valley of the Teign,[3] and in the last of them he concludes that 'the river Teign, or the Teign as we now know it, had not its present course marked out until long after the Oligocene'; but he does not discuss its ancient course. He refers to, and dissents from, the theory that the Teign once flowed along the Tor Valley into Tor Bay.

Still more recently, Mr. H. J. Lowe has written on 'The Teign Valley & its Geological Problems.'[4] He describes and discusses the curious basin-like depression through which the river flows between Chagford and Hunts Tor, considers but rejects the idea that it has ever been a lake, and attributes its formation to a more rapid local decay and disintegration of the granite; he dissents from Ormerod's view that the Teign originally ran out of this basin by Moretonhampstead, and concludes that its exit has always been in the direction which it now takes. He remarks:—

> 'If the river has, for the most part of its existence, followed in the main its present course, it is necessary to assume that it originally took this direction because the head-waters found a natural discharge this way along the most available slope to the sea. But this must have been many hundreds of feet above the level at which it at present runs.'

With this remark I cordially agree, and I think that, if Mr. Lowe had followed out this line of thought, he would probably have come to the conclusion that the course which the Teign now takes beyond this gorge is not likely to have been its original one.

It is certain that, before we can arrive at any satisfactory explanation of the facts, we must consider the probable conditions of the ancient surface out of which the present surface has been developed, to what extent the older rocks around Dartmoor may then have been covered by newer deposits, and what changes have been (or may have been) accomplished between that time and the present.

[1] Quart. Journ. Geol. Soc. vol. xviii (1862) p. 16.

[2] 'The Lignite of Bovey Tracey' 1863, p. 19.

[3] Trans. Devon. Assoc. vol. xxxiii (1901) pp. 517 & 521; and *ibid.* vol. xxxiv (1902) p. 528.

[4] *Ibid.* vol. xxxv (1903) p. 631.

For the date of our ancient surface we need not go farther back than the close of the Eocene Period, because it is evident, from the manner in which the Teign crosses the Eocene of the Bovey Basin, that its valley is of later date than the Eocene Period. We may reasonably conclude that it was at the beginning of Oligocene time that the present river-system of Devonshire was initiated.

I will next endeavour to picture the probable aspect of the surface of this part of England in Eocene and Oligocene times, and to estimate the extent to which it was then covered by Neozoic deposits. It is not necessary for our present purpose to consider how far the Jurassic rocks may have extended over Devonshire, because we know that they were subsequently truncated and overstepped by the Cretaceous strata; but these latter have certainly to be considered.

We know that the sea of the Selbornian Sands (='Upper Greensand') covered what are now the Haldon Hills, and must have stretched to the borders of Dartmoor. The deeper sea of the Upper Chalk must have covered a still larger area, and would have covered the greater part of Dartmoor, unless the relative levels of Dartmoor and the Haldons have been greatly altered since Cretaceous time, a contingency which is very probable. At the close of the Cretaceous Period, the West of England appears to have been raised above the sea-level, and the whole of Devonshire must have been subjected to the detrition of subaërial agents during the time represented by the break between the Cretaceous and the Eocene and by the duration of the Lower Eocene Epoch. That the granite of Dartmoor was then exposed we know, from the frequent fragments of granite and tourmaline-rock in the Haldon gravels.

The Eocene subsidence at length carried the lacustrine area of the Bournemouth Beds westward over the whole of Eastern Devonshire and over the Haldon Hills, which rise to more than 800 feet above the sea. Mr. H. B. Woodward has recorded the existence of deposits which closely resemble those of the Bovey Basin between Axminster and Lyme Regis, at an elevation of 400 feet.[1] They consist of rough flint-and-chert gravel, fine white sand, with white and mottled clays, and they are most probably of Eocene age. Similar gravels and tracts of stony clay (mapped as Clay-with-Flints) cap the tops of the many ridges which lead up from the coastal cliffs to the Blackdown Hills, and they occur also on these hills at levels of between 800 and 900 feet. Mr. W. A. E. Ussher informs me that some of the patches of clay at such levels near Otterford, Churchstanton, and Burnworthy not improbably include remnants of Eocene beds *in situ*.

A plain prolonged westward from the summits of the Blackdown Hills would pass over all the central part of Devonshire between Dartmoor and Exmoor; and as part of such a plain still remains

[1] Summ. Progr. Geol. Surv. for 1901, pp. 53-59; and Rep. Brit. Assoc. 902 (Belfast) p. 601.

on the Haldon Hills, we may reasonably conclude that the Eocene deposits did cover this central area. There is indeed some positive evidence, as will be mentioned on a future page, that this was the case.

As no patches of Chalk remain on the Blackdown or the Haldon Hills, and as the Eocene gravels there rest directly upon the Selbornian Sands, it is evident that most, if not all, of the Chalk had been removed from this central area during Lower Eocene time; so that the Eocene deposits were laid down partly on the Greensand and partly on the older rocks to the westward, the flints remaining from the destruction of the Chalk being spread out as a basement-gravel below the Bovey and Bournemouth Beds.

Here we are confronted with the difficulty created by the curious position of the Bovey Beds. This position does not seem to be explicable by faults. The beds have apparently been bent down into a deep syncline by post-Eocene movements; and as the gravels can be traced from the basin up the slopes towards the Haldon Hills, it is evident, from the map of the Geological Survey, that they here passed across the outcrops of the Selbornian and Permian on to the complex of Carboniferous and Devonian rocks which borders the granite of Dartmoor.

This transgression appears to have taken place within so short a space, that we can only suppose that the surface which is now a downward slope was then either a level floor or had a slight upward slope towards the west. Thus the space between the present termination of the Eocene gravel on Great Haldon and the similar gravel west of Ideford is only a mile, yet in this short distance the gravel has passed across the Greensand and the Permian, descending through a space of about 300 feet. It is the same on the western side of Little Haldon, where the boundary of the gravel is at about 700 feet, and the lower edge of the patch of gravel at Lindridge (resting there upon Devonian Limestone) is at about 370 feet, the space between being about a mile.

The gravel could not have overstepped the boundary of the Permian on a level surface, unless the dip of the Permian rocks was sufficient to bring in a thickness of more than 300 feet in a mile. Now, along the southern base of Little Haldon, the base of the Permian does fall through 250 feet in the space of a mile, so that the dip favoured the transgression, but is not quite enough to account for it. We must therefore assume, either that the gravel thickened in this distance by the amount of 80 feet, or, as is more probable, that there was a gentle upward slope where there is now a downward slope; and if we take the difference between 330 and 250 feet (that is, 80 feet in a mile), the slope comes out as 1 in 66.

Assuming this to have been the average slope of the ground between the plain of the Haldon Hills and the granite-ridge by Elsford, north-east of Lustleigh, a distance of $5\frac{1}{2}$ miles, we find that in Eocene times this ridge would have been 440 feet higher than the level at which gravel was being spread out over the

Haldon area. We know, too, that the Bovey Beds extend as far as Pullabrook, about a mile south of Lustleigh, and are there about 440 feet above the sea. In Eocene time, this place may have been some 500 feet above the level of the Haldon area; and this will account for the rapid increase in the thickness of the Bovey deposits to the eastward, and for the great thickness that they attain at Heathfield, where a boring traversed 520 feet without reaching their base.

I think, therefore, that we may imagine the surface-conditions of the Upper Eocene Epoch in Devonshire to have been as follows:—An extensive lake or lagoon, very little above the surface of the neighbouring sea, extending over the whole of Eastern Devonshire and across the central parts of the county north of Dartmoor; then steep slopes formed of Palæozoic rocks, up to a hill-region composed partly of such rocks and partly of the Dartmoor Granite. The subsidence of Upper Eocene time seems to have carried the lacustrine area some 600 feet or so below the level at which it stood to begin with; but probably deposition kept pace with depression, so that the water was always shallow. By this subsidence the flanks of Dartmoor were partly submerged, but the area of highland was hardly diminished.

Eocene time closed with a general upheaval of the whole British area, the greater part of England becoming dry land, and the water-space being contracted to a comparatively-narrow sea lying over parts of Hampshire, Dorsetshire, and the English Channel. This upheaval would leave the greater part of Devonshire covered with a mass of Eocene beds banked up against the highlands of Dartmoor and Exmoor.

As the only Oligocene sea that we know of lay to the east of Devonshire, it is reasonable to suppose that the prevalent slope of the western land was easterly. It is possible, indeed, that the uplift of Oligocene time was somewhat unequal, being greater in the west than in the east, so that a general easterly tilt was thus early given to the Eocene beds all over England. We cannot yet say positively when the Bovey Basin began to be formed; but I know of no special reason for connecting it with the early Oligocene upheaval, and it seems much more likely to date from a later epoch.

I conclude, therefore, that we may safely assume that when the country arose from the Eocene sea, the streams running eastward off the watershed of Dartmoor began to excavate channels through the Eocene deposits which flanked that area; and that these streams were tributaries of a great river which flowed eastward into the Oligocene sea, over a tract of land which has long since vanished and has become part of the English Channel. It follows that the streams which now run from north to south were then insignificant, and were only represented by short tributaries of the eastward-flowing rivers.

The courses of the rivers of Southern England seem to indicate the influence of two slopes, one prevailing at one time and one at another: the one slope was easterly, and the other was southerly; the latter is now the dominant slope, and consequently I think that it is of later date than the other. This brings us to consider the question of the courses which the ancestors or precursors of the Teign and other Dartmoor streams are likely to have taken.

We shall begin with the Upper Teign. That part of its course which lies through the granitic area of Dartmoor was doubtless marked out at a still earlier period, and was only being more deeply incised during Oligocene time. In all probability, also, the further part of its course, which is now stereotyped as the deeply-cut 'gorge of the Teign,' was initiated in Eocene time, and at a level far above that of the existent parallel ridges. But somewhere this high-level surface of Palæozoic rock passed beneath a superjacent, gently-sloping mass of Eocene deposits. So far as my argument is concerned, it does not matter whether the mantle of Eocene beds spread on to the granite, or whether it thinned out at lower levels: at some point in its upper course the precursor of the Teign left the surface of the older rocks and passed on to that of the Eocene beds; and the general trend of this surface we believe to have been towards the east.

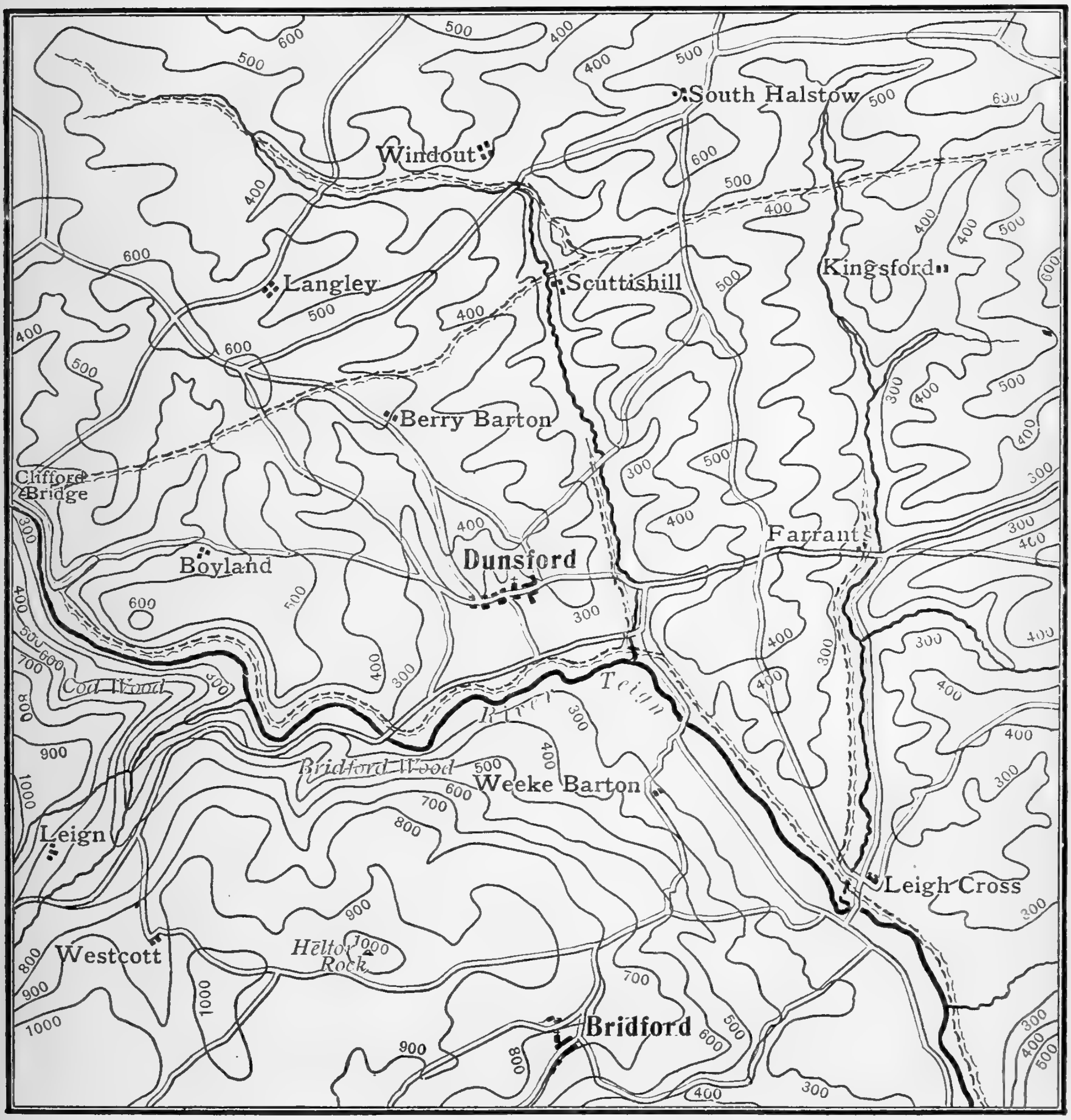
We arrive therefore at the conclusion, that beyond the confines of Dartmoor the drainage-system of Oligocene time was established upon the surface of the Eocene beds, and consequently that this drainage-system was afterwards transferred from the Eocene to the Palæozoic surface. We can also see that the courses of the rivers may have been profoundly modified in the process of transfer, not only by their encountering rocks of varying hardness in the Palæozoic complex, but also by the influence of powerful earth-movements.

If, then, the Teign continued its course over Eocene beds, and if their surface sloped eastward, it is not likely that the river at that time followed its present anomalous course; it is probable that it took a much more direct line towards, and possibly across, the valley of the Exe. The general direction of the Upper Teign, including the North Teign as the main tributary, is from west-south-west to east-north-east; near Sandy Park it changes to nearly east; while at Clifford Barton it bends to the south-east, and passes into what may be called the Lower Teign at Dunsford. My theory is that at this early period the valley of the Lower Teign had no existence, but was part of the plain which sloped gently eastward from Dartmoor across what are now the Haldon Hills, and that there was nothing to prevent the Upper Teign from continuing its easterly course; so that it may have joined or received the Exe (then a much shorter stream) somewhere about the position of Exeter.

The country to the north and south of the Teign gorge, between Sandy Park and Clifford Barton, maintains a high level, rising to over 1100 feet on the south side and to nearly 900 feet on the north side; while the highest parts of the country, between Clifford

Barton and Exeter, do not reach so much as 700 feet (see fig. 2). Consequently, if present altitudes are any guide to the general slope of the more ancient surface, the ancient Teign could easily have made its way over the country which now forms the watershed between the Lower Teign and the Alphin Brook. This I believe to have

Fig. 2.—*Map of the neighbourhood of Dunsford.*




[Scale: 1 inch = 1 mile. Contours indicated in feet. The double broken lines show the probable course of the ancient rivers.]

been its course, until certain changes took place which led to the capture of its waters by a tributary of the river that was forming the valley of the Teign Estuary.

The next point that calls for explanation, is the formation of the valley now occupied by the Estuary of the Teign. The length of this, from near Kingsteignton to Teignmouth, is about 4 miles; and its direction is from west to east, the land on the north side rising to over 800 feet, and that on the south side to about 500 feet. Mr. H. J. Lowe has suggested[1] that this valley is that of a stream which formerly ran from east to west and was a tributary of the Lower Teign, which river he supposed to have then run southward into Tor Bay; but he offers no explanation of the manner in which the slope of such a valley could have been reversed, and have become an outlet for the waters of what he regards as the main stream.

In my opinion, it is much more probable that this estuary is part of a very ancient valley, formed by a stream which ran from the eastern part of Dartmoor over the eastward-sloping plain of Eocene deposits in Oligocene time. The present Bovey Plain is a locally-depressed portion of this ancient plain, and I regard the Bovey River as a comparatively-recent development; but there is another stream which debouches into the Teign at Newton Abbot, exactly opposite to the opening of the Teign estuary. This is the Lemmon, the higher tributaries of which rise on Haytor and Bagtor Moors at a level of about 1200 feet above the sea. It is obvious that a stream rising at so high a level, and flowing eastward, could take a course that was likely to have initiated the valley of the Teign estuary, even if this valley was commenced on a plain which was coextensive with that of Little Haldon (800 feet).

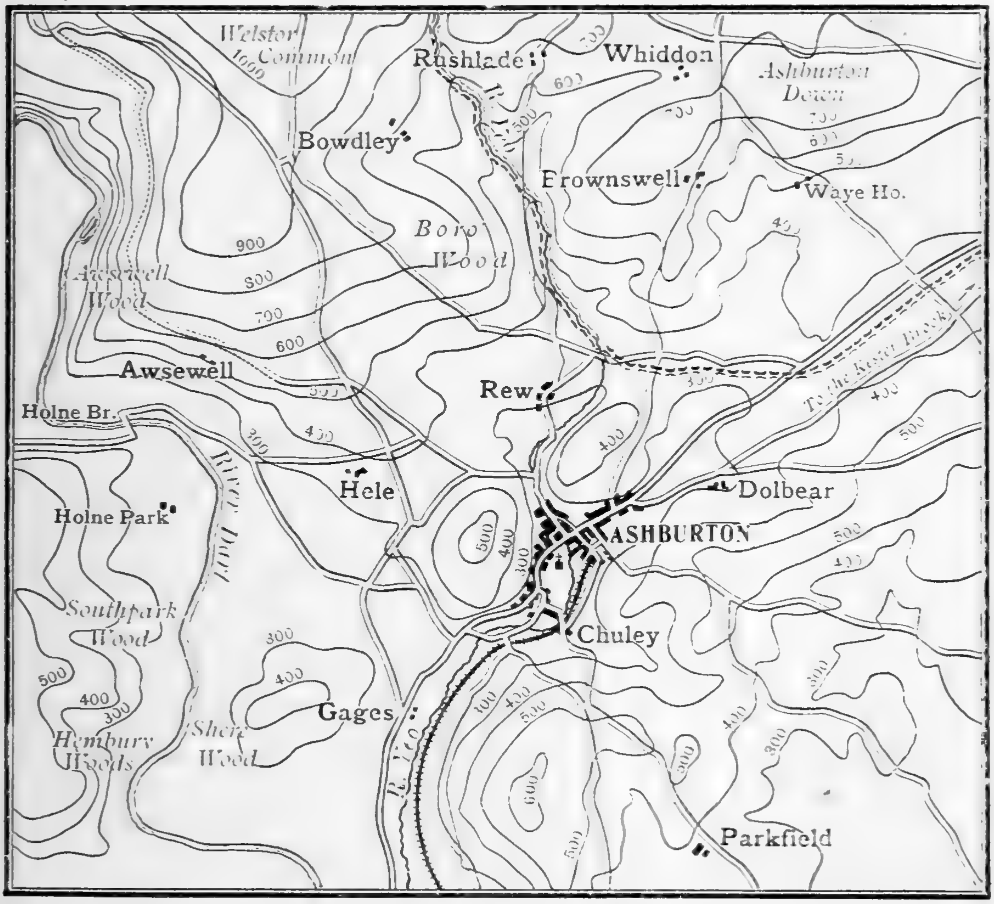
Moreover, there is some reason for believing that the Lemmon was a more powerful stream in Oligocene and Miocene times than it is now, and that its head-waters included those of the stream called the Yeo, which now runs through Ashburton to join the Dart. About 2½ miles west of Newton Abbot, the Lemmon receives a small tributary stream called the Kester Brook, which runs through a well-marked valley, but is now a small and insignificant brook. It seems to be merely a rivulet, fed partly by rainwater and partly by small springs on each side of the valley as far west as Alston Cross and Mead Farm, about a mile and a half west-north-west of Ashburton. But the valley continues beyond this point, and is fairly-well defined by the lines for the 400-feet contour on the 6-inch and 1-inch Ordnance maps (see fig. 3, p. 329). The actual watershed at the head of this valley appears to be about half a mile west of Mead Farm, and only about 15 feet higher than the centre of the valley at Mead Cross near that farm.

In the opposite direction, that is to the south-west, this *col* or gap opens into the valley of a little stream which joins the Yeo in Ashburton. On the west side of this stream is a shallow depression, which looks like a continuation of the Kester-Brook valley; and this opens into the Valley of the Yeo at Cuddaford Bridge. My suggestion is, that the valley of the Kester Brook is really the ancient valley of the River Yeo, which in early times continued the curve of its present course above Cuddaford Bridge, so as to pass through the above-mentioned depression, and thence eastward through the *col* at the head of the Kester-Brook valley.

[1] Trans. Devon. Assoc. vol. xxxv (1903) p. 645.

Of course, the existing depression and dry valley must belong to the very latest stage of this ancient course of the Yeo, just previous to its capture by a tributary of the Dart. No one could indicate precisely the course of the stream which drained the area north of Ashburton in Miocene and Oligocene times; but my contention is that the drainage of this district (which is now carried into the Dart by the Yeo) was in more ancient times directed along the line of the Kester Brook, and helped to swell the volume of the river which made the Teignmouth Valley. It is also noteworthy that the

Fig. 3.—*Map of the neighbourhood of Ashburton.*




[Scale: 1 inch = 1 mile. Contours indicated in feet. The double broken lines show the probable ancient course of the Yeo.]

Yeo rises on Dartmoor at a level of about 1200 feet, and may in ancient times have drained a larger area of the moor than it does at present. So also may the Lemmon.

We now come to the consideration of the changes which must have greatly modified the system of drainage, and, as I think, led to the diversion of certain rivers from an easterly course to a southerly one. These changes were partly regional, and partly local.

The regional change was that which greatly augmented the elevation of the Wealden anticline, and caused or increased the general southerly inclination of Salisbury Plain, of the Dorsetshire Downs, and of the Blackdown Hills. Judging from the elevation of the Older Pliocene deposits in Kent, this change did not take place till later Pliocene time.

The local change was, of course, the formation of the Bovey syncline; and there is nothing to tell us exactly when this was formed, whether in Miocene times during the general elevation of the Anglo-Gallic region, or whether it was coæval with the uplifts of later Pliocene time. I may here point out that I do not regard the synclinal flexure as confined to the Bovey Basin, but think that this basin is only a local downward bulge in the course of a much longer synclinal axis. The curious plain or depression in the granitic area around North Bovey and Moreton Hampstead, where over a tract of about 6 square miles the average level is only 800 feet above the sea, and the communication between this and the still lower basin near Chagford, of which mention has previously been made (p. 319), are in a line with the Bovey Basin, and their existence can be understood if they are regarded as due to a north-westerly extension of the Bovey syncline.

Still farther to the north-west, between Hatherleigh and Marland, there is a tract of clay, sand, and gravel unconnected with any modern river-valley; and Mr. W. A. E. Ussher informs me that these deposits bear a strong resemblance to the Bovey deposits. They may, therefore, be of the same age; and it is a curious fact that a prolongation of the north-western axis above indicated would include this tract. It is also noteworthy that such a line is roughly parallel to the watershed which runs across Devonshire, from a point south of Hartland on the north-west to Tor Bay on the south-east.

Returning now to the Valley of the Teign, let us consider the effect which the general tilting and the local flexure might have had upon the streams that we have supposed to exist in Oligocene times. Neither change could have had much effect upon the course of the Upper Teign flowing eastward from Dartmoor to the Exe; but both changes would have a strong effect upon all streams which ran from north to south, for, by increasing the fall of the ground, they would increase the velocity and the erosive power of the streams.

Such would be the case with the stream which I have called the Lower Teign, and have supposed to be a tributary of the river that flowed eastward through the Teignmouth Valley. This little stream was doubtless carving out a valley between the Haldon Hills and the granitic area west of Christow and Hennock throughout Oligocene and Miocene times. The gradual sinking of the Bovey Basin, and the increasing slope thus given to its watercourse, would cause it to deepen the higher part of its valley, and its upper tributaries would cut back deeply into the watershed separating it from the valley of the Upper Teign.

If that portion of the Teign Valley which lies between Dunsford and Clifford Bridge was originated by one of these tributaries running off the slope of a ridge then connecting Mardon Down with East Down, it seems quite possible that by the gradual detrition of the country this ridge might be reduced to a low col or pass leading from the tributary of the Lower Teign to the valley of the Upper Teign, the latter river flowing at a considerably higher level than the former. Under these circumstances a temporary obstruction in the valley of the Upper Teign, such as might be caused by a landslip, or a sudden rise of the river caused by heavy rains, might easily send its waters over the col and into the Lower Teign; and whenever this happened, the new course would probably become the permanent one, because it led down to a lower level. Such a method of 'capture' has been accepted as an explanation of alteration in the course of the Trent and in many other cases.

If the valley of the Teign Estuary was solely the work of the Lemmon and its tributaries, including the Bovey and the above-mentioned Lower Teign, they would be quite equal to the task of keeping it open, provided that the production of the Bovey syncline was accomplished slowly, so that the rate of river-erosion could keep pace with that of the relative vertical displacement.

As stated on p. 328, it is probable that the volume and power of the Lemmon was materially augmented by the accession of the river Yeo, then flowing along the line of the Kester Brook; for this would add another head of water from the high ground of Dartmoor. If this was so, then the diversion of the Yeo into the Valley of the Dart is a much more recent event than the diversion of the Upper Teign into its present course; for, what seem to be the latest stages of its accomplishment still remain well marked on the geography of the country, and thus afford an illustration of the manner in which the Lower Teign may have captured the Upper Teign.

West of Ashburton the Yeo now passes through quite a narrow cut between two hills which are higher than any of the surrounding land, one of them rising to over 500 feet; and these hills look as if they were remnants of a ridge that once extended right across the Ashburton Valley from north-west to south-east. It is certain, at any rate, that if the high ground south-east of Ashburton were united to Dartmoor by such a ridge at the present time, and if its lowest part were not less than 400 feet above Ordnance-datum, the River Yeo would at once be diverted into the valley of the Kester Brook (see fig. 3, p. 329). There is, consequently, some ground for the remark that the present features of the district harmonize very completely with the theory that the head-waters of the Yeo have been transferred from one valley to the other.

Let us imagine the Yeo flowing as I have supposed, and the Dart running more or less in its present valley, and of course cutting down to a much lower base-level than the Yeo. So long as the general slope was easterly no change would be likely to occur, and the Yeo would continue to deepen the valley through which it ran, the final form of which now remains in that of the Kester Brook.

When, however, the easterly slope was modified and dominated by the southerly tilt given to the country, as I suppose, in late Pliocene time, then every eastward-flowing stream would impinge with greater force on its southern banks and would cut deeper curves out of the southern side of its valley; at the same time, the erosive power of every little rivulet which flowed from north to south would be increased. That part of the valley of the Yeo which lies to the south of Ashburton was doubtless initiated by a tiny tributary of the Dart; and during the gradual detrition of the country, it would naturally encroach upon the watershed which lay between its head and the valley beyond. This process, even without the aid of any earth-movement, is likely to have resulted in the trenching of the dividing ridge; and as the Yeo would be cutting away the northern side of this ridge, it is likely that a time would come when it only required a flood in the valley of the Yeo to make its waters overflow into that of the little stream to the south.

The basis of this theory, by which I have tried to explain the peculiar course of the Teign and the origin of the Teignmouth Valley, is the double assumption that the country had first a general inclination to the eastward and was subsequently given a tilt to the southward; but both these assumptions are in accord with geological facts in other parts of England. They agree also with geological and geographical facts in Devonshire: the drainage-system of Dartmoor is likely to be older than that of the surrounding country; and the biggest rivers of Dartmoor rise near its western border, as they would do if the slope of the Eocene and Oligocene land was towards the east. On the other hand, the long courses of the Tamar and the Exe seem explicable on the supposition of a southerly slope, which has enabled them to extend their system of drainage towards the north. In this connection, I think that an examination of the possible relations between the head-waters of the Exe and the Tone might lead to interesting results.

I suspect that everywhere throughout Devonshire and Western Somersetshire the extension of southward-flowing rivers at the expense of eastward-flowing streams may be invoked to explain the present somewhat-complicated system of drainage. I desire, however, to guard myself against being understood to suggest that either or any of these earth-movements produced a continuous regular slope in one direction. It is quite possible that the general easterly tilt given to the whole region in Oligocene time was interrupted by undulations striking from north to south, and that, while the principal or primary rivers cut across these incipient ridges, local drainage might in some districts be directed into north-and-south lines at an earlier date than that which I have suggested.

The series of domes and basins which now exist in the South of England—I mean such as the basin of Beer and Axmouth, and the dome of the Vale of Marshwood—may have been produced by the intersection of two series of flexures, an earlier series running from north to south, and a later series from west to east; for we know that in the Hampshire Basin the east-and-west axes are of post-Oligocene date.

At the same time, I do not think that the flexures which may have crossed the Oligocene plain were more than broad undulations; and if the Beer Basin marks the site of one of these broad Oligocene synclines, I think that its western limb may have been a continuous slope up to the Dartmoor watershed. If this was the case, it is obvious that the existence of such a shallow syncline would not invalidate the explanation of the Valley of the Teign which has been suggested in the preceding pages.

I have thought it desirable to limit the scope of this paper to the Valley of the Teign and its tributaries, and to exclude the consideration of other rivers; but I wish to point out the possibility that the valley of the Teign Estuary may have been the work of the River Dart. It is a fact that the general course of the Dart across Dartmoor is such as to bring it to a point due west of Newton Abbot, and consequently opposite to the entrance of the Teign Estuary. The Dart now makes its way off Dartmoor through a deep gorge, like that of the Upper Teign; but when it was flowing over the high-level surface out of which this gorge has been cut, there is no obvious reason why it should not have continued its easterly course and have initiated the Teignmouth Valley. In such a case, the Lemmon would have been merely a tributary of the Dart, and the latter would have to be regarded as the head-source of the main Oligocene river, just as the Dorsetshire Frome was, at a later date, the head-water of the Solent River.[1]

## Discussion.

The President said that he was glad to find that the Authors of this and the preceding paper[2] were apparently inclined to refer the principal surface-features of a county chiefly composed of ancient rocks to the Tertiary Period.

Mr. H. B. Woodward remarked that papers on river-development were most difficult to follow; they reminded him of old-fashioned chess-problems where you had to mate in fifty or a hundred moves. He had read the paper, but had not had time to comprehend it fully. When he (the speaker) resided at Newton Abbot many years ago, he thought that the Lower Teign Valley had been started by overflow from the lake in which the Bovey Beds were formed. Since then, Mr. Clement Reid had seen evidence for the extension of the Eocene strata over the Haldon Hills, now in places 800 feet above sea-level; and the aspect of the subject had greatly changed, owing to the earth-movements which had to be taken into consideration. The Author, who had asked Mr. Whitaker to act as challenger, and read the paper, had desired him to be the defender and reply to criticisms, and he asked permission to read a few notes from the Author, if they were required, later on.

[1] See A. Strahan 'Geology of the Isle of Purbeck' Mem. Geol. Surv. (1898) p. 230.

[[2] C. Reid 'On the probable Occurrence of an Eocene Outlier off the Cornish Coast' Quart. Journ. Geol. Soc. vol. lx (1904) p. 113.]

Dr. A. E. Salter enquired whether the Author had studied the various superficial deposits in the area which he described, in order to ascertain whether their constituents were of such a character as to favour his views. These evidences of past fluviatile action often afforded valuable corroboration to such a hypothesis as that which had been put forward by the Author.

Mr. H. W. Monckton said that he had noticed a reference to the effect of a tilt of the ground, and he ventured to remark that mere tilting of the surface need not of necessity alter the direction of the drainage, for as the tilting proceeded the streams would deepen their channels—that is, when a drainage-system was once established. No doubt the inclination of the ground would affect the direction of streams *before* a drainage-system was established.

Mr. Whitaker said that all would agree with the previous speaker's remarks; but very big and rapid earth-movements might alter the drainage of a region. Gravel-beds might be carried off by later erosion. There had certainly been too great a tendency to consider the surface-features of a particular district ancient, because the rocks which cropped out there happened to be old. He welcomed a paper such as that under discussion, because of its suggestiveness and its usefulness in promoting further investigation.

Mr. H. B. Woodward read the following extract of a letter sent to him by the Author:—

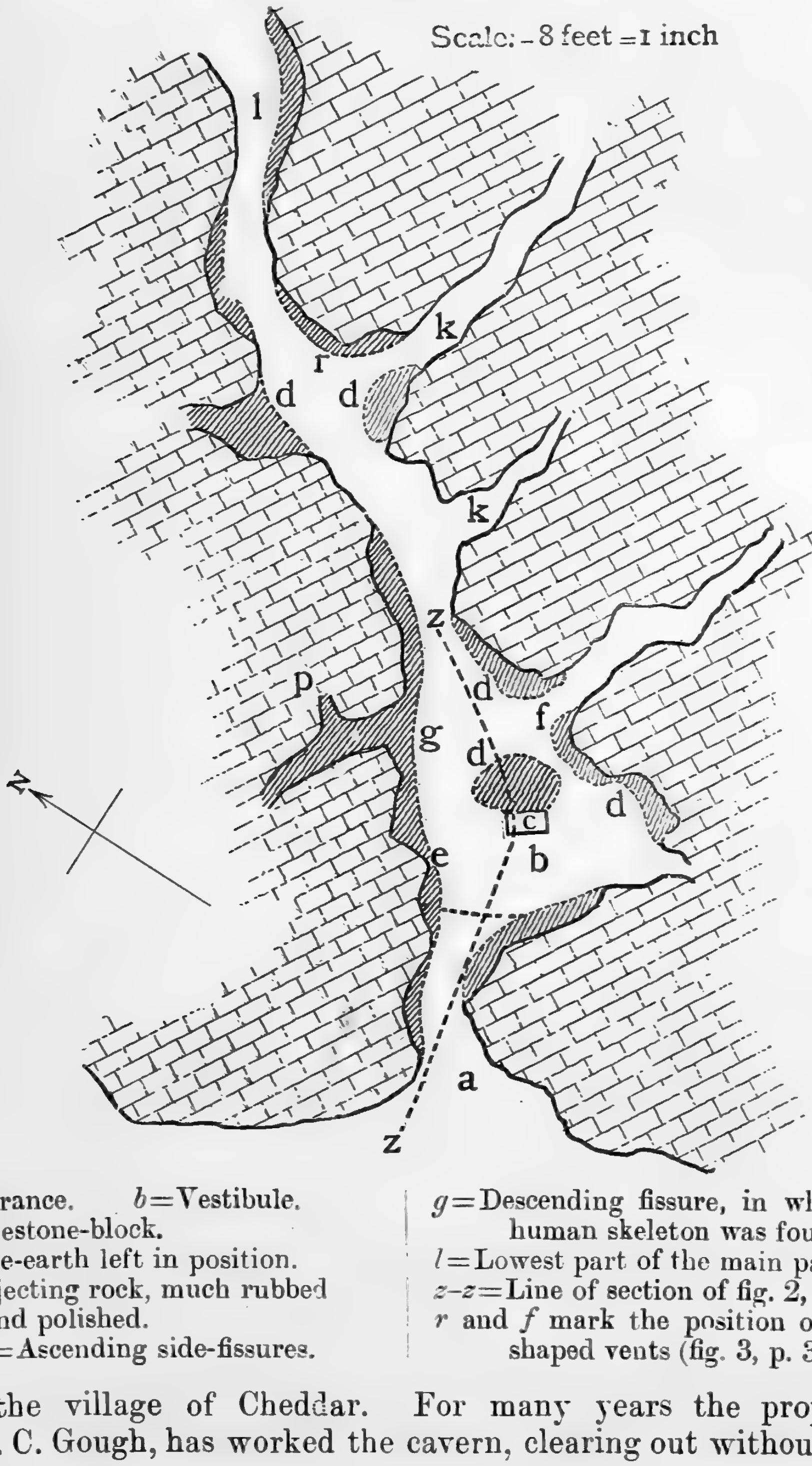
'Some one may perhaps say that the Bovey Basin may have been formed in Oligocene time, and that the formation of this basin was enough to deflect the river southward. My reply would be that there is absolutely no evidence of strong earth-movements in Oligocene time, that those in the Isle of Wight are obviously post-Oligocene, and that the Bovey syncline is comparable with them. Further, the axis of this syncline does not run north and south, but north-west and south-east, and, as I believe, it crosses the granitic area.'

## 22. *The* Discovery *of* Human Remains *under the* Stalagmite-Floor *of* Gough's Cavern, Cheddar. By Henry Nathaniel Davies, Esq., F.G.S. (Read April 13th, 1904.)

[Plate XXIX.]

Gough's Cavern is an extensive and much-branching subterranean waterway, which opens at the base of the cliffs on the south side of a picturesque gorge in the Carboniferous Limestone of the Mendips,

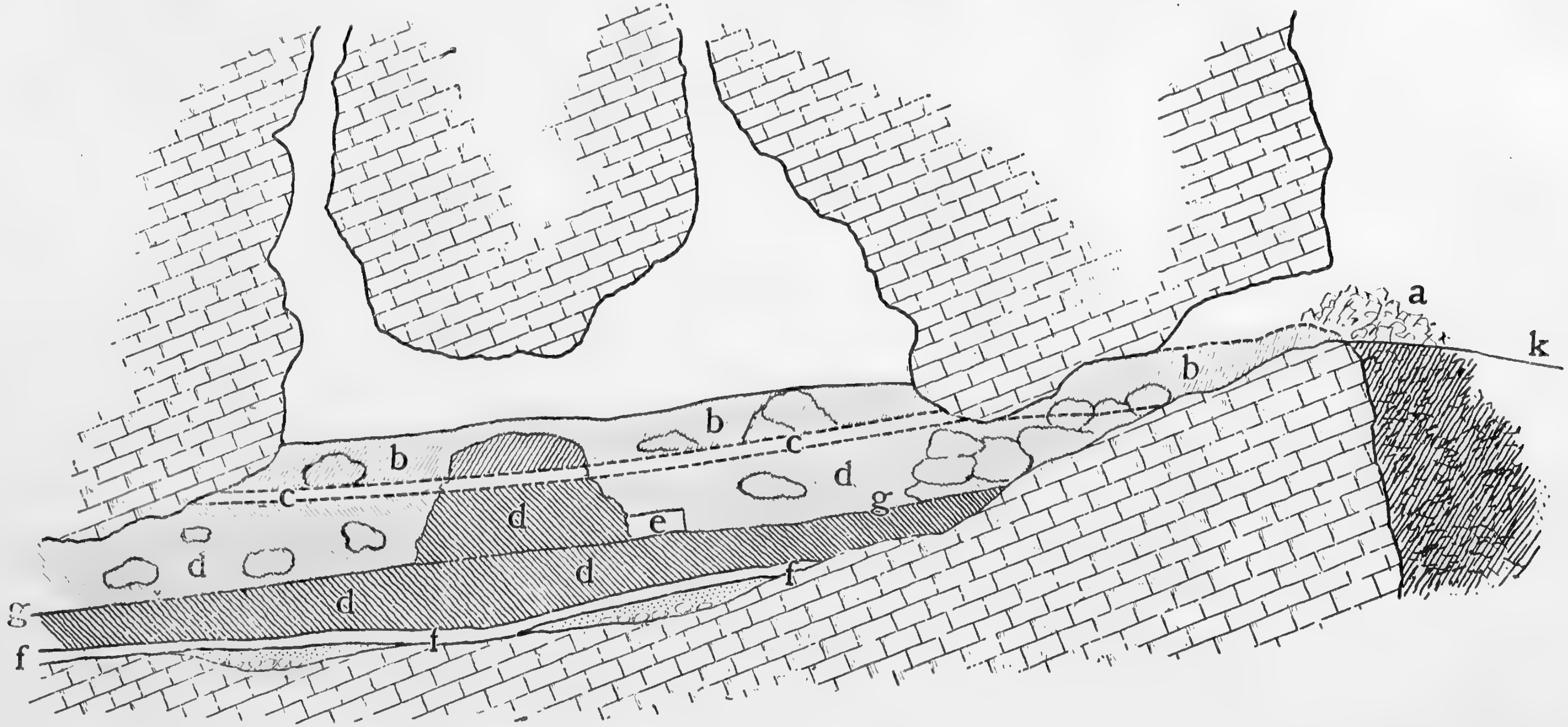
Fig. 1.—*Plan of part of Gough's Cavern, Cheddar.*




*a*=Entrance. *b*=Vestibule.
*c*=Limestone-block.
*d*=Cave-earth left in position.
*e*=Projecting rock, much rubbed and polished.
*f, k, k*=Ascending side-fissures.
*g*=Descending fissure, in which the human skeleton was found.
*l*=Lowest part of the main passage.
*z–z*=Line of section of fig. 2, p. 336.
*r* and *f* mark the position of dome-shaped vents (fig. 3, p. 338).

near the village of Cheddar. For many years the proprietor, Mr. R. C. Gough, has worked the cavern, clearing out without much

Fig. 2.—*Diagrammatic section through the deposits in the entrance and vestibule of Gough's Cavern.*




*a* = Talus removed.
*b* = Recent superficial accumulation.
*c* = Upper stalagmite: 5 to 12 inches.
*d* = Cave-earth: 6 to 8 feet.

*e* = Tabular limestone-block, around which were found numerous flint-flakes.

*f* = Lower stalagmite-floor: 2 to 6 inches.
*g* = Present 'made floor.'
*k* = Roadway ascending to the entrance.

[The lightly-shaded portions have been removed. The more darkly-shaded portions show what still remains.]

method the accumulation of ages, in order to make a comfortable and easy access for visitors to the principal chambers; and quite recently the grandeur of the vaulting and the beautiful stalactites in the more inaccessible parts have been revealed by the introduction of the electric light.

In carrying out these necessary improvements, beds of stalagmite and cave-earth, blocks of limestone, pebbles and sand have been removed from the entrance and passages; and the bones and teeth of extinct and existing animals, with human relics (prehistoric and historic) have been brought to light, and are now to be found crowded together in a small museum near the entrance. The objects prove that the caves were the alternate resort of extinct animals and man. The cases contain jawbones and teeth of the cave-hyæna, cave-bear, cave-lion, woolly rhinoceros, boar, horse, deer, Irish elk, etc., which have at various times been taken out of the cave-earth during the excavations; but they were never found in large numbers, while flint-flakes, knives, scrapers, borers, and chips were plentiful, and bone and horn-borers, needles, and pins were sometimes met with. From the talus at the base of the cliffs, which rose high enough almost to block the entrance to the cavern, a bronze celt of the plainest type and a looped lance-head of later date have been taken, which seems to indicate that the cavern had become choked before the Bronze Age. I have found it quite impossible to locate the position in the cave-earth in which any of the above-mentioned bones and teeth were found. Some, I know, of the cave-specimens were found in the adjoining chamber, or Old Cave, by the father of the present proprietors; but the stock has been considerably added to since the clearing out of the present, or New Cave, was begun in 1892, although it is to be regretted that no record has been kept of the dates, nature, or position in the cave-earth of the finds.

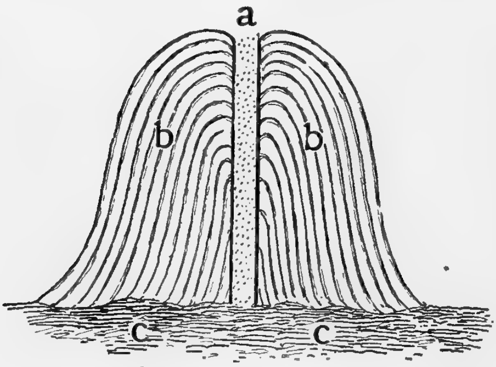
No human bones had ever been found in this cavern until December 1903, when the workmen struck a human skull and other bones of the skeleton under circumstances that suggested their great antiquity.

When the work of clearing out the New Cave was begun, the entrance was only 2 feet high. Great quantities of talus and wash had to be removed before access could be gained to the vestibule (*b*, fig. 1, p. 335). Banks of mud and stone have been left in some places, to show the original height of the floor before it was lowered to its present level. There was no calcareous crust on the top of the thick deposit which filled the entrance-passage. The rock-floor was found to dip steeply inward for some yards, after which a more gentle incline led to the point marked (*l*) on the plan (fig. 1, p. 335), which is the lowest point of the central passage. From this spot the ascent is gradual until a large chamber is entered, when it becomes steep and sudden.

The upper stalagmite.—After the surface-accumulation (*b*, fig. 2, p. 336) had been removed, the upper stalagmite (*c*, fig. 2) was exposed. The deposit is chalky, soft, and laminated, the average thickness of the laminæ being ·08 inch, and that of the whole mass from 5 to 12 inches. There is a considerable mixture of fine sand with the calcareous matter, the residue, after treatment with strong acid, being nearly 40 per cent. of the weight tested. Then beds of a harder and semi-crystalline porous character are found in shallow pockets in the cave-earth in some parts of the cavern, notably near *k* (fig. 1, p. 335).

Curious dome-like masses of granular and semicrystalline material, from 6 to 18 inches in height, occur in two spots marked *r* and *f*, fig. 1. They appear to be growths of calcareous mud, such as may form around the mouths of springs from which waters highly charged with carbonate of lime were issuing. The presence of such springs in the cave might explain the occurrence of the beds of travertine-like deposit which are found, as stated above, at various levels in the cave-earth. That these beds, and the upper stalagmite-floor, are a deposit from such slowly-flowing water, dammed up for a time in the deeper parts of the cavern, and not a drip-formation, is certain. This latter is indeed found in the cavern, and gives rise to some beautifully-formed stalactites and stalagmites, but these are of a different character altogether from the layers of chalky deposit of the upper floor and the dome-like vents.

Fig. 3.—*Dome-like mass of granular and semicrystalline material.*




Height: 6–18 inches

*a*=Pipe; *b*=Calcareous layers; *c*=Floor of cavern.

The cave-earth.—This is a deposit of reddish mud from 3 to 8 feet deep, containing angular masses of limestone, large and small, which have at various times fallen from the roof; and boulders of the same rock, well-rounded at the edges, evidently transported by flood-waters. Bedding is distinctly marked in some parts of the deposit, and the thin bands of crystalline stalagmite occur in small areas and at various depths in it. In portions of the mass, the calcareous deposit has penetrated from top to bottom, and the whole thickness has been cemented into a calcareous breccia. The upper stalagmite-bed covers the cave-earth as a continuous sheet, and the underlying bed, to be next described, forms the floor upon which it rests: there being no break in the continuity of the deposit in those parts of the cavern which have been opened out. It thins out rapidly in fissure *g*, until the upper and lower beds of stalagmite rest one upon the other at a distance of about 25 feet from the mouth of the fissure, where the floor is cut transversely by a deep rent, at the bottom of which is a backwater of the subterranean stream that now flows out a few yards west of the entrance to Gough's Cavern.

Before leaving this part of the subject, two interesting stones in the vestibule should be noted. The one marked *c* (fig. 1, p. 335) is a rectangular block of limestone resting horizontally upon an old surface in the cave-earth, about 3½ feet below the upper calcareous deposit. When the earth was cleared away from it the workmen found a large number of flint-chips embedded in the earth at its base, and some still resting on its upper surface. The tabular block had apparently served as a tool-bench to some cave-dwelling worker in flint.

Near by, on the left-hand side of the entrance, to the vestibule, is a projecting stone which has been rounded at its edges, rubbed smooth, and polished in a striking manner. Buckland,[1] referring to stones similarly polished in the German caves of Zahnloch and Gailenreuth, quotes the opinions of Goldfuss & Rosenmüller, that the rubbing and polishing are due 'to friction from the skin and paws' of the animals (bears) which in remote ages frequented the caves.

Fig. 2 (p. 336) illustrates the mass of successive deposits which have been cleared out of the entrance and vestibule down to the level of the line *g*, which marks the present floor; the darker shading shows what still remains.

The lower bed of stalagmite.—This floor, upon which the cave-earth rests (*f*, fig. 2), is a hard crystalline deposit. It covers the rocky floor of the vestibule and passages in some parts, but in others, and especially in fissure *g* (fig. 1, p. 335), it has some inches of sand and pebbles beneath it.

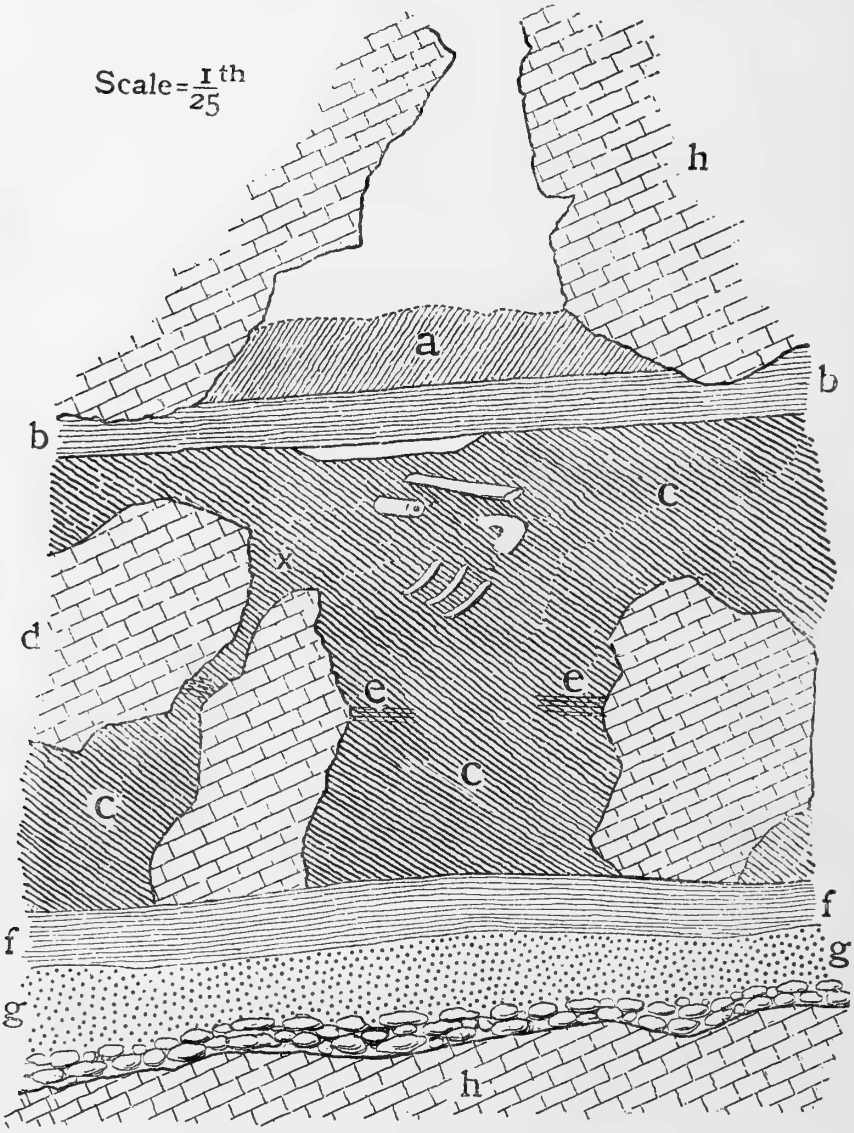
The lateral fissure (*g*, fig. 1), in which the human remains were found, may now be described. Until quite recently it remained absolutely choked with rock-débris and earth. But as the waters that entered the cavern from the fissures on the south side of the cave drained backward towards the low level marked *l* on the plan (fig. 1), the chambers and passages were often flooded; and this state of affairs causing great loss to the owner, he determined to clear out the lateral fissure *g* (fig. 1), and drain off the flood-waters into it: thus, as it afterwards appeared, imitating Nature's own method of getting rid of them. It was while this project was being put into execution that the discovery was made.

The sections (figs. 4 & 5, pp. 340, 341) will give an idea of the succession and proportional thickness of the deposits that had to be cut through. It was found that a sudden drop of a few feet occurred at the mouth of the fissure, and this brought the accumulation to a

[1] 'Reliquiæ Diluvianæ' 1823, pp. 130–37.

depth of over 12 feet. The deposits of the main cavern passed into this branch without break, but they took a downward inclination,

Fig. 4.—*Longitudinal section of the deposits in the lateral fissure* g *(in fig. 1, p. 335).*

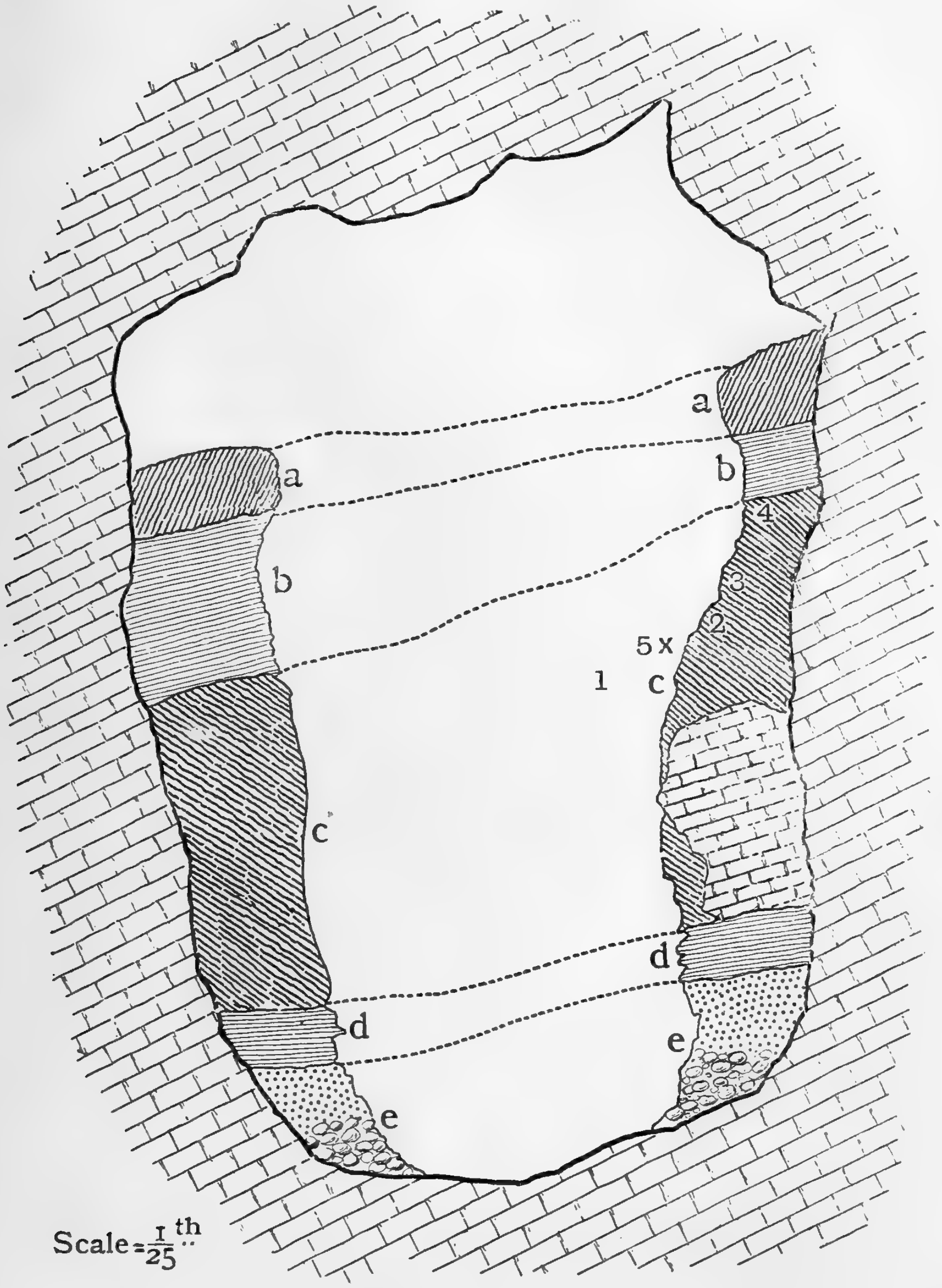



[The bones shown are still *in situ*, and × marks the position in which the skull was found.]

*a* = Recent accumulation of earth and stones: 6 inches.
*b* = Upper bed of stalagmite: here 5 inches thick.
*c* = Cave-earth, with encrusted boulder (*d*) and blocks of limestone and an intermediate band of calcareous deposit (*e*): 3½ feet.
*f* = Lower bed of stalagmite: 6 inches.
*g* = Bed of sand and pebbles of Carboniferous Limestone and Old Red Sandstone: 8 to 12 inches.
*h* = Carboniferous-Limestone roof and floor.

maintaining a certain parallelism with the floor and roof. A space only just high enough to enable a man to crawl in, existed between the upper surface of the drift and the roof at the entrance. About 12 feet within the fissure a smaller rift in the right-hand wall was discovered (*p*, fig. 1, p. 335). It is very narrow above, but widens to 3 feet at the lower end.

Fig. 5.—*Transverse section through the lateral fissure* g *(in fig. 1, p. 335.)*




*a* = Recent accumulation of earth and stones: 6 inches.
*b* = Upper stalagmite-bed: 5 to 14 inches.
*c* = Cave-earth, containing blocks of limestone: 3½ feet.
*d* = Lower (crystalline) stalagmite: 5 inches.
*e* = Bed of sand and pebbles: 8 to 12 inches.

× shows the position of the human skeleton: 1=Skull; 2=Pelvis; 3=Femurs; 4=Tibia; 5=Humerus.

The skeleton was found at the junction of these two fissures. The surface-accumulation had been removed, the stalagmitic crust—here

5 inches thick—had been cut through; and a large quantity of cave-earth and great blocks of stone from the central part of the fissure had been cleared away in making a deep trench for the drain-piping, when 2 feet below the under-surface of the stalagmite, the human skull (Pl. XXIX) was brought to light. It was taken out in pieces, but so carefully that there was no difficulty in putting it together again. The rest of the skeleton was then unearthed; and the bones of an arm and a leg, some ribs, and a part of the pelvic girdle were removed.

Fortunately, it occurred to Mr. A. G. Gough to allow the other bones to remain *in situ*, so that the section (as in fig. 4, p. 340) is now preserved for future reference. One shin-bone touched the bottom-layer of the stalagmite and was encrusted; the other bones were in the earth. The skull was lying in a slightly-lower position than the pelvis and lower extremities, at the spot marked × in fig. 4. The legs were drawn up, one of the arms bent so as to bring the hand to the back of the head, and the whole position of the skeleton such as would have been assumed by the body of a drowned man swirled into its last resting-place by a rushing torrent.

Immediately below the head is another bed of stalagmite, more crystalline than the top-bed, and about half the thickness, but this is not continuous. The blocks of limestone seen in fig. 4 rise out of this; some are rounded, others angular, and one is completely encrusted with a thin coating of granular calcareous deposit. At the bottom of the section, and beneath a lower bed of stalagmite, is a thick bed of sand and large well-rounded pebbles.

I have made a careful examination of the human remains. The cranium is of medium size, the sutures intricate, the roof of exceptional thickness (9 millimetres). The left malar bone and the nasal bone are missing; there is a big hole on the same side, which has removed a portion of the parietal and temporal bones; the front portion of the upper maxillary has disappeared, carrying with it the incisors. The lower jaw is perfect, with the exception of an injured condyle and a missing molar; it is very wide, measuring 11·5 centimetres from one condyle to the other, and is powerfully formed. The frontal is receding, though not sufficiently so to make it an important character of the face; and as a portion of the supra-orbital elevation is gone, it can only be said to have been considerable.

It will thus be seen that the face is much mutilated; but the cranium certainly occupies a much higher plane than the Neanderthal or Spy specimens, approximating very nearly to the form of the Tilbury head described and figured in Owen's 'Antiquity of Man' 1884, pp. 4–9 & pls. i–iii, and now exhibited in the Natural History Museum, South Kensington.

The measurements, as correctly as they can be made, are:—Maximum length = 185 millimetres, maximum width = 130 mm., giving a cephalic index of about 73. The extreme thickness of the frontal bone (9 millimetres) has been already mentioned. The amount of prognathism cannot be determined, but from the form of the lower jaw it must have been a marked feature of the face. The nasal aperture is narrow, the orbits large, and the general shape of the skull oval. The molar teeth are worn on the right side, but the cusps remain well-preserved on the left. The lower canines are much worn and rounded. Two of the phalanges have found their way into the cranium, and are now cemented to the base of the frontal bone at the back of the orbits.

The femur measures $17\frac{5}{8}$ inches in maximum length, and the humerus $12\frac{3}{4}$ inches; and, using Dr. Beddoe's formulæ, we obtain from either of these measurements a height of a trifle over 5 feet 5 inches.

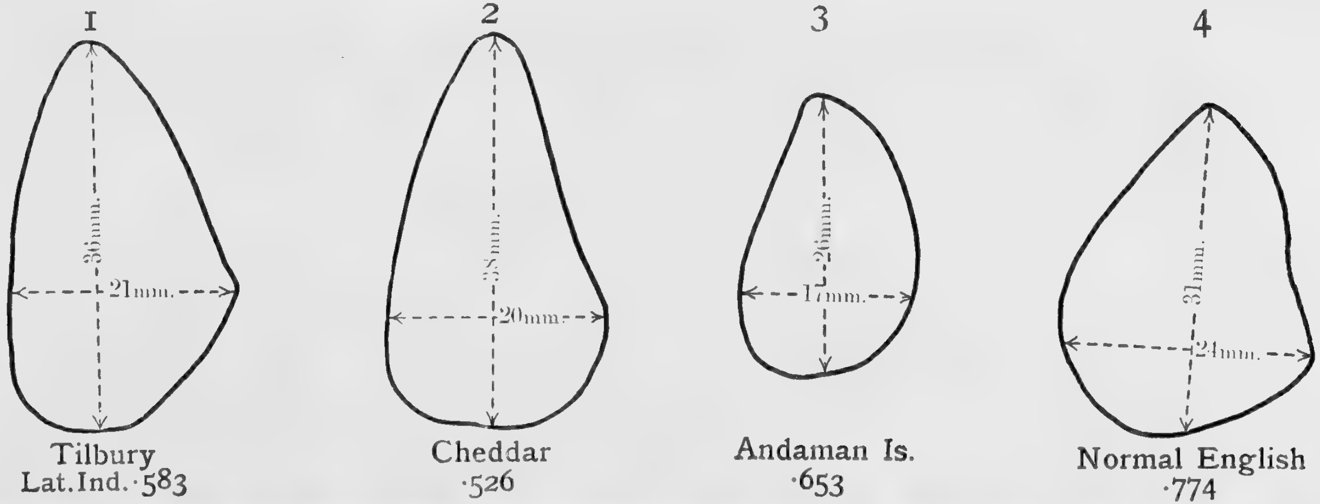
The tibia has a peculiar section, fig. 6, no. 2 (p. 344). The angular portion is very acute, the sides flat, and the widest part about three-fourths back from the ridge. Its antero-posterior diameter is 38 millimetres, and the diameter at right angles to this, drawn from the interosseous ridge, 20 mm.; so that the latitudinal index is ·526, which is exceedingly low. With the kind permission of the Council of the Royal College of Surgeons, and the very valuable help of Prof. Charles Stewart, F.R.S., I have been able to obtain sections of the Tilbury tibia, an Andamanese, and a normal English tibia. They are shown, together with the section of the tibia from Cheddar, in fig. 6 (p. 344); and their measurements are set forth in the following table:—

| *Locality.* | *Antero-posterior diameter.* | *Transverse diameter from interosseous ridge.* | *Latitudinal index.* |
|---|---|---|---|
| | millimetres. | millimetres. | |
| Cheddar cave-earth ......... | 38 | 20 | ·526 |
| Tilbury fluviatile deposit ... | 36 | 21 | ·583 |
| Andaman Islands, recent ... | 26 | 17 | ·653 |
| Normal English ............... | 31 | 24 | ·774 |

From the foregoing measurements it will be seen that the Cheddar tibia is an extraordinary bone, being flatter and more platycnemic than the Tilbury specimen, which is the next most extreme type that I have seen, and is classed in the National Collection at South Kensington, with a query, as Palæolithic.

The flint-flakes taken from the cave-earth of the vestibule *b* and the fissure *g* (fig. 1, p. 335) are beautifully patinated. Some have only a central ridge; others have two, three, or even four ridges. Many are rounded at one end, some at both ends; others are pointed, but not by secondary working. Two appear to have

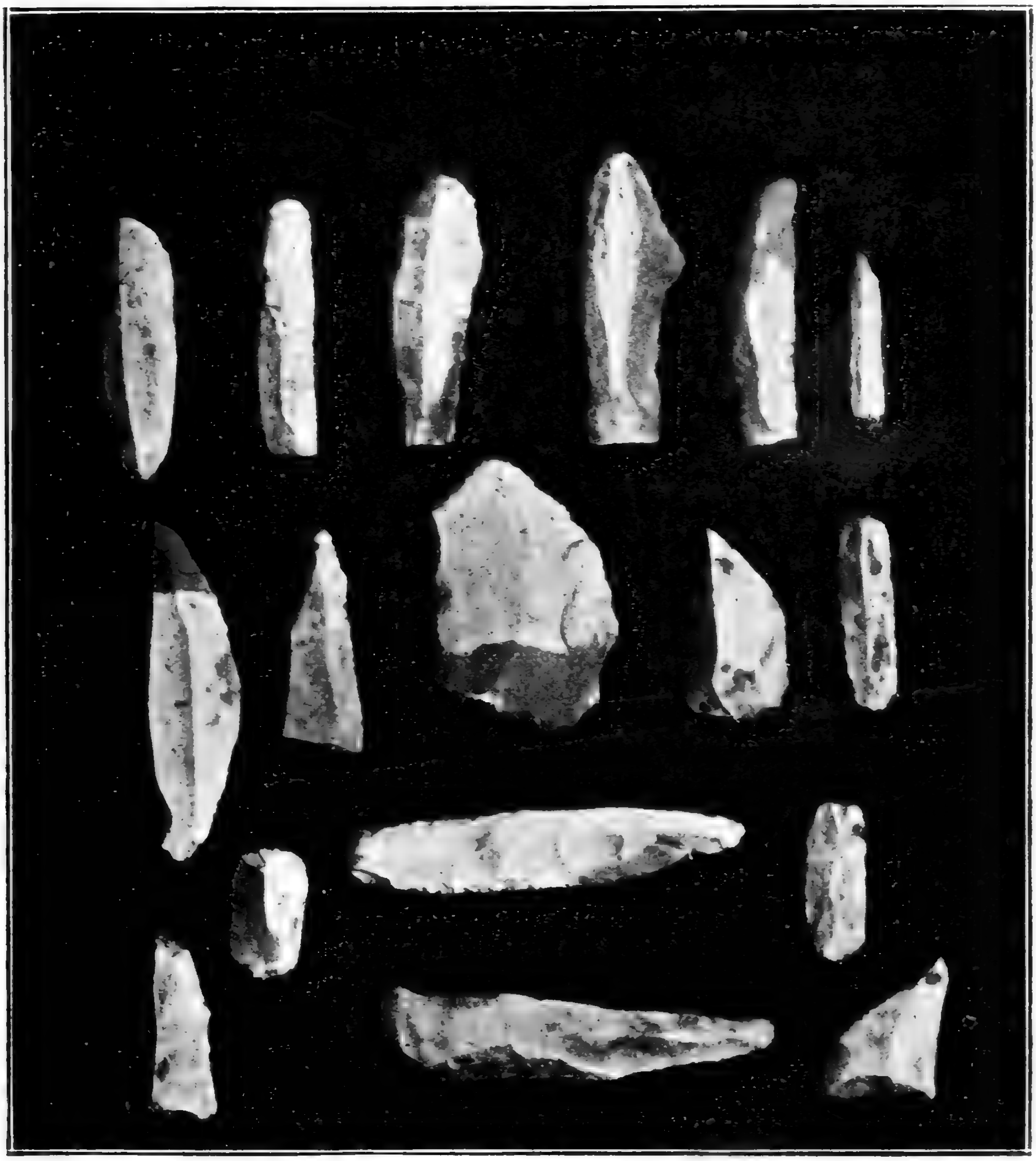
Fig. 6.—*Sections of tibiæ illustrating degrees of platycnemism, and photograph of the tibia from Gough's Cavern.*




[Photograph of the tibia from Gough's Cavern.]

been intentionally serrated, but on the whole there is an absence of distinct traces of secondary chipping or dressing. The flakes must, many of them, have been more than 4 inches long. If the form and workmanship of the implements shown in fig. 7 be

Fig. 7.—*Flint-blades, borers, and scrapers, found in association with human remains in the cave-earth of Gough's Cavern.*



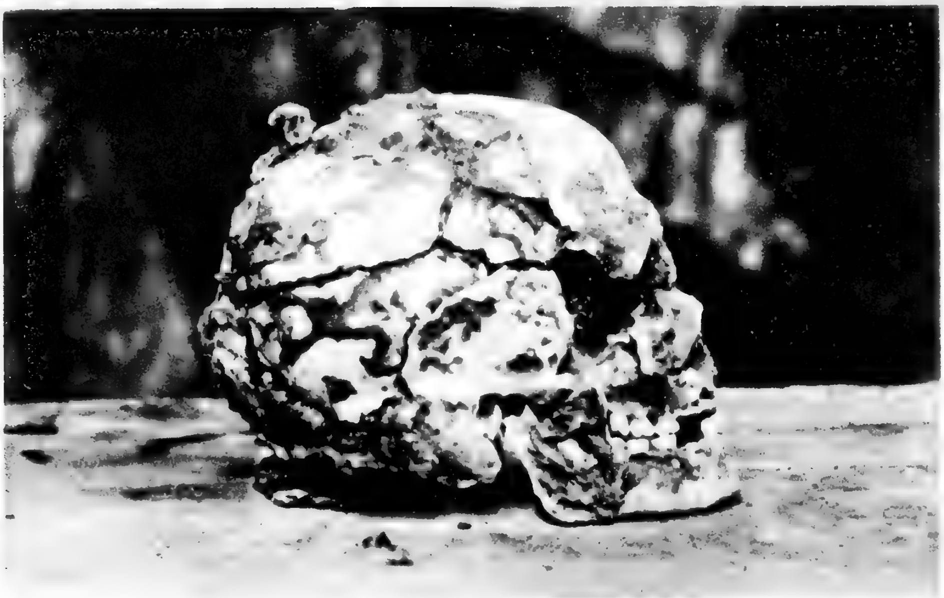
compared with those figured by G. & A. de Mortillet in their 'Musée Préhistorique' 1881, pl. xix, figs. 120, 122, & pl. xxi, figs. 135–37, 139; with some blades from Kent's Cavern shown in the British-Museum Collection: and with a set obtained from Bryan Cave, Torquay, shown in the British-Museum (Natural History) Collection (all of which are classed as Palæolithic), their striking resemblance to all these examples will be apparent.

The animal-remains found in the cave-earth of fissure *g* belonged entirely to the horse; and all the hollow bones had been splintered for the marrow. The proprietor assures me that the bones and teeth of extinct mammals now placed in his collection were found in the cave-earth of the vestibule. These include *Ursus spelæus*, *Hyæna spelæa*, *Felis spelæa*, *Rhinoceros tichorhinus*, *Cervus megaceros (?)*, *Equus caballus*, etc. As, however, i is impossible to fix the exact position of these finds in the cave-earth, and as they were not met with in fissure *g*, I feel that the mammalian remains must not be relied upon to determine the age of the human remains found in another part of the cavern.

The leading features of this interesting discovery may be thus summed up:—

1. The skeleton was found embedded in the cave-earth near its upper surface.
2. A bed of stalagmite of a chalky and laminated character covered the cave-earth, and both the cave-earth and covering stalagmite of the fissure are identical and continuous with those of other parts of the cavern.
3. Above the stalagmite-floor, which covered the cave-earth, a more recent accumulation of earth had been formed.
4. Beneath the skeleton another bed of stalagmite, of a harder and semicrystalline character, was found; and underneath this a bed of sand and well-rounded pebbles.
5. The skeleton was in a cramped position, such as would be assumed by a drowned man.
6. The fissure is narrow, and was completely choked with the cave-earth and its under and upper beds of stalagmite. The latter had never been disturbed, so that interment is out of the question.
7. The bones belonged to a man about 5 feet 5 inches in height, with an exceptionally-thick dolichocephalic skull, slightly-prognathous jaws, and rather prominent superciliary ridges.
8. Flint-knives, scrapers, and borers are plentiful in the cave-earth of the vestibule and of fissure *g*.
9. Bones and teeth of the horse only were found in the cave-earth of the fissure; but the proprietors show teeth and bones of extinct mammals, which they assert were taken from the cave-earth in other parts of the cavern.
10. On comparing the form and workmanship of the flints and the position in which they were found with those figured by G. & A. de Mortillet in their 'Musée Préhistorique' 1881, and classed by them as Solutréen and Magdalénien; and with specimens of undoubted Pleistocene age exhibited in the British Museum, both at Bloomsbury and South Kensington, as referred to previously: noting also that the skeleton and implements were found in cave-earth under a

1.



2.

3.

HUMAN SKULL FOUND IN GOUGH'S CAVERN, CHEDDAR.

*Bemrose, Collo.*

bed of calcareous deposit from 5 to 14 inches thick, I conclude that the human remains are probably of late Palæolithic age (Magdalénien of Mortillet), and that in them we have a valuable addition to those of perhaps earlier date found at Tilbury and Bury St. Edmunds, and the undoubted Neolithic skeletons buried in the Perthi-Chwaren caves or the barrows of Yorkshire and Wales.

## EXPLANATION OF PLATE XXIX.

Human skull found beneath the stalagmite-floor of Gough's Cavern.

Fig. 1. Right side. Showing the prominent supra-orbital ridge and the receding forehead; also the peculiar forward direction of the mastoid processes, which would seem to indicate that the neck was short and thick.

2. Front view. The face is much mutilated, and filled with a concrete of cave-earth and calcareous cement. This view shows well the regularity of the teeth in the lower jaw, and its extreme width.

3. Left side. The thickness of the frontal bone is well shown. Parts of the cranium are still encrusted with calcareous and earthy material. The lower jaw has become slightly twisted in this view.

## Discussion.

The Rev. H. H. Winwood, while alluding to the value of such discoveries as that so carefully described by the Author, gave his reasons for doubting the great antiquity of the human remains. In the first place, evidence of the association of the bones of the extinct animals found in the cave-earth with the skeleton was lacking; secondly, he enquired whether the friable bed of carbonate of lime overlying the bones, so friable that it crumbled at the touch, was stalagmitic in the usual accepted sense; and thirdly, the flint-flakes found in the earth with the remains were (in his opinion) of a distinctly-Neolithic type, and similar to many that he had found on the surface of the neighbouring hills.

Prof. Boyd Dawkins said that the Fellows were extremely indebted to the Author for putting on record the facts of this interesting discovery. But it involved no more evidence of the precise antiquity of the deposits than that brought forward from many other caverns. Indeed, it was impossible to explore any series of caverns in any part of this country without finding human remains. Stalagmite was of practically no value as evidence for age. In 1877 he (the speaker) examined the stalagmite of Ingleborough Cave, previously examined by Prof. Phillips in 1845, and he was able to determine the rate of accumulation of stalagmite as being three-tenths of an inch *per annum*. It was true that the flint-flakes exhibited appeared to be Neolithic, but such implements were in use as late as the Bronze Age. The tibia shown by the Author was, after all, but slightly platycnemic, and platycnemism had no relation to race; it implied merely the free use of the foot, confined at most in moccasins. The great majority of Neolithic skeletons possessed a platycnemic tibia. Nor was the skull older in type than Neolithic, and the stature inferred by the Author was very near the normal stature of the Neolithic Iberic population of this country. Statements in regard to the antiquity of man must always be scrutinized with the narrowest possible criticism.

Mr. W. Dale said that, as a collector of flint-implements for many years, he naturally gravitated towards those on the table as soon as he entered the room, and at once made up his mind that they belonged to the Neolithic Age, and late in that period. Indeed some of the long and skilfully-struck flakes were exactly similar to those often found associated with relics of the Bronze Age.

The Author thanked the speakers for their criticism of his paper. In reply to Mr. Winwood, he referred to the mass of calcareous deposit of travertine-like nature, which lay on the table, and which the Author had himself suggested to have been more rapidly formed than the lower *true* stalagmite. The flints might be Neolithic in appearance, although they were certainly not surface-flints, but found in the cave-earth, of whatever age that might be. Replying to Prof. Boyd Dawkins, the Author agreed that platycnemism was not a characteristic of race, and that well-struck flints might be of late Neolithic Age; but, referring again to their presence in the cave-earth under a stalagmitic floor, and to their close resemblance to the blades and borers found under the same conditions and classed by Mortillet and others as Magdalénien, he thought that his suggestion of a late Palæolithic or very early Neolithic date for these flints was more agreeable to the facts; and, if that were so, the human remains found with them must be of the same age.

## 23. *The* Evidence *for a* Non-Sequence *between the* Keuper *and* Rhætic Series *in* North-West Gloucestershire *and* Worcestershire. By Linsdall Richardson, Esq., F.G.S. (Read June 8th, 1904.)

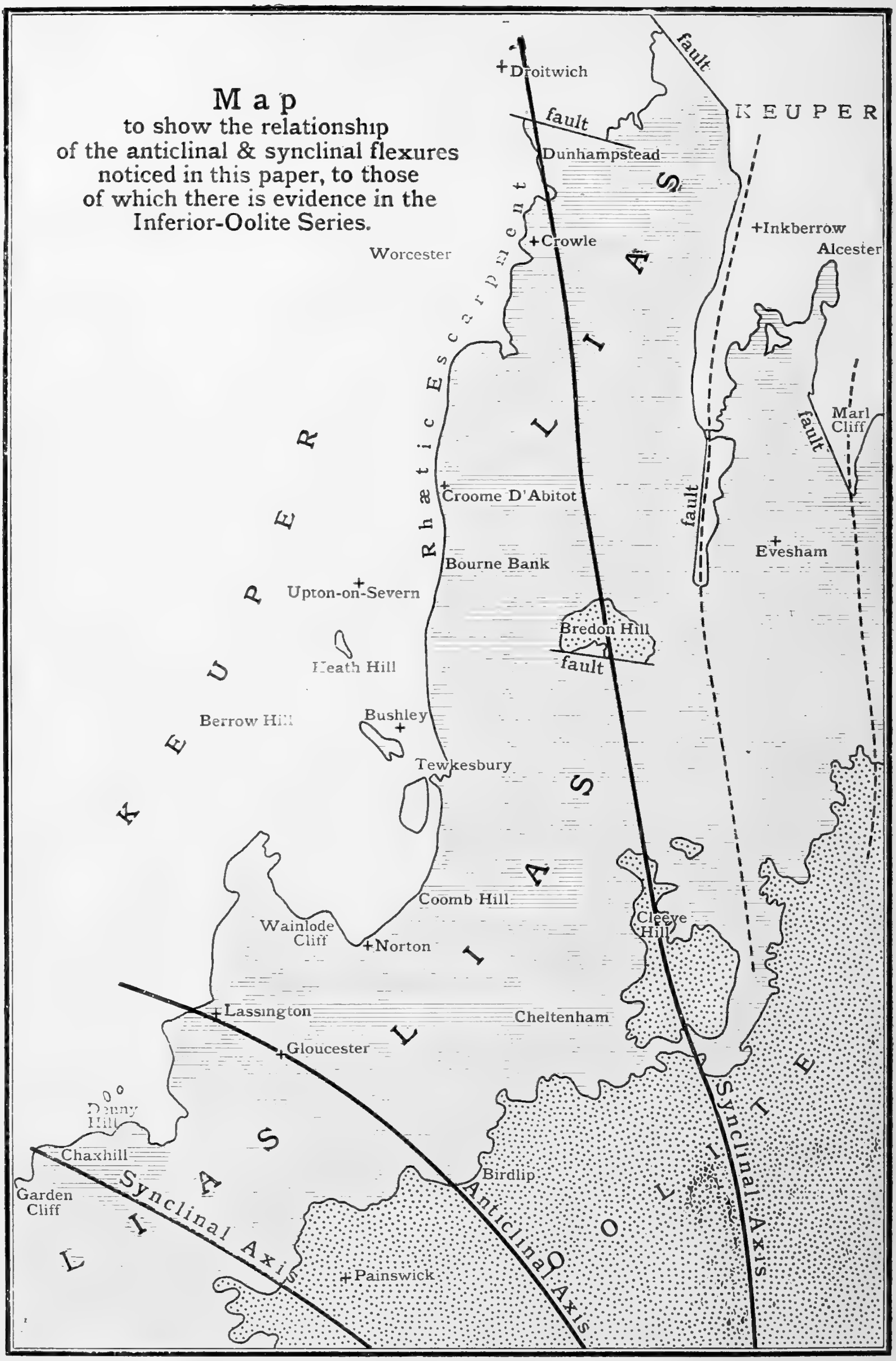
[Map on p. 350.]

During my investigations of the Rhætic Series in Worcestershire and North-West Gloucestershire, the results of which are in part chronicled in the 'Proceedings of the Cotteswold Naturalists' Field-Club'[1] and in the 'Geological Magazine,'[2] two facts were most noticeable. The first was that above a particular bed in the Rhætic Series the remaining component deposits were remarkably persistent; while the second was that below that stratigraphical horizon such persistency was not found. The stratigraphical horizon referred to is that of the well-known Bone-Bed of the sections at Aust and Garden Cliffs, and of the less-known Bone-Beds at Wainlode and Sedbury.

The stratigraphical details may be dealt with first. In most of the sections in Worcestershire a massive bed of sandstone is the equivalent of the thin pyritic Bone-Bed which is so crowded with vertebrate-remains at Garden Cliff, and the contemporaneity of these deposits might be at first doubted. Wainlode Cliff, however, furnishes the clue to the whole question, for in that cliff-section may be observed the change from a thin pyritic stratum (only an inch or so thick) to a micaceous sandstone-bed, usually devoid of vertebrate-remains, and about a foot thick. The latter development, however, contains in some abundance those equivocal casts to which the name of *Pullastra arenicola* has been so frequently applied; and also a broad form of what appears to be *Modiola minima*—but only as obscure casts. The point, however, to which attention is particularly directed is the gradual transition between the two varieties of the Bone-Bed. Below, and separating the Bone-Bed from the 'Tea-Green Marls' of the Upper Keuper, is a deposit of Black Shale 2 feet thick. The line of junction of the shale with the Keuper Marl may be described as sharply defined, and only very rarely is there an extremely-thin deposit of arenaceous matter intervening between the two formations. At Norton, about 1½ miles to the south-east by east of Wainlode, there is a section in a lane-cutting 300 yards north-east of the church, in which the Bone-Bed is seen as a stratum 15 inches thick, with a few fish-remains and an occasional small quartz-pebble. Black Shales, with a thickness of 16 inches, separate this bed from the 'Tea-Green Marls': the line of demarcation between the two being again sharply defined.

[1] Vol. xiv (1903) pp. 127–74, 251–56.
[2] Geol. Mag. 1903, pp. 80–82.

Fig. 1.


Map
to show the relationship
of the anticlinal & synclinal flexures
noticed in this paper, to those
of which there is evidence in the
Inferior-Oolite Series.
Droitwich
fault
KEUPER
Dunhampstead
Rhætic Escarpment
Crowle
Inkberrow
Alcester
Worcester
LIAS
KEUPER
Marl Cliff
fault
Croome D'Abitot
fault
Evesham
Bourne Bank
Upton-on-Severn
Bredon Hill
fault
Heath Hill
Berrow Hill
Bushley
Tewkesbury
Coomb Hill
Cleeve Hill
Wainlode Cliff
Norton
Lassington
Cheltenham
Gloucester
Chaxhill
Garden Cliff
Birdlip
Synclinal Axis
Anticlinal Axis
Synclinal Axis
Painswick
LIAS
OOLITE

At Coomb Hill, near Cheltenham, the Bone-Bed is difficult to find, but I have succeeded in discovering a typical development. From the writings of H. E. Strickland also, it is known that the lithic and faunal characters of the stratum here are similar to those which may be noted at that end of Wainlode Cliff which is farthest from the Red Lion Hotel; for, to quote that author, it

'rarely exceeds an inch in thickness, and frequently thins out in short distances to one-fourth of an inch or less. It consists chiefly of a dense mass of scales, teeth, bones and small coprolites, cemented by pyrites, the golden colour of which contrasts beautifully with the jet-black of the animal-remains.' [1]

The fragments, Strickland noticed, 'have evidently been subjected to a gentle mechanical action,' as they often present 'broken and worn surfaces.'

In the shallow cutting through which the Tewkesbury-and-Ledbury road passes at Sarn Hill, near Bushley, the Bone-Bed-equivalent is a massive stratum of yellowish micaceous sandstone, 14 inches thick, and is separated by 2 feet 8 inches of Black Shale from the 'Tea-Green Marls,' with a sharply-defined line of junction.

At Bourne Bank, near Defford (Worcestershire), the Bone-Bed-equivalent resembles that at Bushley, but is here 2 feet thick, and is devoid of vertebrate-remains. In a 'Postscript to the Memoir on the Occurrence of the "Bristol Bone-Bed" in the Neighbourhood of Tewkesbury,' Strickland brought forward evidence to show that an ossiferous development of this Bone-Bed-equivalent was passed through by a shaft sunk on Defford Common, about half-a-mile to the east of the escarpment.[2] Pieces of this bed brought to the surface yielded to Strickland his '*Pullastra arenicola*,' and teeth, scales, and coprolites of fishes. The actual junction of the Keuper and Rhætic Series cannot be seen at Bourne Bank; but, in a road-cutting about $2\frac{3}{4}$ miles to the north, the deposit intervening between the Bone-Bed-equivalent and the Keuper Marls is seen to be 2 feet 10 inches thick. The Bone-Bed-equivalent here is similar to that at Bourne Bank, and is exposed for a thickness of 13 inches, but that is not its total thickness; the section then becomes obscured, and the details are doubtful.

The most important section now open in Worcestershire is at Crowle. Here, instead of the sequence, 'Tea-Green Marls,' Black Shale, Bone-Bed-equivalent, we have, in ascending order, 'Tea-Green Marls,' Sandstone (with a little shaly matter intercalated near the base), shales, and Bone-Bed-equivalent. The deposit of sandstone above the 'Tea-Green Marls' is therefore an additional deposit, and has come in between this locality and the section near Croome D'Abitot. Indeed, it has come in between the farm called Muckenhill and Croome D'Abitot, for in the farm-yard it is seen resting upon the 'Tea-Green Marls,' and similar phenomena are to be observed at Churchill Wood, near Spetchley.

[1] [Sir W. Jardine] 'Memoirs of H. E. Strickland' 1858, p. 155.
[2] *Ibid.* p. 160.

It may be as well to mention here that had the term 'Bone-Bed' been applied to any bed yielding vertebrate-remains, then in the Crowle section the series of sandstone-layers alternating with shale, and 20 inches above the Bone-Bed-equivalent, would have had to have been thus denominated. But the deposit (Bed 15) is frequently seen to be of 'Bone-Bed' nature, especially at Denny Hill, near Gloucester, and in places in the Garden-Cliff section.

The section in the railway-cutting at Dunhampstead shows the same sequence of deposits as the Crowle exposure, together with higher beds; but from the account of this section given by Mr. W. J. Harrison, F.G.S., and my own observations, there seems to be little doubt that the Rhætic rocks are thicker here than at any other locality in Worcestershire; this is certainly the case with the beds that are visible. The Bone-Bed-equivalent at Dunhampstead is a massive bed, with a maximum thickness of 30 inches.

About 7 miles across country, in a south-easterly direction, is an exposure at Abbots (Hob) Lench, where it is important to note that, instead of a sandstone-bed resting upon the 'Tea-Green Marls,' the Bone-Bed-equivalent itself (14 inches thick) is seen to be separated by a deposit of shale, only about 28 inches thick, from the Keuper Marls. This means that the sandstone-bed, which at Dunhampstead was seen resting directly upon the Keuper Marls, is absent here. As I have elsewhere stated,[1] this Bone-Bed-equivalent partakes of the nature of a true Bone-Bed in this village; for, from a well sunk here, were obtained pieces of typical pyritic rock charged with fish-scales and some other vertebrate-remains.

At Marl Cliff, on the borders of Worcestershire and Warwickshire, a thin layer of sandstone (with a few fish-scales, and but an inch thick) is the Bone-Bed-equivalent, and is separated from the 'Tea-Green Marls' by 2 feet of Black Shale; a state of affairs somewhat similar to that noted at one part of Wainlode Cliff.

Concerning the Bone-Bed of Worcestershire, Strickland wrote:

'It appears, however, that this stratum, which in East Devon, Somerset, and Gloucestershire is so highly charged with organic remains, loses its ossiferous character when we enter Worcestershire. Its identity, however, is not lost; and when it is considered that from Axmouth on the south to Dunhamstead on the north is a distance of about 112 miles, we have a remarkable instance of the continuity of a very thin stratum over a great distance.'[2]

Proceeding now from Wainlode Cliff in a more or less south-westerly direction, the first section to be noted is in the railway-cutting at Lassington. This section is now so much overgrown that very little, and nothing definite, can be made out. W. C. Lucy[3] stated that the 'Bone-Bed' and 'paper-shales' of Westbury are absent, while the Rhætic Beds are represented by a band of stone 6 inches thick, in which *Pseudomonotis decussata* occurs.

[1] Geol. Mag. 1903, p. 81.
[2] 'Memoirs of H. E. Strickland' 1858, p. 157.
[3] Proc. Cotteswold Nat. F.-C. vol. viii (1886) pp. 216, 225.

These details he observed when the cutting was in the course of excavation. Mr. H. B. Woodward,[1] however, states that 'dark shaly marls,' belonging to the Rhætic, are faulted against the Keuper. The phenomena noted by Lucy, and explained by that author as being due to the absence of certain deposits, may, of course, be the result of a fault with some overthrust. I refrain from mentioning the section further, than to express the hope that if any sections of these beds are opened the fact will be at once made known.

At Denny Hill, distant from Lassington a little over 4 miles, the Bone-Bed is seen resting directly upon the 'Tea-Green Marls.' This section has been recently described in the 'Proceedings of the Cotteswold Naturalists' Field-Club',[2] and from that record it will be noticed that the several deposits there visible above the Bone-Bed agree closely with the equivalent beds at Garden Cliff. The absence of the well-known '*Pullastra*-Sandstones' of Garden Cliff is at once apparent; and, since at Denny Hill the Bone-Bed rests directly upon the marls of the Keuper Series, it follows that 6 feet 5 inches[3] of Rhætic deposit—as seen below the Bone-Bed at Garden Cliff—are absent here, and this thickness is, of course, considerable when it is remembered that the true English Rhætic seldom exceeds 35 feet in thickness.

At Chaxhill, about 2 miles south-west by west of Denny Hill, the '*Pullastra*-Sandstones' are present; the total thickness of the deposit below the Bone-Bed and above the Keuper Marls is 7 feet 2 inches[4]; a slight increase really upon the Garden-Cliff section, because of the more equal thickness of the several beds.

As the late Robert Etheridge, F.R.S., has written, it is probable that

> 'this chief Bone-Bed [No. 15 in my sections] was synchronously deposited over the area it now occupies in the West and South-West of England.'[5]

This 'chief Bone-Bed' is seen at Sedbury Cliff on the Severn, near Chepstow, resting upon the 'Tea-Green Marls,' with included rolled fragments of that rock. The Aust and Sedbury sections, however, are outside the district under consideration, and, moreover, it is probable that a barrier of Palæozoic rocks intervened between them and the Garden-Cliff section. That such a barrier, more or less continuous, must have existed in early Rhætic times is shown by the Rhætic Beds resting upon the Carboniferous Limestone in Tortworth Park,[6] and evidence of land in the same epoch is to be had in the railway-cutting at Lilliput, near Yate. If, then, as seems most probable, a Palæozoic barrier separated the Aust gulf from the stretch of water about Garden Cliff, it may supply an answer in the affirmative to Etheridge's statement that the strata

[1] Mem. Geol. Surv.: 'The Jurassic Rocks of Britain' vol. iii (1893) 'The Lias' p. 141.
[2] Vol. xiv (1903) p. 254.
[3] Maximum, 7 feet 9 inches.
[4] Maximum, 7 feet 8 inches.
[5] Proc. Cotteswold Nat. F.-C. vol. iii (1865) p. 224.
[6] *Ibid.* p. 234.

now exposed in the sections at Aust and Westbury 'must have been deposited in a different area, and open to another sea or estuary.'[1]

In the foregoing record of certain stratigraphical details, frequent reference has been made to the Bone-Bed or Bone-Bed-equivalent. That term has been employed for the want of a better. By the use of this denomination I do not imply that the stratum is necessarily crowded with vertebrate-remains: it happens to be so at Garden and Wainlode Cliffs and Coomb Hill in the district under review; hence the reason why it has been made use of to indicate the equivalent deposit in other localities, even if that equivalent does not contain vertebrate-remains. I am inclined to think that this Bone-Bed (15) was accumulated slowly. At Aust and Sedbury Cliffs it is conglomeratic, and might at first sight appear to have been formed somewhat rapidly, but the deposit at these localities is a littoral accumulation. In the Black Shales which were laid down during the *contorta*-age, fish-remains as a rule are not abundant; and I am inclined to agree with Strickland's idea that

'this great continuity of extent [of the Bone-Bed], combined with the prodigious abundance of organic remains in some parts of this stratum, render it probable that a much longer period may have elapsed during its deposit than in the case of an equal thickness of the less fossiliferous clay-beds above and below. . . . . . Generations of fishes and saurians may have added their remains to the common mass, while from the clearness of the water, or from the existence of a gentle current which prevented the deposit of muddy particles, scarcely any mineral matter was added to the bottom of the sea.'[2]

Now, as a rule, the fish-remains in the Bone-Bed at Wainlode Cliff occur in regular layers, and are very evenly distributed: the rock being fissile, and in all respects resembling a deposit which was formed slowly. But the bed, which is about an inch thick at one end of Wainlode Cliff, took the same time in its formation as the 30 inches of sandstone at Dunhampstead.

Accumulations of vertebrate-remains or 'Bone-Beds' occur at different horizons in the Lower Rhætic Stage; for example, the 'Bone-Bed' at Crowle, near Worcester, is Bed 13; at Wainlode Cliff and Coomb Hill, Bed 15; at Denny Hill, Bed 13; while at Garden Cliff there are at least four deserving of the name. Moreover, the *Pecten*-Beds (7 & 5 *b*) are often full of vertebrate-remains, so much so that the bed distinguished in my record as 5 *b* at Wainlode Cliff was noticed by Strickland as 'a second ossiferous bed.' The stratum which has been distinguished as 15 in communications made to the Cotteswold Naturalists' Field-Club, and that dealing with Sedbury Cliff to this Society, may at first sight appear to occupy different horizons, but this is only if the several sections be studied from the base upward.

There is always some difficulty in correlating the various sections, because of the want of fossils known from investigations over large

[1] Trans. Cardiff Nat. Soc. vol. iii (1870–71) pt. ii, p. 47.
[2] 'Memoirs of H. E. Strickland' 1858, pp. 157, 158.

tracts of country to characterize definite horizons; but the *Estheria-* and *Pecten-*Beds are fairly persistent; and it is best in correlating the sections to find these horizons first, and with their aid it will be seen that down to Bed 15 the sections admit of satisfactory correlation. In some sections the Bone-Bed does not occur at all, possibly because the surface of the Keuper Marls, or the rock composing the land-surface at the time of its formation, was not sufficiently submerged.

Down to Bed 15, then, the various sections can be correlated almost bed for bed, and the contemporaneity of deposits which admit of such exact correlation seems most probable. But below Bed 15 we have in one locality no Rhætic deposit, in another as much as between 7 and 8 feet.

The writings of our foremost geologists on questions of historical geology show that the Keuper Epoch closed with a scene of arid wastes and an inland sea reduced to slowly-shrinking lakes; lakes with surrounding land which, I think, was once formed under the waters of the more extensive Keuper sea. Then, as Mr. A. J. Jukes-Browne has written,

> 'the epoch of the *Avicula-contorta* zone marks the time when the depression had proceeded so far as to submerge the lowest tract of land which lay between the great salt-lakes and the widespreading southern ocean.'[1]

Now, may not the same forces which caused the depression in the south-east have affected the Keuper rocks and thrown them into slight anticlinal and synclinal flexures? A few lakes would still remain, but with their outlines somewhat modified by these earth-movements.

Mr. S. S. Buckman, F.G.S., has indicated the axes of certain anticlines and synclines in the Inferior-Oolite Beds of the Mid- and North Cotteswolds among other regions. Such flexuring caused the Bajocian Denudation, and there is moreover evidence to show that flexuring along practically the same lines of weakness took place about the middle of the Harpoceratan Age or in early Ludwigian times (post-*Lilli*, pre-*scissi*). Also earth-pressures were at work during the hemera *concavi*. It seems reasonable to suppose that the Liassic rocks might have been similarly affected long before the epoch in which the Inferior-Oolite Beds were laid down: indeed, Mr. Buckman has remarked that the Lias in the Dundry area 'was laid down on a constantly-moving surface.'[2]

Certain of the anticlinal and synclinal axes noticed by Mr. Buckman in his description of the causes and effects of the Bajocian Denudation may be now mentioned. The most important anticline is along the Moreton Valley, and if the line of elevation be produced in a northerly direction it will be found to coincide with the Pennine axis. A synclinal axis is noticeable at Cleeve Hill; an anticline at Birdlip; and a syncline again between Stroud and Painswick.

[1] 'The Building of the British Isles' 2nd ed. (1892) p. 222.
[2] Proc. Geol. Assoc. vol. xvii (1902) p. 153.

Church Lawford—where the Rhætic Black Shales, according to Mr. H. B. Woodward, are absent—is situated near the Moreton-Pennine anticline; Dunhampstead and Crowle—where the greatest thickness of the Rhætic Series obtains in Worcestershire—are situated on a continuation of the Cleeve-Hill synclinal axis (see map, fig. 1, p. 350); and the Birdlip anticlinal axis makes in the direction of Lassington. This is remarkable, but, as already stated, it is not desirable that the Lassington section be discussed for the present purpose: the Denny-Hill section, however, shows for certain that there is an anticline in this neighbourhood. Again, between Painswick and Stroud a synclinal flexure is noticeable in the Inferior-Oolite rocks, and, what is more, it will be observed that it follows somewhat closely upon the Birdlip anticline. Such is the case in the Rhætic also at Denny Hill there is evidence of the proximity of an anticline, while at Chaxhill—but $2\frac{1}{2}$ miles distant—there is very striking evidence of a syncline.

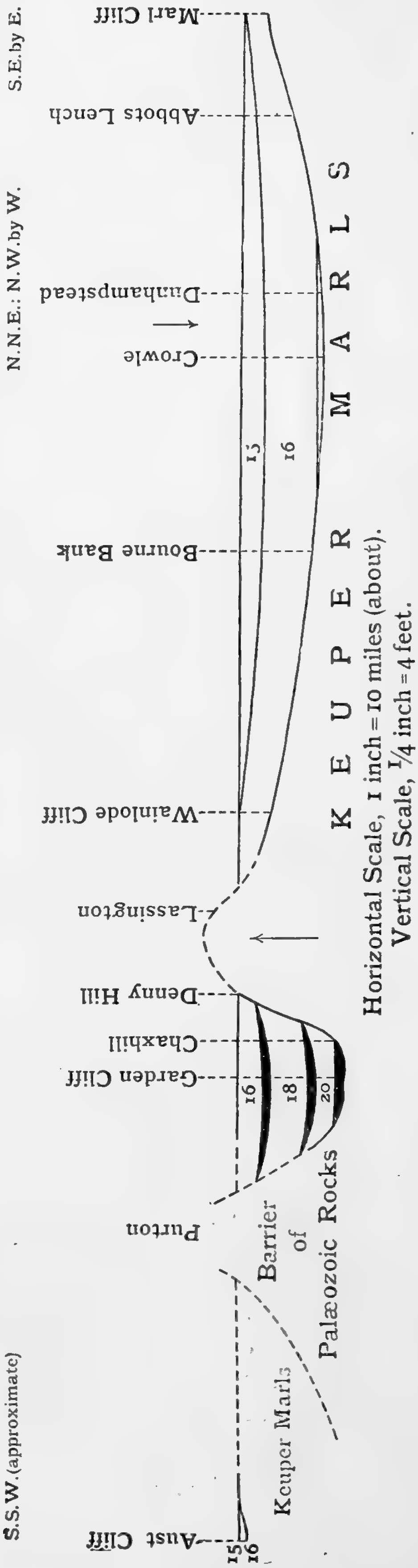



Fig. 2.—*Section showing the relationship of the Rhætic deposits below the Bone-Bed to the Keuper Marls.*

To sum up, then, it will be noticed that—confining our attention to the rocks of North-West Gloucestershire and Worcestershire—there is evidence to suggest that there were earth-pressures at work at the close of the Keuper Epoch, which caused the deposits to be thrown into slight synclinal and anticlinal flexures. In the depressed areas the earlier deposits of the Rhætic were laid down, and successive overlap on to the marls seems to have taken place (fig. 2).

Unfortunately, the products of the Rhætic Beds that are of economic importance are not numerous:

consequently, sections by quarrying and mining are few in number; river-cliffs, railway- and lane-cuttings afford the best exposures. If there were anything like half the number of sections that are obtainable in the Inferior Oolite of the Cheltenham district, this theory, I venture to think, would have had more facts to support it. At one time I was inclined to believe that—allowing, of course, for unequal deposition—the several beds of the Rhætic Series seen below the Bone-Bed had been deposited over the greater part of England; but that subsequent to their deposition they had been thrown into slight synclines and anticlines, and that after the anticlines had suffered erosion the Bone-Bed was deposited non-sequentially over the whole. This view I now consider improbable.

In my opinion, the evidence obtainable suggests that it was the Keuper deposits which were thus affected; and in immediate pre-Rhætic times. According to my theory, when the Rhætic ocean gained access to the British area it spread over an undulating expanse of Keuper Marls. In some areas, however, it has been stated, lakes probably existed, and it would be in these areas that the complete sequence from the Keuper to Rhætic deposits should be looked for. The section of deposits formed under the conditions stated would be essentially of transitional nature, as at Watchet; but where the Rhætic ocean spread over the surrounding ground a non-sequence would result. Thus, at the present time, the junction-line would appear sharply defined; there would be no transitional signs, and practically no erosion. As the area sank gradually the Rhætic ocean slowly encroached upon the land-surface, and successive overlaps and oversteps resulted. The lower deposits of the Rhætic Series now exposed at Garden Cliff and Chaxhill appear to have been laid down in a relatively much-depressed area between the Palæozoic barrier and the anticline, somewhere in the Denny-Hill and Lassington district. If sufficient sections had been obtainable between Chaxhill and Denny Hill, this successive overlap should have been observable.

It seems probable that it was during the formation of the Bone-Bed that the greatest overlap took place. In the sections at New Clifton (Bristol), and again in the railway-cutting at Lilliput, the Bone-Bed is seen to encroach considerably upon what was, at one time in the Rhætic Epoch, land composed of Palæozoic rocks. The 'Tea-Green Marls' of Sedbury Cliff do not appear to have been submerged until the time when the Bone-Bed was formed; and such would appear to be the case with many sections in the Bristol district also. The Keuper Marls of Gold Cliff, near Newport, may have been submerged about this time, for into their fissured surface J. E. Lee noted that Bone-Bed material had been washed.[1] A certain amount of littoral action is shown by the formation of a conglomerate such as that at Aust and Sedbury Cliffs. At Denny Hill the Bone-Bed contains small pieces of derived marl.

There is one other point to which I would direct attention. At

[1] Rep. Brit. Assoc. (Brighton, 1872) Trans. Sections, p. 116; and 'Note-book of an Amateur Geologist' 1881, p. 72 & pls. clxxi–clxxii.

those localities where the distribution of the *infra*-Bone-Bed deposits indicates elevation of the Keuper Marls in immediate pre-Rhætic times, it is noticeable that there is a non-sequence at the base of the Lias. At Sedbury Cliff, a locality where the Keuper Marls were not wholly submerged until Bone-Bed times, a bed of conglomerate separates the basal Liassic deposits from the Rhætic; at Lassington there is a remanié-bed; and in Warwickshire—in a region affected by the movements along the Pennine-Moreton anticlinal axis—the 'Guinea-Bed' points to a non-sequence. Indeed, to quote Mr. H. B. Woodward, near Church Lawford

'It is not improbable . . . . that there was some irregular overlap of the Rhætic Beds, accompanied by reconstruction of some layers, during the changing conditions that ushered in the Lower Lias.' [1]

---

[1] Mem. Geol. Surv. 'The Jurassic Rocks of Britain, vol. iii (1893) The Lias' p. 151.

## 24. *On a* SMALL *PLESIOSAURUS*-SKELETON *from the* WHITE LIAS *of* WESTBURY-ON-SEVERN. By WINTOUR FREDERICK GWINNELL, Esq., F.G.S. (Read June 8th, 1904.)

[Abstract.]

THE remains described were found on the Severn beach at Easter 1904, and had evidently fallen recently from the cliff above, which is there made up of the Upper Rhætic Beds, including the *Estheria*-Bed and the White Lias Limestone. The matrix of the specimen corresponds with the White Lias in colour, texture, and material, and it is similarly traversed by fissures often coated with dendrites. The remains are in excellent preservation, neither pyritized nor appreciably carbonized, as is so usual in 'Bone-Bed' specimens. They include more than twenty small dorsal vertebræ, with spinous and transverse processes, lying in natural sequence. Pseudomorphs in calcite of the spinal cord and intervertebral cartilages occur also in relative position. Several slender ribs, and indications of other bones (probably from the pectoral or pelvic arches), also occur in the slab, but are not yet worked out. Hitherto only single vertebræ or fragmentary bones of *Plesiosaurus* have been recorded from the Rhætics in Britain, and these only from the bone-beds below the White Lias. At present, it has not been found possible to assign the fossil to any existing species, but the characters most nearly approach those of *Plesiosaurus bibractensis*.

The specimen has been presented to, and accepted by, the British Museum (Natural History).

## 25. *On the* Occurrence *of a* Limestone *with* Upper Gault Fossils *at* Barnwell, *near* Cambridge. By William George Fearnsides, Esq., M.A., F.G.S. (Read May 25th, 1904.)

In the course of a recent examination of the great Gault-pit worked by the Cambridge Brick Company, Ltd., at Barnwell, my attention was drawn to an unusual and inconstant hard bed which is occasionally met with in the lowest part of the pit.

On examination, the hard material was found to consist largely of comminuted *Inoceramus*-fragments, with occasional ammonites and other shells, and a careful search in this and the adjoining clay proved them to be quite fossiliferous. Unfortunately, the specimens obtained are only fragmentary, but as they seem to indicate a horizon higher than any yet recorded from the Cambridgeshire Gault,[1] they may perhaps be worthy of record.

The section now seen is as follows, in descending order:—

| | *Thickness in feet.* |
|---|---|
| (1) Surface-soil, with gravel and Chalk-Marl, disturbed in the former working of the Cambridge Greensand. | 15 to 17 |
| (2) Dull leaden-grey clay, which on drying becomes more creamy and very pale. This is generally almost devoid of determinable fossils except *Plicatula*, but contains a few scattered phosphate-nodules, marcasite-concretions, and pieces of carbonized wood. | 39 |
| (3) Compact, well-jointed, homogeneous clay of a distinct bluish colour, containing large but undeterminable ammonites of the *rostratus*- or *Bouchardianus*-type; also occasional sharks' teeth and lamellibranch-shells. | 3 |
| (4) The Hard Band, with numerous specimens of *Inoceramus*, *Schlœnbachia varicosa*, *Terebratula biplicata*, sharks' teeth, and many phosphate-nodules. | 0 to 1 |
| (5) Very blue, well-laminated clay, with abundant fragments of fossils and many pale phosphate-nodules. | 4 seen. |

Of these, the three lowest divisions are the most interesting, and nearly all the fossils come from the beds (4) and (5). The Hard Band (4) is extremely variable in thickness. It occurs in a series of flattened lenticles, generally a few yards in diameter and up to a foot in thickness. It is largely made up of broken shells and phosphate-nodules, with a few bone-fragments and extraneous pebbles of mud, and is harsh to the touch. Some of the ammonites and *Inocerami* are very large, and specimens of the latter 3, 4, and even 5 inches across are not uncommon.

Petrologically, the Hard Band is best described as a somewhat muddy shell-limestone. It contains abundant phosphate-nodules,

[1] See Mem. Geol. Surv. 'The Cretaceous Rocks of Britain, vol. i (1900) The Gault & Upper Greensand of England' p. 287.

of which at least three types occur: these we may distinguish as the green, the pale, and the dark-brown.

The green nodules are more or less irregular, subcylindrical lumps of phosphatized mud. They enclose no obvious shell-fragments, and never contain more than about 10 per cent. of calcium-phosphate. They seem to represent mud-pebbles deposited among the shells, and have probably become phosphatized *in situ*.

The pale nodules (which are sometimes yellow, sometimes brown) are very similar in structure to the green, but contain a much greater proportion of calcium-phosphate, generally about 35 to 40 per cent. They are very irregular in shape, but are never obviously rolled. A few seem to be the internal casts of shells now destroyed.

The dark-brown nodules are less common; they differ from the others in that they have well-rounded shapes, and appear to have been derived from older beds. They are much richer in phosphates than any of the others, analysis showing something more than 50 per cent. of calcium-phosphate. They are often bordered with material like that of the pale nodules, and contain no determinable fossils.

Under the microscope, the rock [1] is seen to be made up of more or less recognizable shell-fragments. About one-half of it consists of the fibrous calcite-prisms characteristic of *Inoceramus*. Foraminifera are also very abundant, and many forms occur. *Globigerina*, *Miliola*, *Nodosaria*, and *Textilaria* are the most prominent genera. As usual, they have the chambers filled with calcite, which is in crystalline continuity with the test, and so shows the usual black cross exceedingly well. Characteristic fragments of various other lamellibranchs, brachiopods, small gasteropods, echinoids, and crustacea are recognizable, but form only a small proportion of the whole. A few of the fragments have become granular, but such as were originally calcite have retained even the most minute of their microstructures. Of other constituents a fibrous, yellowish-brown, non-pleochroic mineral giving low-interference colours and straight extinction, and occurring in shreds and plates, is the most abundant. Some of it appears to show organic structure, and may, I think, be chitin. Chips of clastic quartz occur sporadically, and one or two prisms of fairly fresh orthoclase were observed. A few small and irregular masses of isotropic or aggregate-polarizing glauconite were also seen in the slice examined, and are probably much more abundant in other parts of the rock. A groundmass is present, in small and variable quantity. Much of it is calcite, and is in crystalline continuity with the adjoining shell-fragments, but a certain amount of finely-granular material and irresolvable clay-paste occurs in the interstices. Unfortunately, the slice does not happen to show any of the phosphate-nodules.

The fauna contained in the Hard Band is not markedly different from that of the immediately-underlying clay, and in the following

[1] Slide No. 4308 in the Sedgwick-Museum Collection, Cambridge.

list no attempt has been made to separate the two. The fauna that I have obtained is as follows :—

FORAMINIFERA.

*Globigerina.*
*Miliola.*
*Nodosaria.*
*Textilaria.*

ACTINOZOA.

*Trochocyathus angulatus*, Dunc.

ECHINODERMATA.

*Cidaris gaultina*, Forbes.
**Pentacrinus Fittoni*, Austen.

ANNELIDA.

*Serpula* sp.

CRUSTACEA.

**Pollicipes lævis*, Sow.

BRACHIOPODA.

**Terebratula biplicata*, Sow.
*Terebratulina triangularis*, Ether.

LAMELLIBRANCHIATA.

**Cardita tenuicosta*, Sow.
**Inoceramus tenuis*, Mont.
*Inoceramus* sp., cf. *concentricus*, Park.
**Lima globosa*, Sow.
**Nucula bivirgata*, Sow.
*Ostrea.*
*Pecten orbicularis*, Sow.
*Pinna tetragona*, Sow.
*Plicatula gurgitis*, Pict. & Roux.
*Spondylus* sp.
*Teredo* sp.

SCAPHOPODA.

**Dentalium decussatum*, Sow.

GASTEROPODA.

*Aporrhais* sp.

CEPHALOPODA.

**Belemnites minimus*, Lister.
*Hamites* sp.
**Hoplites splendens*, Sow.
**Hoplites tuberculatus*, Sow.
**Schlœnbachia Bouchardiana*, Sow.
**Schlœnbachia rostrata*, Sow.
**Schlœnbachia varicosa*, Sow.

PISCES.

**Lamna appendiculata*, Ag.
*Scaphanorhynchus rhaphiodon*, Ag.

All these are also recorded from the various members of the Upper Gault of Folkestone. The most abundant forms are :— *Inoceramus tenuis*, *Schlœnbachia varicosa*, *Terebratula biplicata*, *Cardita tenuicostata*, and *Lamna appendiculata*; and the general aspect of the fauna suggests a correlation with the upper part of the zone of *Schlœnbachia varicosa*, Bed IX of Mr. Hilton Price's Folkestone Gault.[1] The species marked with an asterisk are common to the two beds. Most of the other species have somewhat wide ranges, but the occurrence of *Terebratulina triangularis* is notable. This fossil abounds in the Cambridge Greensand, and is not generally supposed to extend much below that horizon; its occurrence in the Hard Band is, however, undoubted, and several specimens of it have been met with. The record of *Schlœnbachia rostrata*, unfortunately, is not so satisfactory; but large pieces of an ammonite, which may be *Schl. rostrata*, are very abundant in the clay just above the Hard Band.

From this new palæontological evidence, and from the fact that the fossils mentioned are all obtained some 40 feet below the upper surface of the Gault, I conclude that the whole of the Upper Gault of Cambridge was not used up in the making of the Cambridge Greensand, but that a thickness of at least 45 feet of it remains at

[1] Quart. Journ. Geol. Soc. vol. xxx (1875) p. 351.

Barnwell. This, with the knowledge that the Gault as a whole is thinning northward and passes into the Red Chalk of Hunstanton, further complicates the problem of the Cambridge Greensand; but into that problem I cannot enter here.

In conclusion, I gladly express my thanks to Mr. R. H. Rastall, of Christ's College, for help in collecting the fossils here recorded; also to Mr. H. Woods and Mr. A. J. Jukes-Browne, of St. John's College, for encouragement and aid in the identification of some of the species.

## Discussion.

The President welcomed the Author's first paper to the Society, which he hoped and believed would be followed by many others. He thought that the Upper-Gault age of these beds was proved by the fossils. Mr. Jukes-Browne, who had done so much work in this district, seemed to speak with great caution as to the absence of Upper Gault in Cambridgeshire. The speaker was inclined to think that the deposit would prove to be local in the county, having been removed elsewhere by denudation not necessarily indicating upheaval, but rather the local action of eroding marine currents.

The Rev. J. F. Blake agreed that the ammonite-fauna exhibited consisted essentially of Upper-Gault forms; and these being found below some 40 feet of Gault-material, proved that the Upper Gault had not been removed from the area. These beds had not been noticed by earlier writers, from the fact that they had never been exposed; there never had been 40 feet of Gault exposed in any working below the coprolite-bed. The fossils exhibited were markedly distinct from those of the 'Cambridge Greensand'. The latter could not have been derived from them; and their presence at this depth threw doubt upon their ever having been reached by denudation anywhere in the district.

The Author thanked the Fellows for their reception of his paper. In reply to the suggestion that the Upper Gault of Barnwell was merely a local ridge which had escaped erosion during the formation of the 'Cambridge Greensand', he pointed out (1) that the total thickness of Upper and Lower Gault at Barnwell was less than that shown in any of the well-sections south of Cambridge; (2) that the yield of phosphate-nodules and fossils from the former coprolite-workings on the site of the present Gault-pit at Barnwell was large, and that the 'derived' fauna contained therein included Lower as well as Upper-Gault forms; and (3) that the Gault-pits at Barrington and Arlesey which showed the junction of Gault and Chalk-Marl yielded numerous Upper-Gault lamellibranchs, and that a well-section at the latter place had proved the existence of a 'Hard Band' like that at Barnwell, but at an even greater depth.

## 26. *On some* Quartzite-Dykes *in* Mountain-Limestone *near* Snelston (Derbyshire). By Henry Howe Arnold-Bemrose, Esq., M.A., F.G.S. (Read May 11th, 1904.)

[Plates XXX & XXXI.]

### I. Description of the Quarry and the Dykes.

About $3\frac{1}{2}$ miles south-west by south of Ashbourne, near Snelston Common, is an inlier of Mountain-Limestone surrounded by Keuper Marl. According to the Geological-Survey Map, the outcrop of limestone is roughly elliptical in shape, the major axis extending for a distance of about half a mile in a north-north-easterly direction, and the minor axis in a west-north-westerly direction for about one eighth of a mile. Cockshead Lane, the road from Norbury to Cubley Common, passes over the inlier, which only forms a slight feature in the landscape, at a height of about 600 feet above Ordnance-datum. On a clear day, some of the churches and chimneys of Derby, distant about 11 miles, can be seen from the top of the quarry.

The limestone has been quarried on both the north and south sides of Cockshead Lane for about 40 feet below the ground-level, so that the lane passes over a high wall of limestone-beds, which have been left intact between the two quarry-floors. The northern quarry is now disused. It contains lead- and copper-ores, which were worked about 30 years ago. It is outside the area of the main mass of Mountain-Limestone to which the curious lead-mining laws apply, and I was informed that the present owner does not allow the lead-ore to be worked.

The quarry south of Cockshead Lane is being worked for road-metal. The inlier is in the form of a dome or pericline, with its greatest extension in a north-north-easterly direction. Only a brief examination is necessary to show that the limestone varies considerably in character in different parts of the quarry. It is generally a massive limestone, with a few chert-nodules in the upper part; at the south-western end of the quarry the grey limestones are seen dipping south-westward at an angle of 30°. They are probably the highest beds in the quarry. The central portion of the dome has been removed down to the present floor, so that it is uncertain whether the thin limestones extended over the whole area at the time when the quarry was first opened, or whether they had been removed by denudation.

Some parts of the rock-face show a slickensided surface, due to differential movement on opposite sides of the nearly-vertical joints. The rock in many places has a broken appearance, and contains small hollow spaces or caverns; large portions of the limestone have been partly or completely dolomitized, and are of a brown colour. In a hand-specimen the partly-dolomitized rock is speckled with brown spots, which with a lens are seen to consist of crystals and groups of crystals of dolomite.

The floor and faces of the quarry are traversed by vertical veins or dykes of calcite, fluorspar, barytes, calcareous sandstone, and quartzite. On my first visit, I noticed several blocks of siliceous rock, which I was informed had been obtained from a so-called bastard limestone on the south-eastern side of the quarry, and that 20 tons of this rock had been removed. The place from which it was obtained is now covered with soil and vegetation, and consequently no outcrop is visible. The bastard limestone or quartzite probably filled a fissure, pipe, or swallow-hole in the limestone.

Pl. XXX, fig. 1, shows one of these dykes traversing the face of the quarry. It varies from 2 to 4 inches in width, and consists mainly of quartzite, but barytes and calcite are also found in it in places. It is darker than the limestone and very hard.

Pl. XXX, fig. 2, shows another dyke, which attains a width of 19 inches, and consists of a hard sandstone or quartzite.

## II. Petrography.

### (1) The Quartzite-Dykes.

A number of thin slices of the quartzite and of the limestone were examined under the microscope, but it will be sufficient for the purposes of this paper to refer to the following.

No. 1316,[1] from the 4-inch vein, examined under the microscope, cannot be distinguished from a quartzite. It consists of angular and detrital quartz-grains with enclosures, a few small pebbles or grains of felspar, and a few shreds of mica. The grains are cemented by silica, and sometimes by calcite; the interspaces are often filled with a secondary growth of quartz around the grains. (See Pl. XXXI, fig. 1.) The limestone (1315) in contact with the quartzite is fine-grained and crystalline.

A specimen from a softer dyke (1318) consists of quartz, a small quantity of mica, and traces of monoclinic felspar. The quartz-grains are both angular and well-rounded. The formation of secondary silica in optical continuity with the original grains is well shown, and calcite is also present. (See Pl. XXXI, fig. 2.)

A specimen (1235) from another dyke consists of quartz-grains and a few felspars cemented by calcite (see Pl. XXXI, fig. 3).

In the south-eastern face of the quarry, near where the bastard limestone was worked, is another dyke of quartzite, which extends to the topmost exposed bed. The rock (1086) consists of quartz, with a small quantity of felspar and mica. Some of the felspars

[1] These numerals throughout refer to the numbers of the slides in the writer's collection.

have straight extinction, but others extinguish up to an angle of 18°. (See Pl. XXXI, fig. 4.)

On a visit to the quarry this year at Easter, I was told by the foreman that some silver-sand had been found in a small fissure or joint in the limestone. I examined the fissure, and obtained some sand of a reddish-brown colour. After it had been washed it was examined under the microscope, and found to consist mainly of quartz-grains, the majority of which were well-rounded, with a few flakes of white mica.

## (2) The Quartzose Limestone.

The rock (1232) in contact with the last-described dyke consists of crystalline calcite, containing a large quantity of quartz in isolated crystals and in granular aggregates. The quartz sometimes encloses calcite. Two feet below No. 1232, the limestone (1233), which is in contact with the same dyke, contains traces of organisms and many bipyramidal crystals of quartz.

A thin slice (1234) of the partly-dolomitized limestone was examined. It consists of remarkably well-defined and often isolated rhombohedra of dolomite, in a matrix of finely-crystalline calcite. The quartz occurs in granular aggregates and in isolated crystals. A small piece of the rock was dissolved in strong hydrochloric acid, and the residue was found to consist of bipyramidal quartz-crystals and a small quantity of brown material.

Quartz-crystals were also found in other parts of the limestone. The thin grey limestones at the south-western end of the quarry are traversed by small calcite- and quartz-veins.

The thin slice (1236) consists of a limestone containing foraminifera, *Calcisphæra*, and a few isolated crystals of quartz. The slice is traversed by a small vein of quartz in a fine mosaic, similar to the quartz-strings or veins in the limestone near Bonsall.[1]

These quartzose limestones are similar to those described by me in a paper read before this Society in the year 1898.[2]

## (3) The Calcite.

Between the thin beds of limestone at the south-western end of the quarry and the 4-inch quartzite-dyke described above, is a vein of calcite several feet thick. It appears in part to be bedded like limestone, and shows horizontal slickenside-faces between the joints. It consists (1237) of crystalline calcite, with polysynthetic twinning well developed. Some portions are red, and are similar to the 'Hartington Red,' formerly obtained near Hartington between Ashbourne and Buxton, and polished as marble. Other portions are white. The red coloration is due to oxide of iron, which occurs in small dendritiform patches.

[1] Quart. Journ. Geol. Soc. vol. liv (1898) pp. 173 & 174, thin slice No. 431.
[2] *Ibid.* pp. 169 to 182.

## III. Silica present in two Forms.

From the foregoing description, it appears that the silica is present in the limestone in two forms, which have had an entirely-different origin. The one, similar to that in the quartzose limestone previously described by me as occurring in various parts of the Mountain-Limestone area of the county; and the other associated with felspar and mica, sometimes forming a calcareous grit, at others a quartzite. In the former case, the quartz occurs in isolated crystals and crystalline aggregates and in small veins or strings in the limestone; in the latter, it occurs in dyke-like masses, which mainly consist of detrital and angular grains.

It may be convenient to refer briefly to sandstone-dykes which have been previously described. The references to them have been obtained from Sir Archibald Geikie's 'Text-Book of Geology,' 4th ed. vol. i (1903) pp. 665–67:—

(*a*) In Ross-shire narrow rifts or cracks in Lewisian Gneiss have been filled with Torridonian conglomerate and sandstone.

(*b*) Dykes of hard fossiliferous sandstone traverse the Neocomian clays of Alatyr, in Russia. These clays are supposed to have been rent open by a submarine earthquake, and filled up with deposits from the sea-floor.

(*c*) In Colorado a series of sandstone or quartzite-dykes traverse a pre-Cambrian granite. Mr. W. O. Crosby suggests that the fissures were formed at the time of the production of the great fault of Ute Pass, and that they were filled with sand from the overlying Potsdam Sandstone.

(*d*) In Northern California Mr. J. S. Diller found dykes of impure quartzose sandstone intersecting Cretaceous sandstones and shales along lines of joint, and suggested that they represented earthquake-fissures filled in with sand rapidly injected from below.

(*e*) Mr. E. Greenly described some sandstone-pipes in limestone in Anglesey, descending from a bed of sandstone into a limestone.

## IV. Origin of the Quartzite-Dykes in the Limestone-Inlier.

The detrital form of the quartz-grains and the slight traces of bedding seen in one of the dykes indicate that the quartz, mica, and felspar were introduced into the limestone-fissures from a b o v e. According to the Geological-Survey Map, the Keuper Marl rests upon the limestone in the neighbourhood of the quarry. The sections seen in the quarries seem to indicate that this mapping is correct. In trying to find an explanation of the origin of these quartzite-dykes in the limestone, I examined the neighbourhood of the quarry for sections of Keuper rocks in the year 1901. At Marston-Common Farm, 1200 yards south-west of the quarry, I found that a well was being sunk for water. It was started in Keuper Marl, went through 8 or 10 yards of it and 21 yards of a very hard grit or quartzite, which was sometimes in thin laminæ and at others contained small pebbles of quartzite. At the time of my visit, the work had just been abandoned, because of the absence of water. The information and measurements were obtained from one of the men who were engaged in the work. I made a selection of specimens of the quartzite from the sinking, and examined several thin slices.

The rock is similar to the quartzite that occurs in the dykes in the quarry. Slides 1238 & 1239 consist of quartz in a mosaic of granitic structure, with a small quantity of mica and pebbles of microcrystalline quartz (see Pl. XXXI, fig. 5). The laminated quartzite (1249) shows the laminations better in a hand-specimen than under the microscope, and contains more mica than 1238 & 1239. A thin slice of Nuneaton quartzite, compared with Marston rock, was found to contain larger grains of quartz, but in other respects to have a similar structure.

The failure to find water was probably because the sandstone-grains were cemented by secondary silica, which had rendered the rock impervious to water.

About 800 feet south of Marston-Common Farm is an old sandstone-quarry, on ground mapped as Keuper Marl by the officers of the Geological Survey. From its position and from the fact that the ground-surface is lower than that at the farm, we may infer that the sandstone-beds are probably on the same horizon as the quartzite found in the well. Two thin slices of this rock were examined (1319 & 1320). They are similar to some of the quartzite-dykes in the quarry. The rock consists mainly of an aggregate of quartz-grains, with a small quantity of mica, and perhaps of felspar. Some grains consist of microcrystalline quartz. (See Pl. XXXI, fig. 6.)

## V. Conclusions.

The Snelston inlier consists of massive beds of limestone with occasional nodules of chert, and is unaccompanied by shales; it must, therefore, belong to the main mass of the Mountain-Limestone, though separated from it by a large synclinal basin. The quartzite in the dykes is similar to the Keuper Sandstone in the immediate neighbourhood of the limestone-inlier. It requires no great stretch of imagination to suppose that the limestone, traversed by joints and fissures, was covered by water in which the Triassic sandstones were laid down. The angular and rounded grains of quartz, with the few felspars and fragments of mica, were probably deposited in these fissures, and solidified as dykes of sandstone. At a later period, the silica was introduced which cemented these sandstone-dykes and the sandstones at Marston-Common Farm into a quartzite, and impregnated the limestone in such a way as to form a quartzose limestone similar to the quartzose limestone near Bonsall, Castleton, Ashover, and in other parts of the county.

## EXPLANATION OF PLATES XXX & XXXI.

### Plate XXX.

Quartzite-dykes in Mountain-Limestone near Snelston (Derbyshire).

Fig. 1. Four-inch dyke of quartzite, passing through the limestone in a vertical direction near the centre of the figure.

2. Larger dyke of quartzite, 10 to 12 inches in diameter. The quarry-face is a slickensided surface.

[Both figures represent an almost vertical face of the quarry-wall.]

Fig. 1.

Fig. 2.

*H. A. B., Photo.* *Bemrose, Derby.*

QUARTZITE-DYKES IN MOUNTAIN-LIMESTONE,
NEAR SNELSTON (DERBYSHIRE)

FIG. 1 x 50.

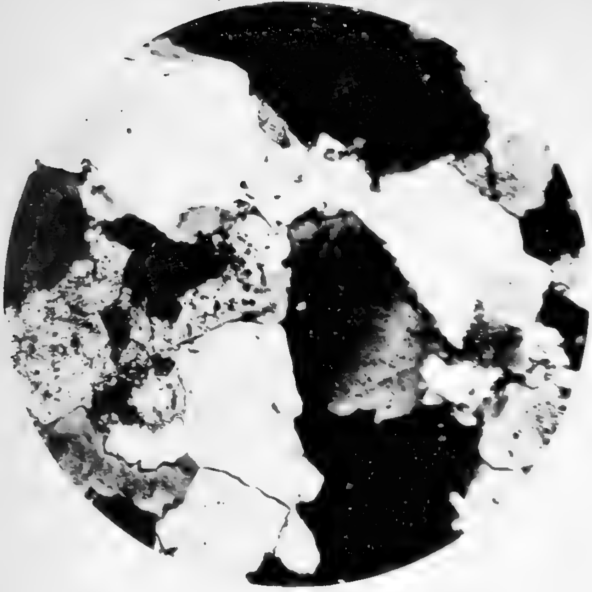


FIG. 2 x 50.

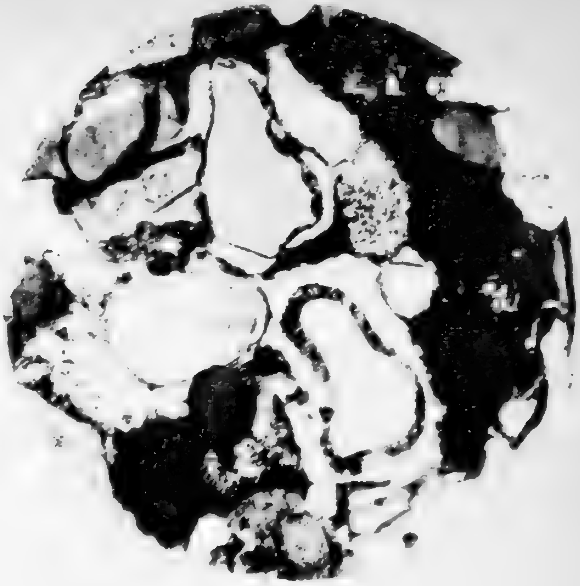


FIG. 3 x 50.

FIG. 4 x 50.

FIG. 5 x 50.

FIG. 6 x 50.

*H. A. B., Photomicro.* *Bemrose, Collo.*

QUARTZITE IN MOUNTAIN-LIMESTONE AND KEUPER SANDSTONE.

PLATE XXXI.

[The figures were photographed by the Author from the microscope, under polarized light with crossed nicols, and enlarged 50 diameters.]

Fig. 1. Thin slice (1316) from the 4-inch dyke shown in Pl. XXX, fig. 1. See p. 365.
2. Thin slice (1318), showing the formation of secondary silica in optical continuity with the rounded quartz-grains, from a second dyke. See p. 365.
3. Thin slice (1235), quartz and felspar cemented by calcite, from a third dyke. See p. 365.
4. Thin slice (1086), quartz and felspar, from a fourth dyke. See p. 365.
5. Thin slice (1238) from Marston-Common well: quartzite. A piece of mica is seen near the centre of the figure. See p. 368.
6. Thin slice (1319) from the quarry south of Marston-Common Farm: sandstone. See p. 368.

DISCUSSION.

The CHAIRMAN (Mr. H. B. WOODWARD) remarked that the subject of sandstone-dykes had not been brought before the Society, except incidentally, for more than 60 years—when Strickland called attention to the remarkable dykes of calcareous grit in Cromarty. It was difficult to say whether those particular dykes were filled from above, or by hydrostatic pressure from below, as they were seen only in plan and not in section. In some cases wind-drifted sand might have filled fissures.

Prof. JUDD referred to the case in Cromarty which was supposed by Murchison to be a 'trap-dyke', but was afterwards shown by Hugh Miller to be composed of sandstone and actually to contain fossils. He suggested that the fissure might have been formed by earth-movements or solution, subsequently to the deposition of the Keuper Sandstone, but before its consolidation. As the fissure was opened, the sand from above might gradually find its way downward, and would at last be converted by soluble silica, traversing the mass, into quartzite.

Mr. STRAHAN remarked that he had described veins of quartzite in the limestone of Flintshire.[1] In the Talargoch Mine some of the veins contained an impalpably-fine siliceous sand, which passed in its unweathered state into a quartzite resembling that described by the Author. Such deposits tended to fill any fissure or cavity in the limestone, and might be derived from any overlying sandstone, whether a bed interstratified with the limestone or, as in the case referred to, from the chert-beds of the Millstone-Grit. At Talargoch there was no Keuper Sandstone overlying the limestone, and he was not satisfied that the material described by the Author had been derived from that formation.

The Rev. H. H. WINWOOD said that he was much interested in the description of the 'dykes', a formation with which he was very familiar in the Mendip district, where the joints in the Mountain-Limestone were filled up by Liassic and Triassic deposits: these,

[1] 'Geology of Rhyl, &c.' Mem. Geol. Surv. (1885) pp. 47–48.

being less easy to work than the adjoining limestone, were left by the workmen in quarrying, standing out like walls. There could not be any doubt that these joints had been filled in from above. In a quarry near Chipping Sodbury these infillings assumed a columnar form, and consisted of sandstone with white quartz-pebbles, probably the result of the denudation of the Triassic sandstones which once covered the district and were washed in and finally consolidated.

Mr. H. W. Monckton complimented the Author on the beautiful photographs of rock-faces shown upon the screen. He then referred to the curious bands of hard calcareous sandstone which run through the Kimeridge Clay at Ethie near Cromarty, and appear to be of much the same nature as those described in the paper. The 'dike' at Ethie is harder than the shale, and stands well above it on the shore. It is probably an infilled crack or fissure in the shale; for, as the country-rock is (in that case) shale, the space occupied by the 'dike' cannot have been due to solution. The speaker thought that the infilling had probably come from above, although he could quite understand that such a 'dike' might be formed by infilling from below, somewhat on the principle of creep in coal-pits. He did not think that the word 'dike' should be confined to bands of rock of igneous origin, for the word was a common one, and in Scotland usually meant a wall. He thought that it was a good term for the bands of rock in question.[1]

Prof. W. W. Watts asked whether the Author had considered the possibility of the dykes being of Millstone-Grit age. He had examined examples of Millstone-Grit in which the secondary growth of quartz was precisely similar to that described in the paper. Prof. Sollas's observations in Funafuti had shown that the reef-limestone was seamed with deep fissures admitting sea-water, and if the Carboniferous Limestone was formed under similar circumstances, the oncoming Millstone-Grit would find the requisite hollows for the formation of steep dykes such as those described by the Author. The speaker had seen dykes of this nature, not only in soluble rocks, but in quartzites like those of the Lickey Hills, and in this case the dykes frequently contained Llandovery fossils.

Mr. Teall referred to the dykes and veins of sandstone in the Lewisian Gneiss of the North-Western Highlands, and pointed out that they occurred at or near the junction of gneiss and Torridon Sandstone. They were similar in petrological character to the sandstone, and had no doubt been filled in from above.

Mr. J. Allen Howe remarked that, a few miles north of Snelston, near Brassington, large pipes and fissures existed in the limestone, containing a mixture of sands and clays of Keuper, Bunter, Millstone-Grit, and possibly of Glacial origin. He asked the Author whether the dykes described in the paper were in any way related to the above deposits, an occurrence which seemed not unlikely, considering their proximity to Snelston. The sand in

[1] See, in confirmation of this, John Brand's 'Hist. of Newcastle' vol. ii. (1789) p. 679, note *d*.

the pipes was frequently re-crystallized, and flakes of mica were abundant. There was no doubt that the pipes had been filled in from above. There were, however, certain features in the Snelston outlier which appeared to present a parallelism to those dyke-districts described by Diller, Crosby, and others, in which the dykes had been filled by hydrostatic pressure from below; then, Snelston was very near a minor earthquake-centre, and had clearly been subjected to pressure resulting in a fracturing or buckling of the strata. He suggested that the Author might notice whether the mica-grains were lying parallel to the sides of the dykes, or at right angles to them; for it had been indicated by the American investigators that the former position was characteristic of dykes filled from below, while the latter position was the rule in dykes filled from above.

The Author thanked the Fellows for their reception of his paper. He thought it more likely that the sandstone had been introduced from above, than through several thousand feet of limestone from below. Although the sand might possibly be of Millstone-Grit age, the presence of Keuper Sandstone in the immediate neighbourhood of the limestone-inlier probably indicated the true source of the sand.

The pits in the limestone filled with sand, shale, and Bunter pebbles, mentioned by the previous speaker, were very different from the dykes or veins described by the Author. He hoped that the facts described in his paper would one day be useful to some geologist, who would be able to explain satisfactorily the origin of sandstone-dykes in sedimentary rocks.

## 27. *On the* Age *of the* Llyn-Padarn Dykes. By James Vincent Elsden, Esq., B.Sc. (Lond.), F.G.S. (Read May 25th, 1904.)

[Plate XXXII—Microscope-Sections.]

### I. Introduction.

The characters of the basic sills of Caernarvonshire have been described in detail by several writers, notably by Mr. Harker in his well-known essay on the Bala Volcanic Series. There is a marked absence of dykes in association with the outbursts of this period, and the numerous basic dykes of this area have generally been assigned to a later series of eruptions. The evidence upon which this assumption rests is, however, not always satisfactory; and although Mr. Harker is inclined to favour their post-Carboniferous age, he does not conceal the uncertainty of this conclusion in several cases, and he adduces evidence which seems to point, at least in some instances, to the possibility of the existence of more than one group of these intrusions.[1] Dr. C. A Matley, also, finds that in Northern Anglesey at least two groups of dykes occur, of which the earlier are pre-Silurian and the later post-Ordovician.[2] But Mr. E. Greenly maintains that the later dykes of Anglesey, including those of the Menai Straits, are certainly post-Carboniferous, and may possibly be even of Tertiary age.[3]

With regard to the Llyn-Padarn dykes, with which this paper is chiefly concerned, no very detailed description appears to have been published, although several authors have incidentally referred to them, as will be mentioned hereafter. It appears to have been generally assumed that these dykes are of the same age as those of the Menai Straits, to which they are supposed to bear a general resemblance, both in petrographical character and in direction. With regard to the former, however, this is by no means the case.

In the present paper it is proposed to examine this question in detail, and to produce evidence which seems to suggest that the bulk of the 'greenstone'-dykes of this area belong to an earlier period of eruption than has been generally assigned to them, and there is proof that some of these 'greenstones' may even be older than the quartz-felsite of the Llyn-Padarn ridge. The greater part, however, if not actually of Bala age, seem to have been intruded before the great post-Bala crust-movements, which produced the folding of the Lower Cambrian rocks of Llanberis, had entirely ceased. At the same time, the evidence does not exclude the possibility that some of the intrusions may be of a later date.

The evidence upon which these conclusions rests is based mainly

[1] 'On some Anglesey Dykes' Geol. Mag. 1887, p. 409; & *ibid.* 1888, p. 267.
[2] 'Geology of Northern Anglesey' Quart. Journ. Geol. Soc. vol. lvi (1900) p. 249.
[3] 'On the Age of the Later Dykes of Anglesey' Geol. Mag. 1900, p. 160.

upon the signs which the intrusions exhibit of having been considerably modified by earth-pressures, more especially in those portions which protrude into the Cambrian strata. Petrographical considerations, also, make it impossible to separate these rocks from the diabase-sills of Bala age occurring farther to the south and south-west of this area; and there is a strong presumption that they represent the last residuum of the magma from which the Bala sills were derived.

## II. Field-Evidence.

The greater part of the basic dykes of Llyn Padarn have a south-easterly strike, and several of them penetrate both the older ridge and the later Cambrian strata which abut upon it. Mr. Harker has given very strong reasons for supposing that the ridge stood up as a more or less firm buttress, against which the Llanberis Slates and Grits were forced by the great south-easterly thrust which took place after the commencement of the eruption of the Bala diabases.[1] The duration of this thrust is uncertain, but there does not appear to have been, in this area, any later movement of a magnitude sufficient to cause such a structural alteration as these rocks exhibit in certain parts.

A careful examination of these dykes discloses the fact that whereas the north-western portions, which are enclosed in the older rocks of the ridge, are comparatively free from dynamic metamorphism, this character gradually disappears as the dykes are followed into the more yielding Cambrian grits and slates, where they become structurally deformed, and often so highly sheared as to become with difficulty recognizable as portions of the same dyke. This feature is not confined to a few instances. It is shown in every case that has come under my notice. Taking, for example, the long dyke shown in the map (p. 376) south of Cwm-y-glo, this rock preserves the character of a typical ophitic diabase, until near Gallod it emerges into the Cambrian sediments. Here its course changes, and it shows a curve concave to the south, as it winds upward to the summit of Y Bigil. At the same time, the appearance of the rock alters, its original structure being altogether obliterated by crushing, and its sheared end has acquired an almost slaty cleavage. Accompanying this structural alteration the mineralogical changes are no less pronounced, as will be more fully detailed in another section of this paper.

Similar features may be noticed in tracing the other dykes in the two areas east and west of Llyn Padarn. The dykes in the ridge on the western side of the lake show only the effects of slight shearing and pressure-metamorphism, while those in the sediments on the eastern side, about Fachwen and Yr Alt Wen, are crushed almost beyond recognition. Not a single example of the many exposures of 'greenstones' in the Cambrian sediments,

[1] 'Bala Volcanic Series of Caernarvonshire' [Sedgwick Prize Essay for 1888] 1889, p. 114.

examined by me, failed to exhibit this character in greater or less degree. It is, in fact, so distinctive, that specimens can often, by the unaided eye, be at once assigned to one or the other of these two regions.

An interesting exposure exhibiting these conditions has quite recently been opened up at Llanberis, where blasting has taken place in connection with an alteration in the road, about a quarter of a mile to the south-west of Plas Coch. This occurs at the top of the hill a little beyond the smithy, where a small 'greenstone'-intrusion, about 5 yards wide, is to be seen near the base of the *Lingula*-Flags. (The same rock is visible in the bed of the Afon Goch close at hand, but the course of the dyke is not visible for any great distance.) Apparently the outcrop of this dyke runs nearly parallel to the strike of the *Lingula*-Flags, which here dip almost vertically; yet, whether the intrusion is a dyke or sill is not quite certain, although the evidence seems to favour the former interpretation. It is here manifest that the igneous rock has been powerfully affected by the crush which folded the sedimentary rocks. The southern side has been much broken and faulted against the flags, while the northern contact is cleaner and less crushed, a circumstance which might be expected when the southerly direction of the thrust towards the north is borne in mind. The whole mass of the igneous rock is greatly sheared, becoming in places almost schistose, the fissures and shear-planes thus produced being strongly marked by veins and coatings of silky asbestos, some of which are nearly 2 inches wide, the asbestos-fibres being arranged transversely to the walls of the fissures. The rock itself is of a light greenish-grey colour, spotted with dark patches of a chlorite-mineral. There is also much secondary calcite, with fan-shaped bundles of epidote in the more weathered portions. A quartz-epidote vein about 18 inches wide traverses the rock in its lower portion near the road-level on the northern side. The rock contains a good deal of pyrites, and the flags at the junction are filled with cubes of this mineral, many of which have been weathered out, or replaced by chloritic pseudomorphs. The petrographical features of this rock will be referred to later.

The exposure in the Afon Goch is exactly similar to the foregoing, and need not now be enlarged upon. There can be no sort of doubt with regard to the age of this intrusion, which must have preceded some part of the earth-movements connected with the post-Bala folding. Previous observers have already called attention to the effects of intense pressure upon the rocks on the southern margin of the quartz-porphyry ridge. Sir Archibald Geikie describes basic dykes near Llyn Padarn which have been converted into a slaty rock by pressure.[1] Similar sheared diabases have been noticed by the Rev. J. F. Blake [2]; consequently, there appears to be cumulative evidence that these 'greenstones,' if not actually intruded before the period at which the curvature and compression of the region took

[1] 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 162.

[2] 'On the Felsites & Conglomerates between Bethesda & Llanllyfni' Quart. Journ. Geol. Soc. vol. xlix (1893) p. 441.

place, were certainly injected before these great earth-movements had died away.

To sum up the field-evidence on this point, we find in these dykes unmistakable signs of dynamic metamorphism and deformation. It would not be expected that those portions of the dykes which were firmly held in the Llyn-Padarn ridge would be so profoundly affected by the post-Bala movements as those enclosed in the more yielding sedimentary strata towards the south, and this agrees precisely with what appears to have taken place. The progressive examination of these dykes from one extremity to the other furnishes many interesting examples of the effects of varying degrees of pressure-metamorphism, to certain of which attention will shortly be drawn.

It must not be supposed, however, that highly-sheared and altered 'greenstones' do not occur in the Llyn-Padarn ridge. I have found several instances of these, and it is suggested that they may belong to a still older group.

I do not propose to reopen the controversy with regard to the stratigraphical succession in this district, but taking the conglomerates on either side of the Llyn-Padarn ridge as the base of the Cambrian, the evidence for the existence of pre-Cambrian greenstones will now be considered. Previous observers have called attention to the occurrence of fragments of basic igneous rocks in the conglomerates,[1] and have expressed some difficulty in refering these to their origin. The Rev. J. F. Blake has described the occurrence at Bryn Efail, on the north side of the Llyn-Padarn ridge, of felsite intrusive in a rock which he believed then to be a slate,[2] but Miss Raisin has since shown this to be a sheared 'greenstone'.[3] It should perhaps be mentioned that the latter observer failed to see any vidence of the intrusion of the felsite into the 'greenstone'. Without, however, entering into the discussion of the Bryn-Efail section, about which a great deal has been written by the above-mentioned authors, the following fact appears to the present writer to furnish independent proof that there is in the Llyn-Padarn ridge a 'greenstone' older than the quartz-felsite.

Passing along the road which runs from the bridge at the lower end of Llyn Padarn along the eastern shore of the lake, near the point where this road crosses the slate-railway (marked A on the sketch-map, p. 376), there is an exposure of 'greenstone' which appears to have been opened up by blasting comparatively recently. To all appearance, this rock resembles the ordinary basic dykes which penetrate the quartz-felsite in this locality, but it has evidently been much sheared.

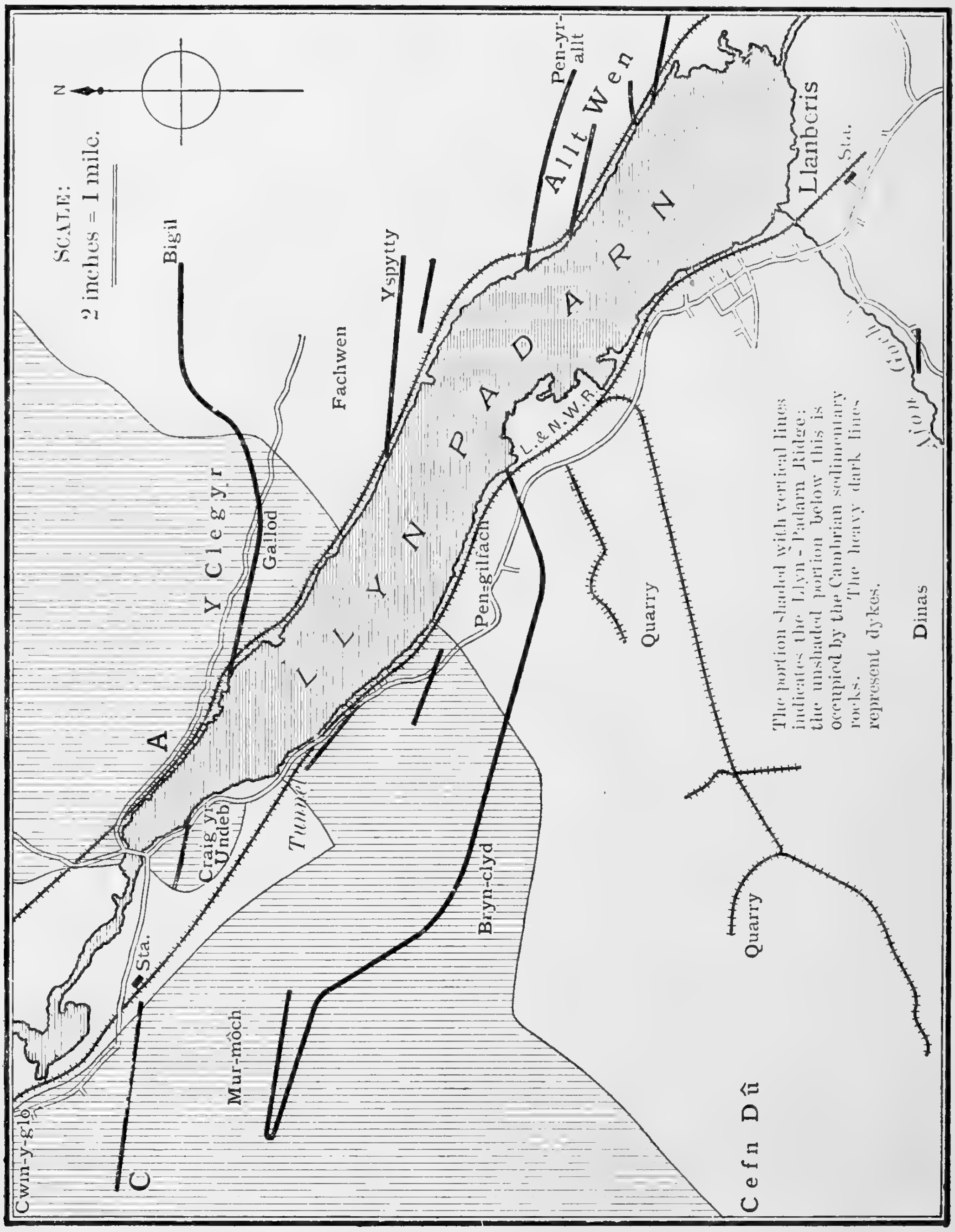
[1] T. G. Bonney & C. A. Raisin, 'On the Relations of some of the Older Fragmental Rocks in North-Western Caernarvonshire' Quart. Journ. Geol. Soc. vol. l (1894) p. 578.

[2] 'On the Cambrian & Associated Rocks in North-Western Caernarvonshire' *Ibid.* vol. xliv (1888) pp. 283, 284.

[3] 'On the Lower Limit of the Cambrian Series in North-Western Caernarvonshire' *Ibid.* vol. xlvii (1891) p. 337.

The contacts with the felsite on each side look fairly clean and regular; but, near the centre of the exposure, which is about 10 feet wide, the 'greenstone' is penetrated by a tongue of felsite, about 2 inches broad near the upper exposed part, and tapering to a point at the lower extremity. The length of this tongue is about 2 feet.

*Sketch-map of the Llyn-Padarn district.*




A thin slice of this rock, if examined beneath the microscope, presents the appearance of a quartz-felsite, and resembles in all essential features the descriptions given by Prof. Bonney of the felsites of this area.[1] The section shows irregular subangular blebs of quartz, giving somewhat undulose extinction, and

[1] T. G. Bonney, 'On the Quartz-Felsite & Associated Rocks at the Base of the Cambrian Series in North-Western Caernarvonshire' Quart. Journ. Geol. Soc. vol. xxxv (1879) pp. 311 *et seqq.*

enclosing portions of the cryptocrystalline groundmass. The latter is granular, and appears to consist almost entirely of quartz, and possibly some felspar. There are also numerous laths of a greenish, strongly-pleochroic mineral, with slightly-oblique extinction, which may be microliths of hornblende. There is much opaque granular matter, and some chloritic patches occur. The rock is apparently modified slightly by contact with the 'greenstone.'

The 'greenstone' in thin section shows abundant laths of felspar, mostly replaced by micaceous aggregates, yet here and there retaining the optical characters of a plagioclase. Augite is fairly abundant, mostly altered to an opaque brownish substance, but occasionally giving bright polarization-colours. There is also a good deal of opaque leucoxene, resulting from the decomposition of titaniferous iron. Calcite and chlorite-eyes are abundant, although there is apparently no secondary quartz. The rock was originally somewhat like the ordinary ophitic type of dyke-rocks in the Llyn-Padarn ridge, the structure having been obliterated by shearing, crushing, and alteration.

Although it would perhaps be going too far to generalize from this single occurrence of an acid intrusion in the 'greenstone,' yet the fact remains, and there does not appear to be any escape from the conclusion that we have here a pre-Cambrian basic rock. There are certain other highly-sheared and altered 'greenstones' in the Llyn-Padarn ridge, which may also belong to this group. A rock from the locality marked C on the accompanying sketch-map (p. 376) is so like the one described above, and differs in so marked a degree from the unsheared rock in the neighbouring dyke south of Cwm-y-glo, that it seems certain that it has been subjected to stresses which have not influenced the Cwm-y-glo intrusion. Unfortunately, I have not been able to discover any but outcrop-exposures of this rock; it is not unlikely, however, that when this district comes to be mapped on the 6-inch scale, additional proofs will be forthcoming that some of these highly-altered basic rocks are older than the main dykes of the Llyn-Padarn ridge.

## III. Petrographical Evidence.

In considering the petrographical evidence as to the age of the main portion of the Llanberis dykes (excluding those of pre-Cambrian age), I shall now attempt to show that it is not possible to separate these rocks from the Bala diabases upon general mineralogical grounds; and that there are indications that these two groups of rocks were in all probability derived from the same magma-basin. At the same time, it must be remembered that, if this supposition be correct, the low horizon at which the Llanberis rocks occur might be expected to disclose certain divergences, resulting from such a differentiation as might take place in the case of the latest phase of an eruptive sequence. Although this point is of the greatest interest, in view of the differentiation-theory put forward by Mr. Harker to account for the sequence of the Bala rocks, it is also one of extreme difficulty; and conclusions, based upon such evidence, can only be drawn with very great caution.

In considering this portion of the subject, it will not be advisable to recapitulate previous observations any further than will be necessary to compare these rocks with the Bala diabases on the one hand, and the post-Carboniferous dykes on the other. With the former group Mr. Harker has already made us familiar.[1] With all the more important features shown by the diabase-sills of the eastern part of Caernarvonshire, these rocks agree down to the smallest detail; though certain points, notably the frequent occurrence of secondary sphene and asbestos, but rarely exhibited in Mr. Harker's specimens, become very prominent in some of the Llanberis dykes. The latter rocks are also sharply separated from the post-Carboniferous dykes of Anglesey described by Mr. Harker,[2] Mr. Greenly,[3] and Dr. Matley,[4] all of whom agree that the latter are not very basic in character, possess no appreciable titanic acid, have two distinct generations of felspar, and show no conspicuous signs of pressure-metamorphism. The pyroxenes, also, in these younger rocks belong to a later stage of consolidation, and are apparently of a different chemical composition from those about to be described.

It will be convenient to consider the minerals in the order of their consolidation, and to divide the area into two parts, in accordance with the previously-described differences shown in the field-examination. These will be designated the dynamic or crush-zone of the more yielding sedimentary rocks, and the static or pressure-zone of the Llyn-Padarn ridge. These terms are used for convenience of description only, for it is evident that a crush-zone must also be a pressure-zone of greater intensity. Prof. Bonney has called attention, in his paper on the crystalline schists of the Binnenthal,[5] to the necessity for differentiating direct pressure from shearing crush; and he has proposed the term catathlastic for structures produced by the former, in contradistinction to the mylonitic structures produced by the latter. The former term, however, does not appear to have been seriously contemplated, and the distinction is not always easy to make, seeing that both structures will be found together. In the present paper, the distinction referred to above is only intended to mark the effects in the rocks described, which are produced by the different kind and degree of pressure in a soft, yielding mass and in the hard resisting buttress against which the forces acted. Perhaps the terms dynamic and static metamorphism, as suggested by Prof. Judd,[6] might be sufficient to describe these two kinds of force exerted upon a rock-mass by great earth-movements. Structurally, all the rocks examined are, or once were, ophitic diabases. They

[1] 'Bala Volcanic Series of Caernarvonshire' 1889, pp. 75 *et seqq.*
[2] Geol. Mag. 1887, p. 409 & *ibid.* 1888, p. 267.
[3] *Ibid.* 1900, p. 160.
[4] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 247.
[5] *Ibid.* vol. xlix (1893) p. 104.
[6] Geol. Mag. 1889, p. 243.

do not, in their unaltered state, show any sign of a second generation of felspar; but in the crush-zone this structure, as might be expected, is obliterated, the ophitic pyroxene becoming granulitic, while the parts which have experienced the most intense shearing have become almost schistose. In some parts, albitization has gone on to such an extent, that the broken pyroxenes are completely enclosed in large secondary felspars, causing a complete reversal of the original structure, the pyroxene then having the appearance of being the first-formed mineral.

The general inference from all the slices is that consolidation took place very slowly, probably under a thick cover of rock, which may possibly explain the rarity of very marked sahlbands, and certain cases of local enrichment in felspar, such as might result from the concentration of this mineral, in accordance with Soret's principle, owing to a prolonged duration of the liquid state. This condition is still further indicated by the phenomena presented by the augite, as will be more fully described later.

The mineral-constituents of the rocks will now be described in turn.

## Apatite.

This mineral is present in conspicuous proportion in many of the rocks of the Llyn-Padarn ridge area, but I have only occasionally recognized it in the crush-zone. Mr. Harker mentions its general occurrence in the Bala diabases. The capricious distribution of this mineral in igneous rocks, and its usual immunity from any marked effects of dynamic metamorphism, render it of little value as an index to the amount of alteration which a rock containing it may have undergone. For present purposes, therefore, it assumes little or no petrographical importance.

## Iron-Ores.

It will be convenient to consider the iron-ores next, although these constituents did not entirely separate at any definite stage. Some are idiomorphic, but they are also very commonly moulded on the felspars and included in the augites. Generally speaking, they agree so closely with Mr. Harker's description,[1] that it will not be necessary to recapitulate these points. Titanic acid, however, appears to be more abundant in all the specimens from the Llyn-Padarn dykes, and secondary alteration has resulted in a large quantity of sphene-granules, in addition to amorphous leucoxene. Mr. Harker noticed granular sphene in the Bala diabase in one locality only, namely, at Pant-Evan, Tremadoc,[2] although he records its presence in some quantity in the Llangwnadl rock, where the intrusion is presumably on a somewhat lower horizon. On the other hand, no titanic acid was recognized in the hornblende-picrite of Penarfynydd. It is also notably absent in the later dolerite-dykes. In the light of these facts, the

[1] 'Bala Volcanic Series of Caernarvonshire' 1889, p. 80.
[2] *Ibid.* p. 81.

plentiful occurrence of compounds of titanium in the Llanberis rocks is of considerable interest.

Still more important is the evident connection between the alteration of ilmenite and the amount of dynamic metamorphism which the rocks have undergone, as Mr. Harker has already noticed in the diabases of Eastern Caernarvonshire. Dr. Teall, also, has found the mineral of great service in tracing the origin of certain schists from sheared diabases.[1] These phenomena are well illustrated in the Llanberis dykes, where every stage in the alteration of ilmenite may be traced as the dykes are followed into regions of increased dynamic influences. An interesting example of this alteration is seen in the production of rutile from ilmenite, as previously described by Prof. Cathrein.[2] This mineral occurs in one of the slides, in the form of abundant hair-like microliths, associated with fragments of still opaque leucoxene. Sphene in distinct granules, as well as the translucent variety usually associated with leucoxene, is abundant. A noticeable feature, however, of many of the yellowish-brown granules is that they do not possess the high double-refraction of sphene, but transmit only a feeble light between crossed nicols. A similar appearance was noticed in the kimberlite of Kentucky by Mr. J. S. Diller,[3] and by Dr. G. H. Williams in the serpentine of Syracuse, in which cases chemical tests showed these grains to be perowskite. It would not be possible to say definitely that these feebly double-refractive granules in the Llanberis rocks are perowskite, merely on account of their optical anomaly; but the possibility suggests itself that a part of the rutile liberated from ilmenite has combined with lime to form this mineral. A similar occurrence of this presumed perowskite has been noticed by me in the diabase of the Santon complex in the Isle of Man. It is, of course, not necessary to assume that this mineral has been derived from ilmenite, as its marked association with chlorite-areas might also suggest a derivation from a pre-existing titaniferous pyroxene.

All the phenomena exhibited by the titanium-compounds in these dykes, both as evidence of a richly titaniferous magma and as proving extensive dynamic metamorphism, are highly characteristic. It is, indeed, possible to trace the kind and degree of pressure-alteration in the successive portions of these dykes by observation of the titanium-minerals alone.

With regard to other iron-ores, such as magnetite and pyrites, these present the usual characteristics, as described by Mr. Harker in dealing with the Bala diabases, and they do not require further description in this paper.

## Felspars.

The felspar is always triclinic, and occurs usually in idiomorphic crystals, with well-marked albite-twinning. Pericline-twinning is

[1] 'British Petrography' 1888, p. 233.
[2] Zeitschr. f. Krystallogr. vol. vi (1882) p. 244.
[3] Bull. U.S. Geol. Surv No. 150 (1898) p. 294.

seen in isolated instances. A prevalent combination shows one half of a Carlsbad twin simple, and the other half with the albite-lamellation. The usual form is in long laths, and in the uncrushed parts the extinctions are sharp. On sections oriented in the zone 100 on 001 the extinction-angle generally exceeds 20°, indicating a predominance of the anorthite-molecule. This is significant, as the post-Carboniferous dolerites have usually a rather less basic felspar, and generally show a second generation of a more acid species, with zonary banding. In the rocks that I have examined from this area, two generations of felspar are apparently not present, and zonary banding is rarely exhibited. This fully agrees with the characters shown by the felspars in the Bala diabases.

In proportion to the amount of crushing that the rocks have undergone, characteristic changes are noticeable in the felspar, the most striking of which are the secondary felspars, often conspicuously present in large water-clear crystals, with ill-defined outlines, and sometimes showing shadowy twin-structures. Where such 'albitization' has taken place, the remnants of the older felspars are easily distinguished by their extensive saussuritization, bent outlines, corroded margins, undulose extinction, and by being often included in the later secondary crystals. The secondary albites also include epidote, viridite, and broken pyroxenes, while here and there the characteristic 'felspar-mosaic' of Lossen is exhibited. It is difficult to measure the extinction-angles of these secondary felspars, suitable crystallographic planes being wanting. In some cases, however, it is possible to compare by Becke's method the refractive index of the felspar with that of an adjacent crystal of secondary quartz. The result agrees with the refraction of albite.

All these characters are very typical of sheared diabases, and indicate considerable pressure-metamorphism. Their importance in the present discussion lies in the proof which they afford that the rocks have been subjected to extensive earth-movements. They are not, so far as I am aware, the characters usually exhibited by the felspars of the later dykes of Caernarvonshire; neither does Mr. Harker mention them as occurring in the Bala diabases. But the specimens described by him were apparently not so much crushed, and were collected from areas more remote from the Llyn-Padarn ridge.

The saussurite and other alteration-products of the felspar show no unusual features. The large quantity of pale epidote and calcite-dust is an additional evidence of a considerable lime-percentage; and all the phenomena go to show that the original magma was of a typically-basic composition, and that the separating felspars belonged to the lime-end of the albite-anorthite series. The original composition of such a felspar, however, may be easily obscured by secondary changes leading to the break-up of the anorthite-molecules, and their replacement by epidote, calcite, and quartz. Such changes may be traced along the course of these dykes, isolated specimens of which, if taken from the crush-zone, would seldom give an adequate clue to their original composition. As before mentioned (p. 379), in certain of these crushed rocks secondary albite has completely enclosed fragments of unaltered augite, causing a total reversal of the original structure.

## Pyroxenes.

It seems clear that there were two distinct generations of pyroxene, causing an apparent deviation from the ordinary type of the Bala diabases on the one hand, and from the post-Carboniferous dykes on the other. It is true that Mr. Harker did find two generations of pyroxene, in a rare instance near Llanrwst; but in the Llanberis dykes this occurrence is more frequent, although the evidence is usually indirect, owing to the ease with which the earlier form has yielded to processes of alteration, where it survived the corrosive action of the magma. In a few instances, however, comparatively-unaltered fragments of the earlier pyroxene are preserved as corroded remnants, included in the ophitic plates of the second generation. More often these remnants are represented only by rounded chloritic and serpentinous inclusions in the ophitic augite. There is no sign of crystalline continuity of the two generations, and the circumstances seem to point to a complete change of phase, the first-formed pyroxene being reabsorbed to a large extent before the crystallization of the later variety, pointing to very slow cooling, during which the conditions of equilibrium in the magma underwent considerable change. The precise variety of the earlier form is uncertain, but the fact that the included fragments are not in crystalline orientation with the later variety would suggest the possibility that the earlier forms were rhombic. In other similar cases, such as the sahlite-diabase of Sweden,[1] the diabase of Connecticut,[2] and in the Whin Sill,[3] the earlier pyroxene is of a paler colour and more easily altered than the later form. In any case, the rounded serpentinous and chloritic inclusions in the ophitic augites of Llanberis are more probably to be referred to an earlier pyroxene than to olivine, as has been suggested by some observers.[4]

Coming now to the ophitic augites, there is evidence that during their crystallization the magmatic conditions were not stable. Their pale colour when fresh and the comparatively-low $c\gamma$ extinction-angle indicate a variety near malacolite. They very commonly possess the peculiarity (noticed also by Mr. Harker in the Lleyn diabases) that the crystals, although apparently homogeneous, are seen between crossed nicols to be polysomatic. The separate areas are crystographically continuous, but possess different extinction-angles. This structure has been explained as a modification of the hour-glass structure, for which the explanation of L. van Werveke[5]

[1] E. O. Hovey, Tschermak's Min. u. Petr. Mitth. n. s. vol. xiii (1893) p. 218.
[2] J. S. Diller, Bull. U.S. Geol. Surv. No. 150 (1898) p. 268.
[3] J. J. H. Teall, Quart. Journ. Geol. Soc. vol. xl (1884) p. 653.
[4] A. Harker 'Bala Volcanic Series of Caernarvonshire' 1889, p. 94: see also J. M. Clements 'The Crystal-Falls Iron-bearing District of Michigan' Monogr. U.S. Geol. Surv. xxxvi (1899) p. 201.
[5] 'Beitrag zur Kenntniss der Limburgite' Neues Jahrb. f. Min. 1879, p. 481.

is often accepted. Neither this theory, however, nor that of Blumrich,[1] seems quite adequate to account for the phenomenon, which appears rather to be a modification of zonary banding, and points to a sequence of different phases during the formation of the crystal, owing to changes in the conditions of equilibrium. In some cases the lines of separation of the different portions correspond to lines of crystalline growth, indicating mere pauses in growth, the next accretion consisting of a new member in the series of isomorphous mixtures. Generally, however, there was more than a pause. Resorption began; the salient angles of the last growth became rounded off, and in some cases even greater corrosion took place, before the crystalline growth was resumed in accordance with the fresh conditions of equilibrium, which had, in the meantime, been established. The difference in the extinction-angles of contiguous areas reaches to as much as 10°, but is generally less. The phenomenon is a very interesting illustration of the application of the phase-rule in geology; and if we accept Dr. Roozeboom's explanation of the formation of mix-crystals,[2] it is possible that we may find in this structure a proof of consolidation under variable pressure, such as might occur in the case of a magma cooling under the influence of earth-movements. The same structure has been noticed in the Holyhead Main Dyke and in the olivine-dolerite of Port Newry,[3] and I have also observed it in the diabase of the Santon complex in the Isle of Man.

The chief difference observed in the augites of the crush-area is the development of mylonitic structures, the ophitic plates being broken up into fragments, round which secondary albite has crystallized. The fragments, however, exhibit the same polysomatic character, and have inclusions of the earlier pyroxenes as described above. An intermediate condition, observed in some of the specimens taken from the Llyn-Padarn ridge, near the southern margin, has led to a very pronounced polysynthetic twinning in the augites, often displaying two sets of twins crossing nearly at right angles, and recalling similar strain-phenomena produced in metals.[4] Such a difference in the effects of pressure upon the dykes enclosed in the quartz-felsite and upon those in the sedimentary area is very interesting, and resembles similar differences obtained experimentally by Prof. F. D. Adams & Dr. J. T. Nicolson in marble compressed under various conditions.[5]

Another effect of pressure-metamorphism, apparently related to the above, is accompanied by a passage into amphiboles and chlorites, to be described more fully under these headings.

I pass over the phenomena caused by simple weathering, as these present no unusual features, and have no bearing upon the points under discussion. I may, however, point out that this factor must

[1] 'Ueber die sogenannte Sanduhrform der Augite' Tschermak's Min. u. Petr. Mitth. n. s. vol. xiii (1893) p. 239.

[2] Zeitschr. f. physikal. Chem. vol. xxx (1899) p. 385.

[3] Geol. Mag. 1888, pp. 269 *et seqq.*

[4] J. A. Ewing & W. Rosenhain, Phil. Trans. Roy. Soc. ser A, vol. cxciii (1900) p. 353.

[5] *Ibid.* vol. cxcv (1901) p. 363.

not be lost sight of when utilizing the optical constants for the determination of augites. For, even an incipient weathering may lead to a change in the position of the optical axes. So far as I can see in the specimens examined, weathering may produce (1) a lowering of the $c\gamma$ extinction-angle; (2) a reduction in the value of $\gamma - \alpha$; and (3) an increase in the value of $\frac{\alpha+\beta+\gamma}{3}$.

## Amphiboles.

In only a single instance have I found a small fragment of an apparently-original hornblende, but secondary amphiboles are represented in a large number of the specimens, more particularly in certain areas where the rocks have been subjected to a particular kind or degree of pressure. Amphibolitization commonly takes the form, in the first instance, of uralite-fringes round the augites, thus bringing these rocks into close agreement with the sills of the eastern part of Caernarvonshire, as described by Mr. Harker; whereas the Lleyn diabases never exhibit this structure. Uralitization is generally associated with pressure-metamorphism,[1] and it is difficult to escape from the conclusion that the same pressure to which the uralitization of the eastern sills was due also operated in the case of the Llanberis dykes. That uralitization is independent of weathering processes pure and simple seems abundantly clear, for the polarization-tints on the uralitized crystals are often high; while in the same slide, other crystals, more weathered and showing lower tints, have no trace of uralite-fringes. In partly-weathered crystals, also, uralite is equally well developed on the freshest portion. It may, however, be mentioned that the development of uralite is apparently checked wherever the crystals have secured molecular relief from the effects of pressure, either by the acquisition of strain-slip cleavage, or by mylonitization. I do not know how far other observers have noticed this feature, which is very well illustrated in these dykes, subjected as they have been to varying kinds and degrees of stress.

More pronounced alteration of the augite leads to the development of a pale actinolite and tremolite; and in some cases fissures and cracks, varying from $\frac{1}{8}$ to upwards of 2 inches in width, are filled with tremolite or asbestos, which also coats shear-planes and slickensided surfaces. Under the microscope, these features recall the examples of 'gewanderte hornblende' described by E. Cohen,[2] Bergt,[3] and Doss.[4] The connection of asbestos with mechanical movement in the containing rock has been already enlarged upon by G. P. Merrill[5] and Van der Bellen,[6] the latter maintaining that a certain plastic elasticity is necessary for its formation. Direct passage of augite into asbestos has been described by J. R. Blum[7]; but in the

[1] J. J. H. Teall 'British Petrography' 1888, p. 161.
[2] Neues Jahrb. f. Min. vol. i (1883) p. 202.
[3] Tschermak's Min. u. Petr. Mitth. n. s. vol. x (1889) p. 356.
[4] *Ibid.* vol. xi (1890) p. 46.
[5] Rep. U.S. Nat. Mus. (Smiths. Inst.) 1899, p. 296.
[6] Chemiker-Zeitung, vol. xxiv (1900) p. 284.
[7] 'Die Pseudomorphosen des Mineralreichs' 1843, p. 165.

present case it appears to be derived from uralite or tremolite, as stated by Dr. Hintze.[1] The exact nature of the change is at present only a matter of supposition. It is not a paramorphic change, since some hydration takes place; in fact, all the phenomena connected with amphibolitization in general point to the effects of dynamic metamorphism.

In connection with this portion of the argument, it may be well to recall the observation of Prof. Grenville Cole & the late A. V. Jennings on the northern face of Mynydd-y-Gader,[2] where the intrusive diabase also shows a great deal of actinolite and tremolite, with greenish asbestos in the clefts, pointing in their opinion to a magma rich in alumina and lime, rather than to magnesia and iron.

The occurrence of asbestos in such quantity as is found in some parts of the Llyn-Padarn dykes, notably along the Afon Goch and on the western shore of the lake, near the mouth of the tunnel, seems to me to have an important bearing upon the separation of these intrusions from any eruptions of post-Carboniferous age in this part of the country.

## Biotite.

This mineral is very sparingly represented. Several of the less-altered specimens contain a few shreds partly altered to chlorite. In the crushed rocks no trace of it appears to be left. This fully agrees with the character of the Bala sills, and it seems unnecessary to dwell further upon this point.

## Chlorite.

The chlorite-areas seen in these rocks have a well-marked relation to the amount of shearing which they have undergone, and are in inverse proportion to the remaining augite. More than one variety of the chlorite-family appears to be present, and they present the following characters:—(1) green, radial, fibrous scales, with parallel extinction and marked pleochroism, possibly representing pennine or ripidolite; (2) granular aggregates; and (3) isotropic, structureless patches: these may be delessite and chlorophæite respectively. The first variety would, therefore, belong to the true chlorites, and the two latter to the saponites of Dr. Heddle's classification.[3] It is possible, however, that the saponites are only more hydrated forms, and may be derived from the chlorites by simple weathering processes. In the more highly-sheared varieties the chlorites are drawn out into distinct lenticles, showing a passage into flaser-diabase (the early stage of a chlorite-schist) as has been already pointed out by previous observers, as the result of the metamorphism of diabase by earth-stresses.[4]

[1] Handbuch der Mineralogie, vol. ii (1897) p. 1195.

[2] Quart. Journ. Geol. Soc. vol. xlv (1889) p. 432.

[3] Trans. Roy. Soc. Edin. vol. xxix (1880) p. 55.

[4] See J. J. H. Teall, Quart. Journ. Geol. Soc. vol. xli (1885) p. 133; T. G. Bonney, *ibid.* vol. xlix (1893) p. 94; T. G. Bonney & C. A. McMahon, *ibid.* vol. xlvii (1891) p. 489; S. Hyland, Geol. Mag. 1890, p. 205; and F. Zirkel, 'Lehrbuch der Petrographie' 2nd ed. vol. ii (1893) p. 730.

## Other Secondary Minerals.

An abundance of quartz, epidote, and calcite would be expected to occur in rocks of this character. In the highly-sheared or crushed rocks, as, for example, at Y Bigil, the quartz-grains have almost the appearance of a clastic origin; but their secondary character is proved by their sharp extinction when rotated between crossed nicols. With regard to epidote, it may be mentioned that Mr. Harker found this mineral to be restricted to the eastern portion of Caernarvonshire. It is not certain, however, that we can regard this mineral as a normal result of the pressure-metamorphism of diabase. As might be expected, also, both quartz and epidote are not confined to the dykes themselves, but have invaded cracks and fissures in the neighbouring rocks. Very beautiful examples of these quartz-epidote veins occur in the neighbourhood of the crush-area. Calcite-eyes are everywhere abundant, and by weathering-out often give the 'greenstones' quite a vesicular appearance. It does not seem necessary to dwell upon these phenomena, which are a direct result of the mineralogical changes described in the foregoing pages.

## General.

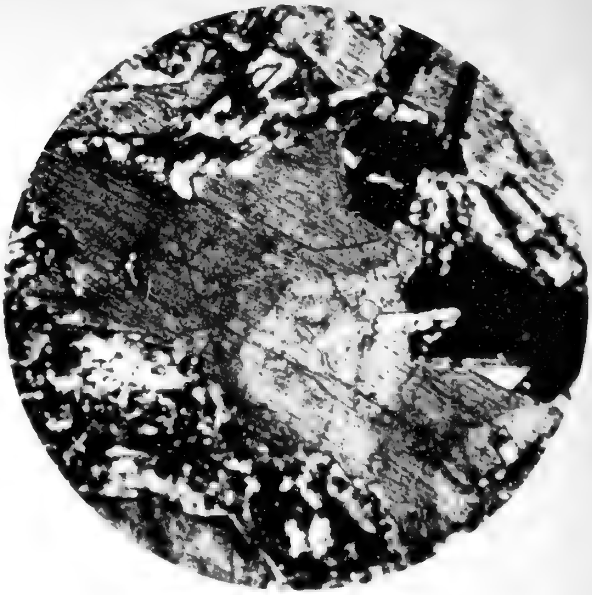
Summing up the above results, these rocks exhibit very varied effects of dynamic metamorphism. In their least-altered parts the minerals are comparatively unchanged, with the exception of alterations produced by simple weathering. Coming nearer to the crush-area, we find, first of all, the effects of molecular re-arrangement under pressure without movement. Then the influence of shear begins to appear, with mylonitization and re-crystallization; and lastly the whole rock becomes more or less cataclastic, with partial or complete obliteration of its original structure. It is not generally possible to draw a sharp line of distinction between these different phenomena, but viewed as a whole the results are sufficiently characteristic. Moreover, the gradual appearance of these features, as the dykes are traced from the quartz-felsite into the sedimentary strata towards the east, is a proof that the deforming agency operated from an easterly direction.

## IV. Conclusion.

In view of the phenomena described in the foregoing pages, it does not seem possible to escape from the conclusion that we have in the Llyn-Padarn dykes a result of the deep-seated conditions prevailing during the latest stage of the Bala eruptions. These dykes appear to have been filled with a magma rather more basic than the Bala sills. The mineralogical evidence seems to point to a larger proportion of titanic acid, and to a greater amount of lime and magnesia. The somewhat-remarkable chemical analysis by Dr. Vœlcker,[1] of a rock

[1] Geol. Mag. 1868, p. 125.

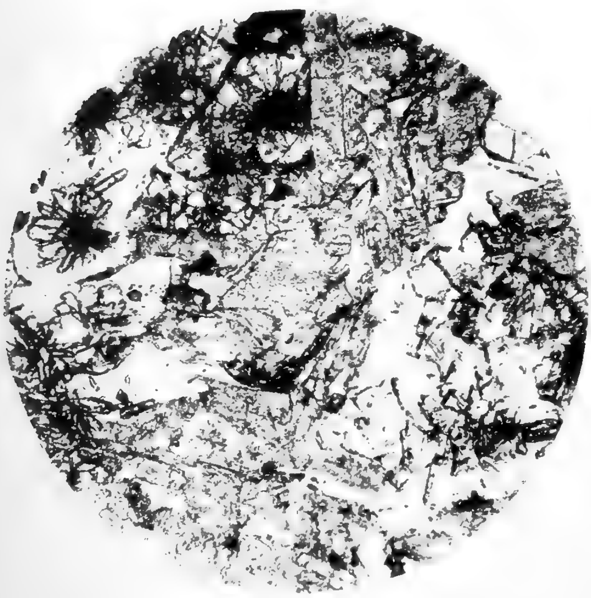
1



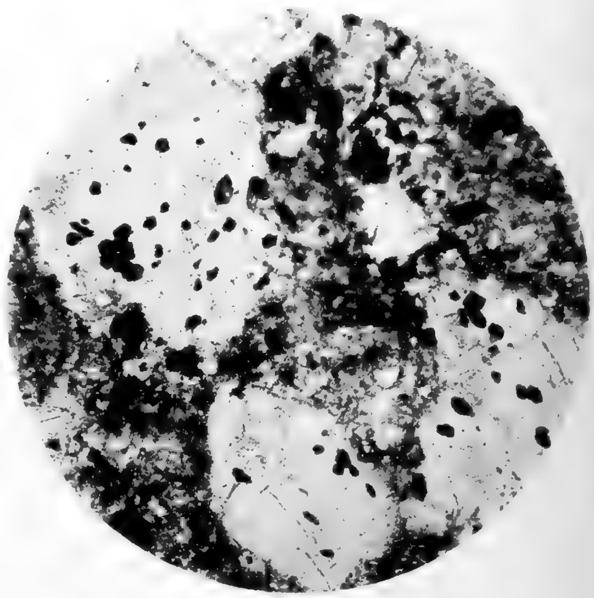
2

3

4



5



6

*Photomicro, J. V. Elsden.* *Bemrose, Collo.*

LLYN PADARN DYKE-ROCKS.

from a 'greenstone'-dyke in the Penrhyn Slate-Quarry, supports this view; but a large number of analyses of the Caernarvonshire rocks would be necessary before Mr. Harker's differentiation-theory could be adequately tested on chemical grounds. This theory is virtually an application of Gouy & Chaperon's principle,[1] which, it is true, receives some support from physical chemistry and from observations in the case of certain alloys.[2]

With regard to the exact time of the intrusions, it is certain that the fissures were not open before the crush began, because there is very little evidence of displacement in the dykes themselves. The Clegyr dyke alone shows any marked sign of deflection. Mr. Harker, however, mentions the occurrence of local thickening of some of the dykes in the slate-quarries[3] owing to the effects of the thrust. It might also be urged as an objection to the view that these fissures are a result of the south-easterly crush, that their direction is approximately at right angles to the axes of the folds. In a perfectly-homogeneous rock, pressed by uniform forces against an immovable buttress, the maximum shear should be at an angle of 45° to the direction of the pressure. These conditions, however, did not exist. The strata were not homogeneous, the pressure was probably by no means uniform, and the buttress almost certainly yielded more or less. It is therefore quite conceivable that the buttress cracked, and thus determined the direction of the fissures in the sedimentary strata.

The assumption that these dykes are of post-Carboniferous age would involve two very unlikely conclusions: namely, that the later magma was almost identical in its composition and in its mode of consolidation with the basic injections of Bala age; and also that earth-movements of sufficient intensity to cause structural deformations of parts of these dykes have operated since the great south-easterly crush which folded and cleaved the slate-rocks of Llanberis. Of this there is no evidence, so far as I am aware; and if such were the case, we should even then have to explain the phenomena with which this paper chiefly deals, that is, that those portions of the dykes which were protected by the ridge have largely escaped the deformation to which their more easterly parts have undoubtedly been exposed. On the other hand, all the facts appear to agree with the suggestion that the Llyn-Padarn fissures were injected with the last dregs of the Bala magma before the effects of the post-Bala crush had entirely ceased.

## EXPLANATION OF PLATE XXXII.

[All the figures are magnified about 30 diameters.]

Fig. 1. Composite augite-crystal, showing crystallographic continuity, but extinguishing in irregular areas. Crossed nicols: 1-inch objective.

[1] 'Sur la Concentration des Dissolutions par la Pesanteur' Ann. de Chimie & de Physique, ser. 6, vol. xii (1887) p. 384.

[2] See A. Findlay 'The Phase-Rule' 1904, chap. xiv.

[3] 'Bala Volcanic Series of Caernarvonshire' 1889, p. 115.

Fig. 2. Composite augite-crystal, similar to that seen in fig. 1, but showing regular zones of crystalline growth. The section is parallel to the orthopinacoid, and therefore extinguishes simultaneously throughout. Crossed nicols.

3. Augite-crystal showing secondary cleavage along glide-planes. Crossed nicols.

4. Crushed diabase, showing secondary felspar, enclosing broken fragments of augite. Crossed nicols.

5. Sheared diabase, showing abundant development of epidote and chlorite. Ordinary light.

6. The same, showing feebly double-refracting granules, presumably perowskite, enclosed in chlorite. Ordinary light.

## Discussion.

The President, while admitting that many arguments might be brought forward in favour of the post-Bala age of the movements referred to, also saw difficulties in this view as to their age. Among these was the smallness of the unconformity between Ordovician and Silurian rocks in the area to the south-east of that described by the Author; and the evidence of cleavage in the Wenlock Beds of the Corwen district, comparable in many ways with that of the Cambrian and Ordovician rocks of Caernarvonshire.

Prof. Watts pointed out that the dykes described by the Author resembled in many respects the sill-rocks of Shropshire and Montgomeryshire. These rocks were probably derived from the same magma as the Bala lava-flows, but they were certainly intrusive into the base of the Silurian of that district as well as into the Ordovician, for the basal Silurian rocks were often metamorphosed at the contact.

Mr. Fearnsides said he thought that the rocks exhibited had many features in common with the basic sills which occurred among the Llandeilo and Bala rocks about Tremadoc. About Tremadoc many of the sills had come up along small thrust-planes, and seemed to have baked rocks which, though already somewhat crushed by the faulting, were still uncleaved. This being so, the sills at Tremadoc must be considerably newer than the Bala Beds, and should be referred to the period of Silurian and post-Silurian earth-movements rather than to the pre-Silurian.

The Author, in reply, said that, while he quite realized the difficulty in assigning an exact age to the intrusions, he felt that the greater the interval assumed to exist between the age of the dykes and that of the sills, the more difficult became the explanation of the facts adduced in the paper. The protective influence of the Llyn-Padarn ridge, also, might be expected to become less marked as the Cambrian sediments became more indurated, and it would then prove less easy to account for the differential deformation of the dykes.

## 28. *The* Genesis *of the* Gold-Deposits *of* Barkerville (British Columbia) *and the* Vicinity. By Austin J. R. Atkin, Esq. (Communicated by the Secretary. Read April 27th, 1904.)

The gold-bearing area of Cariboo is roughly confined within a radius of 20 miles of Barkerville, to the band of varied crystalline rocks known as the Cariboo Schists.

These rocks show evidences of fragmental origin, notably below the mouth of Stouts Gulch. They represent in all probability the silt and detrital matter deposited in a deep ocean lying off the shores of the ancient Archæan ridge, and are generally assigned to the Lower Palæozoic age.[1] They seem to have a tendency towards fracture in a north-easterly direction, owing to pressure exerted at right angles to their trend.

The steep northerly escarpments of the mountains are to be attributed to the inclination of the beds, favouring the erosive action of adjacent streams.

The whole schist-belt, with the exception of the mountain-tops, is thickly covered with detritus of Glacial age and origin, which obscures many features important to a thorough understanding of the phenomena connected with the distribution of gold in this district.

The quartz-veins, exposed in those places where Glacial débris have not covered the original rocks, are all of one general type, although two systems of fracture traverse the country. Most of these fissures are infilled with veins, the richness of which has contributed to the wealth of the placers below. The most striking feature of a district in which the placers are so rich is that the reefs at the heads of the gulches and along the sides are of very low grade. This has led to much speculation as to the site of the original deposits from which the gold was derived.

The chief characteristics of the reefs of both systems are:—

(*a*) The veins follow the strike, but not as a rule the dip, of the enclosing schists: an exception being the Forrest Reef on Proserpine Mountain.

(*b*) The gangue is similar to that found with the nuggets in the creeks—lustreless, milky-white quartz, sometimes sugary.

(*c*) The mineralization is sulphide of iron, distributed in coarsely-crystalline bunches throughout the reef. A little galena, low in silver, is sometimes found; but rarely copper-pyrites, or blende. The average contents of sulphide do not exceed 6 per cent.

Some of the sulphides are of good value, but others are quite worthless. Their quality cannot be determined, except by assay. Galena has not been found to exert any beneficial influence on the gold-values of the reefs.

(*d*) All the reefs show very little oxidized ore, some none at all: which goes to show that the present outcrops are recent exposures, and cannot have been the original surfaces presented on the tilting of the schist-bed.

---

[1] The age of these rocks was determined by Mr. A. Bowman, of the Canadian Geological Survey.

The origin of the gold in the reefs is probably the same as the origin of the reefs themselves. Both were deposited in fissures formed by strains during the upheaval of the schists. There is evidence that some of the veins are accretions formed in gradually-widening fissures, and were not deposited in one gaping chasm.

This is especially apparent in the B.C. ledge, where thin films of graphitic schist appear as partings in the vein on the hanging-wall side, giving the reef a banded appearance. These may be taken as part of the original wall which broke away with the early accretions of silica, and became enveloped in the subsequent depositions as soon as the fissure widened again sufficiently for the ascending waters to deposit a fresh crust of mineral salts. At present, the parting on the hanging wall consists of a soft gangue of frictional débris, among which the acid mine-water may still be depositing mineral wealth.

These reefs, deposited by waters ascending from profound depths, holding in solution their minerals dissolved under conditions of great heat and pressure, would have a tendency to increased richness, at the depth where the gradually-lessening conditions of their solubility favoured the precipitation of mineral salts.

As most probably this rich zone is still intact, and awaits the advent of deep-mining for its discovery, another source must be looked for in trying to solve the problem of the occurrence of the gold in the placers.

While all the reefs carry gold in greater or less quantities, none have been found the richness of which would account for the placer-gold; yet it is a well-known fact that rich outcrops exist in most quartz-veins, unless removed by weathering of the enclosing rocks. This greatly-enriched zone above the water-level must be considered as of purely-secondary origin: a concentration, in fact, from the rock-masses of the reef above.

This concentration takes place in two ways. The first by leaching of the pyrites, while the less soluble gold is left in the honeycombed quartz, whereby the vein-matter is made lighter while not reduced in bulk, which so becomes the richer per ton. The second method is purely chemical, and is an actual enrichment by precipitation.

The key to this secondary enrichment is found in the solubility of gold in solutions of ferric sulphate, as pointed out by Le Conte and Wurtz. The ores of these reefs are such that, on their decomposition, quantities of this substance would be formed from the pyrites present. While the pyrites furnishes the solvent for the gold, it acts also as a precipitant for the same; and the two processes of solution and precipitation are going on at the same time, and are taking place at the present day.

The area of the reef in which these forces come into play is limited by the level of the circulating surface-waters, which remove the dissolved gold and carry it down to a lower level, where, coming into contact with undecomposed pyrites, it is again precipitated. This process, going on continually—for although Nature works with very dilute solutions, their volume is large and time is unlimited,—in the course of ages produces a zone of great enrichment in the neighbourhood of the permanent water-level.

The writer has seen specimens of gold showing the impress of the pyrites upon which the gold had been precipitated, clearly proving the order of deposition to have been, first, the pyrites in the reef, and, secondly, the gold on the pyritic nodule.

While the enriched zone was being formed, the weathering of the surface continually removed the leached outcrop and constantly exposed fresh surfaces to the atmospheric influences: these, having become more active than the solution and precipitation, in time overtook the latter agencies and wore down the enclosing rocks until what had been the permanent water-level became a very rich outcrop.

To the weathering of such outcrops we may assign the rich placers.

While the comparatively-recent removal has not left time for another bonanza to be formed, it is only a matter of time when the present exposed outcrops will become honeycombed gossans, indicating rich zones below.

With the exception of the Perkins ledge on Burns Mountain, no free-milling ore has been encountered which in any way adequately accounts for the splendid placers of Williams', Lowhee, Lightning, Grouse, and many smaller creeks.

The gold found in all these placers is of purely-local origin, and, being to a great extent associated with quartz, must have come from reefs not far away. Indeed, some of the nuggets show no signs of attrition, and would seem to have been derived from ledges in their immediate vicinity. As no such ledge has been discovered in the creek-bottoms, and any washing, such as a theory of transportation from up stream requires, would have broken up the delicate filaments of gold, some other explanation must be looked for to account for these unwashed grains.

The most probable and satisfactory one is that these nuggets were brought to their present place in a soluble matrix, and in the course of time the matrix dissolving away left the gold in the condition in which we now find it. This matrix was most probably calcite, as nuggets have been found with limestone attached to them, and many large beds of limestone traverse the schist-belt.

The origin of the quartz-bearing nuggets is easily accounted for when we consider the conditions of the country in middle and later Tertiary times. By the former date the hills now existing had been swept clear of the pre-Tertiary gravels, and the deep channels eroded to their present depth. After the hills had been exposed to the action of frost and weather for many ages, the soft schists were decomposed and gradually washed into the present creek-bottoms, together with the gold set free from the rich surfaces of the quartz-veins that we now see on the mountain-tops; and with the gold from many others hidden under the Glacial and post-Glacial gravels.

Towards the end of Tertiary times a greatly-increased rainfall took place, which washed the last remains of the decomposed quartz-reefs and surrounding rocks into the valleys, together with the last of the Tertiary gravels, which are at the present day found associated with the gold in the lowest-known placers.

The present filled condition of these deep cuts is due to deposition of material in later Glacial and Pleistocene times. In the open workings of lower Williams' Creek there is an interesting section of these formations. Above the old drift-workings is a streak of flat schist-pebbles, separated from the Tertiary gravels by a seam of Glacial clay. This streak, about 2 feet thick, indicates a recession of the ice, and was deposited while Williams' Creek brought down the waters from the melting ice-caps on the surrounding mountains, together with the rock-detritus from their sides.

It would be interesting to know whether this streak carried much gold farther up. This would be likely, as the upper part of the creek must have had very little gravel in it at this time, and so would offer facilities for the gold being washed down on to the first stratum of Glacial sediment. The auriferous upper streaks sometimes found along this creek are to be attributed to slight recessions of the ice-cap: their limited extent showing merely a short duration of the period when the creek was bringing down material from its higher reaches.

Although, viewed in the above light, the occurrence of surface-bonanzas is unlikely, it must not be forgotten that the reefs which originated the placers still exist. Deeper exploration will probably show an enriched zone deposited by the deep ascending waters which gave the reefs birth, in no way connected with the secondary enrichments which have made the placers famous, and are in most gold-veins of doubtful continuity.

## Discussion.

Mr. H. W. Monckton asked whether gold had ever been found in a calcite-reef.

Mr. Bedford McNeill remarked that the paper was a very interesting example of the generally-accepted theory of 'secondary enrichment' as applied to a particular ore-occurrence. Naturally, one would have preferred to have visited the locality before discussing the paper. Our present views were mainly the outcome of the comparatively-recent work of Pošepný and others; but, given low-grade auriferous iron-pyrites and given descending oxidizing waters, there was no doubt that the chemical changes alluded to did take place. In this connection, the experiments mentioned by Mr. T. A. Rickard,[1] as having been commenced by Daintree in 1871 in Dr. Percy's laboratory at the Royal School of Mines, should not be overlooked. A number of small bottles, each containing solution of chloride of gold, were taken, and to each a crystal of the more common metallic sulphides was added, such as pyrites, galena, blende, etc.

[1] Trans. Am. Inst. Min. Eng. vol. xxii (1893) p. 313.

At the time when Daintree died, a few years later, no results could be discovered; but one of the bottles was removed to Dr. Percy's private laboratory, and there in 1886, or 15 years after the commencement of the experiment, a cluster of minute crystals of gold was discovered upon the smooth surface of the iron-pyrites.

In the case of the New Guston and adjacent mines in Colorado, with which the speaker was connected some 12 years ago, the ore-occurrence presented at that time many points of great obscurity, but, as since pointed out by Emmons, Rickard, and others, if the theory of secondary or zonal enrichment were applied, these difficulties largely disappeared. As regarded the New Guston mine—galena was most abundant from the surface down, say, to 300 feet, the ore carrying 8 to 50 per cent. of lead, 9 to 30 ounces of silver with a trace of gold. At a depth of about 180 feet copper-pyrites with stromeyerite came in, and continued down to about 700 feet, the assays being: copper 5 to 15 per cent., 25 to 700 ounces of silver, one-tenth to 3 ounces of gold. At about 600 feet solid bodies of iron-pyrites were discovered, which continued to the deeper workings, carrying 1 to 3 per cent. of copper, 4 to 20 ounces of silver, and two-tenths of an ounce of gold. Bornite was met with between 700 and 1200 feet, carrying 18 to 25 per cent. of copper, 60 to 175 ounces of silver, and a quarter to $1\frac{1}{2}$ ounces of gold. Free gold, which was never seen above the 700-foot level or in any other instance, was found associated with the bornite below the 700-foot level. The workings were suspended at about 1500 feet.

With reference to the previous speaker's remark, it might be stated that calcite was not unknown as a matrix of gold; and A. G. Lock had stated that most of the rich quartz-reefs at Gympie (Queensland) contained abundance of calcite in strong veins and patches, often richly impregnated with gold. A fine specimen from these showed actual veins of fairly-large gold specks, irregularly distributed through white opaque calcite.

## 29. *EOSCORPIUS SPARTHENSIS*, sp. nov., *from the* MIDDLE COAL-MEASURES *of* LANCASHIRE. By WALTER BALDWIN, Esq., F.G.S., and WILLIAM HENRY SUTCLIFFE, Esq., F.G.S. (Read April 27th, 1904.)

CONTENTS.



### I. LOCALITY AND HORIZON OF THE TYPE-SPECIMEN.

IF reference be made to Sheet 88 of the Geological-Survey Map of Great Britain, it will be seen that a portion of the Middle Coal-Measures is repeatedly thrown in, between Rochdale and Heywood, by several large faults, so as to form two isolated patches and two large promontories jutting out northward from the general range of the Middle Coal-Measures. About half a mile to the south-west of Rochdale Town-Hall there is, at an elevation of 400 feet above Ordnance-datum, an isolated eminence at Sparth Bottoms, which is fast disappearing, as the shale is being excavated for the purpose of making bricks.

This eminence is situated almost in the centre of one of the before-mentioned promontories. At this point several beds of greyish-blue shale, containing clay-ironstone nodules, crop out; and there is also a bed a few inches thick, with nodules containing for the most part well-preserved remains of *Carbonicola acuta*. These beds dip in a south-westerly direction. The *Carbonicola*-bed may perhaps be taken as a fairly-constant horizon above the Royley or Arley-Mine seam, since we have found it in Dawson's Wood, about a mile distant, and have calculated that it occurs about 135 feet above the Royley-Mine coal-seam.

These beds have yielded remains of well-preserved ferns, *Calamarieæ*,[1] *Sigillariæ*,[2] and fine specimens of Merostomata, both *Prestwichia rotundata*[3] and *Belinurus bellulus*[4] have been found here. A nodule which was found, in October of last year, about 8 feet above the *Carbonicola*-bed has added a new species to the list of Carboniferous scorpions.

[1] D. H. Scott, 'Studies in Fossil Botany' 1900, p. 35.

[2] S. Sidney Platt, 'Fossil Trees found at Sparth Bottoms, Rochdale' Trans. Rochdale Lit. & Sci. Soc. vol. iii (1891–1892).

[3] Trans. Manch. Geol. Soc. vol. xxvii (1902) p. 149.

[4] *Ibid.* vol. xxvii i(1903) p. 198.

## II. Description of the Type-Specimen. (Figs. 2 & 3, pp. 396–97.)

[Registered number in the Manchester-Museum Collection L. 6271.]

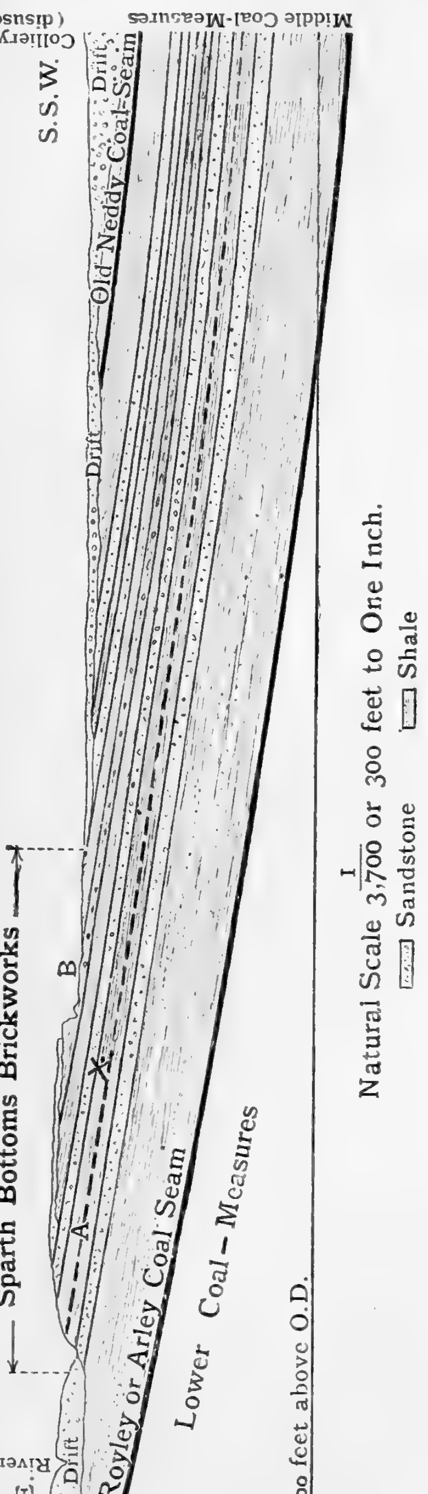



Fig. 1.—*Section of the Coal-Measures at Sparth Bottoms (Lancashire).*

B = Drab-coloured shale, with nodules containing *Prestwichia. Strepsodus sauroides*, ferns, *Calamarieæ*, etc.
A = Nodules containing *Carbonicola acuta, Belinurus, Euphoberia*, ferns, *Calamarieæ*, etc.
× = Position of nodule containing *Eoscorpius sparthensis*, sp. nov.

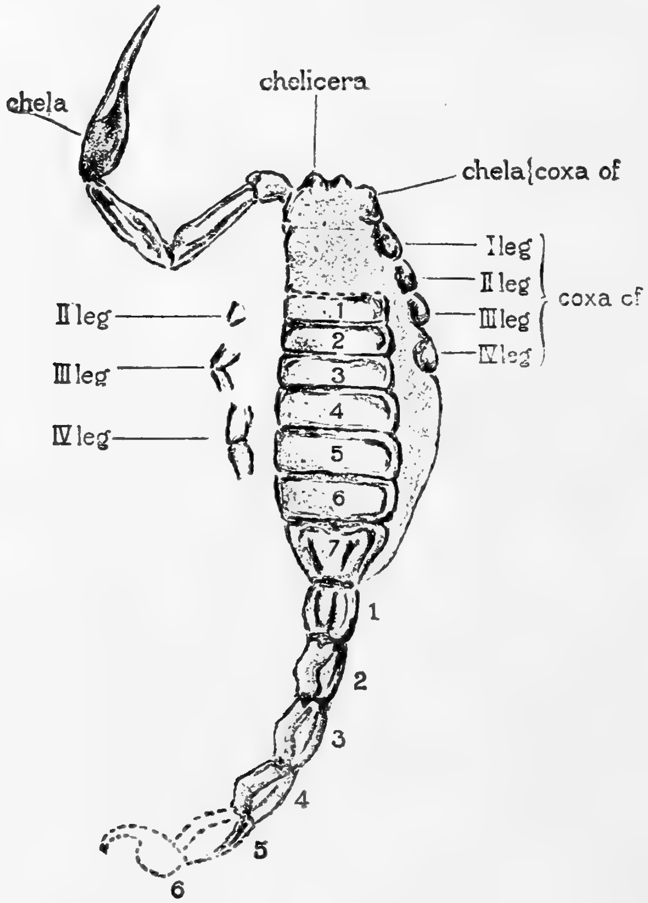
The animal is well represented by both the intaglio and relievo impressions on the respective halves of a clay-ironstone nodule, which is roughly circucular in shape, unfortunately showing the dorsal and not the ventral aspect of the animal. We calculate the length of the whole animal (when extended), from the anterior margin of the carapace to the point of the tail-sting, to have been about 74 millimetres. Some portions appear broader than they really are, owing to the specimen having been crushed.

Cephalothorax.—The carapace is subquadrate in form, slightly narrower in front than behind. We are unable to make out the character or position of the eyes; nor can more be said about the carapace, owing to its crushed state.

Appendages.—Traces of the chelicerae are observed, but are insufficiently preserved to admit of determination. The left second appendage is well preserved and is long, slender, and chelate, and free from tubercles.

The hand is long and slender (17 millimetres in length by 4 in breadth), and the biting-edge is free from denticulation. The finger is, however, missing. Of the right second appendage, the coxa only is preserved.

Fig. 2.—Eoscorpius sparthensis, *sp. nov.* (*Natural size.*)




[The shaded portion shows what is actually seen: the dotted portion is restored.]

On the left side portions of the second, third, and fourth legs are preserved. The fourth exhibits a longitudinal crest, and the segments appear to be stout.

On the right side the coxæ of the first, second, third, and fourth legs are clearly seen, but the legs themselves are missing.

Pre-abdomen.—The anterior segments of the pre-abdomen are short, each succeeding segment gradually becoming longer, so that the sixth is a little more than twice the length of the first. The dividing-line between the carapace and the first segment is indeterminate, because of the crushing of this portion.

Measurements in millimetres.

| | *Length.* | *Breadth.* |
|---|---|---|
| First segment ............... | 2·5 (?) | 10 |
| Second segment ........... | 3·0 | 11 |
| Third segment ............... | 3·0 | 11 |
| Fourth segment ........... | 4·0 | 12 |
| Fifth segment ............... | 4·25 | 12 |
| Sixth segment ............... | 4·25 | 12 |

These are all sub-ovate in shape, and have a smooth articular border dividing them. The seventh is sub-trigonal in form, and narrows so rapidly that its posterior border is only half of the breadth of the anterior border, which is as broad as the posterior border of the sixth segment. The anterior border is 8 millimetres in length, the posterior border 4, while the segment is 5 millimetres long. The whole surface of the animal appears almost smooth to the naked eye, but when viewed through a lens it is seen to be granular, with more pronounced granules on the seventh segment.

A dark stain is observed next to the abdominal portion of the animal, and probably represents the soft portions which have been squeezed out by pressure.

Fig. 3.—*Abdominal segments of* Eoscorpius sparthensis, *sp. nov.* (*Enlarged 2 diameters.*)


1 = First segment of post-abdomen.
2 = Third segment of post-abdomen.
3 = Sixth and seventh segments of pre-abdomen.

The post-abdomen lies sideways, with the right side uppermost. The dorsal and lateral keels are well marked on the first four segments. Nearly all the segments seen are flattened. The first is 5 millimetres long, 5 mm. broad, and shows a row of granules on the left lateral keel. The second is 5 mm. long and 4 mm. broad. The third and fourth segments are 6·5 mm. long by 4 mm. in breadth respectively. The fifth segment is only partly preserved, but may reasonably be inferred to have resembled the fourth. The tail-spine or sting is absent.

The following are some of the measurements of the specimen :—

| | *Millimetres.* |
|---|---|
| Greatest length of cephalothorax ...................... | 10 |
| Greatest breadth of cephalothorax ...................... | 10 |
| Total length of pre-abdomen ...................... | 26 |
| Greatest breadth of pre-abdomen ...................... | 12 |
| Total length of post-abdomen preserved ........... | 27 |
| Length of chela of second appendage ............... | 18 |
| Greatest width of chela of same ...................... | 4 |

## III. Comparison with other Species.

It is unfortunate that the carapace is not better preserved, so as to show the median and lateral eyes, for these are the organs on which generic classification proceeds. Although deprived of the chief aids to generic distinction, the general form of the animal leaves no doubt that it belongs either to *Eoscorpius* or to *Eobuthus*.

In appearance, it is almost identical with *Eobuthus rakovnicensis*, Fr.,[1] though in measurement it differs slightly from that species. The whole animal is shorter, being about 74 millimetres when extended, whereas *Eobuthus rakovnicensis* measures 75 mm.

[1] Fritsch, 'Palæozoische Arachniden' 1904, pp. 73, 74, & pl. xii.

on stone. The pre-abdomen is shorter and narrower, while the segments of the post-abdomen are each respectively shorter.

It is upon the length and breadth of the hand that we rely principally for distinction, and this, too, we find to be slightly less than that of *Eobuthus rakovnicensis*, which measures 19 mm. by 5. The hand also is sufficient to distinguish it from *Eoscorpius anglicus*, Woodward,[1] *E. glaber*, or *E. euglyptus*.[2] It is longer than that of *E. glaber*, and shorter than that of *E. euglyptus*, but is of almost the same length as *E. anglicus*, although it differs in shape from any of them. The remaining joint of the second appendage is devoid of tubercles, and differs in this respect from the corresponding joint of *E. glaber* or *E. euglyptus*.

The sculpture on the pre-abdominal segments of *E. carbonarius*[3] and *E. tuberculatus*[4] at once distinguishes them from this specimen.

What is preserved of the carapace is sufficient also to distinguish it immediately from *E. inflatus*.[5]

Taken generally, the present specimen differs from all previously-described Carboniferous species in possessing a more graceful form and proportion.

At the suggestion of our colleague, Mr. W. A. Parker, of Rochdale (who has devoted over 20 years to a study of the geology of the district, and has very kindly brought the specimen before the writers' notice), we have named the specimen *Eoscorpius sparthensis*, the specific name being suggested by the place of its disinterment.

## IV. Geological Bearing of the Discovery.

In the eyes of geologists such a discovery has a special interest, because it not only gives some slight indication of the zoological and climatic conditions of this Palæozoic land, but serves to mark roughly the probable position of an old land-surface, since this scorpion is too well preserved to have been borne far from its original habitat. Dr. B. N. Peach, F.R.S.,[6] writes :—

> 'It may be that, as recent scorpions feed extensively on the eggs of various invertebrates, the Silurian species also visited the shores for the eggs of animals left bare by the tides, among which . . . the eggs of . . . the Eurypterids (if the latter had the habits of their near relation, the recent king-crab) would form a bonne bouche. If this suggestion should prove to be well founded, we may suppose that it was this habit of frequenting the shores that led the present specimens to be embedded in marine strata.'

The association of *Eoscorpius* with the king-crabs in the beds at Sparth Bottoms appears to prove that Dr. Peach's suggestion is well founded, and that the Carboniferous scorpions, like the recent ones, fed extensively on the eggs of various invertebrates.

[1] H. Woodward, Quart. Journ. Geol. Soc. vol. xxxii (1876) p. 58 & pl. viii.
[2] B. N. Peach, Trans. Roy. Soc. Edin. vol. xxx (1882) pp. 400–402.
[3] Meek & Worthen, Geol. Surv. Illinois, vol. iii (1868) pp. 560–62.
[4] B. N. Peach, Trans. Roy. Soc. Edin. vol. xxx (1882) p. 398.
[5] *Ibid.* p. 405.
[6] 'Ancient Air-breathers,' in 'Nature' vol. xxxi (1885) p. 298.

So interesting an addition to the numerous forms of arthropoda from the Upper Carboniferous rocks of England deserves to be made known as widely as possible, in order to stimulate a greater number of geologists in the neighbourhood of coalfields to pay more attention to splitting clay-ironstone nodules, by which means they may perhaps increase our knowledge of the terrestrial air-breathing animals of the Carboniferous Period.

In conclusion we should like to express our thanks to Dr. B. N. Peach, F.R.S., for his kind examination of the scorpion; to Dr. A. Smith Woodward, F.R.S., and Dr. F. A. Bather, who allowed one of us every facility to compare personally the specimen with *Eoscorpius anglicus* and *Eobuthus rakovnicensis* in the British Museum (Natural History); to Mr. R. I. Pocock, who gave much valuable advice on the partial restoration of the animal; and to Mr. S. S. Platt, F.G.S., for particulars of the strata cut through by the Sparth-Bottoms Colliery-shaft, which enabled us to show more detail in the section (fig. 1, p. 395) than we otherwise could have done.

## Discussion.

Dr. Bather congratulated the Authors on their find of an interesting and well-preserved fossil. He would be glad to hear on what characters they relied for their statement that it was distinctly a new species. The other fragments exhibited appeared to belong to arthropods, possibly Merostomata.

Prof. P. F. Kendall, in adding his congratulations to those of the previous speaker, complimented the Authors on the careful manner in which they were working up these deposits, which were shown to include three arthropod-horizons. He asked whether the Authors had studied the beds above the Arley-Mine seam in other localities, and cited an exposure of beds of similar age in the Irwell Valley where air-breathing arthropods had been found.

Mr. Baldwin thanked the Fellows, on Mr. Sutcliffe's & his own behalf, for the kind way in which they had received the paper. In reply to Dr. Bather, he said that the Authors relied principally on the dimensions of the hand and post-abdominal segments in describing the scorpion as a new species. The new species, viewed as a whole, was of a more graceful and slender build than any of the other Carboniferous species. Replying to Prof. Kendall, he said that the beds at Sparth Bottoms were the only beds in the district that were being properly worked by the Authors, in which they had found remains of arthropoda; they had no doubt that at other places on the same horizon arthropodan remains would be discovered, as specimens of Merostomata had been obtained at Glodwick, near Oldham. He was not aware that arthropoda had been found near Bury, in Lancashire.

# 30. *On the* Moine Gneisses *of the* East-Central Highlands *and their* Position *in the* Highland Sequence.[1] By George Barrow, Esq., F.G.S. (Read March 23rd, 1904.)

[Plates XXXIII–XXXVII.]

Contents.



## I. Introduction.

The object of this paper is: First, to describe the Moine Gneisses in Perthshire and Aberdeenshire, and to show that in their mode of occurrence and field-characters, as well as in their composition and microscopic structures, they are identical with the Moine Gneisses of the North-Western Highlands.

Secondly, to trace the mode of ending-off of these gneisses, and to show that, while retaining their characteristic parallel banding they pass into a small zone of rocks, locally known as the Honestones, which, in varying phases, lie persistently for miles on the white margin of the Central-Highland Quartzite. The parallel-banded Moine Gneisses are, in fact, simply the flaggy margin of this Quartzite.

Thirdly, to show, that in this special area, as the flaggy rocks thicken, there is usually a small hiatus in the succession, owing either to the contemporaneous erosion of the finer material that should lie next them, or to its non-deposition. When this parallel-banded material, however, attains a certain degree of fineness, this erosion rarely occurs, and then the other limit of the group is the Little Limestone. In fact, when the succession is complete, the Moine Gneisses can be shown to pass laterally into the rocks of the Honestone Group, and to lie between the white margin of the Quartzite and the Little Limestone.

Whether these flaggy rocks lie above or below the Quartzite is at present a matter of dispute. The view here taken is that they come above the Quartzite, and the evidence for that view will be given in detail.

The area examined extends from the River Garry, between Blair Atholl and the summit of the Highland Railway, in a north-easterly and easterly direction to Glen Girnoch, east of Balmoral in Aberdeenshire, a distance of some 50 miles.

## II. The Moine Gneisses.

The district over which the undoubted Moine Gneisses occur may be divided into three parts: (*a*) the Struan area, which lies to the

[1] Communicated by permission of the Director of H.M. Geological Survey.

west of the great Glen-Tilt igneous complex; (*b*) the area lying between the Glen-Tilt complex and the great Cairngorm mass of granite; and (*c*) a tract which forms a small portion of the ground to the south-east of the latter intrusion. These masses of granite are chosen to fix the position of the areas, simply because they are shown on most small-scale geological maps, and are easily recognized.

### (*a*) The Moine Gneisses of the Struan Area.

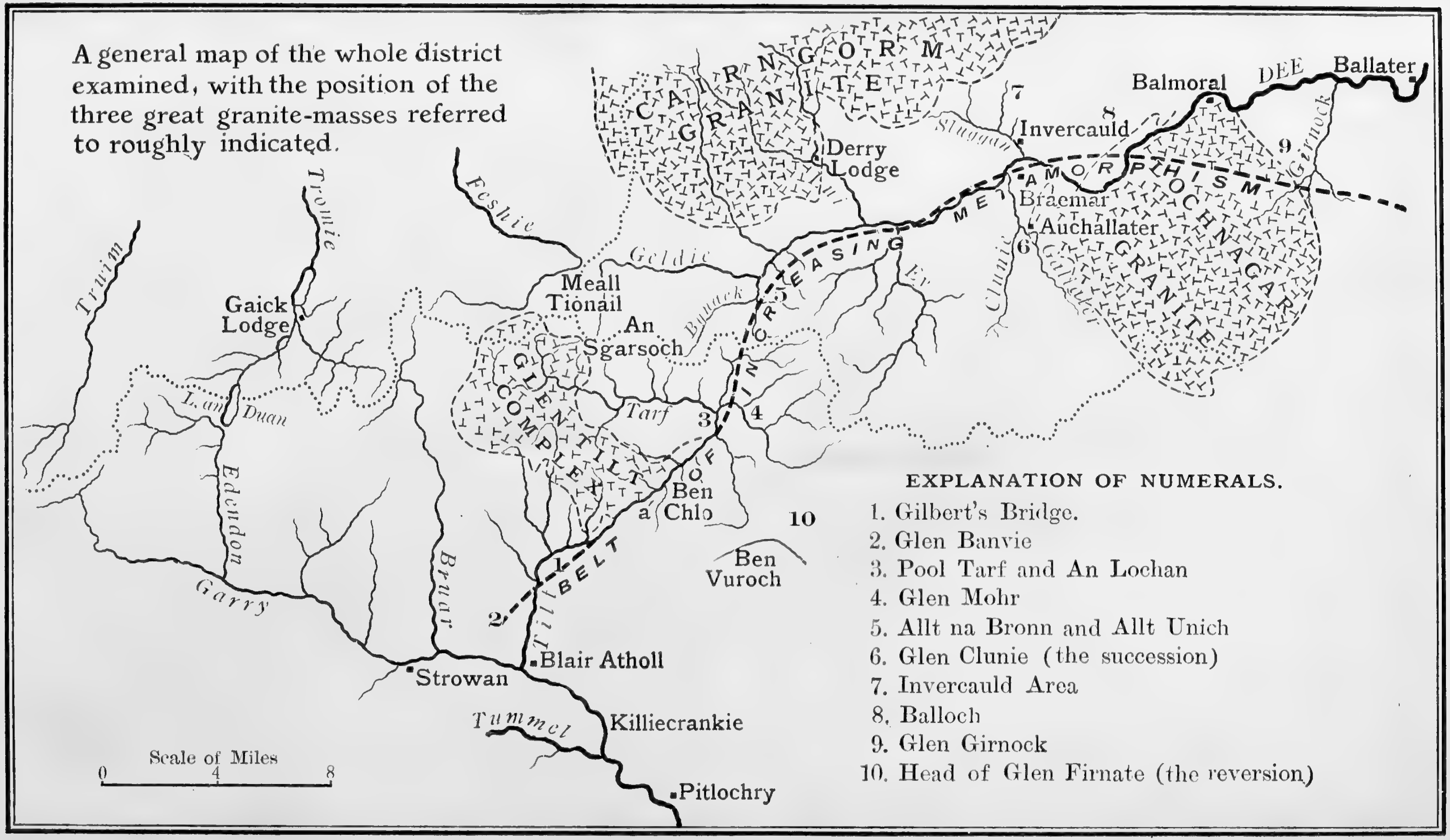
This area is bounded on the west by the River Garry, and, as the sections are easily accessible, it will be convenient to begin with a description of the gneisses there exposed, and to use this as a standard of reference in describing the gneisses elsewhere.

The Garry Section.—Since the days of McCulloch, the River Garry above Struan has been famous for the sections of flag-like rocks which are exposed in its bed and banks, from Struan, almost without interruption, to the summit of the Highland Railway. Its most striking feature is the extraordinary simulation of a normal sequence of enormous thickness, the dip being apparently persistent in one direction (the south-east), at an angle of from 20° to 30°. As seen from a distance, almost the whole sequence consists of well-bedded flags, the component bands varying in thickness, the average of which is about 6 inches, or perhaps less. It will be shown later that thicker bands predominate at one portion of the series, and thinner at another.

The imitation of a sequence of enormous thickness, and the perfect preservation of the parallel banding, together with their highly-crystalline condition, enable these rocks to be easily identified. Since the days of McCulloch, many observers have noted the extraordinary resemblance of the rocks to the flaggy gneisses of the North-Western Highlands, now known as the Moine Gneisses. Further, the mapping of the Highlands has progressed far enough to leave no reasonable doubt that the Struan Flags and the Moine Gneisses are one and the same group of rocks, and it is consequently advisable to recognize this identity in describing them. Additional facilities for their study have been afforded by the cuttings recently made in widening the Highland Railway above Struan, by means of which fresher material can now be obtained for microscopic examination. (See figs. 2 & 3, pp. 404 & 405.)

The Grey Gneiss.—The dominant member of the Moine Gneisses in this area is an evenly colour-banded and markedly-granular, acid gneiss, containing a variable, but often considerable, amount of brown mica. White mica is frequently present in the typical gneiss, but as a rule in smaller quantity than brown, while it is in many bands absent altogether. Though the amount of brown mica varies incessantly, taking the group as a whole, it is for the most part evenly distributed through small thicknesses of the gneiss, varying from a fraction of an inch to sometimes as much as

Fig. 1.


A general map of the whole district examined, with the position of the three great granite-masses referred to roughly indicated.
CAIRNGORM GRANITE
LOCHNAGAR GRANITE
GLEN TILT COMPLEX
INCREASING METAMORPHISM
BELT OF
Ballater
DEE
Balmoral
Invercauld
Braemar
Auchallater
Derry Lodge
Sluggan
Clunie
Girnock
Feshie
Geldie
Bynack
Tromie
Gaick Lodge
Truim
L. an Duan
Edendon
Garry
Bruar
Meall Tionail
An Sgarsoch
Tarf
Ben a Chlo
Ben Vuroch
Tilt
Blair Atholl
Strowan
Tummel
Killiecrankie
Pitlochry
Scale of Miles
0
4
8
1
2
3
4
5
6
7
8
9
10
EXPLANATION OF NUMERALS.
1. Gilbert's Bridge.
2. Glen Banvie
3. Pool Tarf and An Lochan
4. Glen Mohr
5. Allt na Bronn and Allt Unich
6. Glen Clunie (the succession)
7. Invercauld Area
8. Balloch
9. Glen Girnock
10. Head of Glen Firnate (the reversion)

2 feet, or even more. This increase and decrease, in different bands, of evenly-disseminated brown mica imparts different shades of grey, pale-grey, or pinkish-grey to the banded gneiss, and is the principal cause of the evenly colour-banded aspect, which is its most characteristic feature. The bedded aspect of the series is often intensified by the arrangement of the individual crystals of biotite parallel to the colour-banding. But it is still further accentuated by the presence of films of felted dark mica, which are always rigidly parallel, and appear on a cross-fractured surface as fine black lines.

These films decompose more readily than the rest of the rock, and give rise to planes of diminished coherence, so that when fragments become detached from a scar-face they break away along those parallel surfaces. Further, this decomposed material weathers out, leaving a series of minute parallel grooves that have the appearance of dark lines when seen from a distance of a few feet. It is, indeed, to the presence of these films that the flaggy weathering of the Moine Gneisses is essentially due; and when the gneisses occur in thicker bands, or the films are much farther apart, the flaggy character is partly lost. It will be shown later that the presence of these films is of the utmost importance in tracing these rocks when they thin away to the south-east.

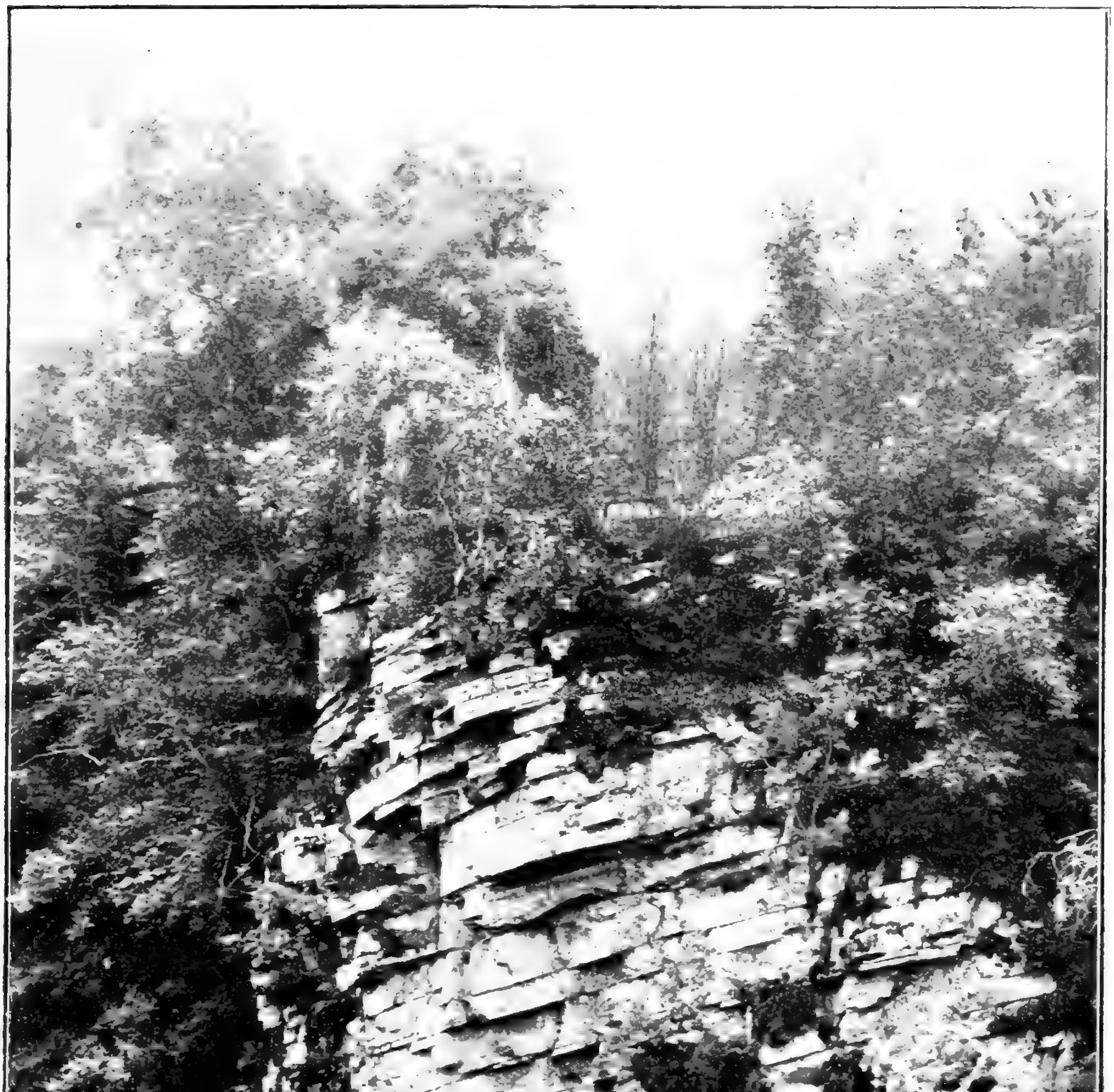
That these rocks are altered sediments, and that the colour-banding is coincident with the original bedding, is, in many cases, perfectly clear from their chemical and mineralogical composition; but, if any further proof were wanted, it is to be found in the small cross-cleaved, highly-micaceous bands, originally more of the nature of shales, that occur at intervals throughout the whole of the Struan section. This cleavage of the original shale-material obviously took place prior to any crystallization, and, as a rule, it ends abruptly against the colour-banded rocks, which, from their present composition, must have been of a more sandy nature originally, and would not cleave. The phenomenon is identical with that observed so often in cleaved and folded Silurian rocks, although the latter have not since been crystallized. Equally important, from this point of view, is the occurrence in the deep cutting at the Perth 42-milepost of a special type of grey gneiss, in which there is scarcely any parallel banding; even the parallel arrangement of the biotite in the rock is not well marked, and the felted films of biotite are entirely absent. This rock differs from the more common type of gneiss in its mode of weathering, and on open ground forms rounded blocks of massive aspect, somewhat resembling a very fine granite. The absence of any indication of the original bedding suggests that the material was deposited under somewhat different conditions from those of the parallel-banded gneisses. It may be here noted that no thick band of such material ever occurs near the south-eastern margin of the Moine Gneisses, or in the ground where they end off.

It may not be out of place, in concluding this account of the macroscopic character of these gneisses, to draw attention to the

Fig. 2.—*Typical view of the Moine Gneisses in the bed of the Tilt, looking up stream from Gilbert's Bridge.*

[The persistent dip of the flaggy structure and the imitation of a normal sequence are well shown.]

Fig. 3.—*Typical scar formed of Moine Gneisses, showing the resemblance to unaltered sandstones: on the River Garry, near Clune, 2 miles north-west of Struan.*



fact that their highly-crystalline character is shown, not by the quartz or felspar, but by the persistently-large size of the micas, when these are present in notable quantity. Years of study have proved that this is by far the most sensitive test by which to judge of the degree of crystallization in altered sediments, such as were originally normal sandstones and shales.

Microscopic Characters of the Gneisses in the Struan Area.—Great light is thrown on the structure and composition of these gneisses by the aid of the microscope. Taking first the prevalent type—the parallel-banded rocks, we find that they are essentially felspathic gneisses, the felspar being usually in excess of the quartz, and in some cases occurring almost to the exclusion of the latter. As the quartz decreases in amount it tends to assume a rather rounded form, embedded more or less in the felspar, and constituting 'quartz-bleb structure.' It may, when present in very small quantity, occur as minute globules in the felspar, imitating exactly the micropoikilitic structure of igneous rocks. The felspar is of two kinds—microcline, for the most part fresh and showing the typical cross-hatching; and plagioclase, usually much decomposed. It is almost impossible, in many cases, to be certain of the nature of the plagioclase-felspar, but in some instances it is clearly oligoclase. The relative proportion of microcline to plagioclase in the gneisses of the Struan area varies greatly. In the lighter-grey varieties plagioclase seems to be, as a rule, slightly in excess; in the darker-grey varieties, microcline often exceeds the other in amount. When the gneiss weathers with a distinctly-pink edge, the microcline seems usually to be the dominant felspar in this area; and it is, at times, more abundant than plagioclase and quartz taken together. A good idea of the general structure may be obtained by selecting a specimen in which the quartz, microcline, and plagioclase are present in nearly-equal proportions.[1] It will be seen that the grains are, on the whole, evenly distributed, as if they had been first mixed in a pepper-pot and then shaken out. This granular arrangement of the component grains may be described as a 'granulitic structure'; but it cannot be too clearly understood that it is unlike the granulitic structure of many of the schists of the Southern Highlands. The microcline usually retains this granular mode of occurrence, even when present in large quantity, and it rarely helps to bring out the foliated character or parallel structure of the rocks. But, if the plagioclase increases in proportion, it assumes irregular forms, and tends to occur in much larger and often elongated patches that help to define the parallel structure. The quartz in the latter case frequently appears embedded as 'blebs' in the felspar, a mode of occurrence that can often be made out by the aid of a hand-lens.

The foliated aspect, in hand-specimens, of a single band or flag

[1] See Pl. XXXIV, fig. 1 (No. 88). The low numbers refer to photographs in the possession of the Geological Survey; the high ones (10,422) to the microscopic rock-sections.

of the gneiss is mainly due to the parallel arrangement of the micas; and microscopic sections show that, as a rule, these are so set in the rock as to interfere only to a small extent with the granular structure shown by the quartz and felspar. It is only when mica is present in sufficiently-large quantity to impart an almost-fissile character to the rock, that its influence appears in the rock-structure. In that case, almost continuous films of biotite or biotite and muscovite separate well-defined parallel strips of quartz-felspar material. The edges of the grains in contact with the mica are now distinctly flattened, and, moreover, the grains within the parallel strips tend to assume a somewhat quadrangular form (Nos. 85, 89, & 90).

In the Struan and adjacent areas, the biotite of the Moine Gneisses, when fresh, is always of the normal haughtonite-type—that is, when seen in cross-section and rotated under a single nicol, it changes in colour from brown to a watery-black. Inclusions with more or less pleochroic halos occur in the biotite, although they are not a marked feature of the mineral. Chlorite is present in many of the rocks, more particularly in the micaceous gneisses. It is very difficult to say whether this is a replacement-product after brown mica or not. It is too often forgotten that lime, though in small quantity, is an essential constituent of normal biotite; and, in many cases, the more or less chloritic original material from which these rocks were produced did not contain sufficient lime to form even biotite when metamorphosed, and then the chlorite is the direct product of thermal metamorphism. Pleochroic spots are common in this chlorite. The white mica presents no feature of importance, except in its mode of occurrence. It does not conform to the foliation so closely as the biotite, and in some of the rocks it is set with the basal plane at right angles to the foliation.

In addition to the minerals just enumerated, small crystals of sphene are common in some of the specimens, and present in almost all. They are often pointed, elliptical in shape, and are frequently coated with a film of iron-oxide. They have usually the aspect of metamorphic sphene, and are never strictly original. Apatite occurs occasionally, as also zircon. The latter is not nearly so common as might have been expected in such rocks, which clearly originated from fine felspathic and micaceous sands. Small garnets occur in certain dark blotches in one band of very pale gneiss, but the mineral is not common in this area.

Taking the grey gneisses as a whole, they are remarkable for the amount of microcline present, and, in this respect, they differ from the grey gneisses of the areas farther to the north-east (to be described later), where microcline is less common, despite the close external resemblance between the rocks in the two areas.

The Pink-edged Gneisses.—In addition to the dominant grey-banded gneisses, there are also present some that weather with a pink edge, even though they are grey on a freshly-fractured face. These pink-edged varieties are especially interesting, because they serve, more than any other members, to correlate the Moine Gneisses of different areas despite local variations of character. It has been found in the Struan and adjacent areas that these rocks are especially rich in microcline. Moreover, when the pink coloration is well marked, they usually contain in addition some calc-silicate, which is most commonly epidote or zoisite, but at times hornblende is present. Typical examples of the epidote-bearing variety are abundant in the second cutting above Struan Railway-station. The most interesting example of this pink type, however, occurs in the bed of the Garry, immediately in front of Dalnacardoch Lodge. Like all the rocks close by, it splits into comparatively-thin slabs, owing to the presence, at short intervals, of the thin films of felted biotite already mentioned. Between these films the rock is not particularly fissile; indeed, it is rather tough, and shows a mottled red-and-green coloration, on a cross-fractured surface. A section shows that it is composed mainly of the typical cross-hatched microcline. This forms a kind of groundmass, in which are set a number of aggregates of green mica, the long axes of which are parallel to, and, indeed, serve to mark, the foliation of the rock. A small amount of plagioclase (in irregular patches) and a little white mica are also present. Apatite is fairly common, and occurs in much the same manner as the quartz. This latter mineral is present in very small quantity, and most of it is found as tiny blebs in the microcline, affording a perfect example of micropoikilitic structure. The occurrence of this rock, so rich in alkali-felspar, is especially interesting, as it tends to recur again and again over a very large area, and apparently at a definite horizon.[1]

The highly-micaceous Gneisses.—These rocks are characterized by abundant white mica and biotite or chlorite. For the most part they are cross-cleaved, as already stated; but where only a very thin parting occurs, the gneiss is at times 'rodded,' that is, the micas are all elongated in a definite direction, and there is no specially-marked plane of schistosity. This variety serves to show that the originally-softer parts of the series have often suffered considerably from dynamic action prior to crystallization.

These micaceous bands possess a somewhat different structure from that of the other gneisses. In the cross-cleaved variety there is a tendency to form lenticles, free from mica, as in the true schists, but the lenticular structure visible in the hand-specimen is not nearly so obvious under the microscope. Comparatively-little microcline is present, and only a moderate amount of felspar. Quartz, on the other hand, is more abundant than would have been suspected. Apatite is much more common than in the parallel-banded rocks. The abundance of quartz explains, what is specially noticeable, the total absence from the micaceous gneisses of silicates of alumina, such as sillimanite, cordierite, andalusite, etc. Clearly,

[1] See Pl. XXXVI, fig. 1 (No. 84). Further investigation has shown that this is the 'Pink Felspathic' rock described on p. 416, and marks the top of the Moine Gneisses.

after the formation of the micas, there was not an excess of alumina sufficient to form such minerals, and the microscope confirms the inference that the shale was originally somewhat gritty and impure.

### Other Exposures in the Struan District.

The flaggy gneisses just described cover a large area on both sides of the Garry, above Struan. On the open ground, however, good exposures of them are not numerous, because the flanks of the hills are much obscured by Drift, and the crests of the hills are frequently covered by a somewhat angular rubble, which is due to the disintegration of the rocks. About the Dalnacardoch area, and for some distance eastward, the massive grey gneiss is especially abundant, where it weathers in the form of rounded blocks. Owing to its greater power of resisting decomposition, it is often seen *in situ*. Excellent sections are exposed, however, in the streams that drain into the Garry, and these are often continuous for considerable distances. Microscopic examination shows little variation in the type-rocks; while the appearance of a continuous dip is at times even more marked than in the Garry section.

In the area between Struan and Blair Atholl, the gneisses undergo a slight change, becoming, on the whole, more micaceous, and in many cases rather more fissile. The latter character is shown by microscopic sections to be due to the parallel arrangement of the white mica, as well as of the brown, the two being often in contact. Good examples of this type occur in the cutting near the Manse, north-west of Blair Atholl, where the rocks appear to contain rather less microcline than usual. Around the igneous complex of Glen Banvie, and for some distance to the south-east, the gneisses are rather more quartzose than usual, becoming at times almost quartzites. A typical example of the latter is essentially a granular mosaic of quartz and felspar, with a little brown and white mica, but it differs from the Central-Highland Quartzite in the large amount of microcline present. Farther down the Banvie Burn greyer-banded types occur, well shown in the quarry under the road at the western end of the Whim Plantation. One of these (10,422) contains many oval crystals of microcline, within which are numerous poikilitic grains of quartz, as well as minute flakes of mica and grains of garnet and epidote. Most of the grey bands, with parallel biotite, contain much microcline, but when the biotite is abundant it begins to show a reddish-brown tint. A little band (10,424) having much the appearance of the material that forms the more massive rocks about Dalnacardoch, is also seen here; and it is especially worthy of note that this contains hardly any microcline, but much plagioclase in sheets enveloping the quartz.

Before leaving the Garry area, attention may be drawn to two special rocks. The first occurs in the river-bed at Dalnacardoch, and has already been described (p. 408); the second is associated with the typical grey-banded gneiss, and is composed of white quartzose-looking material, within which are set a number of dark blotches

The latter was first seen in the railway-cutting below the Perth 42-milepost, and later on at the Perth 44-milepost. Mr. Macconochie found it in the bed of the river at Struan and in a number of other places, but it does not seem to be associated with the more massive gneiss. This band, which we propose to call the 'Blotch-Rock,' can be immediately recognized; indeed it has been met with over a large area, and serves to show more than anything else that the rocks composing the colour-banded gneisses were originally quite thin.

### Area north of Struan, about the watershed of Perth and Inverness.

As we approach the watershed, the south-easterly dip slowly changes, and becomes northerly. In the Gaick Burn, although the typical grey gneiss is present, most of the bands are thin, and of the type of those seen at Dalnacardoch. Three varieties of these thinner bands are worthy of special notice. One is a kind of spangled gneiss, and contains a considerable amount of biotite, and at times a few crystals of muscovite at right angles to the banding (11,055). From its mode of occurrence, we may assume that it was almost certainly a shaly rock originally, but its dominant constituent now is well-crystallized microcline, which forms 60 per cent. of the rock. There can be little doubt that this microcline in such a rock results mainly from the action of finely-divided micaceous material on finely-divided quartz, thereby forming microcline; for it will be seen later that this excessive amount of microcline, in many cases, characterizes the limestone and the adjacent shales. A specimen, on the other hand, with much white mica contains little alkali-felspar, suggesting that in this case no such interaction took place (11,058). Associated with these, is a little band containing epidote along certain lines. But one of the most striking features of the exposures about the Gaick Burn is the frequent repetition of the little 'Blotch-Rock,' showing that over a large area we do not move more than a few feet from one horizon in the original sequence.

Near the watershed the more thinly-banded rocks slowly disappear, and the normal grey gneiss is again met with. The most abundant phase (11,052) is rather light-grey in colour, with quartz-grains, somewhat rounded 'quartz-blebs' set in a matrix of felspar, most of which is the typical microcline (97). Some plagioclase is present, mostly decomposed. A somewhat darker phase (11,053) contains slightly less microcline, with more quartz, and in this the 'quartz-bleb' structure is not so well shown. In both, the mica shows the usual parallel arrangement; the typical small sphenes are fairly abundant, while minute zircons are more numerous than in most of the specimens from the Garry area.

## (*b*) Area East of the Glen-Tilt Igneous Complex.

In the Perthshire portion of the area east of the Glen-Tilt complex, several important differences in the Moine Gneisses are visible, as compared with those already described; and, in addition, small outcrops of other members of the succession are met with, by the aid of which the position of the parallel-banded gneisses can be fixed. A distinct, though slight, change in composition is shown by the increase of biotite in the rocks as a whole; and this is accompanied by the development of sillimanite in some of the more micaceous thin partings, thereby fixing the phase of crystallization. Obviously, the original material had become more muddy on the whole, and less of a fine arkose or sand, though the latter character was still retained in one part of the group.

Two types of the gneiss in this area are worthy of special notice. The first weathers with rounded outlines, is of somewhat massive aspect, and resembles a fine granite. It forms the long, rounded ridge stretching from An Sgarsoch, at the county-boundary, in a southerly direction to Sron na Macranach, on the north side of the Tarf. Considerable masses of similar rock occur on Cairn Fidhleir, farther west. This tract lies in a line with the other outcrops of the massive, round-weathering gneiss already mentioned, of which it seems to be a slight modification. Sections of these rocks show that they contain singularly-little microcline and an unusual amount of plagioclase (mostly oligoclase), often fringed with vermicular pegmatite, and at times partly idiomorphic with respect to the quartz (11,059).[1] In both localities, the round-weathering type of gneiss is succeeded by a singularly-flaggy phase, in which microcline is abundant and parallel structures are well marked: thus strongly suggesting that the rock so rich in plagioclase marks a distinct horizon. As in the Struan area, thin bands of somewhat similar material occur to the south-east; and in these the plagioclase has frequently much vermicular pegmatite on its margin, forming clubbed ends to the narrow crystals (11,066).

The second type of gneiss of special importance in this area is sharply separated from the normal phases hitherto described by the occurrence within the individual bands of a lenticular or 'thrust-plane' structure, similar to that met with in the grits of the Southern-Highland border, and due to mechanical deformation. A typical specimen (11,076) is a grey gneiss with thrust-plane structure, in which the movement-planes are coated with dark mica. It is composed of abundant oligoclase and quartz occurring together in lenticles, separated by films rich in reddish-brown mica. These films alternately approach and recede from each other, and show the typical undulatory parallelism of a true schist of the Southern-Highland type. The occurrence of this structure is highly important, as it shows that when the material of the Moine Gneiss was strongly affected by dynamic action, the rocks crystallized as typical lenticular or phacoidal schists. It is a fair inference, that the persistent absence of any such structure from the typical grey gneisses is conclusive evidence that they suffered practically no mechanical deformation prior to crystallization within the individual

[1] See Pl. XXXV, fig. 2 (No. 107).

bands, though considerable sliding may have taken place along the greasy chloritic parting-films. The belt within which this structure occurs commences at the Tilt Valley, on both sides of the Tarf, and stretches to the foot of Sron na Macranach. It will be described in detail in the Survey memoir on the district.

### Aberdeenshire Area, west of the Lochnagar Granite.

The feature of this area, on the whole, is the perfection with which the parallel structure is shown in the field, especially in stream-sections; the bands are perhaps thicker than in the Garry area, and they have a singularly-massive habit, owing to which they may be described as of the 'massive-pavement' type. These massive pavements are admirably shown in the bed of the Geldie above its junction with the Dee, where the river runs approximately parallel with the strike. The dominant type of gneiss is grey, and highly crystalline. Granulite and quartz-bleb structures are common in many of the rocks, and they contain, on the whole, little white mica. The biotite varies: sometimes it is normal haughtonite, but more often it is of the reddish-brown type. Garnet occurs in microscopic sections more frequently than the external appearance of the rocks would lead one to expect. Plagioclase-felspar is far more abundant than microcline, though here again there is one horizon at which the latter is fairly abundant. Three types are worthy of special reference. The first is a banded grey gneiss (8512), in which Dr. Teall noted a line specially rich in iron-ore and zircon, clearly indicative of original bedding and parallel to the colour-banding; it is a typical granulite, with no trace of quartz-bleb structure. The second is remarkable for the number of small pink garnets in it, which enable the band to be easily identified (8510). Like the 'Blotch-Rock' of the Struan area, this little garnet-band has been met with again and again over the area west of the Cairngorm Granite, thus indicating that the whole group was originally of no great thickness. The third type is a pink-edged epidotic gneiss containing much microcline, which, though present over a limited area, is abundant close to the margin of the granite, and specially so near Monadh Mor, just inside the boundary of Inverness-shire. A typical specimen (8519) is almost identical with (8518) from the Allt Unich, south of the Geldie, which, on account of its importance, will be referred to again (see p. 436).

### Area flanking the Dee above Braemar.

In and about the Allt Unich, just mentioned, a considerable portion of the Moine Gneisses is highly quartzose, and differs markedly from the typical grey- and pink-banded rocks, which are here present only in subordinate quantity. This is due to the fact that the flaggy gneisses are here largely composed of the Central-Highland Quartzite, exhibiting many of the curious structures so characteristic of the Moine Gneisses. Although these quartzose rocks possess a flaggy aspect on the whole, it is not so marked as in the parallel-banded grey gneisses; for the typical highly-chloritic films of the latter were never present in the original quartzite. On the splitting-face a thin film of fine, evenly-disseminated muscovite is present, which gives rise to the flaggy aspect of the quartzose gneiss. It was doubtless developed along buckling-planes from the felspar in the Quartzite. This type of material is the dominant constituent of the Moine Gneiss on the south side of the Dee, for a considerable distance to the east.

Approaching Braemar, the colour-banded pink-and-grey rocks increase once more in amount; but still, in small openings by the roadside, portions of the true quartzite can be identified, despite the new structure developed in it, by certain fine dark lines of heavy minerals, to which special reference will be made in describing the Quartzite.

### (*c*) Area south-east of the Cairngorm Granite.

In that portion of Invercauld Forest which lies between the Sluggan Burn and the ridge of Cairn Liath to the east, the Moine Gneisses vary somewhat in appearance. Highly-quartzose rocks are more abundant in the south-eastern part of this ground, and the bands are distinctly thinner; but farther to the north-west they thicken and, on the whole, become more felspathic and variable in composition. Where thinner, they consist essentially of three small bands: the first being practically quartzite, the second darker with more brown mica, and the third a kind of pink-edged quartzite. These three thin bands, by repeated foldings on themselves, form great rock-masses, which can be admirably studied in the low crags alongside the Sluggan-Burn footpath, at about a mile above the junction with the Dee.[1]

A little to the south-east of these crags, it is again often impossible to say where the Moine Gneisses end off and the Central-Highland Quartzite begins; for the latter now occurs in a 'Moine-phase.' The typical white margin of the latter can be identified on the footpath above the house, near the northern end of the plantations; and, starting from this point, it is clear that the greater part of the quartzose gneiss must be formed of the Main Quartzite.

On the ridge between Meall Gorm and Cairn Liath, little but the three quartzose bands already mentioned can be seen. The palest band is met with first, and is just sufficiently banded to be separable from the true Quartzite. Farther north the greyer band appears, slowly becoming more felspathic and more like the typical grey gneiss. On the southern part of Cairn Liath, the pink quartzose band is the dominant rock, and must be folded on itself to an extent that is almost incredible, to form so large a portion of this hill. Farther west, the thickening and the change in composition are soon well marked: the pink-edged rock in particular having darker and more felspathic bands in it. One of these has a rather mottled

[1] See p. 435 for a description of these bands where the Moine structure is not developed.

aspect, and possesses the typical granular structure of a Moine Gneiss; it is composed of both potash- and plagioclase-felspar, which together exceed the quartz in amount. Biotite is fairly abundant, and epidote occurs along certain lines. This is the typical pink-edged epidotic gneiss, which occurs over a wide area. Still farther west, both angular and round-weathering grey bands appear; but the pink-edged rocks still predominate, always containing a considerable amount of potash-felspar, the latter often fringed with vermicular pegmatite. Closer to the head of the Sluggan Burn, infolds of more highly-quartzose rock are met with, and increase in size, until the large mass separated-out on the map is reached, which is once more, in the main, the Central-Highland Quartzite, with the Moine-Gneiss structure superimposed on it.

On the south side of the Dee, to the east of Braemar, the old difficulty recurs in separating the true Quartzite from the highly-quartzose Moine Gneiss; but a faint remnant of the typical, parallel-banded, grey material is seen in the little quarry, close to the gate of the footpath that passes on the south side of Creag Choinnich.

One of the few cases in which the Quartzite in a 'Moine-phase' can be separated from the quartzose gneiss is met with on the hill-top above Balloch Farm, some 2 miles north-east of Invercauld; the latter being seen practically in contact with the white margin of the former. The best locality for studying this is between the limestone and the small mass of diorite and granite,[1] farther west.

## Summary.

This account of the Moine Gneisses may be summed up briefly as follows:—

1. These gneisses are a parallel-banded series of sedimentary origin, usually rich in felspar (largely microcline), and containing dark biotite in variable quantity.
2. The gneisses are thinly-bedded, as a whole; and their structure is essentially parallel, but not lenticular or phacoidal. This parallel structure is in most cases shown by the arrangement of the biotite.
3. Certain types can be recognized again and again throughout the whole area; and their repeated occurrence shows that the whole series is really thin, although by intense folding it simulates a succession of enormous thickness.
4. Although the variation in the typical grey gneisses, as they are traced eastward, is not great, still it is important. Biotite is, on the whole, more abundant; and the highly-micaceous partings become more aluminous, that is, were more of the nature of fine mud originally.
5. A striking feature of the grey gneisses is seen in the films of felted biotite, derived from original clastic chlorite, and

[1] The position of these rocks is shown on the Geological-Survey 1-inch map, Sheet 65, to be published shortly.

indicating the former bedding-planes. Their presence is highly important, especially when we consider the mode in which the Moine Gneisses end off when traced to the south-east, as it will be seen that they link the gneisses with the Dark Schist, of which the same material was an abundant constituent.

6. Lastly, a considerable mass of highly-quartzose material, which, for purposes of mapping, must be included in the Moine Gneiss, can in the eastern part of the area be shown to be really the Highland Quartzite (in what may be conveniently called a 'Moine-phase'), and should be excluded from the group in discussing the origin of the grey gneisses.

## III. Mode of Ending-off of the Moine Gneisses.

Having shown that these gneisses extend in a south-easterly direction to the Tilt Valley, the Geldie, and the Dee, almost to Braemar, we may pass on to consider the question why they do not appear in their typical phases to the south-east of this long line. The simplest explanation would be that they have been faulted-out; and in the Glen-Tilt area this, at first, seems to be the true one. That it is not sufficient, however, is clear from the fact that in some cases the gneisses cease to be recognizable before the main fault is reached, while in the district east of the Geldie they cross the fault in mass. Two other causes may be suggested: first, that they become less crystalline, and so cease to be recognizable as Moine Gneisses; or, secondly, that they thin away. It will be shown that both causes co-operate to render the further tracing of them a matter of difficulty.

### (*a*) The Belt of Decreasing Crystallization.

The first of the causes above suggested is most important in the Tilt Valley, where the decrease in crystallization is unusually rapid. It occurs along a belt that has been traced from the coast north of Stonehaven to a point north-east of Blair Atholl, a distance of about 100 miles. This belt passes in a somewhat curving line from the eastern coast to the head of Glen Isla, where it sweeps round in a north-easterly direction almost to Ballater; thence it turns westward, and crosses the Dee somewhere between Balmoral and Braemar. From the latter point it coincides roughly with the Dee Valley as far as the Geldie Burn, after which it follows, approximately, the belt of faulting in the Tilt Valley to within 3 miles of Blair Atholl. West of the Geldie, this area of decreasing metamorphism corresponds approximately with the belt along which the Moine Gneisses disappear; but east of the Geldie the two are less intimately connected. When this belt of decreasing metamorphism attains its full development, we pass from the 'sillimanite[1]-aureole' to that characterized by the presence of kyanite and

[1] See 'On an Intrusion of Muscovite-Biotite Gneiss in the S.E. Highlands of Scotland' Quart. Journ. Geol. Soc. vol. xlix (1893) p. 332.

staurolite; but on either side of the belt the metamorphism remains singularly constant over very large areas.

In the Tilt Valley, as the gneisses are followed, they lose rapidly their crystalline character. But, in addition to this, they also thin away and change in composition, passing into a thin group of equally parallel-banded rocks, known locally as 'the Honestones.'

To establish clearly and fully these changes in the aspect of the Moine Gneisses, it was necessary to find a more or less continuous section that should at once show both the decreasing crystallization and the decreasing thickness. Such a section has been found in the Tilt Valley, in the neighbourhood of Gilbert's Bridge, where the river, instead of continuing its usual rather straight course, makes a big bend toward the north-west. Now the arch of this bend is at one side of the belt of decreasing metamorphism and thickness, while the two ends are at the other; and it is by means of this section that the whole explanation was ultimately arrived at.

### (*b*) The Section at Gilbert's Bridge.

(Map, Pl. XXXIII & fig. 9, p. 444.)

Standing on Gilbert's Bridge, and looking up the Tilt, we see a typical section of the parallel-banded gneissose flagstones or Moine Gneisses, striking up-stream, and having an even dip to the south-east, at about 30°. Below the Bridge the same rocks are seen for a few yards, but farther down only small patches of gneiss are exposed, as the rest of the section is composed of numerous infolds of other beds. An examination of the river-channel shows that these rocks are intensely folded, one of them, consisting of limestone, being repeated no less than eight times in a distance of 150 yards. This bed may be either in contact with the Moine Gneiss (here, at times, highly quartzose) or separated by one or all of three beds or bands. Of these, the most striking is a curious 'pink rock,' of which the dominant constituent is obviously felspar. Another is a dark and often tough schist, which varies somewhat in aspect; while the third is a little sill of hornblende-schist, which, by folding on itself, may attain a thickness of more than 6 feet, but is sometimes not seen owing to a slight change of horizon, one of its characteristic features. This little sill is of considerable importance, as fixing, approximately, the horizon with which we are dealing.

The 'Pink Felspathic Rock,' or rather material (for it is found in the other sedimentary rocks) consists mainly of microcline. Where purest, it forms a separate band, which, a little below Gilbert's Bridge, attains a thickness of 6 feet, owing, partly, to repetition by folding. Some way below the Bridge it occurs as lenticles in the quartzose rock. It is evenly disseminated through part of the limestone in one place, while at another it forms a segregated patch, which has so completely recrystallized as to simulate a pegmatite, a mode of occurrence that has been noted over a wide area. A specimen from the thicker band (10,534) is composed of abundant microcline, quartz, decomposed felspar, and a considerable quantity of green and brown mica, with a parallel arrangement. In some portions of this band microcline is even more abundant, the principal accompaniments being green mica and granular sphene.

The Dark Schist occurs as discontinuous patches that lie next the Limestone, and between it and the 'Pink Felspathic' material, when both are present. These dark patches have proved of exceptional importance, and will be discussed later on.

The Limestone varies greatly in composition. As a rule, however, it contains some snow-white, coarsely-crystalline calcite, and this may be present in separate thin bands or mixed with other minerals. In no case does this rock possess the grey coloration of the typical Blair-Atholl Limestone and the Loch-Tay Limestone. One of the thicker exposures (10,526) contains abundant epidote and microcline, the latter mineral identical with that of the Pink Felspathic Rock, and a small quantity of either optically-anomalous garnet or idocrase. In one place the calcareous material is obviously mixed with a pink felspar, forming a coarsely-mottled pink-and-green rock. The green mineral is malacolite, and the pink the typical microcline.

At the junction of the tough Dark Schist with the base of the limestone occurs a finely-banded rock. The paler bands are composed of abundant epidote and zoisite, with a smaller quantity of hornblende and calcite. The darker films were more aluminous originally, and are now composed of plagioclase and quartz, associated with chlorite and biotite. There are small spots in this part of the rock, dusted over with minute biotite-flecks, exactly as in a typical hornfels.

It is thus apparent that the Limestone has not always the same rock at its margin, and does not always rest upon the Moine Gneiss; and there is clear evidence of a slight local erosion, or a small hiatus in the succession.

After a thorough investigation of the section below the Bridge, the section above it may be examined. The rather massive and highly-crystalline Moine Gneisses occupy the bed of the stream,[1] but the Limestone lies in the bank above, and its base is exposed in places, while at the mouth of the little burn at the northern end of Dalginross Wood, both the felspathic rock and the Limestone are seen. At the base of the latter is a finely-banded, markedly-fissile rock. This fissility is due to the perfect parallelism of a large number of pale-brown micas, associated with a small quantity of actinolite. The rock is structurally a fine quartz-felspar-biotite-granulite, with a considerable amount of microcline, and a little carbonate and granular sphene (10,528). It is of considerable importance, as suggesting a passage to the felspathic material, and recalling the rock at Dalnacardoch and the Gaick Burn.

A few yards farther up the main stream the Pink Rock is seen again in contact with the Moine Gneisses, and continues in this

[1] See fig. 2, p. 404. For the photographs, from which this figure and figs. 3 & 5 are reproduced, I am greatly indebted to Mr. Lunn, of the Geological Survey.

position for some distance. Immediately below the big bend at Auchgoul it changes suddenly in composition, in a manner that seems to exclude the probability of an igneous origin.

The big bend just mentioned is cut in Drift, but at its northern end, the Limestone, repeated several times by folding, is seen either close to or touching the Moine Gneiss. One outcrop of limestone is so much purer, and more like the normal Blair-Atholl Limestone, that it seems at first difficult to believe that we are still dealing with the same bed.

Opposite the mouth of Glen Mhairc the river once more flows along the strike of the rocks, and the Moine Gneisses are now seen to be rather more quartzose and more finely-banded. In the bank close to and above the river are several infolds of the Limestone, associated in one case again with the Pink Felspathic Rock. A few patches of tough Dark Schist, almost a Moine Gneiss at times (10,548), intervene between the Limestone and the Gneisses. In the next long bend, immediately above Glen Mhairc, the river flows exclusively over the Gneisses, which now lie to the north-west of the last outcrop of the Limestone. Beyond this bend, to the north-west, the Moine Gneisses stretch for many miles in an unbroken sheet.

A peculiar interest attaches to this section, for the curve of the bend penetrates more deeply than usual into the belt of increasing metamorphism; and, comparing the rocks at the centre with those at the two ends, the contrast, both in crystallization and thickness of the bands, is well-marked. Moreover, if the steep bank at the south-eastern extremity of this bend be ascended for a short distance, the decrease in crystallization and the thickness of the bands are still better seen. A similar change may also be noted in the small quarry close to the roadside, just at the commencement of the next bend.

A little farther on, in the river-bank, the Limestone is clearly seen, lying in an eroded hollow in the now-attenuated representative of the Moine Gneisses; while apparently above the Limestone is the Dark Schist, but in reality this is a deception, the meaning of which is explained on p. 431. Still farther up the Tilt, the slow decrease in the crystallization of the gneisses may be noted, as fold after fold of the Limestone is crossed. Accompanying this change is an alteration of the material of which the gneisses were originally composed. It is obviously becoming more of the nature of a sandy mud.

We now reach the famous section of the Glen-Tilt Marble-Quarry, known to geologists since the days of Hutton, Playfair, McCulloch, and Murchison, who noted its resemblance to certain limestones and their associated rocks in the North-Western Highlands.[1] Here the Limestone is folded again and again on itself, so as to form a rather thick mass; next to it comes the little sill of hornblende-schist,

[1] See Quart. Journ. Geol. Soc. vol. xvii (1861) p. 223, second footnote.

seen at Gilbert's Bridge, and many other parts of the section already traversed. This, in turn, is succeeded by the Parallel-Banded material (10,556), now obviously an even-banded alternation of fine sandy and muddy sediment. This rock can be at once identified; it is a phase of the Honestones, a well-known member of the Highland Succession. The Limestone itself is of special interest, not only for its beauty, for which it was once so famous, but also from a peculiarity in its composition. It contains a considerable amount of serpentinized forsterite along certain bands. The rock was cut parallel to these bands, so that, when set up, it gives the deceptive appearance of a thick mass of serpentine. A little farther up the river, the thinness of the parallel-banded Honestones allows the white margin of the Quartzite to come into view, and the two are seen folded together again and again, almost to the end of the sharp bend, where the extraordinarily-straight and deep portion of Glen Tilt commences. In this part of the section it will be noted that the Honestones vary somewhat in composition, being slightly more siliceous at one point than at another. They vary also in thickness, and in one place either thin out entirely or become a mere film, so that the margin of the Limestone is almost, if not quite, in contact with the Quartzite. Just before reaching the sharp bend already mentioned, we suddenly come upon a good-sized exposure of the typical bluish-grey Blair-Atholl Limestone, and it seems at first incredible that this can be the same limestone as the one so often referred to; but in the course of some recent traverses it was clearly proved that they are really one and the same. A little farther up the stream the Limestone is succeeded by the Dark Schist, rich in kyanite, that is so abundant in portions of the Braemar area, and all trace of the Moine Gneisses close to the Limestone has now disappeared.

This long section thus clearly shows that the parallel-banded Moine Gneisses, as they cross the belt of decreasing crystallization, not only become less crystalline, but that they gradually change in composition, passing into the 'Honestones,' which were originally a finer and more muddy type of sediment, slowly thinning away as they do so. Where present in mass, the original thickness is so enormously increased by folding that only one side (that next the Limestone), whether top or base, can be seen. When, however, they have become very thin, the other side also is visible, and the rock that lies next this is the fine white margin of the Quartzite. It is thus clear that the Moine Gneisses lie between this Limestone and the Quartzite, and that they may be regarded as the flaggy margin of the latter. Sections have been made to illustrate the progressive change in the nature of the original material of the Moine Gneisses. The first (10,555) was taken from the small quarry close to the road, above the junction of Glen Mhairc with the Tilt. It is a fine-grained banded rock, built up of alternate layers of quartzose and grey granulitic gneiss, or perhaps schist, for the decreasing crystallization to the south-east already begins to be noted here. The structure of the part of the rock that has been cut is essentially that of a very fine or less crystalline Moine Gneiss, but there is little microcline present, and the biotite is reddish-brown. Another specimen of the more muddy, but still parallel-banded material, was taken from the Tilt close to Marble Lodge (10,556). This is grey throughout, but the darker bands were clearly finer mud originally. These are rich in red biotite and white mica associated with plagioclase, in exactly the same way as in parts of the Dark Schist to be described later. The lighter bands are composed of quartz and decomposed plagioclase, with a little microcline, and possibly some orthoclase. A little biotite, chlorite, and white mica are also present. This rock thus forms a link between the more quartzose, banded material and the curious felspathic and micaceous rock, containing much dark dust, which is so typical of the Black Schist near the Little Limestone.

Returning to the little stream, above Gilbert's Bridge, at the northern end of Dalginross Wood, and examining its bed, we find the change in the nature of the parallel-banded rocks taking place far more rapidly, for we now cross this zone at right angles, instead of diagonally.

The section below Gilbert's Bridge shows phenomena essentially similar to those already recorded. It is, however, far more difficult of access, and the absence of bends, and the fact that the river runs more nearly along the course of the strike, make the progressive change less clear. There are, nevertheless, a few points of special interest. The band nearest the limestone in the Moine Gneisses is often a pure white quartzite, which can be distinguished from the white margin of the Main Quartzite only by the fact that it does not weather rusty-brown. As before, small patches of Dark Schist occur occasionally between the Limestone and the Gneiss, and one of these, 250 yards below the bridge, contains a considerable quantity of kyanite.

At the sharp bend of the Tilt in Crombie Wood (see map, Pl. XXXIII) there is an especially-fine exposure of the Pink Rock, partly in thin pure bands, partly commingled with other material. A little south of Crombie Burn, on the west side of the Tilt, is a small scar, composed of very finely-banded and much less crystalline material, showing that a change takes place below Gilbert's Bridge similar to that already described above it. The stages of the change are not, however, so well seen, and the decrease in crystallization is not so rapid.

## (*c*) The Banvie-Burn Section.

A section somewhat similar to that of Gilbert's Bridge occurs in Banvie Burn, at the Whim Plantation, to the north-north-west of Blair Castle. At the western edge of the wood, close to the burn, the typical Moine Gneisses are exposed in a quarry (already referred to, p. 409), and, descending the stream from this point, we cross the usual parallel-banded rocks, locally more siliceous, until we reach the first outcrop of the Limestone. Between this point and the next bridge, a distance of 250 yards, the Limestone is repeated no less than seven times by folding. As before, no two of these outcrops are exactly alike; but in this case the apparent suddenness of the change is considerably increased, owing to the fact that we now cross the folds at right angles. Certain materials, such as pale hornblende, calcite, granular sphene, etc., are rarely wanting; microcline may be either abundant or absent. The second outcrop, above the lower bridge, is mainly composed of very pale-green hornblende, while that next the small mass of hornblende-schist contains idocrase, garnet, and pyroxene. Below the hornblende-schist the limestone is coarsely mottled green-and-white, the green patches consisting of radial bundles of pale hornblende. The westernmost outcrop is a nearly-white and rather siliceous limestone, identical with that seen in several places below Gilbert's Bridge, and in many other localities; while that part of the Moine Gneiss which is next the Limestone is also highly quartzose.

Again, as in the Gilbert's-Bridge section, small patches of Dark Schist, varying both in thickness and composition, occur locally between the Limestone and the Moine Gneiss. The 'Pink Rock' is also present in one place, commencing as a thin infold at either end of the small mass of hornblende-schist, and thickening towards the centre of the outcrop. Here it seems to merge insensibly into the top of the Moine Gneiss, which just appears, in the bed of the river (10,521).

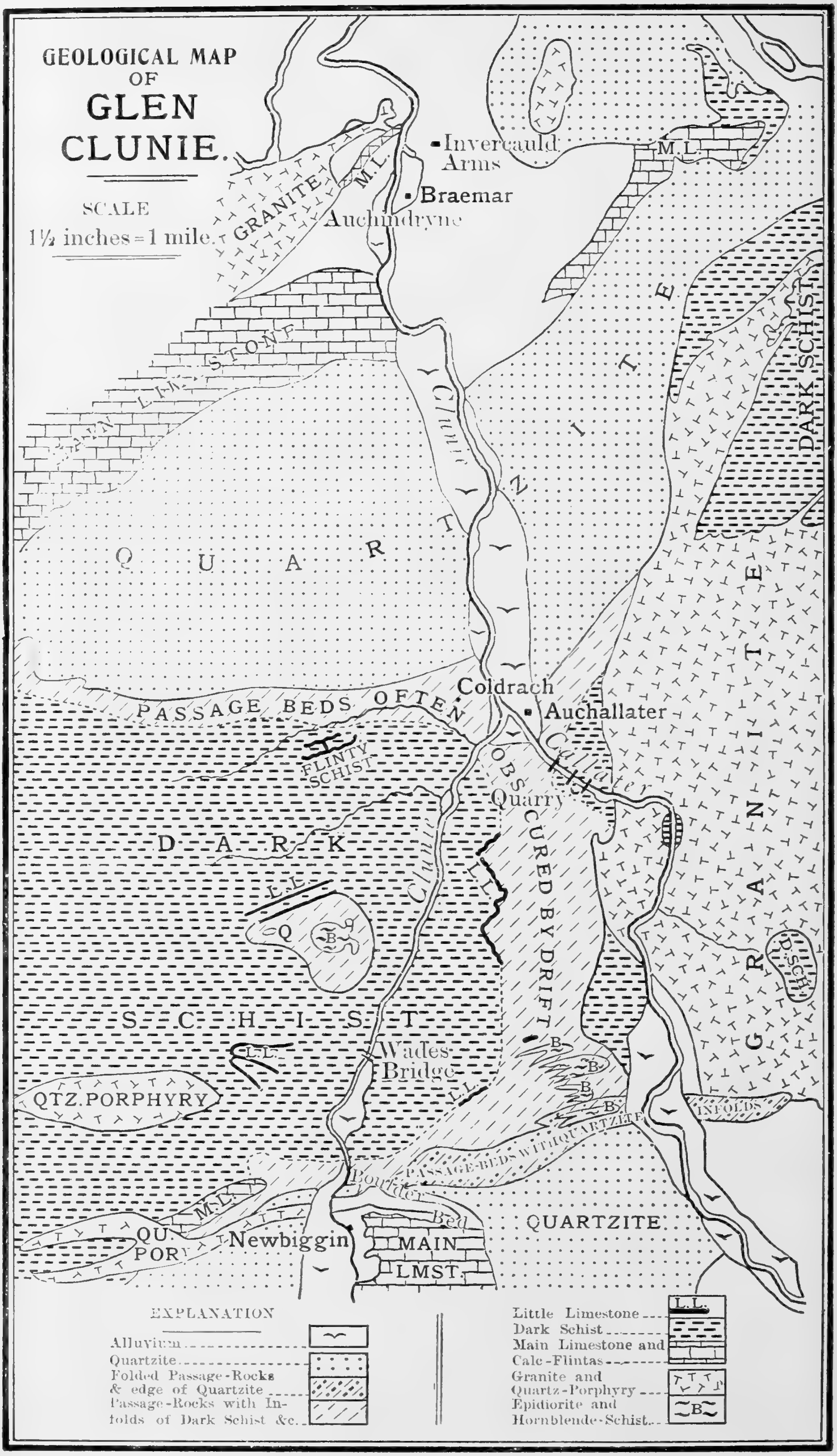
## (*d*) The Hiatus in the Succession.

The rocks associated together in the sections hitherto described are as follows:—

1. The Limestone.
2. The Dark Schist (in lenticles).
3. The Pink Felspathic Rock.
4. The Moine Gneisses; elsewhere the Honestones.
5. The Epidiorite-sill, not always at the same horizon.
6. The white edge of the Quartzite, succeeded by the main bed.

It has already been noted that the Limestone may be in contact with any of the first five bands, and in one place it almost touches the last, if it does not quite do so. There must consequently be a small hiatus or line of erosion at the base of the Limestone. But, in addition to the bands enumerated above, there are others present in certain parts of the Aberdeenshire area, and apparently absent here. It is consequently advisable now to fix exactly the order of succession of the rocks, to ascertain the extent of the hiatus, and see how far it throws any doubt on the fact that we are dealing in the main with a regular succession. As the full sequence is exposed in the area south of Braemar, which lies in the belt of ground under investigation, this succession in the Braemar area may now be conveniently described.

Fig. 4. (See note on p. 423.)



### (*e*) The Succession in the Braemar Area.

The Sequence.—One of the most striking features of the scenery of the East-Central Highlands is the great chain of quartzite-mountains that stretches from Beinn y Ghlo, near Blair Atholl, to Mor Shron, close to Braemar. Parallel to this are minor chains, composed of the same material. While the quartzite is intensely hard, and resists denudation, the rocks associated with it, and in particular a bed of limestone, are much softer, and yield readily to erosion. These beds, in consequence, have weathered away to a great depth, and hence much of the district is characterized by an alternation of high ridges and deep valleys; the trend of which is determined by the strike of the outcrops of the Quartzite. It is with the composition and order of succession of the rocks forming this special type of scenery that we have now to deal. The locality selected for the purpose lies 2 miles south of Braemar; but other parts of the district will be referred to, for the purpose of aiding the investigation.

The succession in this group of rocks, in this area, whether ascending or descending, is as follows:—

1. The Central-Highland Quartzite.
2. The Parallel-Banded Series; Honestones, etc. (passing into Moine Gneisses).
3. The Little Limestone.
4. The Dark or Leaden Schist.
5. The Main Limestone.
6. The altered, parallel-banded Calcareous Shales (Calc-Flintas).

1. The Central-Highland Quartzite.—The Quartzite was originally a bed of sandstone, more felspathic in some parts than others, that has been intensely folded on itself, so as to build up enormous masses of highly-quartzose rock. It is conveniently called a 'quartzite,' because, however much recrystallized, it almost always retains the angular weathering of an ordinary quartzite. Often there is no sign of the mechanical deformation usually met with in the other members of the series; and it is clear that it was altered to a quartzite, not only before the crystallization of the Highland rocks took place, but prior to their crushing. Over almost

---

*Note on the Map, fig. 4, p. 422.*—In this map the sequence is built up. Here, again, the stream and scar-sections are mostly clear, but the flatter ground is greatly obscured by thin peat and Drift; owing to the intense folding, there is often no sharp junction between the different rock-groups. Starting from the margin of the Quartzite, we sometimes see, first the edge of the Quartzite repeatedly folded with the Passage-Beds, then the Passage-Beds folded with the Little Limestone and Dark Schist, and, finally, the Dark Schist only. There is, however, in many cases, a fairly-sharp junction with the Quartzite. The line separating the Passage-rocks from the Dark Schist often implies simply that one rock is the dominant component on one side of the boundary, the other rock on the other. The outcrop of the Little Limestone is so narrow as to be often untraceable. The quartz-porphyry outcrop, shown west and north-west of Newbiggin, also extends to the east of the burn, immediately north of the Main Limestone.

the entire area, the Quartzite varies little in appearance and composition, and can be divided up into three parts, as follows:—

(*a*) The fine white edge of the Quartzite, characterized by its whiteness and its generally-fine grain, and usually containing but little felspar. There is often present, however, a considerable amount of unevenly-distributed pyrites, which, on decomposition, imparts a rusty-brown aspect to this portion of the rock, and this rusty aspect is even more characteristic than the unaltered white colour. It cannot be too clearly understood that this is the only margin of the Quartzite ever met with in the whole of the area under discussion; the reverse side, whether the top or the base, is never seen.

(*b*) The Quartzite, with dark lines of heavy minerals.—This part contains a little more felspar than the last, although still practically white. The fine dark lines in which the heavy minerals occur ndicate the bedding; at times they show that the rock was originally false-bedded.

(*c*) The porous Quartzite.—This portion of the rock, which commences some 6 or 8 feet from the outer margin, must have been coarser originally, and contains more felspar; at times it is markedly felspathic. Owing to the indestructible nature of the quartz, the felspar in an exposed face weathers out completely, leaving a number of small holes in a homogeneous mass of quartz, and imparting to this weathered face its typical porous aspect.

The white edge of the Quartzite can be recognized in almost every clear section, south of Braemar, where the junction with the other members of the series is exposed. In what may be conveniently termed the type-locality, it occurs close to the roadside north of Coldrach. The other parts of the bed may be seen by ascending almost any of the quartzite-mountains in the neighbourhood.

2. The Parallel-Banded Series.—Immediately next the white edge of the Quartzite is a rock composed of a few thin, yellowish, quartzose bands, separated by pale, cross-cleaved, micaceous films: obviously a passage-rock. This is succeeded by greyer material, still in alternating layers of more siliceous[1] and more micaceous composition, the latter again often cross-cleaved. In addition, the face of the micaceous bands is often covered with small spots or projections, proved in many cases to be minute garnets. As we recede from the main Quartzite, the micaceous material darkens in colour, and becomes more like the Dark Schist above; moreover, it exceeds the grey siliceous material in amount.

The section here seen differs from the typical Honestones in the greater proportion of shaly material between the more siliceous bands in the original rock. Moreover, this softer material contains much of the dark dust and clastic chlorite characteristic of the horizon next above. The parallel-banded or passage-rocks are seen in part near Coldrach, and in the low ground between Glen

[1] See Pl. XXXVI, fig. 2 (No. 136).

Clunie and Glen Callater, continuing a short distance up the latter. Two other exposures occur in the neighbourhood: one in the nose and crest of the hill overlooking the junction of the two streams; the other along the crest of the southern face of the corrie behind Coldrach. It is easily seen that these passage-rocks, before they were folded, could not have been more than a few feet thick.

3. The Little Limestone.—The typical form of the Little Limestone, as seen in Glen Callater and Glen Clunie, is a remarkable rock, the origin of which becomes clear only after the bed next to it has been examined. The latter shows conclusively that the Little Limestone was originally an admixture of calcite, very finely-divided clastic chlorite, and marcasite, with possibly a small portion of carbonaceous material. When raised to a high temperature, an unusual combination of elements took place, resulting in the production of a glass-white hornblende (tremolite), in which lime and magnesia are mixed in equal parts, the iron-ore being rejected. The latter being dusted through the rock, which is essentially of massive habit, imparts to it an almost black colour, although the dominant constituent is glass-white. Occasionally yellowish films, mainly composed of epidote and zoisite, occur in it. In some cases there was slightly more lime than was necessary for the formation of the tremolite, and this is now scattered through the rock in small grains of crystallized calcite. The rock often bears a close resemblance to an epidiorite, and has to be carefully examined in order to place its identity beyond dispute. So long as the Dark Schist, to be described next, is of constant composition, the Little Limestone retains this aspect, and has been recognized as far away as the neighbourhood of Ben Vrackie, near Pitlochry; but, if the Dark Schist changes in composition, the Little Limestone changes too. The rock is met with in Glen Callater at the first small rapid above the bridge, though another and more interesting outcrop occurs at the sharp bend farther up, a little beyond the quarry, in the flaggy hornfels. The total number of outcrops in this neighbourhood is almost incredible, and shows conclusively the intense and complicated folding of the rocks.

4. The Dark Schist, with the 'twinned-chlorite-rock' and the 'felspar-rock.'—In a type-area, such as that south of Auchallater, where the Dark Schist attains its full development, it is characterized by the presence of an excessive amount of magnesian silicates, due to the existence in the original rock of an extraordinary quantity of finely-divided clastic chlorite. This material attained its maximum in the film of rock next the Little Limestone (the Twin-Chlorite Rock), and this is now seen in the form of abundant twinned crystals of chlorite. From this zone upwards, the clastic chloritic material steadily diminishes, on the whole, attaining its minimum close to the Main Limestone, where the most characteristic aluminous silicate is kyanite, or more rarely andalusite, containining no magnesia. As we descend,

staurolite appears, and twin-chlorite and other magnesian silicates steadily increase in amount. Where the metamorphism is more intense, the same phenomenon is shown by the greater abundance of cordierite in the lower part of this bed, while andalusite is more abundant in the upper.

Another characteristic of the zone a little above the Twin-Chlorite Rock, is the presence in large quantity of a felspar proved by Dr. Teall to be of the oligoclase-andesine group, containing curving lines of dark dust (the 'Felspar-Rock'). It occurs, to a small extent, through most of the bed, but appears to be abundant only towards the lower part. Its distribution seems to be the same as that of the tremolite-rock; the two, so to speak, go together, and have been recognized as far away as the neighbourhood of Druid Farm, north-west of Ben Vrackie (10,777). The dark dust that occurs in this felspar is met with throughout the whole of the Dark Schist in the Braemar area, but as a rule is most abundant about the Twin-Chlorite Rock. Here, a small portion of it is undoubtedly graphite, though, in most cases, very little of this material is of that nature. The dark dust seen under the microscope is often in part leucoxene, but by far the greater portion of it is iron-ore; its real origin was suggested by Mr. A. Dick's examination into the cause of the blue colour of unweathered London Clay. This proved to be the presence of a large number of minute spheroids of marcasite, and there can be little doubt that the dark dust of these rocks had a similar origin. The iron-ore in these rocks is slightly magnetic, and, if a specimen be ground to very fine powder, the greater part of the rock can be picked up with a magnet, owing to the even dissemination of the iron-ore throughout it.

5. The Main Limestone.—The typical Main, or Blair-Atholl Limestone, is well seen at the southern end of the corrie opposite Newbiggin in Glen Clunie, where it possesses the characteristic pale bluish-grey colour and crystalline aspect. The Clunie area shows well the tendency of the rock to become more impure as it approaches the belt along which the Moine Gneisses set in; or where there is a hiatus in the succession, and parts of the beds are missing. As a rule, however, only the basal portion is markedly impure, and as (in many cases) it is this part repeated by folding that is really seen, it gives the erroneous impression that the whole bed is impure.

6. The Calc-Flintas, or Parallel-Banded Calcareous Shales.—This bed consists of thin laminæ alternately richer and poorer in lime. The peculiarity from which it takes its name, is its more or less persistent flinty aspect, due to the presence of a variable number of bands composed of quartz, biotite, calcite, pyrites, and leucoxene. These originally contained much quartz and clastic chlorite in a fine state of subdivision, which, when heated, form a kind of hornfels at a specially-low temperature and this hornfels is so intensely hard, that it resisted shearing

movements anterior to the main crystallization of the Highland rocks.[1] Associated with the flinty bands are much paler, almost white, layers. The dominant constituents of these are white pyroxene and calcite. Other pale bands rich in epidote occur. All these phases may be found in the Calc-Flintas associated with the Main Limestone at the corrie opposite Newbiggin. They also show another feature of the rock: here and there special bands occur, differing in type from the normal. At this locality, a few bands have an almost micaceous aspect, owing to the presence of a great number of small parallel crystals, determined by Dr. Flett to be pale hornblende. The proportion of the more flinty material is small here, but the parallel banding is well shown. A very small infold of the pyroxene-bands is associated with the limestone in the bed of the Clunie at the southern end of Auchyndrine (Braemar).

## (*f*) Further Evidence of the Succession.

It has already been shown that the Quartzite is succeeded by the Parallel-Banded Rocks; the best locality for ascertaining the nature and succession of the zones above the latter occurs in Glen Callater, at the bend of the stream above the quarry in the flaggy hornfels, above the bridge at Auchallater. At this bend, when the water is low, we see first the Little Limestone (tremolite-rock, 8091); next this comes the Twin-Chlorite Rock (8092) of a characteristic dead-black, due to the presence of graphite; while next this again come the various portions of the Felspar-Rock (8094, etc.), often known as the Felspar-Hornfels[2] of Glen Callater. At the southern edge of the quarry (see map, fig. 4, p. 422), in the flaggy hornfels, we see again the Felspar-Rock, with its glistening crystals of felspar rendered dark by the presence of the dark dust, which serves to fix the horizon of the rocks within the quarry. These are characterized by a flaggy habit, the splitting-faces being coated with bronzy mica and, at times, with small spots. The different bands vary in colour and compactness. The darkest have a somewhat flinty cross-fracture, and contain a great quantity of fresh andalusite showing the typical pink pleochroism. Except on the splitting-face the amount of biotite present is small, but there is a considerable quantity of shimmer-aggregate material replacing some alumina-silicate. Quartz is subordinate in amount, and a small quantity of felspar is present. The typical dark dust is abundant, and the structure of the rock is essentially that of a hornfels. A band, in which the flinty cross-

[1] The hornfels-like aspect of this rock, traceable over half the breadth of Scotland, is due to the fact that, after induration, it usually escaped crushing owing to the plasticity of limestone at a high temperature (as proved by the experiments of Prof. Adams & Dr. Nicolson). The limestone next the flintas gave way readily and relieved the latter from the crushing stresses. Many other rocks must have been similarly indurated, but possessing no such yielding margin they have been since crushed.

[2] See § IV, p. 442, at the end of which the bearing of this rock on the absence of metamorphism due to the neighbouring mass of granite is discussed.

fracture is not so marked, contains less andalusite but far more shimmer-aggregate material. The most micaceous part of the rock, with numerous spots on the splitting surface, shows marked parallel structure under the microscope, and is composed of abundant pale biotite associated with quartz, a little felspar, and some andalusite. The elongated micas sweep round small patches in which no parallel structure is seen, and these are probably eyes of material that have been indurated anterior to the main crystallization of the mass, and have thus escaped crushing.

Now, the rock so rich in andalusite is seen again close to the Main Limestone, both at the head of the corrie about a mile to the north-north-east of Auchallater, and 2 miles to the south-south-west, in the corrie opposite Newbiggin. It is thus clear that there is not much more rock present in the whole of the Black Schist than the few bands above described, and it cannot have been much more than 15 feet thick originally. This will be understood by following up Glen-Callater Burn as far as the ford; there, except the granite, nothing is seen but the Felspar-Rock and the closely-adjacent material, repeated incessantly by folding. A difficulty arises from the different phases of metamorphism; for, when the material was considerably heated anterior to the main metamorphism and indurated so as to escape subsequent crushing, it is found, in this area, finally to crystallize as an andalusite-hornfels; but generally, if much crushed, it finally assumes the form of a kyanite-schist. In both cases, it will be noted that it is a non-magnesian silicate that is so abundantly developed in the highest band. In some cases, the andalusite appears as a number of minute laths that in their mode of occurrence simulate kyanite, and in other localities are replaced by kyanite. This gradual diminution in the amount of clastic chlorite present in the original shales has been noted over a wide area, and suggests continuous deposition or an unbroken sequence from the Little Limestone to the rock rich in kyanite or andalusite next the Main Limestone.

For the purpose of building up the sequence the most valuable evidence, however, is obtained from the association of the Main Limestone with the Calc-Flintas, or altered, parallel-banded, calcareous shales. The accumulated experience of years of detailed mapping makes it certain that in these two rocks we have a record of continuous deposition, or a portion of an original and unbroken sequence: no other bed in the series can intervene between them, and in any account of the succession they must always be taken together. Again, experience has shown that, with very rare exceptions, the calcareous shales always overlie or succeed the main bed of Limestone. Now these Calc-Flintas occur in most of the broader valleys over a very large area, especially where the beds between the Quartzite and the Main Limestone are wholly missing. It must be remembered that in the former case it is not merely the original thickness of the beds that is missing, but the great mass of rock built up by their intense folding; a large gap is consequently left to be filled up by the folded higher beds. This happens along almost the whole length of the south-eastern side of the Ben-y-Ghloe Mountains, which rise from comparatively low ground to a height of more than 3600 feet above sea-level. The gap to be filled up is exceptionally large, and in consequence the largest known outcrop of the Calc-Flintas occurs here, and we see in addition a small number of thin infolds of the altered dark shale originally above the Calc-Flintas. But over the whole of the rest of the country, the rock on the reverse side of the flintas to the Main Limestone is never seen; and the flintas must in all other cases be either the highest or lowest rocks in this part of the South-Eastern Highlands, and the evidence is conclusive that they are the highest.

This view, that there is a descending succession from the Main Limestone to the Quartzite, is greatly strengthened by the frequency with which a hiatus occurs at the margin of the Main Limestone, a good example of which is shown on the map (fig. 4, p. 422) in the corrie opposite Newbiggin. Sometimes the whole of the Dark Schist and the Little Limestone are missing, sometimes portions only; but as the investigation proceeds, it will be seen that the line of erosion at the base of the Main Limestone is not by itself sufficient to explain all the phenomena met with.

### (*g*) Meaning of the Patches of Dark Schist and Proof that the Sequence is incomplete in the Glen-Tilt Area.

The meaning of the patches of Dark Schist in the Gilbert's-Bridge and Banvie-Burn sections can now be investigated.[1] Below Gilbert's Bridge, close to Crombie Burn, one of these patches intervening between the limestone and the Moine Gneiss is a kyanite-garnet-staurolite-schist, obviously well above the bottom of the dark shale, but almost certainly a little below the top. There are several other small patches below Gilbert's Bridge, and these appear to be approximately at the same horizon. Nearer Gilbert's Bridge a film of tough schist occurs between the Limestone and the Pink Felspathic Rock. This (10,549) is a highly-micaceous rock, built up of alternating films of quartzose and micaceous material; the latter consist largely of white mica and chlorite, often enveloping large cracked and decomposed garnets. Iron-ore is abundant, both in good-sized grains and as fine dust, and it is often embedded in a clear, almost glassy material, which is known to be plagioclase although it here shows no striation. There can be little doubt that this is a siliceous modification of the Felspar-Rock, and it illustrates a difficulty that occurs repeatedly. As the area is approached where the more sandy material, now forming the Moine Gneisses, was deposited, the Dark Schist tends to become slightly more siliceous, and differs slightly in appearance from the rocks of the type-area. If the siliceous material increases beyond a certain point, the zone can, of course, be no longer identified. So far as is

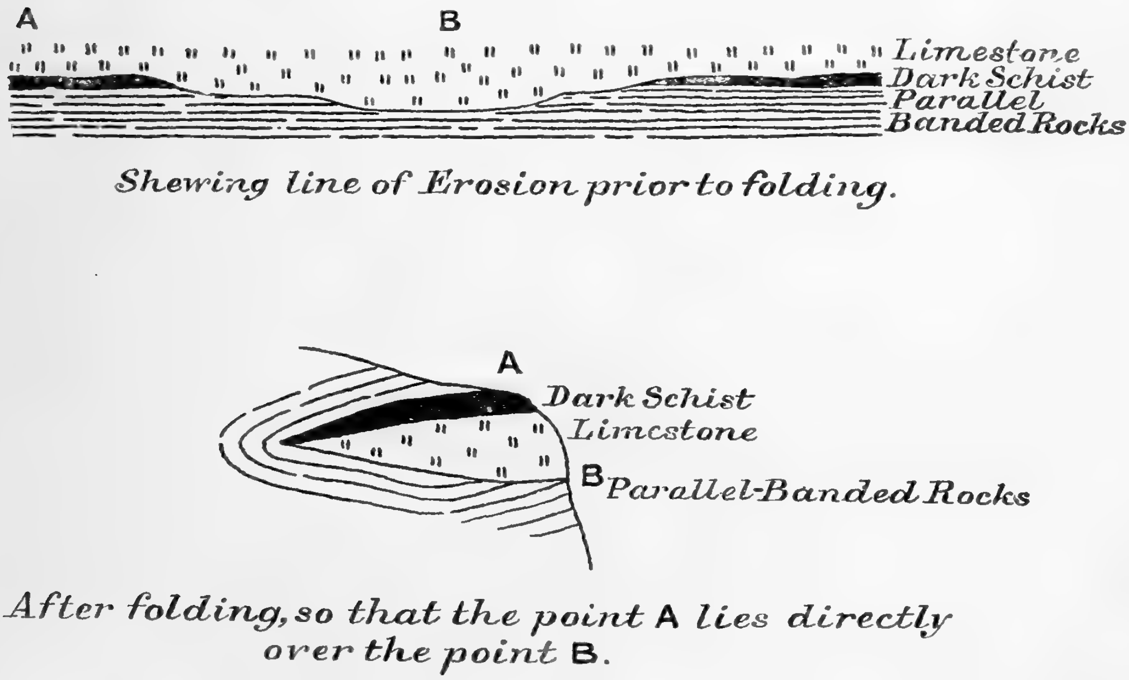
[1] See Map, Pl. XXXIII.

Fig. 5.—*Line of erosion in fine Moine Gneisses at the base of the Main Limestone: Glen Tilt, below Marble Lodge. (The spot is denoted by an asterisk * on the map, Pl. XXXIII.)*

known at present, this increase is more marked in the lower part of the Schist than in the upper.

Of all these patches of Dark Schist, the most interesting is that which lies apparently on the top of the Limestone in the river-bank at the first bend below Marble Lodge. (See fig. 5, p. 430.) Here the Limestone is shown resting in an eroded hollow of the attenuated Parallel-Banded Rocks into which the Moine Gneisses have slowly passed, while lying a p p a r e n t l y above the Limestone is the patch of Dark Schist now mentioned. It is a dark, somewhat massive rock, evidently rich in biotite, but containing a number of very minute lenticular films of quartz, suggesting that, as we approach an area of more sandy deposition, the Dark Schist

Fig. 6.—*Diagram showing the Dark Schist and Parallel-Banded Rocks apparently on opposite sides of the Limestone, while in reality they are on the same side.*




has become more quartzose (10,421). The rock contains much granulitic quartz, which represents the minute lenticles referred to, and a great quantity of more or less aggregated crystals of red biotite; the typical felspar with much dark dust, like the Glen-Callater hornfels, is abundant, and there is one crystal of andalusite. It is clearly a slightly-siliceous phase of the upper part of the Felspar-Rock. The occurrence of the Felspar-Rock above a thin band of Limestone, with the Parallel-Banded Rocks below it, seems, at first, conclusive evidence that the limestone must be the Little Limestone. In reality it is an ideal example of the kind of deception so often produced by folding of a slightly-vague succession in the Central Highlands. If we consider carefully the meaning of the sporadic occurrence of lenticular patches of Dark Schist below Gilbert's Bridge, it becomes obvious that the folding may so involve one of these patches, as to make it appear that it is on the opposite side of the Limestone to the Parallel-Banded Rocks, while, in reality, it is on the same side. The foregoing diagram (fig. 6, p. 431) shows clearly both the deceptive structure and its explanation.

Similar patches of dark schist occur in Glen Banvie, and of these the most interesting lies next the small mass of hornblende-schist 100 yards above the lower bridge, in the Whim Plantation. It consists of two parts: one very dark, with a dead-black film, and a fine grey siliceous schist or granulite. Three microscope-slides were made of the dark portion (10,551–10,553), and these show that part of the rock contains much dark dust, rich red biotite, while epidote and zoisite are abundant along certain lines in an adjacent portion. Another is tougher and darker, intensely chloritic, containing decomposed garnets and a little andalusite; a third is composed of felted white mica and pale chlorite. The dead-blackness of part of this rock, along with the occurrence of epidote and zoisite along certain lines, suggest that we may have here a representative, though very thin, of the Little Limestone; for the Little Limestone will be shown later to pass into an epidote-zoisite rock, containing much dark dust, before its outcrop is finally lost. It is the only known occurrence of this dead-black material within a short distance of the actual Moine Gneisses. The rock next it is very fine in grain, and composed of white and dark mica arranged parallel in a fine granular matrix of quartz and felspar. It can be very closely matched from the Honestones and, by its texture, shows how rapidly the rocks become finer in grain as we cross the belt of decreasing crystallization.

The examination of these patches of schist clearly shows that they belong to different horizons; not only is there a hiatus at the base of the Main Limestone, but there is also liable to be one at the top of the Moine Gneisses, or the Parallel-Banded Rocks into which they pass. It seems as though, in an area where the originally-coarser material of the Moine Gneisses was deposited, the currents were strong enough, either to prevent the deposition of the fine mud, or to wash it away after it was deposited. Owing to the shifting nature of the currents, patches of the fine mud were, however, left, and these lie at different horizons. The finest material of all was probably that which formed the Little Limestone and the Twin-Chlorite Rock, and this is the portion of the sequence that is most persistently missing. But, as already stated, the total thickness of the Dark Schist was quite small, and the hiatus is of no great consequence. In connection with it, however, we note a remarkable fact: it is succeeded by a limestone, very impure and very variable in composition. Now, at the top of the Upper Lias in East Yorkshire a similar sifting-away of the fine mud took place, followed by the deposition of a very impure and very variable limestone, now altered to ironstone, the Dogger or base of the Lower Oolites. Proceeding in one direction, the succession beneath this impure limestone becomes complete at Blea Wyke, on the coast south of Robin Hood's Bay. Proceeding in the opposite direction—inland—

the sifting-away occasionally takes a stronger form, and large holes were dug in the soft dark mud, one of which occurs at Bilsdale (nearly 100 feet deep), the other near Rosedale Abbey; in both cases, the eroded hollow was filled up with impure limestone.

No further evidence, bearing on this investigation, is met with till the northern end of the long straight portion of the Tilt Valley is reached. Here, just above the junction with the An Lochan, a section occurs closely resembling that at the sharp bend in the Tilt at Crombie Wood, below Gilbert's Bridge: the Pink Felspathic material being again present. Ascending the river-bed from this point, when the stream is low, the Honestones can be seen to pass gradually into fine Moine Gneisses. This part of the river is somewhat obscured by numerous small protrusions from the Glen-Tilt complex; but the passage can be well seen a little above Pool Tarf, along the bed of the Tilt, and in the first small stream south of the Tarf. Here, the passage of the Honestones into the Moine Gneisses is practically unbroken. This is due to the lucky accident that only the less markedly-siliceous part of the Honestones is present; a single infold of the more markedly-siliceous portion would have broken the continuity of a gradual change.

On looking at the map, the reason why this gradual change can be traced becomes at once obvious. As in the Gilbert's-Bridge section, the Tilt once more makes a large bow. As before, one end of the bow lies at one side of the belt of decreasing alteration, the other almost at the opposite side; it does not quite do so, and this is why, in addition, the small burn has to be ascended in order to see the full change.

### (*h*) The Falar Area.

Considerable light is thrown on the present investigation by the clear, continuous sections in the deep gorges that characterize the Falar portion of the Tilt drainage-area. The most convenient starting-point lies at the junction of a little burn with Glen Mohr, immediately north of Glen Bheag. In the lower part of the little burn, the small sill of hornblende-schist and part of the Dark Schist are exposed, repeated several times by folding. In the bed of the main stream below, is an excellent section of the Honestones with the Little Limestone next them, and beyond this a high bank composed of the Dark Schist. The locality was often visited in former years by farmers and shepherds, who came from considerable distances to procure a certain portion of the parallel-banded material to be used as honestones, and it is to this fact that the beds owe their distinctive name. These Honestones are characterized by their even colour-banding, and are composed of a number of alternating softer and harder layers, most of which contain a considerable amount of biotite, arranged parallel to the banding or bedding. The portion of the rock nearest the Little Limestone is, on the whole, the softest; and it at first contained most clastic chlorite. This often occurred in little felted films, obviously identical originally with the felted biotite-films in the Moine Gneisses, and along which the rock readily splits. Close to the Quartzite, a few far more siliceous pink and white bands occur, and in these muscovite is more abundant and there is less biotite. The intermediate portion is a thinly-banded, fine-grained, brown or grey rock, obviously containing a great deal of fine brown mica. This is the dominant constituent of the group, and in a typical example (9797) the more siliceous bands are composed of a singularly-even admixture of quartz-grains and minute flakes of biotite, with, possibly, some water-clear felspar; the structure is essentially that of a fine biotite-granulite. The more micaceous portion contains far less quartz or felspar, and is largely composed of finely-felted brown mica, with which some larger crystals of muscovite are associated, set athwart the foliation as in a spangled gneiss. These micaceous films are peculiarly interesting, for they have been met with over a large area, among others, on the north-west side of Ben Vuroch.[1]

The Little Limestone, though still containing the typical dark dust, differs from the tremolite-rock in the fact that the bulk of the hornblende is now actinolite. A still more important difference occurs in the schist forming the steep bank above the stream. It is lighter in colour than the typical Dark Schist, and a series of sections shows that it originally contained far less clastic chlorite and fine dark dust; still, the maximum amount of chlorite occurs in the portion of the bed next the Little Limestone (9794, 9792, 9795, 9790). It is thus seen that, although we have here the full sequence of the beds about the Little Limestone, each band differs slightly in composition from the type-rocks of the section about Auchallater. It places the true position of the Honestones, however, beyond dispute, and is especially important because it will be seen immediately that this is, so to speak, the most siliceous phase in which the Honestones are ever known to occur in this area accompanied by the full sequence. So soon as they become markedly more siliceous, the Little Limestone and part of the Dark Schist appear to be almost always missing in the area here described.

This fact can be seen at once by ascending Glen Mohr. A little above the junction with Glen Bheag, the stream flows along the strike of the rocks. In the bank on one side we have the repeatedly-folded margin of the Limestone, on the other the white edge of the Quartzite: the bed of the stream being formed by the Honestones, now somewhat more siliceous, but still unmistakable. In quite a short distance, the Honestones pass into a small group of quartzite-bands, with a patch in the centre in which the honestone-character is still traceable. Of these quartzite-bands, the one nearest the limestone is quite white and almost indistinguishable from the margin of the Quartzite; the other bands are pink and grey. When the ground was first examined, the limestone was taken for the Little Limestone; for it appears to be very thin, has a bright pink colour, and is exactly in the position where the Little Limestone should be. The recent traverses, however, make it more probable

[1] See explanation of the Geological Survey 1-inch map, Sheet 55 (Scotland).

that it is the base of the Main Limestone, which has here undergone one of the startling changes in appearance so often noted; for quite close by, and over much of the Falar area, the Main Limestone has the appearance of the normal rock of Blair Atholl.

This change of the Honestones into a series of quartzite-bands of variable colour is highly important for two reasons. In the first place, it is obvious that these are the bands that, repeated incessantly by folding, form the Moine Gneisses along the Sluggan Road in Invercauld Forest, already described (see p. 413); the highest white band, in particular, is especially important, for it forms the top of the Moine Gneisses below Gilbert's Bridge and in many other localities. The second point is that a change in composition, similar to that along the main line where the Moine Gneisses begin, is now taking place in a south-easterly instead of a north-westerly direction; in other words, the change in composition of the rocks, due to powerful current-actions accompanied by the deposition of more siliceous material, is repeated to the south-east. The survey of the whole area has shown that this tendency to revert to more sandy conditions of deposition occurs again and again south-east of the Moine Gneiss area and, though carried to a far smaller extent, it is almost invariably accompanied by the silting-away or non-deposition of the finer clastic material.

Below the type-section in Glen Mohr, the Honestones are often exposed in the bed and sides of the gorge. A little above Falar Burn they have an almost flinty aspect, and are characterized by even banding, recalling a very fine phase of the Moine Gneiss (11,125). Structurally, the rock is a very fine quartz-biotite-granulite, but its most striking feature is the arrangement of the crystals of brown mica. Though rigidly parallel, they are oblique to the bedding, which is clearly seen under the microscope. Just at the mouth of Falar Burn there is a distinct increase in the amount of originally-softer material present, and a type-specimen (9453) could be matched from the mouth of Glen Callater. Near the foot of Glen Mohr the whole of this softer material has disappeared, and now only a thin film of the more quartzose pink-and-grey material separates the Main Limestone from the Quartzite. It is obvious that there is a slight line of erosion at the base of the Limestone, showing that it must be above the Quartzite. The pink-and-grey material (9406) is singularly like a portion of the Moine Gneiss, except that it is finer in grain; and the resemblance is equally marked in a microscopic section.

### (*i*) The Aberdeenshire Area.

Turning now to the Aberdeenshire area, and following these finer Parallel-Banded Rocks in a direction parallel to that along which the coarser Moine Gneisses have been traced, an interesting outcrop occurs about half a mile up Allt-na-Bronn, to the east of the Bynack. Here the quartzite is succeeded by a thin series, composed of alternations of yellow or grey quartzose laminæ and films of dark material, the whole bearing an unusual resemblance to unaltered sediments (8522, 8523, & 8524). The grey siliceous laminæ closely resemble the typical Honestones from Glen Mohr, but as a whole they are intermediate in composition between these and the parallel-banded rocks at Glen Callater; indeed, 8524 can be exactly matched at Glen Callater. Similar material occurs in several instances in this neighbourhood next the Quartzite, and at the head of Glen Chonnie it is succeeded by the Little Limestone (8549). The latter shows well the change that takes place as the Parallel-Banded Rocks become more siliceous or the dark partings become thinner. In place of being built up mainly of white hornblende, the Limestone is now composed of aggregated patches or crystals of this mineral set in a matrix of calcite, biotite, quartz, and iron-ores. The fine dark dust is present in smaller quantity. In this part of the district the Limestone always loses its typical aspect as the border of the Moine Gneisses is approached, and in one case resembles a film rich in epidote noted in the Banvie Burn (8551, 8552).

The Parallel-Banded material just described is obviously the equivalent of the more micaceous portion of the Honestones. In the next burn to the north (Allt Unich), the more siliceous pink-and-grey material next the Quartzite is more persistently exposed. Starting where the two branches of the burn join, the Quartzite and the marginal rocks (Honestones) are well shown, the latter being clearly the same as No. 9406 from the foot of Glen Mohr. These rocks were obviously part of one bed of sandstone originally, and they now fold together as one rock, and are quite inseparable. Farther down the stream they not only become more crystalline, but the pink-and-grey portion rapidly thickens. The burn is obscured by Drift for a short distance, but fortunately the rocks can be followed in the bank to the south-west; and, returning to the burn once more, just before the fault is reached we find the coloured bands now so highly crystalline that a specimen (8518) taken from a little scar at the burn-side is a typical pink-edged epidotic gneiss, practically identical with No. 8519 taken 7 miles away from the heart of the Moine-Gneiss area, and close to the margin of the Cairngorm Granite. It will be noted that, in this little scar, the low dip of the Moine Gneiss and its accompanying structures are met with. To the north-east of this point, towards Braemar and well up the hill-side, it is evident that the Quartzite is also involved in the movements that produced the Moine-Gneiss structure; and this is placed beyond dispute by the distinctive pink-and-grey colour of the marginal rock. From this burn, then, almost to Braemar, a large portion of the Moine Gneisses are really the Quartzite, in what may be conveniently called a 'Moine-phase.'

At the northern foot of Morone, rather more than 2 miles south-west of Braemar, the Limestone and Parallel-Banded Rocks are exposed in the face of a small scar. In this, the margin of the Limestone is repeatedly folded on itself, and has almost the typical low dip characteristic of the Moine Gneisses in this area. Close to, or in contact with it, is the more micaceous portion of the Honestones, which are here thicker and so markedly crystalline that it is questionable whether they are to be called Honestones or Moine Gneisses. They contain much biotite, and the characteristic original films of chloritic material now largely altered to biotite. These obviously represent the softer, or more micaceous portion of the typical Honestones that are farthest from the margin of the Quartzite. The portion closer to the Quartzite forms the lower hill above the road and is a highly-quartzose, more or less banded gneiss. The flat ground at the foot of the scar between the two types of rock is unfortunately obscured by Drift, and their relation to one another is not at first clear. Briefly put, the doubtful Honestones, or softer bands, are a little way within the belt of increasing crystallization, but not sufficiently far to give them a decisive character; the more quartzose gneisses farther down the hill are well within the belt, and their character is unmistakable.

At this locality, the Pink Felspathic material of the Gilbert's-Bridge area is again intimately associated with the Limestone and, to a smaller extent, with the adjacent rocks; the most important constituent of this pink material is again microcline. Further, the softer rocks close to the Limestone are identical with the more crystalline portions of the Honestones below Pool Tarf in the Tilt, where, as previously stated, the further passage to Moine Gneiss is practically unbroken.

We may conclude this account of the mode of ending-off of the Moine Gneisses with a brief description of three sections, in all of which the horizon of the Parallel-Banded material can be fixed just before it becomes too thin to be shown on a map.

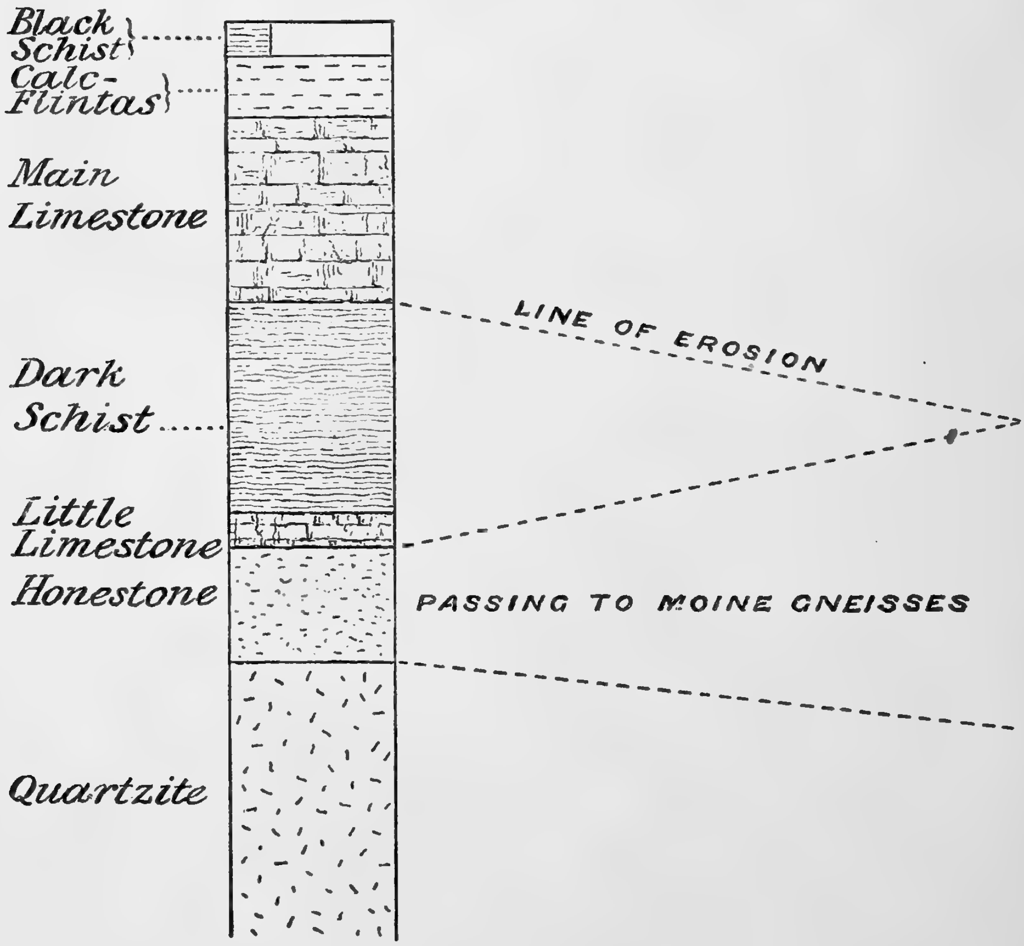
The first occurs about the hill of Creag-na-Dala Bige, in the Invercauld Forest, overlooking the head of the Cairn. To the west of this hill the Moine Gneisses cover a considerable area, although this is largely composed of a single folded band, characterized by pink edges and containing much epidote, already referred to. The gneiss is succeeded to the east by a considerable mass of well-foliated Dark Schist, here highly crystalline and containing some sillimanite, and so much cordierite as to show that it was highly chloritic originally, and is the lower part of the bed (8435). A few small infolds of the Main Limestone occur within this Dark Schist. On the opposite or eastern side of the Dark Schist, the Moine Gneisses are represented by a small thickness of faintly-banded quartzose rock, quite inseparable from the main Quartzite seen a little farther down the hill.

The second occurs on the hill above Balloch, about a mile and a half east-north-east of Invercauld House, and has been already referred to (p. 414). The thin, faintly-banded, highly-quartzose representative of the Moine Gneisses is here succeeded directly by the Main Limestone (9825); and there is clearly a slightly-larger hiatus than at the locality just mentioned. A little farther west, the Parallel-

Banded material is seen in the scars to have thinned away, and to be no longer separable on a map. In this direction the Dark Schist slowly thickens, until in a few places the full sequence may be seen.

The third section occurs about 3 miles to the south-east of Balmoral, on the ridge north-west of Girnoch Burn. Here the Main Limestone (9828) is often separated from the Quartzite by quite a thin parting of dark siliceous schist, which locally thickens to a flinty Parallel-Banded rock (9816), resembling the specimen 11,125 of the Honestones from Glen Mohr. It is, however, still more like a flinty biotite-schist that occurs repeatedly in the corrie behind Coldrach in Glen Clunie, but is there in contact with the Little Limestone. The extent of the hiatus at the Girnoch ridge is thus clearly defined; the whole of the Dark Schist and the Little Limestone is missing, and this is exactly the hiatus with which we started, at Gilbert's Bridge, 30 miles away.

Fig. 7.—*Diagram showing the true succession of the rocks described.*




From the evidence adduced, it will be seen that along a line more than 30 miles long the Moine Gneisses, when traced to the south-east, tend both to thin away and to pass into a material which was originally of a more muddy nature. Along a considerable portion of this line, the change is accompanied by a rapid decrease in crystallization; and this materially increases the difficulty of ascertaining the mode of ending-off of the recognizable gneisses. When an area of more sandy deposition is approached, there is always a tendency for a hiatus to occur in the sequence, the Little Limestone and part of the Dark Schist being almost always missing. Moreover, the Dark Schist itself tends to become more siliceous and to contain less dark dust. A similar change undoubtedly occurs in the Little Limestone before it disappears; but the bed is so thin that it is often difficult to find, and its exact mode of ending-off has not been satisfactorily determined. The hiatus is most frequently noticed at the base of the Main Limestone, which is clearly above the Dark Schist and the Moine Gneisses. But the missing beds were originally of no great thickness, and are only those that lie between the base of the Limestone and the Parallel-Banded rocks, except where the latter were originally composed of comparatively-fine mud. Over the whole belt of ground examined, more than 30 miles long, this hiatus never exceeds these limits, clearly showing that it cannot be claimed as an important stratigraphical break in the sequence of which the Moine Gneisses form a part. Where no hiatus at all occurs, the Parallel-Banded rocks are succeeded by the Little Limestone; and the true stratigraphical position of the Moine Gneisses is thus defined, as lying between the Little Limestone and the white edge of the Quartzite, of which, indeed, they are simply the flaggy top. The succession in the group of rocks described and their mutual relations are briefly expressed in the appended diagram (fig. 7, p. 438).

### (*k*) Horizon of the Gneisses north-west of the Belt along which they thin away.

When well across the line of thinning-away, the upper limit of these gneisses can often be fixed; and a few type-localities may be selected for this purpose. One of the best lies about Derry Lodge, where both the Limestone and the Dark Schist are present. Close to the Derry Falls the Moine Gneisses are succeeded by a small portion of the Dark Schist; but this is so much more quartzose, and contains so little dark dust, that it is practically impossible to fix its exact horizon (10,882), although the occurrence of the Main Limestone next to it shows that this must be a representative of part of the Dark Schist. A small quantity of the typical felspar is present; and the rock possesses the flaser-structure so characteristic of the Highland metamorphism. Some distance to the south-east of Derry Lodge, a rather similar section occurs; but here the Limestone is associated with the Pink Felspathic material once more (8274).

Even when no limestone is present, the upper limit of the gneisses can be approximately fixed by the presence of identifiable portions of the Dark Schist. Two good illustrations of this occur in the Tarf Valley. On the south side of the stream the infold is too large to leave any doubt as to its horizon; but on the north side the infolds, which occur at the south-western foot of Sron na Macranach, are so small that they can be identified only by the aid of microscopic sections. One of these (11,137) is substantially identical with another (11,136), taken from the south-west of the Glen-Tilt complex, and lying between the Limestone and the Quartzite. Both lie well across the belt of increasing crystallization, and both contain a small quantity of sillimanite

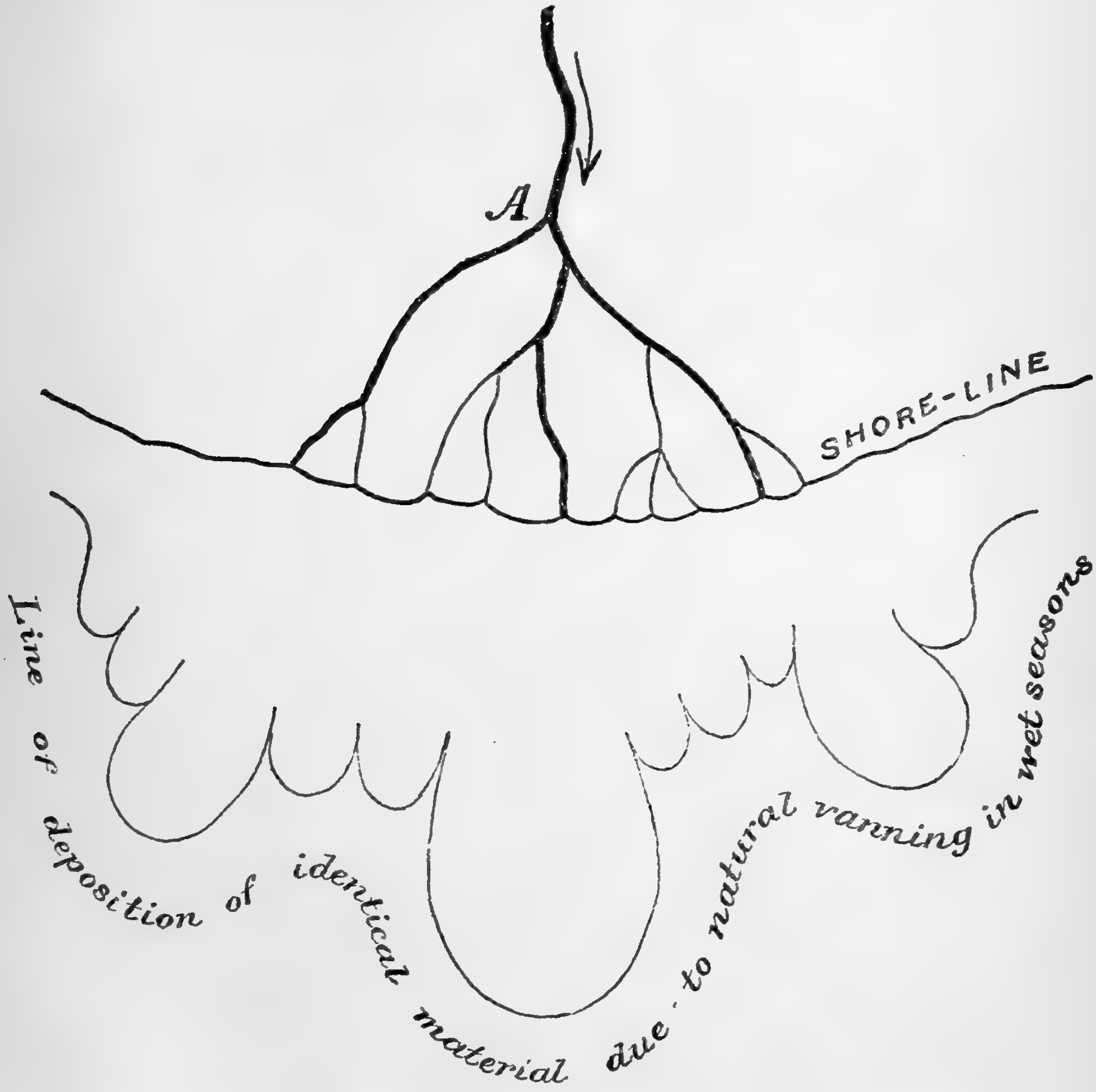
The evidence thus shows that here and there small patches or infolds of Dark Schist and of the Main Limestone may be found within the main area of the Moine Gneisses; but, as previously explained, there is now a tendency for the Dark Schist to become more siliceous and to contain less dark dust, so that it is difficult to identify. But, by first studying the more siliceous phases where the Main Limestone is present to fix their position, such as those seen at Derry Lodge, the true horizon and meaning of these infolds become clear.

Attention has already been drawn to the fact that a great deal of the most highly-quartzose Moine Gneiss is simply the Central-Highland Quartzite in a Moine-phase; and if this, as well as the infolds just referred to, be deducted from the areas in which the Parallel-Banded rocks occur, it is soon seen that the true Moine Gneisses need have had no great thickness originally. The evidence of the incessant recurrence of some easily-recognized small band in a typical area strongly supports this idea.

### (*l*) Slight Reversions to Similar Conditions of Deposition.

Attention was drawn to the fact that in Glen Mohr a change in composition in the Honestones takes place in a south-easterly direction, on similar lines to that seen in a north-westerly, as the main area of Moine Gneiss is approached. But the change is more local, and not carried to the same extent. In Glen Ey, also, the Honestones become locally more siliceous and, moreover, are occasionally mingled with the Pink Felspathic material, evenly disseminated through them. Similar small local changes occur in other areas; and an excellent example occurs in Glen Loch, in the upper part of Glen Firnate, in Perthshire. Here, on the margin of the Quartzite, a thin band of material occurs (3838, 3839), practically identical with that seen in the less-altered rocks of the Unich section (Pl. XXXVII, fig. 2, No. 150). These small reversions are of considerable importance, as they afford the key to the phenomena of the distribution of the Parallel-Banded material. This distribution has resulted from the natural vanning of the detrital material brought down by a large river with many mouths, of widely-different sizes, but all tapping a common source at A (see fig. 8, p. 441). There must be a series of points in front of these streams, at which clastic material of a definite texture and composition will be deposited, provided local currents do not intervene. By joining up these points, we obtain the line shown in the diagram. In this investigation the line

Fig. 8.—*Diagram to illustrate the mode of arrangement of the areas in which the typical flaggy Moine Gneisses now occur, and also the origin of the film-partings, now rich in felted biotite, to which the flaggy aspect of the gneisses is essentially due.*




[For convenience of illustration, it is assumed that the distribution of the detritus brought down is not interfered with by other local currents. This interference would, of course, occur, and has doubtless added to the difficulty encountered in unravelling the meaning of the distribution of the Moine Gneisses.]

may be taken as defining the fans of the more sandy material from which the Moine Gneisses have been formed. The typical areas are the larger fans; the instances of slight reversion to similar conditions of deposition lie within the smaller ones. In addition, the origin of the fine films of chloritic material now becomes clear. While the coarser material is deposited within these fans in wet periods, in dry the line of deposition of finer material would penetrate far within the fans (or towards the shore-line), and thus the coarser material within them would be separated by these films at more or less regular intervals. The origin of the flaggy aspect of the typical colour-banded gneisses is thus accounted for. In this investigation we have been dealing with the phenomena along the margin of one of the larger fans; but the identity of the Moine Gneisses over large areas makes it clear that there must be several larger fans.

Briefly, then, the Moine Gneisses are simply the flaggy top of the Central-Highland Quartzite: this flaggy top is restricted to certain larger fans of deposition. As we approach the margin of each fan, the flaggy material becomes of a more muddy nature originally; and while the typical parallel banding is retained, it becomes very much finer and the whole bed thinner. It is to the fact that this change in original composition has not been hitherto quite fully grasped, that the difficulty in accounting for the disappearance of the gneisses is essentially due.

## IV. Appendix.

A peculiar interest attaches to the easily-identified phases of the Felspar-Rock of Glen Callater, as by means of them it can be proved that the great masses of newer granite, shown on a geological map of this area, have rarely produced any serious effect on the already-metamorphosed Highland rocks. The following series of slides (as well as a number of others) was cut so as to put this fact beyond dispute, as well as to identify the zone in the Dark Schist.

10,777. Quarter of a mile north of Druid Farm, above Killiecrankie, and north-west of Ben Vrackie. Perth; 1-inch-sheet 55.

9454. Near the head of the Tilt, north of Falar. Perth; Sheet 64.

8548. Near the head of Glen Choinnich, one of the branches of the Ey Burn. A branch of the Dee above Braemar. Aberdeen; Sheet 64.

10,778. Glen Ey, below Aucherrie. Aberdeen; Sheet 65.

3455. Glen Callater, just outside the Lochnagar Granite. South of Braemar. Aberdeen; Sheet 65.

7975. A small patch of Dark Schist, completely enveloped in the Lochnagar Granite. Close to the last.

The Lochnagar Granite is 10 miles in diameter, yet this inclusion of the Felspar-Rock does not appreciably differ from any of the others. The first specimen was taken 25 miles from this inclusion, and there is no newer granite anywhere near it. Thus it is evident that the great mass of the Lochnagar intrusion has produced practically no effect on the already-altered Highland rocks. All these specimens have been taken from the south side of the great belt of increasing metamorphism.

On the north side of the belt similar phenomena are observed. Here the original chloritic material is absorbed in the formation of cordierite, but if the right portion of the Dark Schist be selected, the felspar with the dark dust is still seen to be present. A good illustration of the failure of the newer intrusions to affect the Highland metamorphism is afforded by the two specimens (11,137 and 11,136) selected to fix the upper limit of the Moine Gneiss. The first is a small infold on the north side of the Tarf, and a considerable distance from any granite. The second was taken near the margin of the Glen-Tilt diorite, and forming really part of its thin roof. The metamorphism of the two is substantially identical; indeed, it is not easy to obtain two rocks, so far apart, which have so nearly the same composition, and show so exactly the same metamorphism.

The published Geological Survey-Maps of Scotland (sheets 66 & 67) equally show that the course of the great 'sillimanite-aureole' is entirely unaffected by the Kincardineshire granite, for the aureole meets the margin of the intrusion at right angles on its eastern side.

## Explanation of Maps and Section.

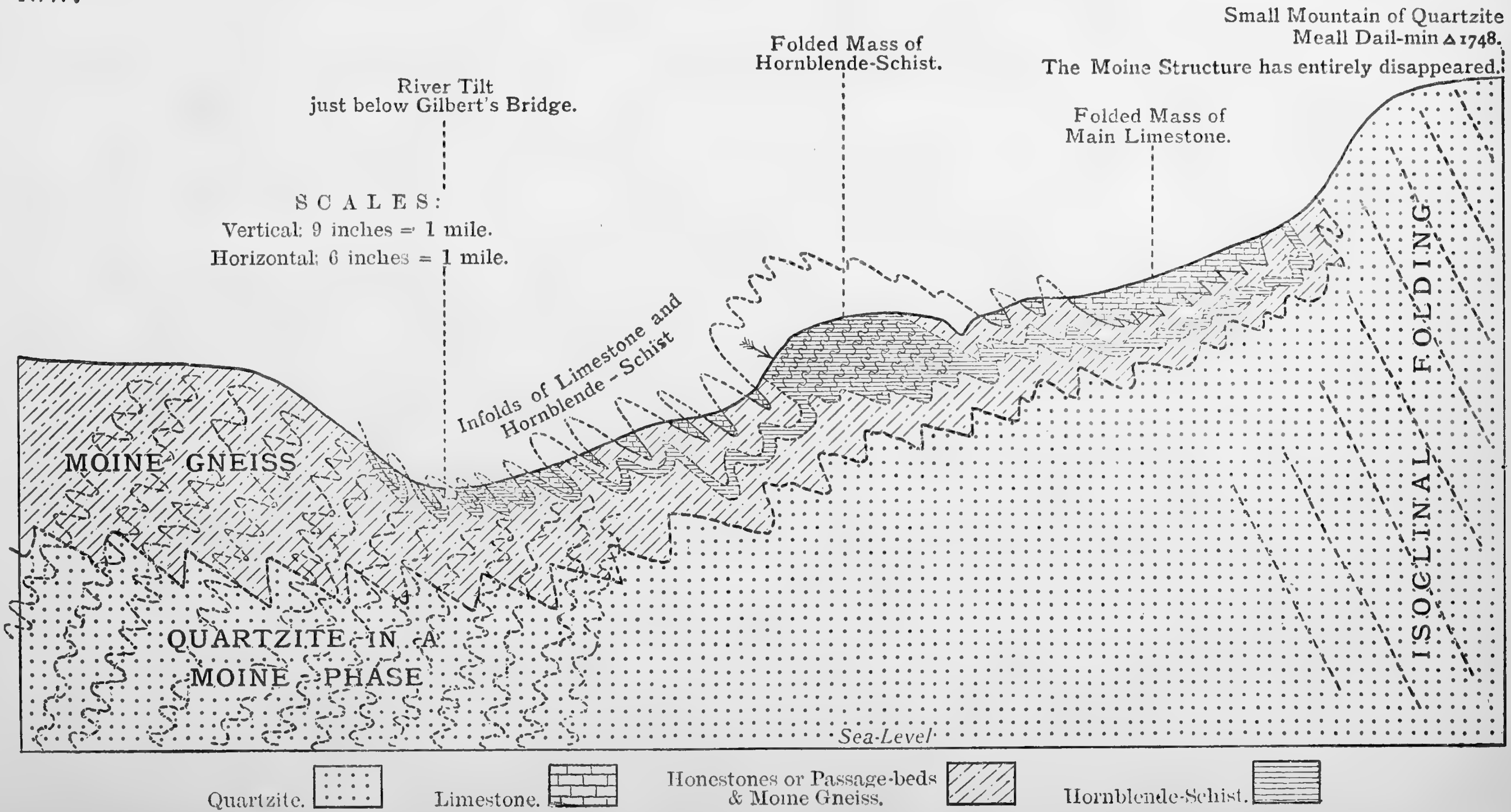
In order to understand the meaning of the maps and section that accompany this paper, it is necessary to realize that the outcrops here shown of such a rock as the Central-Highland Quartzite are not the outcrops of an ordinary bed. They are really the outcrop of a great sheet formed by the repeated folding of a bed on itself, after the manner of the bellows of a concertina when shut up (concertina-structure).

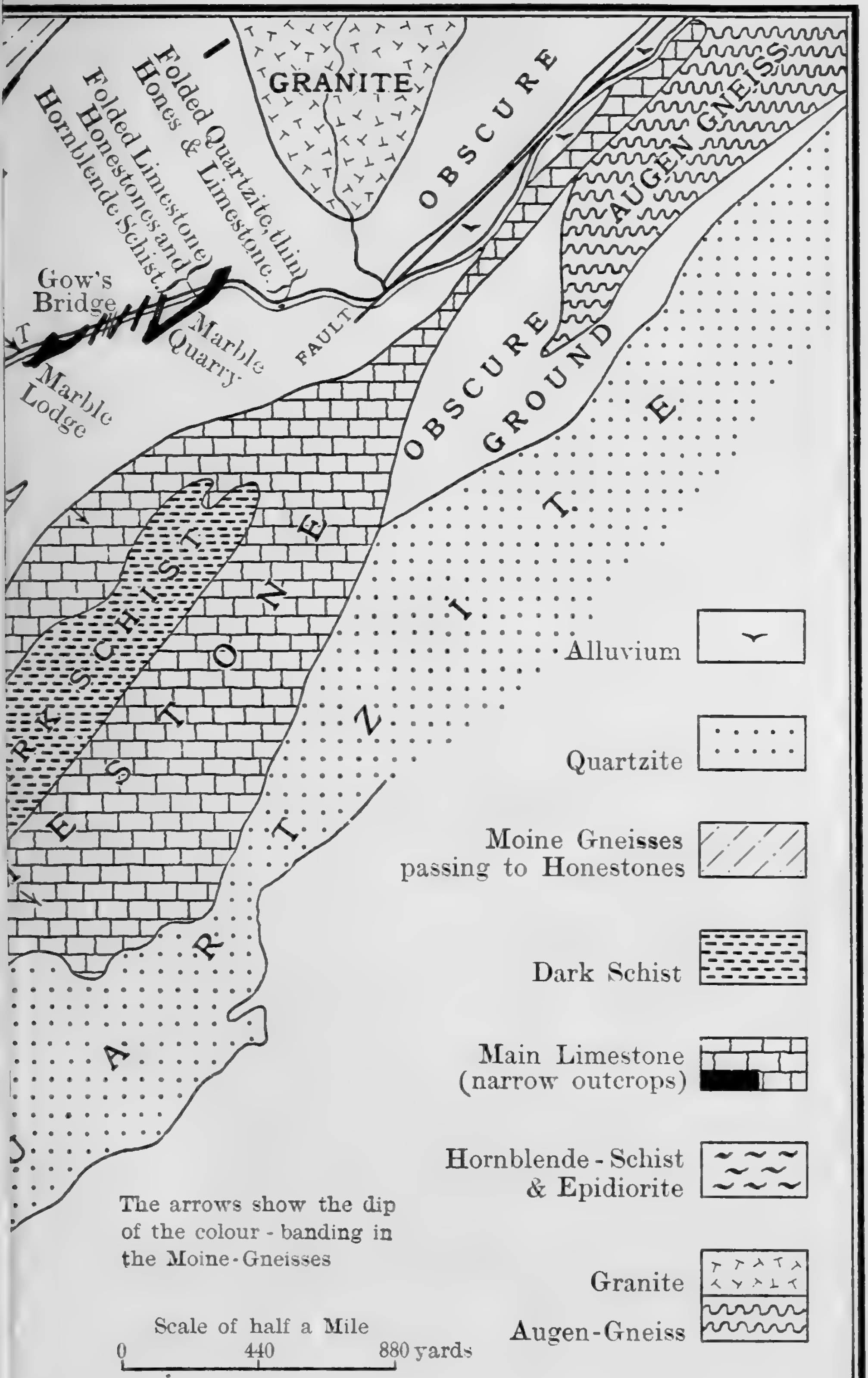
This concertina-structure was produced by the first and greatest folding of the Highland rocks, and to it is due the erroneous idea that the latter were of great thickness originally. A section drawn across the country, after this folding was completed, would closely resemble that drawn through a comparatively-undisturbed area, except that the original beds have to be replaced by these horizontal sheets. The structure has been considerably blurred, in many cases by later movements; but over large portions of the typical 'Moine-Gneiss areas,' this sheet-structure must be still retained, for these gneisses cover an area of several thousand square miles, and must obviously, when viewed on a large scale, be still roughly a horizontal sheet. To the south-east of Glen Tilt these sheets have lost this horizontality, and been thrown into anticlines and synclines that give rise to the ridge-and-valley scenery referred to in the section on the 'Succession in the Braemar Area' (p. 423).

This type of folding, however, attains its full development only in the harder bands, which must, moreover, have a certain thickness before its development is possible. A perfect illustration of these principles is afforded by the little sill of hornblende-schist shown in the section across Glen Tilt (fig. 9, p. 444), the thickness of which has to be greatly exaggerated to enable it to be shown. But in one place, owing to a sudden increase in its original thickness, it was able to fold on itself, and form a homogeneous mass $1\frac{1}{2}$ miles long, and 300 yards broad at the observed outcrop, having a

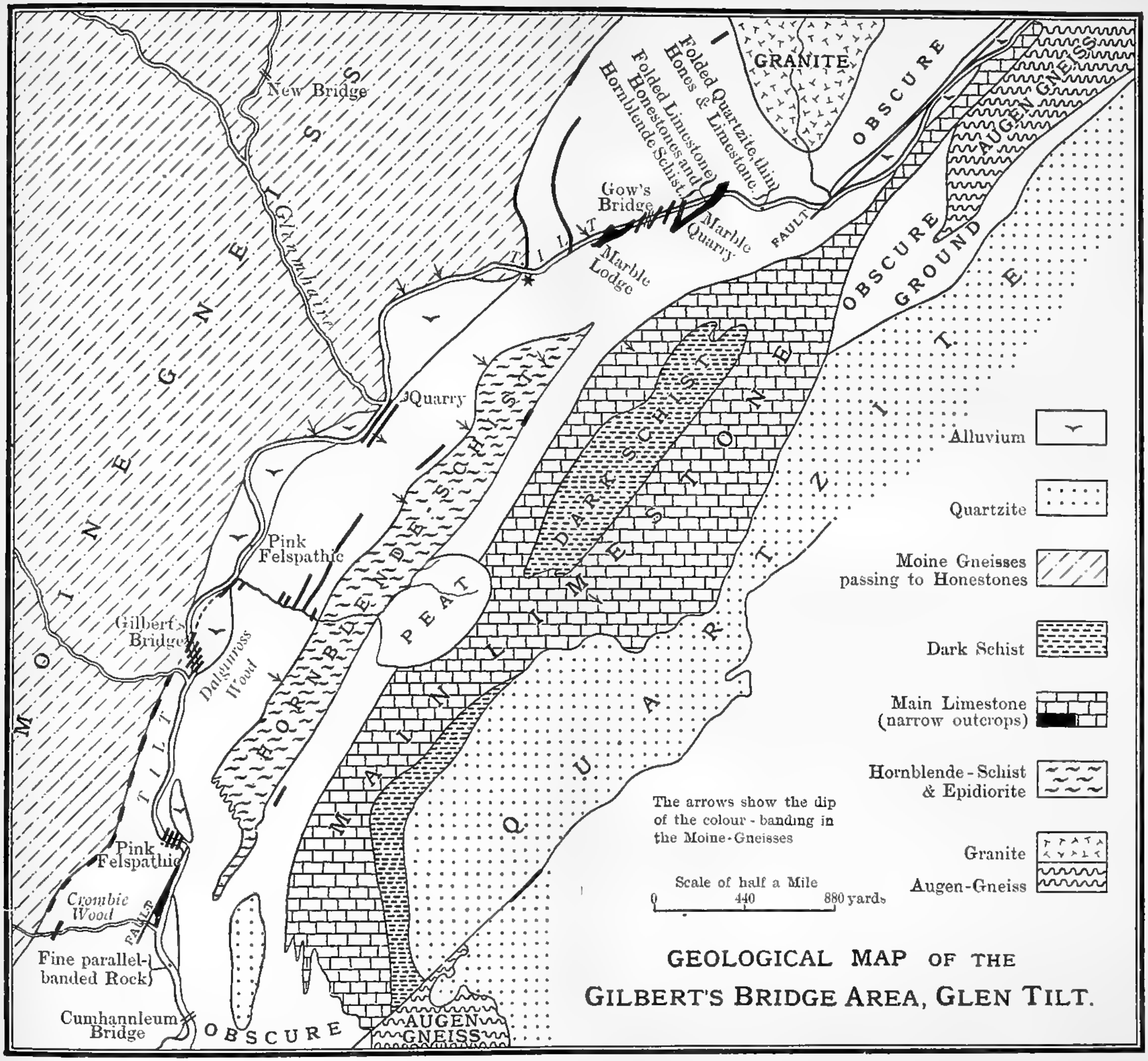
Fig. 9.

SECTION ACROSS GLEN TILT, passing close to Gilbert's Bridge.






GEOLOGICAL MAP OF THE GILBERT'S BRIDGE AREA, GLEN TILT.




GEOLOGICAL MAP OF THE GILBERT'S BRIDGE AREA, GLEN TILT.

thickness of at least 100 feet. Over a very large area, however, this little sill rarely exceeds 3 feet in original thickness, and it must often have been less, while its outcrop can in many cases be crossed in a single stride. It is, of course, still repeated by folding, but now it and the associated beds fold together as one little group, or 'entity in the folding,' together building up a sheet, and thus at each complete fold of the group both the top and the base of the little sill are exposed in the outcrops.

Now, just as this sill, owing to its original hardness, folds on itself, and forms a homogeneous sheet when it thickens, so the Honestones on the margin of the Quartzite form a similar but larger sheet when they not only thicken to the north-west but were composed of harder material originally. Here, however, the change is no longer local, but is maintained over a very large area.

## Later Structures.

In a typical quartzite-mountain the original isoclinal folding is left, and this structure only is shown on the south-east side of Glen Tilt; but as the line along which the Moine Gneisses set on is approached a remarkable buckling structure is set up in the rocks, conveniently known as 'Moine-structure,' shown on the left of the section. It is obviously impossible to say exactly where this structure ends off underground.

Considerable light is again thrown on these points by the little sill where folded on itself. Some little distance north-east of the line of section there is a scar of hornblende-schist, and in this the stages in the formation of the mass can be made out as follows:—

I. The sill was folded on itself to form a large mass free from infolds of the other material (concertina-structure).

II. A fine buckling-structure, reproducing in miniature that of the Moine Gneiss, has been superinduced on the older folding. Specimens showing this can be easily found.

III. A powerful strain-cleavage was set up in the mass, and the cleavage-planes intersect the convex faces of the minute buckles that face the south-east. They never cut those that face the north-west: an important fact, as showing that the crushing movements came from the south-east. This cleavage imparts to the rocks, at first sight, the aspect of a well-bedded mass, with a steady south-easterly dip of some 10° to 20°; but a careful inspection of the scar-face already referred to soon shows how complex the structure and history of the rock-mass really is. Thus study of this sill throws great light on the history of the Moine Gneisses, which cover so large an area to the north-west.

## EXPLANATION OF PLATES XXXIII–XXXVII.

### Plate XXXIII.

Map of the Gilbert's-Bridge area, Glen Tilt. In this the principal small outcrops of the Main Limestone are shown about the bed of the Tilt. On the hillside above is a large mass of the same limestone, in a much purer phase, greatly folded. Numerous infolds of Dark Schist occur in this, but they cannot be traced on the ground. A belt of ground to the south-east of the main mass of the Moine Gneisses, within which the passage from Moine Gneiss to Honestone occurs, is left blank. The limit of the main mass of the Moine Gneisses is obtained by joining up the westernmost outcrops of the Main Limestone, which occur as small infolds. The area is typical of the whole district; while the stream-sections are unusually clear, the flanks of the valley are greatly obscured by downwash and patches of Drift, and the boundaries between the different outcrops are often uncertain.

## Plate XXXIV.

[For the microphotographs from which this and the following three plates are reproduced, I am greatly indebted to Mr. Hall, of the Geological Survey.]

Fig. 1 (88). First cutting above Struan Railway-station, Garry area. Moine Gneiss with typical granulite-structure. (See p. 406.)

2 (86). Bed of the Garry below Dalnacardoch Lodge. Much microcline; also showing quartz-bleb structure. (See p. 408.)

## Plate XXXV.

Fig. 1 (99). Gaick Forest. Inverness. Epidotic gneiss. (See p. 410.)

2 (107). Cairn Fidhleir. Tarf Area. The round-weathering oligoclase-gneiss. (See p. 411.)

## Plate XXXVI.

Fig. 1 (84). Bed of the Garry, opposite Dalnacardoch Lodge. Abundant microcline, containing minute quartz-blebs. Green mica and a little plagioclase. (See p. 408.)

2 (136). The Passage-Rocks at Auchallater, Glen Clunie, Braemar. Showing the fine biotite-granulite, always present in the Honestones or Passage-Rocks, and often their dominant constituent. (See p. 424.)

## Plate XXXVII.

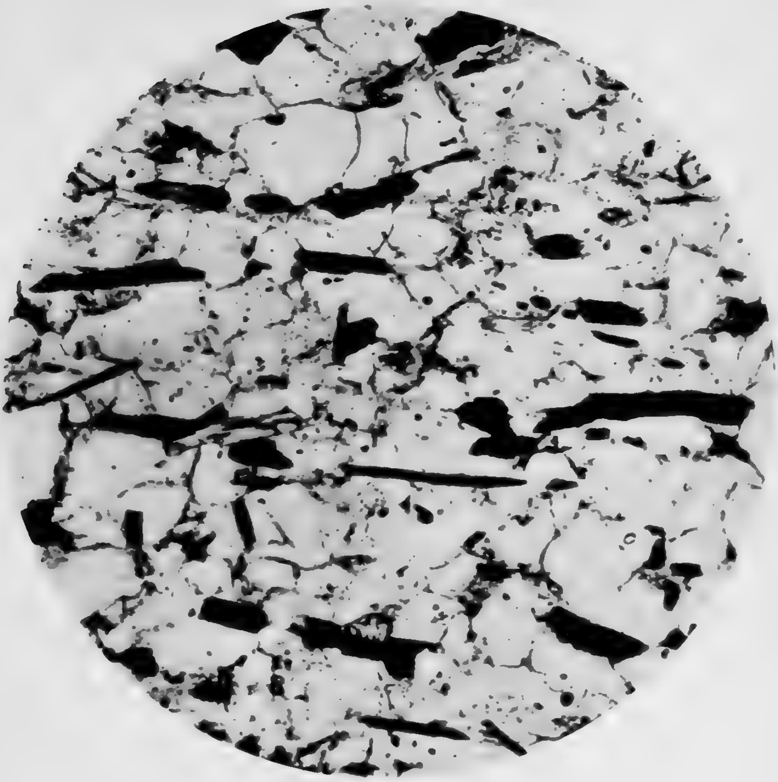
Fig. 1 (113). Just above the road on the west side of Braemar. Highly-quartzose Moine Gneiss, with lines of heavy minerals (see p. 424). This is part, probably, of the Quartzite in a 'Moine-phase.' But it is difficult to say, at this locality, where one rock begins and the other ends: they were obviously all part of the same bed originally.

2 (150) Sron-Dias Crags, upper part of Glen Firnate, south-east of Beinn y Ghlo. An illustration of a slight reversion to conditions of deposition similar to those south-east of the main area of the Moine Gneiss, the rock on the margin of the Quartzite having the composition and structure of a fine Moine Gneiss. (See p. 440.)

## Discussion.

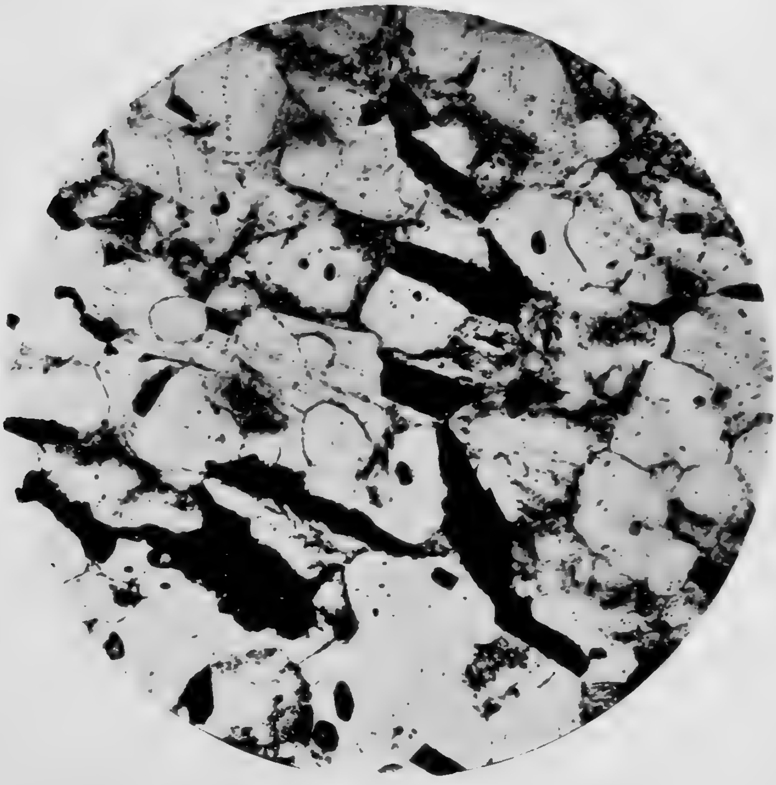
Dr. Horne said that he was glad to have the opportunity of taking part in the discussion, because he had recently visited the sections between Blair Atholl and Braemar under the guidance of the Author, and had the privilege of reading his manuscript now submitted to the Society. He wished to express his high appreciation of the detailed mapping done by the Author, and of his prolonged study of the petrographical characters of the rocks of that region.

Fig. 1. × 32.



No. 88.

Fig. 2. × 32.

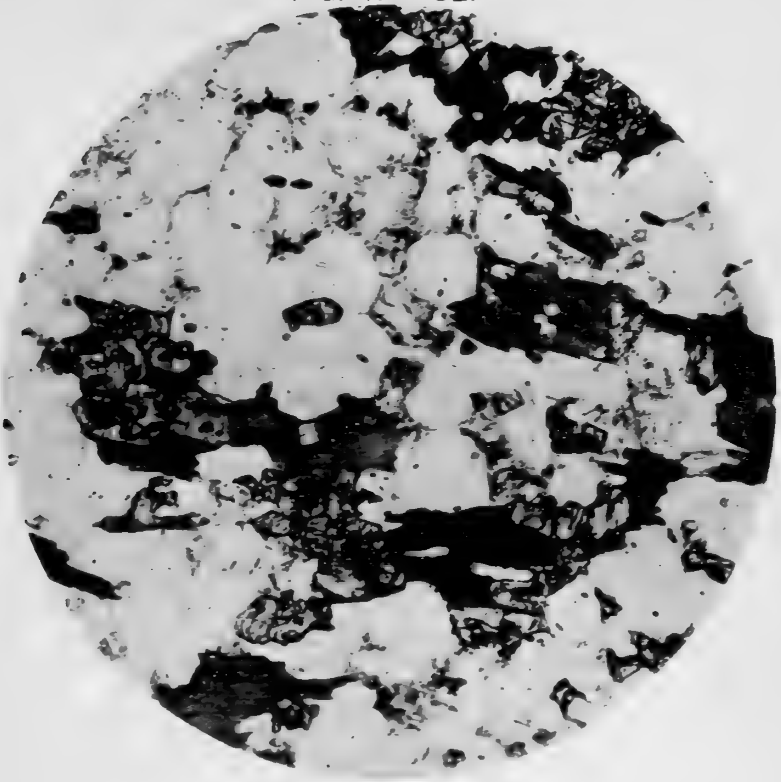


No. 86.

G. B. Photomicro.

Bemrose, Collo.

Fig. 1. × 32.



No. 99.

Fig. 2. × 32.

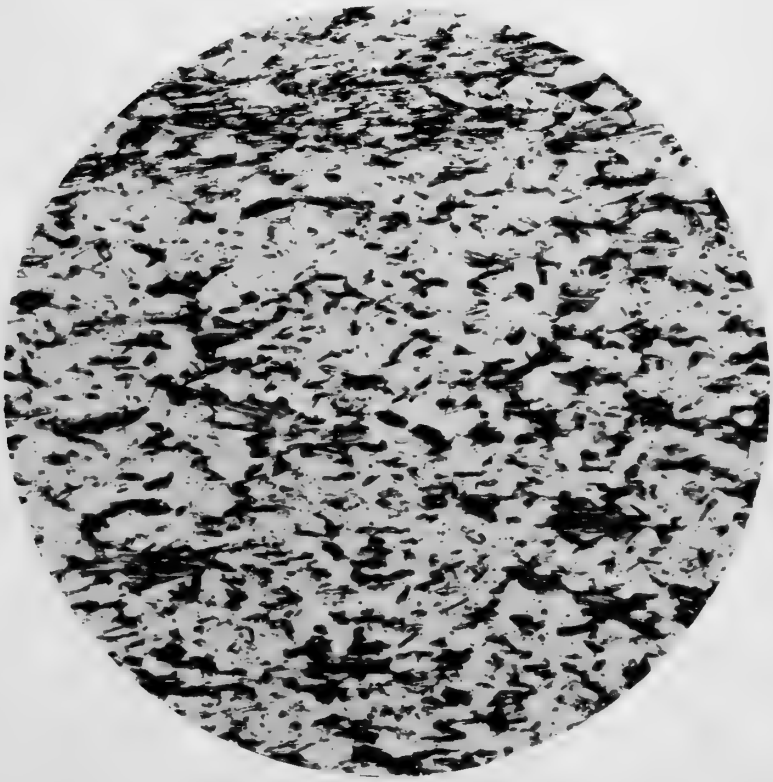
No. 107.

*G. B. Photomicro.* *Bemrose, Collo.*

Fig. 1. × 32.

No. 84.

Fig. 2. × 32

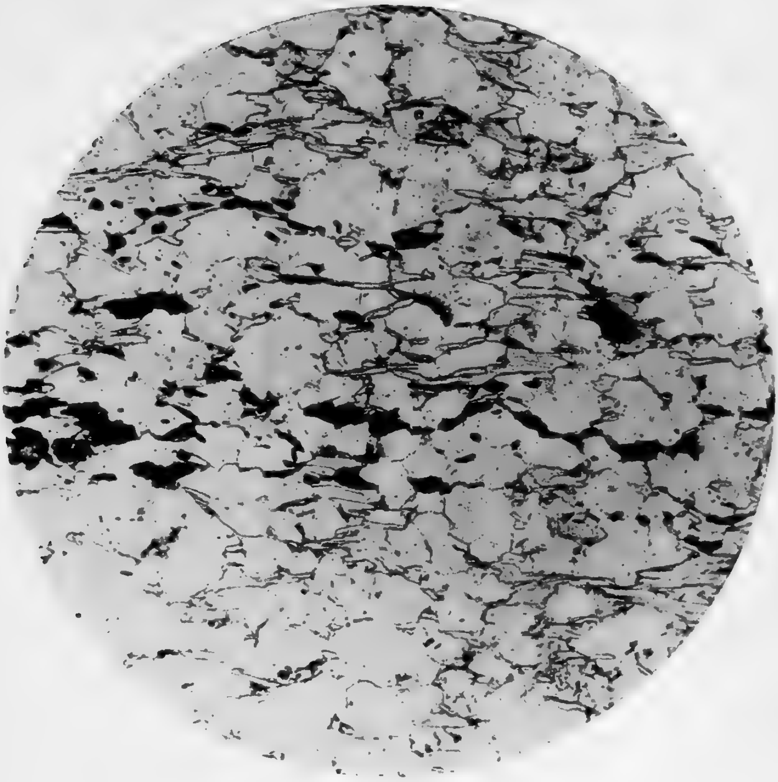


No. 136.

G. B. Photomicro.

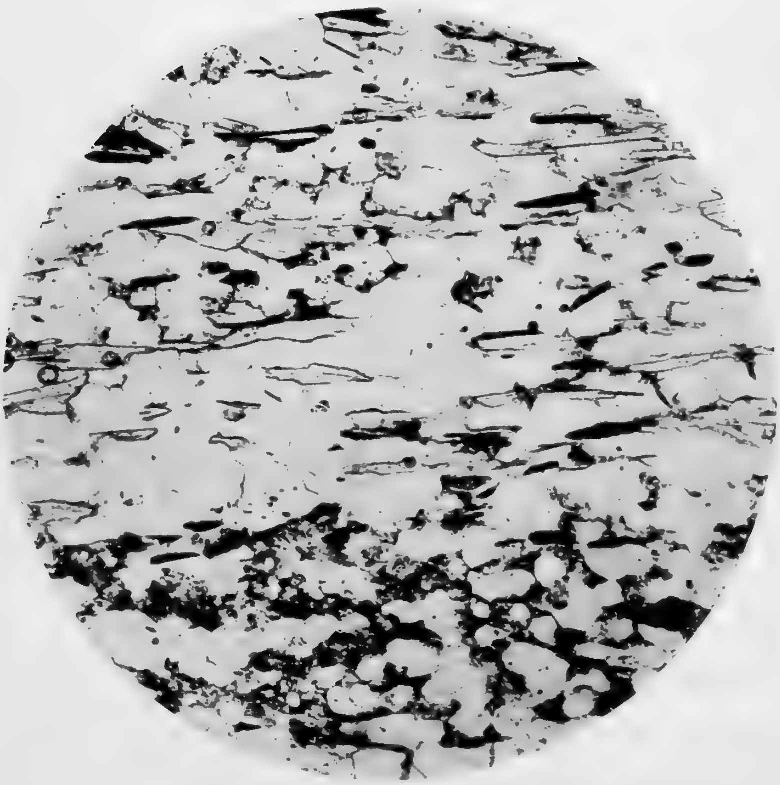
Bemrose, Collo.

Fig. 1. × 32.



No. 113.

Fig. 2. × 32.



No. 150.

G. B. Photomicro.

Bemrose, Collo.

It is now recognized that the granulitic gneisses and mica-schists of Moine type cover wide areas of the Highlands, from the north-west of Sutherland and Ross to the Grampians; and it is further admitted that they represent sediments of siliceous and argillaceous types. The speaker believed that the first part of the paper would form a valuable addition to our knowledge of the petrography of the Moine Gneisses. The second part, dealing with the probable stratigraphical horizon of these altered sediments, raised questions of great interest and importance. Along their north-western margin their boundary is defined by the Moine Thrust, while along their south-eastern limit in the Grampians, where they come into contact with the sedimentary strata of the Eastern Highlands, no such line of disruption had been detected. He agreed with the Author in thinking that no set of faults like that of Glen Tilt and Loch Tay could explain the relationship, for the obvious reason that the Moine Gneisses occur to the south-east of that line of disruption in Perthshire and Aberdeenshire. The Author advanced the ingenious explanation that the Moine Gneisses pass laterally into the Parallel-Banded or Hone-Rock group of the East-Highland sequence which, according to him, lies between the Perthshire Quartzite below and the Little Tremolite-Limestone (or, when the latter is absent, the Blair-Atholl Limestone) above. It had been clearly proved, as contended by the Author, that there is decreasing crystallization of the Moine Gneisses along their south-eastern margin, and it had been further conclusively proved that both the Parallel-Banded series and the Perthshire Quartzite merge into granulitic gneisses along their junction with the Moine Gneisses. Indeed, this feature is so marked that several members of the Geological Survey had drawn a line to guide the colourist, but not a stratigraphical line between the Moine Gneisses to the north and the schistose Dalradian sediments to the south.

Regarding the section at Gilbert's Bridge, in Glen Tilt, it was doubtless true that a band of limestone with dark schists is there repeatedly infolded with the Moine Gneisses, as the Author showed, and the speaker agreed with him in thinking that it represented the Main Limestone of Blair Atholl. Similar evidence had been obtained in the valley of the Tarf, north of the Tilt; while north of the Dee the Blair-Atholl Limestone, the Dark Schist, and even the Perthshire Quartzite, had been found within the area of the Moine Gneisses, and infolded with the latter. The Author's reading of the section at Gilbert's Bridge involved his interpretation of the East-Highland or Dalradian sequence. But some of his colleagues had been led by their detailed mapping to the same conclusion as that of Prof. Nicol, namely, that the Perthshire Quartzite overlies the Black Schist with the Little Limestone. The speaker referred to the transgression of the Quartzite and to the evidence furnished by the Boulder-Bed at Newbiggin, south of Braemar, where it rests upon the eroded edges of the Parallel-Banded series, and is folded over an arch of the Tremolite-Limestone. In the opinion of the speaker, the view that the Quartzite is the highest member of the series, although not free from difficulties, was a more reasonable interpretation of the sequence than that adopted by the Author. He therefore inferred that the Author had not proved his main point regarding the stratigraphical horizon of the Moine Gneisses. Indeed, he considered it improbable that the latter were represented by a few feet, and at one locality by a few inches of the Parallel-Banded series. The speaker then referred to the resemblance of part of the Moine Series to the pre-Torridonian sedimentary schists north of Loch Maree, and to the development of structures akin to those of the Moine schists in the basal division of the Torridon Sandstone. In conclusion, he expressed the hope that the paper would be published with the necessary illustrations, as it embodied the views of one who had studied the crystalline schists in the areas mapped by him with great energy, enthusiasm, and ability.

Sir ARCHIBALD GEIKIE remarked that, although it had been satisfactorily proved that the main mass of the rocks of the Central Highlands is of sedimentary origin, great difficulties still remained in the determination of their true order of succession. He had had the advantage of traversing some of the Author's ground with him in former years, and could bear testimony to the zeal, capacity, and ingenuity with which he attacked the complex problems which these rocks present. The speaker, however, thought that the difficulties involved in the Author's present theoretical explanation were too formidable, and he preferred the view of the structure of the ground which had commended itself to the rest of the members of the Geological Survey. In the exposition of his paper given by the Author that evening, no reference had been made to the Boulder-Bed which formed so conspicuous a band across the Highlands, although no doubt this band had been fully dealt with in the paper as written. The speaker was disposed to attach great importance to this horizon as a clue to the sequence of the formations. Yet it illustrated some of the perplexing features of the region. Though conspicuous along the northern margin of the central chain of quartzite-ridges, it had not been recognized along the southern margin. But, even along its line of outcrop, it appeared not to be a continuous sheet of conglomerate; it disappeared for considerable distances, and came in again on the same horizon, even as far as the islands of Islay and Garvelloch. Probably it represented a series of local shingle-beaches which were not developed farther south. The paper would be a valuable record of the observations and conclusions of one of the most active and enthusiastic among the workers who had given their time and energy to the elucidation of Highland geology.

Mr. GREENLY felt that it was impossible at that late hour to deal with the many points of great interest which were raised by this paper, the question of the relation of the gneisses of Moine type being one of great magnitude. In Sutherland, where the speaker had worked, they certainly appeared to represent a very large formation. He drew attention to the unique opportunity for geological science presented by the work of the Geological Survey in the Highlands. Tracts of metamorphic rocks with which single workers could deal were too small for general purposes; while the great continental masses of them in other countries could only be sketch-mapped during the lifetime of the present generation. In the Scottish Highlands we had a metamorphic region large and varied enough to be of world-wide interest and application, and yet it could be mapped in great detail, because it was possible to bring the united efforts of a whole staff of surveyors to bear upon it. Herein lay the very great value of the work of the Author and his colleagues, work which might have other applications than those of pure science.

The Author thanked the Fellows present for the kindly way in which they had received his paper. With regard to the suggestion that rocks of various ages might be involved in what may be termed a 'Moine-Gneiss' area by folding, the Author pointed out that the newest or most recent must be older than the oldest intrusion that cuts the folding. As an illustration of this important point, he referred to the Meall-Gruaim 'augen-gneiss' shown on the map to the south of Gilbert's Bridge, and suggested its pre-Torridonian age.

# 31. *The* Igneous Rocks *of* Pontesford Hill (Shropshire). By William S. Boulton, Esq., B.Sc., A.R.C.S., F.G.S., Professor of Geology in University College, Cardiff. (Read June 22nd, 1904.)

[Plates XXXVIII–XLIII.]

Contents.



## I. Introduction and Previous Literature.

Pontesford Hill is situated on the north-western flank of the Longmynd range of Shropshire, about 7 miles south-west of Shrewsbury. With a length of about a mile, and a breadth of half a mile, it rises to a height of just over 1000 feet, and from its summit, which is the site of a well-preserved Roman camp, a fine view of the surrounding country is obtained. A mile to the west, and running through the village of Pontesbury, the Stiper-Stones Quartzite, the local base of the Ordovician System, crops out; while to the south-west stretches nearly the whole sweep of the Ordovician district of Shelve and the Corndon. Immediately to the east and south rise abruptly the conglomerates and purple grits of the Western Longmynd, making up the conspicuous woody ridges of Radlith and Oakswood. Between these and Pontesford Hill is a deep and picturesque wooded gorge, cut by the Habberley Brook. Here, about a third of a mile east of the northern end of Pontesford Hill, is the Lyd Hole, a big, circular pot-hole, at and near which are some conspicuous exposures of rocks referred to by Mr. Blake and Dr. Callaway in their papers dealing with the geology of the district. Northward stretches the great plain of Shrewsbury and Chester.

The hill, which is nearly severed into two roughly-equal portions by a north-eastern and south-western gulley, rises from the valley with abrupt and steep slopes, but with a general rounded outline. On the north-eastern side it is thickly clothed with fir and larch, while on the south-eastern flank the rocks stand out in bold, bare crags, at the foot of which a thick deposit of coarse screes has accumulated. On the 1-inch map of the Geological Survey the hill is marked as 'greenstone,' surrounded by *Lingula*-Flags, but for a long time rocks other than greenstone have been known to exist in the hill. Murchison, in his 'Silurian System' 1839 (p. 264), describes the 'fine-grained, crystalline, dark-coloured greenstone,' and remarks on the previous page: 'Other veined and altered rocks adhere to the north-eastern face of Pontesford Hill.'

In 1882 some of the rocks of Pontesford Hill were recognized by Dr. Callaway as belonging to his Uriconian Series.[1]

The resemblance of the banded and spherulitic rhyolites of the northern end of the hill to the Wrekin lavas, especially to the type of Lea Rock near Wrockwardine, is pointed out; while the pronounced flow-lines in the rhyolite are said to

'dip to the south-south-west at 45°. . . . [The basalt] is apparently intrusive; and as it is not found in the neighbouring Cambrian conglomerates it is probably post-Cambrian.' (*Op. cit.* p. 121.)

In a synopsis of the microscopic characters of the rocks collected by Dr. Callaway, Prof. Bonney (in an appendix to the same paper) describes a specimen of the nodular rhyolite at the northern end of the hill and of the basalt of the camp at the summit. (These are referred to on pp. 457 and 479 respectively of the present paper.)

In 1890 the Rev. J. F. Blake, in a paper dealing with the Longmyndian and associated rocks,[2] refers to Pontesford Hill, and says:

'The igneous portion of the hill consists of two masses of acid rock, everywhere separated by a mass of basic rock. . . . . The whole of the western slope (of Habberley Brook), which is formed by Pontesford Hill, is occupied by well-bedded, soft, compact, pale slate, with a moderate dip of about 30° to the west. It is above these slates, on the higher slopes of the hill, that the igneous rocks are met with. On the other, or western, side of the hill only part of the slopes is occupied by a spur of decomposed basic rock; the rest of the ground between the two masses of acid rock shows numerous exposures of pale slates and grits of varying coarseness, with the usual high dip and strike of the district.' (*Op. cit.* p. 402.)

After referring to the section at Lyd's Hole, in which he endeavours to show that the rhyolite there is intrusive in the 'purple slates and grits, which are recognized as Cambrian,' he further says: 'On the other, or eastern, side of the hill the slates and grits are of a different character' (*op. cit.* p. 403). In the sketch-map accompanying Mr. Blake's paper (pl. xvi) the hill is shown with 'volcanic acid rocks' to the north and south, 'higher Cambrian

[1] 'The Pre-Cambrian (Archæan) Rocks of Shropshire, Part II, with Notes on the Microscopic Structure of some of the Rocks by Prof. T. G. Bonney' Quart. Journ. Geol. Soc. vol. xxxviii (1882) pp. 119 *et seqq.*

[2] 'On the Monian & Basal Cambrian Rocks of Shropshire' Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 386.

rocks' in the middle of the hill, with 'volcanic basic rocks' and 'crystalline basic rocks' in amongst the latter.

Thus it will be seen that Dr. Callaway regards Pontesford Hill as made up in part of Archæan rhyolite and hornstone belonging to his Uriconian Series, with intrusive basalt of post-Cambrian age, the whole faulted against the Shineton (Upper Cambrian) Shales, which occupy much of the valley between the Longmynd and Stiper Stones. Mr. Blake, on the other hand, regards the hill as made up of slates and grits of Upper Cambrian age, with two felsites and a basic group, all of which are intrusive in these Cambrian rocks.

My attention was first directed to the Pontesford district, when assisting Prof. Lapworth in its mapping; and in 1890 I commenced the detailed study of its petrology. At that time Prof. Lapworth had ascertained that the hill is practically made up of igneous rocks, both bedded and intrusive; and that there are two acid and two basic groups present, the older basic group forming an interbedded part of the local, so-called 'Uriconian' volcanic group, while the newer basic is intrusive in this older series. His microscopic sections of some of the lower basic rocks had been identified as palagonite-tuffs by Dr. Teall. As it appeared that most of the lithological types of the so-called 'Uriconian' Series of Shropshire exist within the limits of the hill, Prof. Lapworth urged that I should work the petrology of its rocks in detail as types for other Shropshire areas; and, as Pontesford Hill is isolated and circumscribed by faults, such a study had also this further advantage, that it did not involve the stratigraphical relation of its rocks to those of the neighbouring Shropshire formations.

## II. General Structure of Pontesford Hill.

(Map, Pl. XXXVIII, & Sections, Pl. XXXIX.)

The hill is diamond-shaped in plan and bounded on all sides by faults. Although, so far as I am aware, a boundary-fault is actually visible at one place only (see p. 465 & fig. 3), the line of the faults can be precisely traced: partly by the sudden change in the slope of the ground, owing to the hard volcanic rocks of the hill coming against the relatively-soft shales of the valley, and partly by a line of springs, which occur at short intervals along the foot of the hill. Along the western flank the rocks brought down against the Pontesford volcanic rocks are dirty-green, or pale-buff, well-laminated, shivery shales, exposed only in very few places. In these I have so far failed to detect fossils, but they are classed by Dr. Callaway as Shineton (Tremadoc) Shales.[1] At one place (see p. 465) these shales are seen faulted against the andesite-tuffs and intrusive dolerite of the hill; while, in a stream-course a little to the west, the same weathered shale is visible *in situ*, with loose fragments of drifted fossiliferous Bala rock. Still farther west and

[1] Quart. Journ. Geol. Soc. vol. xxxviii (1882) pp. 121, 126.

to the north thin Coal-Measures, consisting largely of blue brick-clays, wrap round the hill; while on the eastern side, between the hill and Habberley Brook, no bedded rocks are visible, everything being buried up in a thick mantle of screes from the rocks of Pontesford Hill. To the north-east around Earlsdale, the tumpy nature of the ground, and the loose, fragmental, and varied character of the rocks, point strongly to the morainic origin of much of this ground. Immediately to the south-west of Pontesford Hill, a narrow wooded ridge, nearly half a mile in length, extends as far south as the village of Habberley, made up of the intrusive amygdaloidal dolerite of Pontesford, and apparently faulted on both sides against the Cambrian shales of the valley.

The general trend of the hill is north and south, while the average strike of its beds is north 30° E., south 30° W., with a high dip towards the east-south-east. In his account of the hill already referred to, Dr. Callaway states [1] that the strike of the beds in Pontesford is east and west, and indicates it thus on the map which accompanies his paper. Further, he lays stress upon this east-and-west (or south-east and north-west) strike of the Uriconian rocks of Pontesford and elsewhere in Shropshire, as emphasizing a strong discordance between them and the Longmyndian ('Cambrian') rocks, which strike roughly north and south. As regards Pontesford Hill, the dominant strike, as above stated, is not east and west, but nearly north-north-east and south-south-west: practically parallel, indeed, to that of the purple grits and conglomerates of the Longmynd on the eastern side of Habberley Brook.

Running from north to south through the northern and central part of the hill, there appears to be a fault with probably a smaller branch-fault immediately to the west of it. Although at no point is it possible to prove the existence of either of these faults, the surface-features of the ground, together with the sudden displacement of the edge of the dolerite (see map, Pl. XXXVIII), seem to demand the existence of the larger of the two; while the sudden change of direction of the banded structure along a definite line in the Northern Rhyolite appears to be adequately accounted for by the smaller fault. A small west-north-westerly cross-fault brings down the basic group, at the extreme southern end of the hill, against the andesitic and rhyolitic tuffs and lavas.

In carefully following single beds in the rhyolite or andesite-group along the strike, say from south-west to north-east, numerous small breaks are encountered, where the bed slightly but suddenly changes its strike, generally adopting a more easterly course. Indeed, the rocks as a whole seem to have settled down into a position of compromise between a northerly and southerly, and north-easterly and south-westerly trend, and the result has been that, while the general or *average* strike is nearly north-north-east and south-south-west, the beds, owing to the slight jumps referred to, may have a local strike nearly due north and south, or north-east and

[1] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 123 & *ibid.* vol. xlvii (1891) pp. 119–22.

south-west. The more easterly strike becomes more pronounced as we pass from south-west to north-east, and therefore, as already pointed out, it is nearly east and west in the rhyolite at the extreme north-eastern end of the hill.

A pronounced jointing, affecting both the older bedded series and the newer intrusive dolerite and basalt, runs from west-north-west to east-south-east, that is, at right angles to the average strike.

The general sequence of the rock-groups in the hill, beginning from below at the northern end, may be summarized as follows (see sections, Pl. XXXIX):—

### A. Bedded Rocks.

(1) The Northern Rhyolite.—A pale-pink and purple rhyolite with much epidote, chlorite, and secondary quartz, showing vesicular, spherulitic, pyromeridal, and banded structures. Thickness about 1000 feet.

(2) The Andesite-Group.—This is made up of felsitic-looking gritty tuffs, pink and green in colour, passing up into and interbedded with andesitic glassy (palagonite) and crystal-tuffs, hälleflintas, and lavas. Thickness about 1800 feet.

(3) Rhyolite-Breccias (glassy and crystal-tuffs) and grits. Thickness about 150 feet.

(4) The South-Eastern Rhyolite.—Dark-red or purple in colour, coarsely vesicular, often with bright-green and white amygdules, and well-banded. Thickness about 250 feet.

### B. Intrusive Olivine-Dolerite and Basalt, making up the higher portions of the hill.

---

At the extreme north-western end the rhyolite is dipping at about 30° south-eastward, but the banded and flaggy rhyolite a little higher up dips 40° southward. The average dip of the andesite-tuffs and lavas is from 70° to 80°, while the South-Eastern Rhyolite and its associated breccias and grits dip at about 85° west-north-westward, a dip opposite to that of the rest of the bedded rocks.

This arrangement of the beds, together with the general similarity in composition of the acid rocks at the northern and southern ends of the hill respectively, might suggest that the acid rocks of the north are on the same horizon as those on the south; and that we are dealing, either with a steep (and probably faulted) syncline, or with the anticlinal limb of a fan-fold. But, as will appear when these rocks are dealt with in detail, important differences exist between the northern and southern rhyolite-rocks, and we must regard the whole of the bedded tuffs and lavas, with the possible exception of the Northern Rhyolite (see pp. 477 & 478), as a regular upward succession. But whether the Northern Rhyolite is really the stratigraphical base of the series, as would appear probable from the evidence within the limits of Pontesford alone, or whether all the bedded rocks, except the South-Eastern Rhyolite and breccias, are inverted, can only be definitely determined after the entire Uriconian and Longmyndian groups of the Longmynd, etc. have been mapped in detail.

The bedded rocks of the hill, including the rhyolites, andesites, and tuffs, thus have a total thickness of about 3200 feet.

All the higher portions of the hill are made up of olivine-dolerite and basalt, that has forced its way up, mainly along two planes, overspreading the bedded rocks, and forming a laccolite-like mass, now separated into two parts by the north-easterly and south-westerly cross-gulley.

## III. Detailed Description of the Rocks.

### (1) The Northern Rhyolite.

This is typically a hard, massive, highly-siliceous rhyolite of a pale-pink or purple colour, and showing many of the characters of Uriconian rhyolites, which have been so admirably described by Allport.[1] Throughout the rock there is much yellow epidote, green chlorite or viridite, together with calcite and secondary quartz and chalcedony, either filling vesicles, or in veins traversing the rock in all directions.

On the north-western flank of the hill, and in the upper part of the mass, as far east as the larger of the two faults marked on the map, the rock is in general well banded, with very small elongated vesicles filled with quartz, the lines of flow running round them (6).[2] The gnarled fluxion-banding is well shown at (432), where the strike of the bands is north-east and south-west. East of the smaller of the two faults, however, the banding runs nearly due east and west, as may be well seen at (42) and (43). The dip of these bands is 30° or less at the extreme northern end, but it increases southward, so that at (42) it is 40°.

On the north-eastern side of the hill, nearly halfway up the steep slope, there is an exposure of the rhyolite some 60 yards wide, separated from the main mass by about 150 yards of dolerite. It is hard, dense, and pink in colour, and has a brecciated look, as if it might be a tuff. At the junction with the dolerite, the rhyolite is considerably discoloured, and shows clear marks of having been affected by the basic intrusion. Microscopically, this rock (559) has a very breccia-like appearance, made up of small equal-sized grains measuring about 0·001 inch in diameter, but without distinct outlines. Between crossed nicols the whole mass is seen to be micro-crystalline, with here and there angular and broken crystals of felspar and quartz. The rock is clearly either a very fine-grained rhyolite-tuff, or a rhyolite which has become finely brecciated

[1] 'On certain Ancient & Devitrified Pitchstones from the Lower Silurian District of Shropshire' Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 449.

[2] Throughout this paper the numbers in parentheses refer to rock-specimens and sections in the author's Pontesford collection, the localities of the more important of these being indicated on the map (Pl. XXXVIII).

during its movement and consolidation.[1] From the map it will be seen that, allowing for the displacement produced by the fault, this outlying mass of rhyolite is in the line of strike with the uppermost beds of banded rhyolite (43), or possibly the more acid of the tuffs of the Andesite-Group.

A specimen (4) about 70 yards from the dolerite, of a dark purple-red colour, and showing vesicles and white veins, has the following microscopic characters:—The slide shows much veining with infillings of quartz and calcite, and cavities (originally elongated vesicles or spaces occupied by phenocrysts), which are now filled with quartz and calcite, some of the quartz-crystals containing needles of rutile. Patches of secondary ilmenite altering to leucoxene occur; while, under a high power, the matrix is seen to be cryptocrystalline, with minute needles of felspar and grains of magnetite. Much brown colouring-matter occurs throughout the matrix, but especially around the filled-up cavities and bordering the veins; it consists of minute rhombs of chalybite, now oxidized to limonite, and in some cases hæmatite. Phenocrysts of felspar up to 0·05 inch in length are plentiful, mostly with Carlsbad twinning, but with occasional albite-lamellation. The abnormal quantity of calcite and oxidized chalybite, together with the presence of ilmenite, clearly points to metasomatic changes brought about in the rhyolite by the proximity of the dolerite, which at one time probably covered the former. (See p. 482.)

The silica-percentage and specific gravity of the Northern Rhyolite, together with the silica-percentage and specific gravity of the South-Eastern rhyolite are tabulated below.[2] Some pre-Cambrian and Ordovician rhyolites are included in the same table for comparison.

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. |
|---|---|---|---|---|---|---|---|---|
| Silica-percentage | 81·93 | 75·78 | 72·18 | 72·57 | 83·802 | 79·72 | 78·40 | 73·23 |
| Specific gravity | 2·61 | 2·63 | 2·62 | ... | ... | ... | ... | ... |

I. Pale-pink, finely-nodular rhyolite, northern end of Pontesford Hill.
II. Dark purple-red, compact rhyolite, south-eastern end of Pontesford Hill.
III. Devitrified perlitic pitchstone, from the 'Lea-Rock' Quarry. J. A. Phillips, Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 457.
IV. Purple quartz-felsite (pre-Cambrian), from Brithdir Farm, near Bangor. J. J. H. Teall, Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 485.
V. Felsophyre, from the summit of Aran Mowddwy, containing porphyritic felspar-crystals in a felsitic matrix. John Hughes, Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 400.

[1] Mr. John Parkinson, F.G.S., who has examined this slide, is of opinion that the rock is a rhyolite-tuff.

[2] I am indebted to Miss Maud Lightfoot, B.Sc., late of University College, Cardiff, for the silica-percentages of some of the acid rocks of Pontesford Hill.

VI. Matrix of nodular felsite, from the Lledr Valley, near Conway-Falls Inn. F. H. Hatch, Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 485.
VII. Matrix of a nodular rhyolite, Boulay Bay (Jersey). Hyndman & Bonney, Geol. Mag. 1896, p. 367.
VIII. Spherulite of same.

It will be seen that the rhyolites of Pontesford, especially the Northern Rhyolite, are more acid than those of the 'Lea Rock' (Shropshire) and Brithdir Farm, both of which are of reputed pre-Cambrian age. On the other hand, they are in fair agreement with some of the Ordovician felsites; while the mean silica-percentage of the spherulites and matrix of the rhyolite from Boulay Bay (Jersey), which is very similar in character to the Northern Rhyolite of Pontesford, agrees almost exactly with that of the South-Eastern Rhyolite. Although every care was taken in selecting varieties as little altered as possible, it may be that the specimens of the Pontesford rhyolites analysed contain more or less secondary silica than some of the others quoted in the foregoing table. In any case, without an analysis of a large number of specimens taken from different parts of the mass in all these localities, it would be unsafe to decide finally as to the relative acidity of these different felsites.

## (2) Nodular Structure of the Northern Rhyolite.

A very pronounced feature of the Northern Rhyolite is the abundance of 'nodules,' which include some of the largest hitherto described in Britain. They are nearly all confined to the centre of the rhyolite-mass, the best specimens occurring on the north-western slope, immediately under the Lower Camp (433), and thence along a line to the Old Quarry (561). The diameter varies up to 8 inches or more, and there is considerable variation in their internal appearance and structure. In this part of the rock, where the pyromerides occur, there is practically no sign of flow-structure.

Prof. Bonney[1] has described the microscopic characters of a specimen of the nodular rhyolite, from the North-End Quarry, probably (561). He speaks of 'hollow spherulitic concretions, subsequently partially or wholly filled by infiltrated minerals,' and says that the rock of Lea Hill is very similar in structure to this one from Pontesford Hill.

More recently, a reference has been made to the Pontesford pyromerides by Mr. Parkinson,[2] who points out their strong resemblance to those of Wrockwardine and Boulay Bay.

Specimen 15 is a pale-pink, finely-nodular rhyolite, which, under the microscope, shows a light-brown matrix with bright-green and reddish-brown patches, highly coloured in places with bright-blue ferrous sulphate. Between crossed nicols, the whole mass is seen to be devitrified. The matrix has a spongy appearance,

[1] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 124.
[2] 'The Hollow Spherulites of the Yellowstone & Great Britain' Quart. Journ. Geol. Soc. vol. lvii (1901) p. 223.

with an evident perlitic structure (see Pl. XL, fig. 1). It is made up of little bodies measuring 0·05 inch across, each consisting of roughly-concentric arcs of glassy material, often of a bright-green colour, alternating with crescentiform spaces, which are now filled with clear quartz, or light-brown dusty material. Centrally there are often irregular or roughly-circular spaces, usually filled with clear quartz. Sometimes the peripheral, crescentiform, glassy portions are very irregular in shape, though retaining their sharp edges and curvilinear outline, strongly resembling in shape the cavities and intervening glassy matter of the Wrockwardine lithophyses figured by Mr. Parkinson.[1] The crescentic arcs of glass above mentioned resemble closely the vitreous splinters, with sharp, curvilinear edges, so characteristic of the rhyolite-breccias and tuffs immediately to the north-west of the South-Eastern Rhyolite (see p. 475 & Pl. XLIII, fig. 4). In common with these, they often show the characteristic longitudinal tension-lines in the glass, as if formed by its distension; but these might be explained by contraction during the development of the perlitic structure.

It seems possible that some of these small bodies represent vesicles (lithophyses), similar in structure to the much larger vesicle in artificial slag shortly to be described (fig. 2, p. 461), and now filled with secondary quartz. At the same time, it is clear that the structure of the matrix is largely perlitic, much of the original glass having been replaced by silica, the remaining devitrified portions (green and brown in colour) showing the characteristic outlines of the perlitic structure.[2]

Prof. Bonney, in describing the nodular felsites of North Wales,[3] holds that the nodular structure has been produced

> 'by simple contraction and roughly-concentric cracking of the mass in cooling, being thus intermediate between the perlitic structure common in glassy acid lavas and the spheroidal structure common in basalt . . .' or 'by similar contraction in cooling, which is determined by the presence of a cavity.'

It may be that the matrix of this Pontesford rock with perlitic structure, and what appears in places as a microlithophysal structure as well, owes its finely-nodular character to the causes referred to by Prof. Bonney.

The nodules proper in this specimen (15) are quite small (0·1 to 0·3 inch) and usually imperfect and irregular. Each consists of a fibrous growth, in some cases, apparently, round one or more vesicles; but in the absence of flow-lines curving round them, or other direct evidence of the gaseous origin of the cavities, it is possible that these cavities may have been occupied originally by spherulitic growths. Into these cavities, and around them, the brown fibrous material has developed, forming tufted or mushroom-shaped growths. The same fibrous material has finally surrounded

[1] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 221.
[2] T. G. Bonney & J. Parkinson 'On Primary & Secondary Devitrification in Glassy Igneous Rocks' Quart. Journ. Geol. Soc. vol. lix (1903) p. 440.
[3] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 295.

the whole mass, though often very imperfectly. In the brown fibres are many circular clearer spaces, which were originally spherulites (in some cases possibly vesicles) with the brown fibres crossing them, but now filled with a mosaic of irregularly-outlined quartz-crystals. The brown fibrous growth is by no means confined to the nodules: it occurs sporadically in small and often quite irregular patches anywhere in the perlitic, and what I have termed the microlithophysal, matrix. But usually it seems to have started to develop along a definite line, such as a crack,[1] or the edge of a vesicle or crystal, and then gradually spread, fungus-like, through the surrounding material.

The following descriptions are from slides kindly lent to me by Mr. Parkinson:—

(*a*) Pyromeridal nodule from the north-west of the hill, about 1·3 inch across, with a roughly-oval cavity filled with quartz and pale-brown angular chips, and with a double fractured border of yellowish and reddish-brown fibrous material (Pl. XLI, fig. 1). Under the microscope, the matrix, in which the nodule is embedded, is greenish and yellow-brown, and much stained with iron-oxide, and it shows in polarized light a microcrystalline aggregate largely made up of secondary quartz-grains. The wall or border of the nodule is much fractured and veined with secondary silica, while angular, broken portions of the wall appear towards the centre of the amygdaloid. This border is made up of the usual brown microfelsitic fibrous matter, often in radiating tufts, and spreading out into mushroom-like growths, where it has had a free space in which to develop. Groups of felspar-phenocrysts or isolated individuals, showing simple or albite-twinning, occur in the fibrous border; and the fibres are usually deflected round the crystals, and not infrequently radiate outward from their walls. The cavity is now filled with a mosaic of clear quartz-grains, enclosing small brown spherules, generally with a well-marked radial structure, and showing the black cross in polarized light. Usually, these spherulitic bodies are surrounded by a border of perfectly-clear quartz, the smaller ones by perfect little hexagons of quartz. Often chalcedonic silica is arranged in agate-like bands.

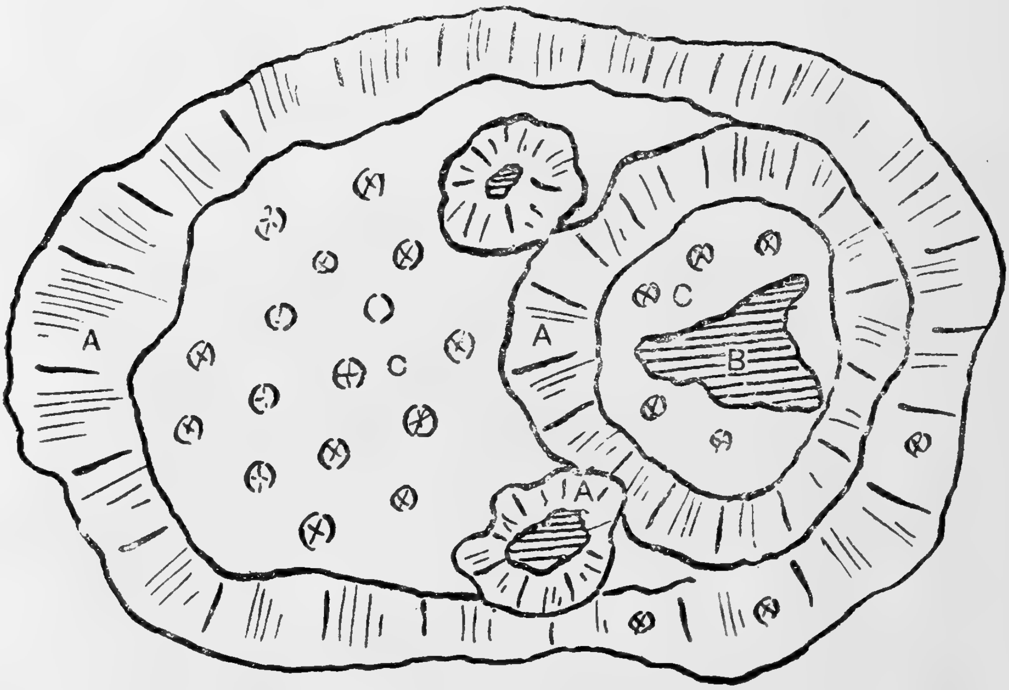
(*b*) Another nodule from the same locality, about 1·5 inch long, contains an irregular quartz-amygdaloid, and shows a much-fractured border, looking, indeed, as if the fracturing occurred when the nodule was hollow (Pl. XL, fig. 2). Under the microscope, many felspar-crystals, some 0·1 inch long, are seen in the fibrous border, and the material of the latter is often arranged in radial bunches, like that of the spherulitic bodies of the Lea Rock. The central cavity is now filled with a brightly-polarizing mosaic of quartz, in which are crowds of small brown spherules, with a pronounced radial structure and showing the usual black cross with crossed nicols. Lining the inside of the surrounding fibrous border is a thin band of clear silica, and then a layer of the small, brown,

[1] There is, of course, the possibility that, in some cases, such cracks are the result of contraction due to the crystallization of the fibrous material.

spherulitic bodies, while these latter are sometimes arranged in bunches radiating from the wall of the amygdaloid towards its centre. It is clear that the brecciation of the wall of the nodule occurred before the infilling of this silica and brown spherulitic matter, for they are arranged in concentric borders around the angular and isolated fragments of the wall.

Fig. 1 is a sketch of a nodule 7 inches across, collected by myself from locality (433). There appear to be three generations, as it were,

Fig. 1.—*Sketch of a nodule of complex structure, measuring 7 inches across.*



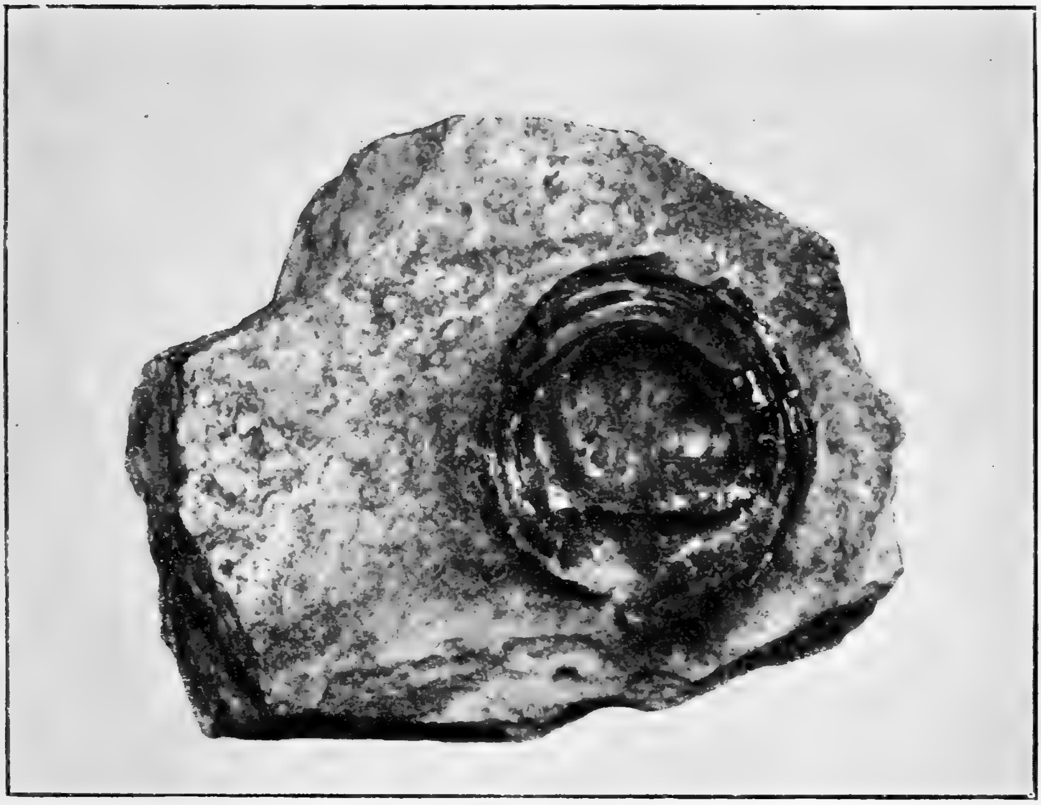

A = Fibrous border.
B = Quartz-amygdaloid.
C = Quartz and brown spherulites.

in the formation of this nodule. Fibrous borders have been formed apparently around two small vesicles; one nodule thus formed, containing a more or less rounded amygdaloid, has become partly enveloped by a larger, including an irregularly-stellate quartz-amygdaloid, while all three have been enveloped in a dark-brown fibrous layer, which forms the outer wall of the nodule.

A specimen of slag given to me some years ago by Mr. H. T. Waller is interesting in this connection, and seems to have some bearing upon the origin of these pyromeridal and lithophysal structures. It is a compound vesicle or lithophyse, $1\frac{1}{4}$ inches across, in a bluish-grey glassy slag (fig. 2, p. 461). The main vesicle is surrounded by roughly-concentric arcs of light-brown transparent glass, and between these glassy layers are crescentiform spaces. If this structure occurred in a rhyolite, if the glass then devitrified, and brown fibro-radiate microfelsitic matter developed in and around it, and the empty spaces subsequently filled with quartz, we should get a very close resemblance to some of the nodules that are found in the ancient rhyolites of Pontesford and elsewhere.[1]

Without entering, for the present, into a further detailed account of these pyromeridal structures, the general conclusions so far arrived at may be thus briefly summarized. In many cases, though certainly not in all, the nodule appears to have commenced as a vesicle, often irregular in shape, and sometimes, possibly, with

Fig. 2.—*Complex vesicle in artificial slag. (Natural size.)*



crescentiform spaces around the main cavity, and separated from it by similarly-shaped portions of the glass. Such vesicles probably occur, on a very small scale, in the matrix of the rhyolite, and show little or no further change, beyond the infilling of the cavities with quartz and other secondary minerals, the fracturing and deformation of their walls by subsequent movements of the

[1] There is a striking similarity between this lithophyse in slag and many of those in the rocks of Obsidian Cliff described by Prof. J. P. Iddings, 7th Ann. Rep. U.S. Geol. Surv. 1885–86 (1888) pp. 265 *et seqq.* It should be noted that while this vesicle occurs at the surface of the slag, and was due solely to the rapid distension and cooling of the slaggy magma, the lithophyses of Obsidian Cliff, and of the ancient rhyolites of Pontesford, Boulay Bay, etc., are in the body of the rock, and may have been produced, in some cases, by the progressive crystallization in a 'hydrous patch,' as explained by Prof. Iddings and Mr. Parkinson.

mass, and, in some cases, a slight development of the brown fibrous material. But, in the case of the larger cavities, the brown fibrous growth has developed conspicuously, encroaching upon the cavity, as well as the surrounding matrix, evidently in much the same way as in the admirably-described cases of the much smaller lithophyses of the obsidian of the Rocche Rosse, Lipari.[1] Thus, fibrous, radiating, or mushroom-shaped masses can frequently be seen penetrating the 'vesicle,' now filled with quartz, and spreading across smaller cavities in the surrounding matrix. This fibrous growth starts in general from the wall of the vesicle or cavity, but it may develop from other lines or points. Thus felspar-phenocrysts, which appear to be more numerous in the vicinity of the vesicles than elsewhere, frequently form the centres for radiating growths, which, by their coalescence, help to form the boundary-wall of a nodule. Possibly, some of the vesicles, with their borders of brown fibrous and often spherulitic matter, remained empty for a long time, for the wall is often much fractured, angular fragments of it occurring in the cavity, and now surrounded by concentric layers of quartz and brown dusty or fibrous felspathic or microfelsitic matter, usually with a well-marked spherulitic structure. Thus the fibrous growth probably represents a phase of the early devitrification of the glass, while the quartz, chalcedony, and brown spherulitic aggregates were introduced subsequently. Indeed, some of this fibrous matter may represent the original crystallization of the magma during cooling, rather than the devitrification of solidified glass.[2] At the same time, it would seem that the formation of the fibrous material is not confined to one stage in the process of devitrification, for, as already remarked, it is found traversing old spherulites, now occupied by secondary quartz.

There seems to be no limit to the size of such nodules, for the fibrous material may successively surround smaller individuals, producing composite nodules, of which the smaller constituents may be of true lithophysal origin, their amygdaloids or filled-up vesicles having a definite relation to their boundary-walls; while the outer enveloping walls have no such related amygdaloids, but, instead, smaller nodules which have played the part of vesicles or phenocrysts in inducing devitrification in the form of a fibrous layer.

Nevertheless, it is clear, from a study of the Pontesford nodules, that some are quite solid to the core, without any quartz-amygdaloid, and with a more or less irregular, radial-fibrous structure. These may be looked upon as imperfect spherulites or 'skeleton-spherulites,' that probably commenced to develop from the centre outward, as in the ordinary type of small spherulite. Further, it would be rash to deny that in some cases the centres of these

[1] G. A. J. Cole & G. W. Butler 'On the Lithophyses in the Obsidian of the Rocche Rosse, Lipari' Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 438.

[2] See J. Parkinson 'Some Igneous Rocks in North Pembrokeshire' Quart. Journ. Geol. Soc. vol. liii (1897) pp. 469–71.

once solid spherulites (as contended by Prof. Cole and Mr. Harker)[1] have been destroyed, and replaced by secondary mineral matter, generally quartz, which now forms the so-called amygdaloid. If the mass is coarsely vesicular or lithophysal, there will be a strong tendency for the fibres to surround these cavities, extending outward into the matrix and inward towards the centre of the vesicle. Similarly, fibrous matter may develop radially outward from phenocrysts, or, as in ordinary spherulites, from central points or lines, where the conditions have been such as to induce crystallization.

It would seem, then, that many of the nodules are spherulitic growths, where the spherulitic fibres develop in general, not from a central point outward, as in the small, true spherulites, but locally from vesicles or other cavities, crystals, etc., coalescing finally to form in some cases larger and larger growths. Those nodules which have roughly-concentric or crescent-shaped cavities, now filled with quartz, may be due in some cases to a progressive or 'spasmodic' crystallization of a 'hydrous patch' during the solidification of the rhyolite-magma (see p. 461). But in other cases, they may have arisen as compound vesicles, due to the local distension of the magma, and the subsequent development of the brown, fibrous and spherulitic material. The spherulitic type of devitrification is not all of the same age, for fibrous growths undoubtedly traverse small and earlier-formed spherulites, which have been dissolved out and replaced by quartz.

In a specimen of the South-Eastern Rhyolite, a spherulitic growth has taken place around an undoubted vesicle, now filled with quartz, for the flow-lines can be seen distinctly curving round it.

## (3) The Andesite-Group.

(*a*) The more Acid Grits and Tuffs.—The actual junction of the Northern Rhyolite and the succeeding tuffs is not seen, but the felsitic-looking grits and tuffs follow on immediately, the line of junction being marked by a hollow in the ground with springs. No reliable dip in these basement-tuffs can be made out, but when a good dip is seen higher up in the andesite-series, the beds are dipping at about 80°. These acid-looking tuffs crop out along the road and lower skirts of the hill (537, 566, 556, 555, 554, 553, 552, 551). They are pink and green, fine-grained, gritty tuffs, with a distinctly-acid look, though containing very few quartz-grains.

No. 566 is a fine-grained grit, the grains being pink, set in a greenish matrix. Under the microscope the grains, measuring up to 0·04 inch across, are seen to consist of lapilli of vesicular, devitrified glass with well-marked fluxion-banding, together with broken crystals of felspar with lamellar twinning. One fragment, 0·05 inch across, contains skeleton-crystals of orthoclase in a decomposed greenish glassy matrix, a few subangular quartz-grains,

[1] G. A. J. Cole, Geol. Mag. 1877, p. 299; A. Harker, 'The Bala Volcanic Series of Caernarvonshire' [Sedgwick Prize Essay for 1888] 1889, pp. 28–40.

and some secondary silica. The rock is undoubtedly a tuff, and from the abundance of simply-twinned felspar, and the felsitic look of the lapilli, apparently more acid than the andesite-tuffs higher up.

No. 554.—A dull-green and red ashy-looking rock, with 55·8 per cent. of silica and a specific gravity of 2·694. Microscopically, it is clearly a fine ash with lapilli measuring up to 0·05 inch across, made up mostly of decomposed glass with skeleton-crystals and microlites of felspar, most with simple twinning, but some (one 0·05 inch long) showing lamellar twinning. The rock is rather more basic-looking than No. 566, and the fragments are much stained with iron-oxide.

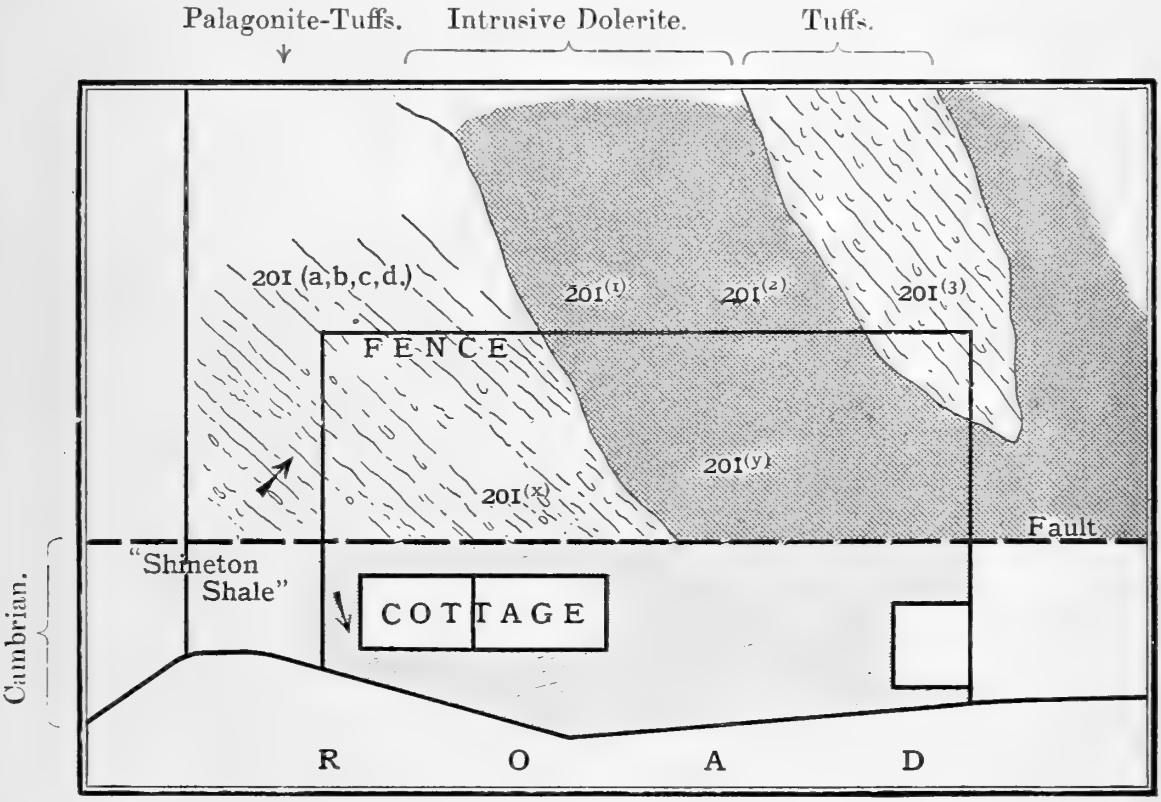
No. 551, of pinkish colour, much-jointed, fine-grained, weathering a dull green, is exposed at the back of a ruined cottage, near the road. (Silica-percentage = 57·07; specific gravity = 2·57.) Under the microscope, it is seen to be a very fine-grained tuff, made up largely of broken crystals of felspar with simple and lamellar twinning (0·001 inch or less), minute particles of reddish-brown glass, with sharp edges and curvilinear outlines, and containing minute vesicles, together with very few quartz-grains.

All these tuffs and grits clearly belong to the Andesite-Group, for they pass at once without a break into the typical palagonite-tuffs, and indeed are interbedded to some extent with them. From their colour and texture and lower specific gravity, one is tempted to class them with the rhyolite as a group of felsite-tuffs, rather than with the andesites; but they contain, on an average, only about 5 per cent. more silica than the palagonite-tuffs, and their microscopic characters are practically the same as those of many of the andesite-tuffs higher up the series. It may be here remarked that many of the small pink chips and lapilli in these tuffs, of a pronounced rhyolitic or felsitic appearance in the hand-specimen, generally show under the microscope precisely the same characters as those in the tuffs which, on analysis, prove to be of andesitic composition. The felsitic appearance is doubtless due, in part, to the smallness of the grains allowing of the complete oxidation of the iron to the ferric state.

(*b*) Palagonite-Tuffs, Grits, and Hälleflintas.—Behind the cottage at the top of the road leading to Pontesbury (201 on the map, Pl. XXXVIII) occurs an interesting exposure, showing the newer basic rocks penetrating the tuffs, and both faulted against the buff-green shivery Shineton Shales, that abut against the hill (see fig. 3, p. 465). Here (201 *a*, *b*, *c*, *d*, *x*) we get, for the first time, the palagonite-tuffs of the Andesite-Group. They are dull-green, bluish when fresh, but weathering yellowish-green, and fine-grained with white flecks.

No. 201 *a* consists of irregular fragments of yellow and greenish-yellow decomposed glass measuring up to 0·04 inch across, including small round vesicles and minute felspar-microlites, and with curved, sharp outlines, set in a matrix of very fine glassy dust, containing in places much secondary calcite. The lapilli of palagonitized glass, often covered with minute brown pigment-spots, like spots on a leopard's skin, show no reaction with crossed nicols. The round vesicles have a clear transparent border of a doubly-refracting zeolite, and a faintly-polarizing substance in the centre, while many elongated vesicles have a yellow border of palagonite, and enclose a colourless zeolite in the centre. Broken crystals of felspar, measuring up to 0·02 inch, occur, as also occasional angular grains of quartz.

Fig. 3.—*Sketch-map showing Pontesford rocks faulted against Cambrian shales, at the top of the road leading to Pontesbury [201].*




[Scale: 1 inch = about 20 feet.]

No. 201 *b*, though occurring quite close to 201 *a*, is very different in colour and texture. It is made up of lapilli of yellowish-green vesicular palagonite and crystal-fragments. A fragment of brown glass (0·0025 inch) contains minute needles of felspar and larger laths of the same mineral showing distinct lamellar twinning, together with small green patches that may be decomposed pyroxene. Lapilli, measuring up to 0·1 inch across, vesicular, slaggy, and twisted, are common, with some secondary calcite in the matrix.

No. 201 *d* is harder, and paler in colour with pink and green flecks, and contains lapilli of greenish andesite-glass with minute black vesicles. Microscopically, it shows good felspar-crystals, measuring up to 0·05 inch across, with simple and lamellar twinning, and an extinction-angle up to 16°.

No. 201(3) is a buff rock with pink grains, which microscopically shows decomposed glassy particles and many broken crystals of felspar (0·05 inch), parts of short rectangular prisms with albite-lamellation. A lapillus, 0·03 inch across, is much stained with red iron-oxide and is crowded with minute felspar-laths.

In among these tuffs the coarsely-amygdaloidal intrusive dolerite has made its way. No. 201(1) is a fine-grained, granulitic dolerite with serpentinized olivine-phenocrysts, in general character similar to No. 28, described on p. 481. No. 201 *y* is a somewhat doubtful rock. It is dull yellowish-green, fine-grained, with green needles and larger greenish-black patches with a dull pitchy lustre, made up of a soft substance which is greenish-yellow when scratched—probably palagonite. Microscopically, it is of uneven texture and colour, with small laths of cloudy plagioclase, milk-white in reflected light, occurring ophitically with pale-green, much-cracked augite, altering to a dark-green chloritic mineral. There is a good deal of pale-green and yellow substance, with cracks that suggest olivine, and red, slightly-pleochroic deposits in small flakes and needles along the cracks. The description of this rock would seem to apply equally well to the ophitic dolerite with serpentinized olivine, and the andesite-lava with patches of palagonitized glass. On the whole I am inclined to put it in the latter group (see p. 471).

At (434), in a small opening near the road, is a dull purplish-red, fine-grained rock, which, microscopically, is seen to be much stained yellow, brown, and black, and made up of minute angular chips of felsite and quartz, in a fine brown dust. Fragments measuring 0·1 inch across, composed of these chips, are embedded in a matrix of the same material, with crystals in nests or clusters, the whole showing traces of bedding. This rock is distinctly more acid-looking than the palagonite-tuffs just described, and shows a temporary return to the more acid type which follows the Northern Rhyolite.

A conspicuous crag on the south-west of the gulley, referred to as 'Agglomerate-Crag' in my field-notes, is made up of a coarse andesite-agglomerate or tuff, but very varied in colour and texture. Some parts consist of yellowish-green palagonite-tuff with minute angular dark-grey patches, with a flaggy and slightly-schistose structure, crumbling readily when struck with a hammer, others being of harder, fine-grained, pink and green, gritty tuff; or again extremely fine-grained, purple, yellow, or green hälleflinta. Angular fragments, sometimes several inches across, of purple amygdaloidal andesite, often showing most pronounced fluxion-banding, are embedded in a green or pink, fine-grained matrix. The entire crag is much jointed, the fragments showing elaborate faulting on a small scale, and epidote and chlorite are common as secondary products. Immediately behind the main crag, the tuff, with banded and vesicular purple andesite-lapilli, embedded in a fine matrix of the same material, is well seen; while to the south-east of it is a bright-yellow, hard, and exceedingly fine-grained hälleflinta, 2 feet thick, which can be traced along the hillside for many yards, thus accurately fixing the strike.

The following examples show the more typical microscopic characters of these rocks:—

(Agg. Crag, *a*.)—Red and green gritty tuff, with fragments measuring up to 0·2 inch across, of decomposed glass, crowded with minute round vesicles, now filled with pale-green doubly-refracting zeolite, together with microlites of felspar showing very low extinction-angles; crystals of felspar, partly broken, measuring up to 0·04 inch, with good lamellar twinning; occasional angular grains of quartz; twisted pieces of vesicular glass; lapilli of previously-consolidated glassy tuff, one being made up of a granular bright-green matrix, full of minute felspar-laths with a parallel arrangement.

(Agg. Crag, *b*.)—A good specimen of palagonite-tuff, with lapilli of reddish-brown and bright orange-yellow palagonite (pale-yellow by incident light) of curvilinear outline, and crowded with minute felspar-laths, and vesicles which are as a rule perfectly circular, but sometimes much elongated. These have usually a ring of clear doubly-refracting zeolite, with a similar material, or, in some cases, a yellow isotropic substance, in the centre. Some amygdules show a black cross with polarized light; and there is much dirty-white calcite in the matrix. (Pl. XLII, fig. 2.)

(Agg. Crag, *c*.)—Shows a fragment, 0·75 inch across, with fine red and green bands, embedded in a matrix of pink and green grains. This matrix is a fine crystal-tuff, made up of broken crystals of plagioclase with repeated twinning, pinkish-brown in colour, and set in a fine green dust, while the lapillus consists of alternating bands of purplish-red dust and crystal-fragments.

(Agg. Crag, *d*.)—A green tuff, with dull green and pinkish-brown lapilli measuring upwards of 0·75 inch across. These consist of black glass with felspar-microlites; pale-red, altered glass with many round vesicles filled with a green substance, one pear-shaped fragment of glass 0·06 inch long showing marked perlitic structure.

No. 205—near Agglomerate Crag—is a coarse, pink-and-green gritty tuff, showing well all the different kinds of lapilli, which measure generally about 0·1 inch across (Pl. XLII, fig. 1). An included fragment in the tuff, of a pale yellowish-green, is a piece of decomposed andesite-lava, the matrix being crowded with felspar-needles, milky-white by incident light, and containing vesicles filled with pale yellowish-green, doubly-refracting zeolite with spherulitic structure.

A buff-yellow finely-laminated hälleflinta,[1] near by, shows bands of very fine glassy dust, alternating with coarser bands made up of

[1] The term 'hälleflinta' is here used, as elsewhere in this paper, as a general field-term for a hard, felsitic, fine-grained, laminated rock. In Pontesford Hill all the hälleflintas are fine glassy and crystal-tuffs of andesitic composition.

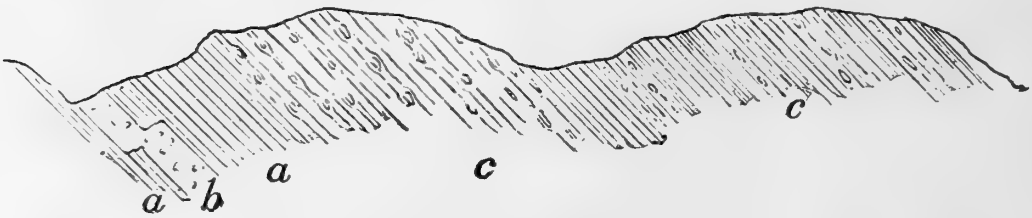
crystal-fragments, and splinters of yellow palagonite enclosing felspar-needles (Pl. XLIII, fig. 3).

These rocks can be easily followed cropping out along the south-western face of the gulley, but higher up the slope towards the wood at the top of this part of the hill, the beds are found to be harder, more massive and fine-grained, less flaggy and more gritty, until at the top near the wood (512) the rock is a very hard massive grit, dark green with pink grains, having a specific gravity of 2·79, and dipping at 80°. Microscopically, it resembles No. 205, but is not so coarse, and contains many grains of ilmenite altering to leucoxene, a constituent which probably accounts for its rather high density.

A band of these hard grits, 70 yards thick, can be traced all down the north-eastern slope of the gulley, dipping about halfway down at 60°. They are followed at once on the south side by beautifully-laminated green and yellow hälleflintas, with interbedded andesite-lavas; while on the other, or north-west, side they are covered by the newer basic rocks.

Some of the best and most accessible spots for observing the typical andesite-rocks are along the foot of the western slope of the hill, south of the gulley, in the little gardens behind the cottages that occur at intervals along the road. Thus at (209) the following section is seen:—

Fig. 4.—*Section under the fence, western flank of Pontesford Hill* [*209*].




[Length of section = about 30 feet; dip = 85°.]

*a* = Finely-laminated green hälleflintas, 8 feet thick, striking obliquely with the fence and dipping at 85°, containing a red and white siliceous band 12 inches thick (*b*), which, under the microscope (530), appears to be a tuff-band with broken felspar-crystals, but very largely replaced by a mosaic of secondary quartz-crystals.

*c* = A coarser, andesite-tuff with circular, oval, and subangular lapilli of andesite-glass, 2 or more inches across; and interbedded with beautifully banded red, blue, and yellow hälleflinta.

The lapilli of andesite-glass occur also in the fine hälleflinta, the lines of which flow round them, showing some resemblance to a finely-banded lava with phenocrysts. A lapillus of andesite (531), taken from the finely-banded tuffs, shows microscopically an andesite-glass, pale yellowish-white by reflected light, containing laths of felspar 0·05 inch long, often in radiating groups, much decomposed, but some showing lamellar twinning. Crystals of a pyroxene-like mineral, now replaced by a yellowish-green product, have evidently crystallized out after the felspars, for they often enclose the latter. Irregular, but rounded portions, which macroscopically might be taken for filled-up vesicles, are found to be fragments of previously-consolidated palagonite-tuff, with minute angular bits of palagonitized vesicular glass, enclosing needles of felspar, and occasional crystals of augite. These fragments of tuff embedded in the lava have been partly re-fused: for, although of irregular shape, their edges are quite rounded.

Along the same line (305, 308) are very typical examples of the palagonite-tuff. In (305) angular lapilli, measuring up to 0·15 inch across, of green and orange-coloured palagonitized glass are present, containing abundant circular vesicles filled with zeolites, together with minute needles of felspar. Many of these lapilli have a markedly-twisted and slaggy appearance, and some are strongly stained with iron-oxide. The matrix of the rock is a very fine dust, now largely replaced by calcite and other secondary minerals. (Pl. XLII, fig 3.)

Ascending the hill from the gulley towards the Higher Camp on the main summit, the andesite-lavas, coarse and fine andesite- and palagonite-tuffs, with hälleflintas, are met with in many isolated crags, all along the north-western and western face, extending half-way, in some places two-thirds of the way, up the slope, where they are covered irregularly by the basic rocks (520, 522, 523, 524, 525, etc.). These tuffs are of types already described, but the finer tuffs or hälleflintas are hereabouts more common, and are especially well-displayed at intervals along the lower slope, where crags showing beautiful lamination may be seen, as well as quantities of hälleflinta-débris brought to the surface by rabbits.

The following is a complete analysis of palagonite-tuff from Agglomerate Crag, by Dr. C. F. Baker, late of the University of Birmingham :—

| | *Per cent.* |
|---|---|
| $SiO_2$ | 53·41 |
| $Al_2O_3$ | 11·52 |
| $Fe_2O_3$ | 8·36 |
| FeO | 3·38 |
| MnO | 1·48 |
| CaO | 13·16 |
| MgO | 2·63 |
| $K_2O$ | 0·63 |
| $Na_2O$ | 0·71 |
| Loss at about 110° Centigrade | 1·54 |
| Loss, extra, at dull-red heat | 3·56 |
| (Specific gravity = 2·743.) | 100·38 |

Sir John Murray & the late Prof. Renard,[1] in comparing an analysis of palagonitic matter with that of the anhydrous silicate (basic glass), from which the palagonitic substance was derived, say :

'The transformation which has taken place seems to tend to the formation of a zeolitic substance ; lime and magnesia are eliminated, the protoxide of iron

[1] *Challenger* Reports : 'Deep-Sea Deposits' (1891) p. 307.

passes into peroxide, alkalies derived from the action of sea-water enter into combination, the quantity of alumina remaining almost constant.'

In the palagonite-tuff of Pontesford most of the iron is in the peroxide-state, while the percentage of lime is high, and magnesia low. It must be remembered that the rock contains a fair amount of secondary calcite, so that both original lime and magnesia may have been removed from the glass during the formation of palagonite. It would be difficult, or impossible, however, to demonstrate these changes in a tuff with secondary deposits (calcite and zeolites) in the matrix, as is the case with this Pontesford specimen.

(*c*) Andesite-Lavas.—The andesite-lava, which, as already noted, occurs as lapilli in the tuffs, is also found interbedded with the tuffs, though covering a relatively-small area. It has been found very difficult, in the field, to separate some of these andesite-lavas from the newer basic rocks, for both may be fine-grained, with a dull blue- or grey-greenish colour. Typically, however, the andesite is bluish-green, weathering yellowish-green, fine-grained, with small white, and often squat-shaped, felspars, easily recognized with a lens, and small soft black specks, giving greenish scratches, which under the microscope are found to be portions of the interstitial glassy matrix converted into palagonite, together with vesicles filled with a chloritic substance; while the compact varieties of the intrusive dolerite usually weather reddish-brown, and the felspars are less prominent. Where the andesite occurs near to the intrusive dolerite (and indeed it is never far from it) it is often darker than usual, owing, as microscopic examination shows, to the development of large numbers of minute magnetite- or ilmenite-grains, so that it becomes increasingly difficult to distinguish it from the finer dolerite. Moreover, there is always the possibility of the dolerite showing through among the andesite-lavas, as, indeed, it actually does in one or two places (516 *d*). The difficulty of separating these rocks does not completely disappear when a microscopic examination is made: for, as will appear in the following descriptions, many of the mineralogical and structural characters are common to some specimens in both groups. By slicing a large number of rocks at all the doubtful points, and repeatedly noting their field-relations in the light of the knowledge obtained from an examination of these rock-sections, it has been found possible to distinguish the two groups, and map their boundaries with tolerable accuracy.

At the south-western end of the gulley, at the foot of the northern face and opposite 'Agglomerate-Crag,' is a typical specimen of the andesite-lava (57), interbedded with green-and-yellow finely-laminated hälleflinta; and a few yards to the west (516) is a group of crags showing two similar thin beds of lava (516 *a*, 516 *c*), a few yards wide, separated by relatively-soft green palagonite-tuff (516 *b*), while a small sill of intrusive dolerite abuts against 516 *c*. The same lavas are seen in among the hälleflintas and palagonite-tuffs all along the lower slope of this part of the hill, and up to the line of the intrusive dolerite (525, etc.).

Under the microscope, the andesite-lava (516 *c*, 57 *a*) is found to be made up of a felted mass of felspar-laths about 0·02 inch in length, milky-white by reflected light, but still showing both simple and lamellar twinning, generally extinguishing parallel to their length, or nearly so, indicating a felspar of the oligoclase-series. A good deal of very pale-green, nearly-colourless, highly-refractive and much-cracked augite (malacolite) occurs in short prisms, usually with octagonal sections, and exhibiting a well-marked prismatic cleavage. It is frequently twinned, and occasionally encloses felspar-prisms. These minerals are embedded in a dull, greenish-brown, glassy matrix, largely converted into yellow-and-green palagonite, which in its turn has been replaced in part by zeolites. Small magnetite- or ilmenite-granules are plentiful. The ilmenite, which is evidently secondary, occurs in minute rhombs and hexagonal plates, with the ordinary white leucoxene-products, some of the skeleton-crystals showing very good examples of the characteristic mesh of white rods. The altered glass has the same general character as that of the palagonite-tuffs; it occurs in roundish patches, portions of which are milk-white in incident light, and with weak chromatic polarization, and sometimes exhibits a fibrous or spherulitic structure. Minute green granules, milk-white in reflected light, are common in these palagonite-areas, especially along their borders, representing a further change in the alteration of the glass. It is possible that some of the larger circular areas represent vesicles. The rock is an augite-andesite with a hyalopilitic groundmass, in which much of the residual glass is converted into palagonite, and a good deal of secondary ilmenite occurs (Pl. XLIII, fig. 5).

In some cases (516 *a*, 528) phenocrysts of felspar measuring up to 0·05 inch, as a rule simply twinned, and often arranged in radial groups, are embedded in a mesh of much smaller crystals; while in (528) many elongated vesicles are seen, filled with a pale-green, spherulitic, brightly-polarizing substance, often with a bordering zone of colourless zeolite, which, between crossed nicols, shows a fibro-radiate or minutely-spherulitic structure.

No. 525, just below the dolerite, is much darker in colour than the typical andesite, very fine-grained, with pale-green flecks, and in the hand-specimen it is almost impossible to distinguish it from the fine-grained compact dolerite. Under the microscope, the matrix is nearly black, and, with a high power, appears dusted all over with very minute grains of secondary magnetite and ilmenite, which appear not only in the matrix, but covering largely the phenocrysts. Much pale augite is present, together with squarish felspar-phenocrysts of low extinction-angles, as well as felspar-microlites in the glassy matrix, and many vesicles filled with a pale-green, faintly-polarizing substance (? delessite), often showing zonary banding, and a fibrous or spherulitic structure. In spite of the close microscopic resemblance of this rock to some of the finer dolerites or basalts, there can be no doubt that it belongs to the Andesite-Group.

At the top of the gulley, a little way down the north-eastern slope, and just outside the wood (573, 513), are dark, fine-grained, basic-looking rocks of much the same type as No. 525, which, in my first examination of the hill, were mapped as intrusive basalt. Microscopically the felspars are milky-white by reflected light, in places blotched with hæmatite, while the matrix is of a pale yellowish-green. Much secondary ilmenite with leucoxene; the pale, much-cracked augite of the andesite-lava; and a hyalopilitic groundmass, with much of the glass converted into green palagonite, are also seen. Circular vesicles are common, filled with concentric zones of a green substance exhibiting well-marked spherulitic structure, a colourless, brightly-polarizing substance, and calcite. These rocks are associated with hard hälleflintas, as appears to be the case generally. The close proximity of the newer basic group probably accounts for the large quantity of secondary iron-ore present, and the consequently more basic appearance of the rock.

The silica-percentage of No. 516 *c*, a typical specimen of the augite-andesite, is 50·67; while the specific gravity of five different specimens from various points on the hill varied from 2·76 to 2·83, giving an average of 2·80. The rock is thus practically basic; but, from the comparative abundance of felspar (probably oligoclase) and the absence of olivine, it is perhaps more convenient to style it a basic augite-andesite, or andesitic basalt.

(*d*) Summary of the Andesite-Group.—A marked feature of the Andesite-Group just described is the preponderance of tuffs, generally glassy, but sometimes made up almost entirely of broken crystals of oligoclase or andesine. These tuffs are the fragmental representatives of a basic augite-andesite lava, which in places is interleaved with the tuffs. From the blade-like character of some of these masses of andesite, and, in places, their tendency to an ophitic structure, it would be unwise to ignore the possibility of the intrusion of some of them into the tuffs. But the evidence, both petrological and in the field, and especially the occurrence of lapilli of similar andesite in the associated tuffs, seems to point to their bedded origin; and, in any case, there can be little doubt that both tuffs and andesites belong to the same petrological series, and are of the same general age.

The quantity of palagonitized glass in these tuffs and lavas is remarkable, and equally so the comparative freshness of the palagonite, considering the great antiquity of the rocks.

The substance, palagonite, is not uncommon in the older glassy volcanic rocks of Britain and elsewhere, both in basic tuffs, and as an alteration-product of the glassy residue of basic lavas. Thus Prof. Cole has described and figured it in the andesite-tuff of Snead near Bishop's Castle, as well as in the associated andesite-lavas [1]; and palagonite-tuffs in the Carboniferous rocks of the Forth Basin,

[1] 'On some Additional Occurrences of Tachylyte' Quart. Journ. Geol. Soc. vol. xliv (1888) pp. 305–306 & pl. xi, fig. 5.

and the Pebidian of St. David's (Pembrokeshire), have been figured and described by Sir Archibald Geikie[1]; while Prof. Zirkel has described tuffs of this nature from Nevada and elsewhere.[2] But the finest palagonite-tuffs are the more recent ones of Sicily, Iceland, the Canary Islands, etc., including those of Palagonia with the type-palagonite of Waltershausen, the characters of which have been summarized by Prof. Penck.[3] Through the kindness of Prof. Judd, I have been able to examine some of these rocks, as well as specimens from Samoa, given to me by Mr. H. T. Waller.

In the palagonite-tuff from Galdar (Grand Canary), lapilli of orange, reddish-brown, and yellow palagonite (average measurement = ·2 inch across), contain fresh clear olivine-phenocrysts; circular vesicles lined or filled with zeolites; and the same zeolite (phillipsite) forms a fibro-radiate, mammillated border round the lapilli, the outside margin of this border having a bright-yellow colour.[4]

In the Samoan rocks the palagonite is yellow, orange, or reddish-brown, with a singular absence of separated iron-oxide, and enclosing microlites of felspar, and phenocrysts of fresh, nearly colourless olivine, together with round or elongated vesicles filled with zeolites.

The tuff from Samoa contains lapilli, up to half an inch across, of yellow and orange-yellow, faintly-polarizing palagonite, crowded with minute and perfectly-round or much-elongated vesicles, and containing fresh, nearly-colourless phenocrysts of olivine. The vesicles are mostly filled with zeolites, a clear, colourless border of a doubly-refracting substance, and a dark, nearly-opaque centre of minute brown granules, possibly iron-oxide, the whole giving a dusky cross in polarized light. Distinct from these vesicles, and much smaller, minute gas-pores are visible, often filled with palagonite; while others, with a faintly-marked radial and concentric structure, are slightly affected by polarized light, and probably represent globulites, or the variolitic structure on a small scale. In one specimen from Samoa, each fragment of pale yellowish-brown palagonite, crowded with microlites and skeleton-crystals of felspar, is ringed round with a darker border of orange-yellow palagonite, and the vesicles have a border of the same brown material, the centres being filled with colourless zeolite. Except for the presence of olivine in these rocks, and the somewhat fresher, clearer, and almost isotropic character of this palagonite, there is scarcely a detail of structure and appearance that cannot be matched in the palagonite-tuffs of Pontesford.

In the volume on the Deep-Sea Deposits of the *Challenger*

[1] Trans. Roy. Soc. Edin. vol. xxix (1880) pp. 513–16; and 'On the supposed pre-Cambrian Rocks of St. David's' Quart. Journ. Geol. Soc. vol. xxxix (1883) pp. 295–300.

[2] U.S. Geol. Explor. Fortieth Parallel, vol. vi 'Microscopical Petrography (1876) pp. 272–75 & pl. xii, figs. 3–4.

[3] 'Ueber Palagonit- und Basalttuffe' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxxi (1879) pp. 504–77.

[4] Compare *Challenger* Reports: 'Deep-Sea Deposits' (1891) pl. xviii. figs. 2 & 3.

Reports,[1] Sir John Murray & the late Prof. Renard described palagonite-, glassy-, and crystal-tuffs, dredged from the bottom of the ocean, which again show characters almost identical with those of the Pontesford rocks.

It seems probable that the conversion of the basic andesite-glass into palagonite, in the case of the Pontesford rocks, took place soon after their eruption, and that further and later changes in the rocks have affected the crystalline constituents and fine matrix of the tuffs, rather than this palagonitized glass. It has been contended by Prof. Penck, Sir John Murray & the late Prof. Renard,[2] and others, that the conversion of basic glass into palagonite is brought about largely by the hydrochemical action of sea-water, whereby changes take place which tend to the formation of zeolites. That the tuffs of Pontesford were deposited in water is abundantly clear, from the fine and regular lamination of some of the tuffs and hälleflintas, and the pronounced bedding of some of the volcanic grits.

### (4) Rhyolite-Breccias and Grits associated with the South-Eastern Rhyolite.

It will be seen from the map (Pl. XXXVIII) accompanying this paper that a strip of dolerite at the southern end of the hill interrupts the succession of the bedded volcanic group. Andesite-tuffs and lavas can be traced right up to this dolerite on the western side, and the same rocks are met with along the footpath in the adjacent field (535) cropping out through the dolerite, which makes up nearly all the ground at this extreme southern end. On the eastern side of the dolerite, along the footpath by the side of the fence, which roughly corresponds to the little cross-fault marked on the map, the andesite-rocks are again met with in small and rather obscure outcrops (536, 537). No. 536 is much brecciated, iron-stained, and under the microscope shows a large amount of secondary quartz (it yielded on analysis 84·70 per cent.). If the longitudinal fault through the centre of the hill (see p. 453) runs as far south, it would probably come through this point.

No. 537 is a pale, siliceous-looking rock, with a distinct banded appearance, the bands running parallel to the general strike of the andesite-group. Under the microscope it is found to be a crystal-tuff, with broken crystals of felspar 0·01 to 0·07 inch long, showing both simple and lamellar twinning, and set in a finely-banded, dusty matrix, containing a few lapilli of decomposed vesicular glass.

No. 17 L is a fresher-looking rock, but with much iron-staining, and yellow and green secondary products. It is full of small felspar-laths with a parallel arrangement, extinguishing parallel (or nearly so) to their length, with a few larger crystals showing

[1] Pp. 304–311 & pl. xviii.
[2] *Ibid.* p. 307.

extinction-angles up to 15°. The structure is typically pilotaxitic, though in places, where there is more residual glass, it might be more exactly termed 'hyalopilitic.'

These rocks, which are evidently of the andesite-series, though perhaps originally more acid than those in the same series farther north, pass at once into typical acid tuffs or breccias, which culminate in the South-Eastern Rhyolite.

A hard, flaggy, pink, felsitic-looking rock with green angular chips (538, 540, 543, 545) is the first band of these markedly-acid tuffs, with structures generally like those in the Westphalian Devonian tuffs described by Mügge.[1]

No. 538 is a rather fine-grained variety, made up of very small fragments of red, vesicular, altered glass with the typical 'Bogenstruktur,' set in a dirty-green matrix of fine glassy and crystal dust. Larger crystals of felspar, showing both simple and lamellar twinning, are present, together with rounded lapilli of vesicular glass measuring up to 0·14 inch across; in one place the vesicles have been drawn out into long and extremely-fine tubes. The rock has the same general structural character as the palagonite-tuffs, and was evidently formed under much the same conditions, in this case by the breaking up of a perlitic and very vesicular acid glass, the glass becoming afterwards strongly coloured with iron-oxide. Its percentage of silica is 74·83, and the specific gravity is 2·64.

No. 540 is in the same band as 538, but is coarser in texture, with green chips measuring up to 0·3 inch in length. The matrix, greenish in colour, is made up of fine glassy dust, embedded in which are many minute red splinters of glass, with curved edges, and often showing the optical phenomena of tension, like those observed in Rupert's drops; together with phenocrysts of orthoclase-felspar (some 0·03 inch long), and irregularly-shaped lapilli of green, fine-grained, banded tuff.

This glassy breccia is followed by a bright-red and green flaggy grit (539, 541), in places dipping north-westward into the hill at about 80°. A specimen (539) is a very striking rock under the microscope (Pl. XLIII, fig. 4). It is made up of lapilli measuring about 0·02 inch across, mostly of green and brownish-red vesicular glass, often showing what looks like perlitic structure, but may be the vesicular structure previously described in the matrix of the Northern Rhyolite (pp. 457, 458); others are fragments of dark-brown, nearly black glass, crowded with felspar-microlites; others again of felspar-crystals, more or less broken, usually exhibiting simple twinning, together with occasional rounded blebs of quartz 0·05 inch across. The rock bears a general structural resemblance to the grit in the Andesite-Group at the top of the gulley (512), but the fragments are more glassy and the rock as a whole more acid. The bright-red colour of this rock is due to the large amount of hæmatite that has developed in the glass.

[1] 'Untersuchungen über die Lenneporphyre in Westfalen & den angrenzenden Gebieten' Neues Jahrb. Beilage-Band viii (1893) p. 642.

The red-and-green grit is followed by a breccia of the type of that on the other side of it (538, etc.), but distinctly coarser, with a pinkish matrix containing angular yellow and green splinters measuring 1 inch or more across. Sometimes the rock is bright bluish-green with pink glassy splinters, making up one of the most striking rocks of Pontesford Hill.

These three bands (the red grit and glassy breccias above and below it) can be followed along the south-eastern flank of the hill, extending nearly up to the Camp, where they abut irregularly against the basalt. In the glassy breccia (545) a vein of barytes about a foot thick, running nearly east and west, has been partly exposed.

## (5) The South-Eastern Rhyolite.

The bedded rocks of the hill end southward in a rhyolite which skirts it on the south-eastern side, and extends to the eastern boundary-fault. It is a dark purple-red rhyolite, in some places compact, but generally slaggy and coarsely vesicular and amygdaloidal, the vesicles measuring often 1 inch or more in length, sometimes drawn out into fine tubes, and filled with yellow and green secondary minerals.

Under the microscope, the vesicular, slaggy and banded structures are very pronounced; there is much staining with red iron-oxide, and occasionally phenocrysts of felspar are present, generally showing albite-lamellation. Much secondary quartz, yellow epidote, and green chlorite, frequently in spherulitic aggregates, together with radial growths of a colourless, brightly-polarizing, fibrous substance, fill cracks and vesicles. Some of the larger irregular vesicles are partly filled with highly-vesicular and spongy rhyolite, squeezed in while the rock was still plastic; while, in other cases, sharp, angular portions of the felsitic matrix have been forced in by movement more probably after partial or entire consolidation, as in the case of the more angular fragments of fibrous felsitic matter in the quartz-amygdaloids of the Northern Rhyolite.

In some specimens, the rock appears to consist of two magmas that have imperfectly mixed, a darker and more ferruginous one irregularly penetrating a paler variety; while, in other cases, the bands vary considerably in colour, owing to the irregular distribution of the iron-oxide, so that the rock has a peculiar gnarled and twisted appearance, suggestive of the knotty or grained structures of wood. This gnarled structure is doubtless to be explained by the partial separation of a more basic and ferruginous constituent of the original rhyolite-magma *before* the extrusion of the lava.

In one place there is an included fragment, 0·05 inch across, of nearly-black glass with clear vesicles. In a slice (1 Y 1) of one of several of these rocks kindly lent to me by Mr. Parkinson, a well-marked spherulitic structure is visible to the naked eye, the spherulitic bodies measuring 0·1 inch across. The rock was originally the usual highly-vesicular and slaggy type of this South-Eastern

Rhyolite, but a fibro-radiate structure, which is almost invisible until the specimen is examined with crossed nicols, has developed: in one place round an elongated vesicle, and in other places around felspar-phenocrysts. A mosaic of secondary, colourless quartz, possibly due to solfataric action, has largely replaced some of the original brown glassy matter of these spherulites, but more especially the spaces between them, so that the spherulitic bodies appear light-brown in a nearly-colourless matrix (Pl. XLI, fig. 2).

The rock, as a whole, is more basic and slaggy-looking than the Northern Rhyolite, contains little or no visible primary quartz, and the felspars have more generally the albite-twinning. Its percentage of silica is 75·78, and its specific gravity 2·63.

## (6) Summary of the Bedded Rocks.

TABLE SHOWING SILICA-PERCENTAGES AND SPECIFIC GRAVITIES.

| *Rock-specimens.* | *Percent. of silica.* | *Sp. gravity.* | *Average sp. gr.* |
|---|---|---|---|
| 1. Northern Rhyolite (15) | 81·93 | 2·610 | 2·61 |
| 2. Andesite-Group. | | | |
| (*a*) Red-and-green grits (554) | 55·58 | 2·694 | 2·63 |
| (*a*) Red-and-green grits (551) | 57·07 | 2·570 | |
| (*b*) Palagonite-tuff (Agg. Crag) | 53·45 | 2·743 | 2·75 |
| (*b*) Palagonite-tuff (green, flaggy) | ...... | 2·837 | |
| (*b*) Palagonite-tuff (coarse agg.-breccia) | ...... | 2·700 | |
| (*c*) Green hälleflinta | ...... | 2·670 | |
| (*d*) Green grit (512) | ...... | 2·790 | |
| (*e*) Andesite-lava (516 *c*) | 50·67 | 2·760 | 2·80 |
| (*e*) Andesite-lava (528) | ...... | 2·800 | |
| (*e*) Andesite-lava (57 *a*) | ...... | 2·820 | |
| (*e*) Andesite-lava (513) | ...... | 2·800 | |
| (*e*) Andesite-lava (204) | ...... | 2·830 | |
| 3. Rhyolite-grits and breccias | 74·83 | 2·640 | 2·64 |
| 4. South-Eastern Rhyolite | 75·78 | 2·630 | 2·63 |

The foregoing table shows that a considerable gap in silica-percentage occurs between the Northern Rhyolite and the more acid of the andesite-tuffs that immediately follow. This fact, combined with the discordance in strike between the banding of the Northern Rhyolite and the succeeding tuffs (see map, Pl. XXXVIII), might be taken to imply, either that a considerable break in the volcanic history here exists at the base of the tuffs, or that the junction is a disturbed one. Unfortunately, the junction is largely obscured by the dolerite, and where this is not the case, it is impossible to see the relation of the two rock-groups. There still remains another alternative, namely that the Northern Rhyolite is intrusive, as stated by Mr. Blake,[1] and does not belong to the bedded volcanics of the

[1] See *ante*, pp. 451, 452.

hill. While it may be impossible to disprove its intrusive origin (for the banded and pyromeridal structures do not necessarily negative its intrusion), it seems more in accordance with the facts[1] to consider the rhyolite as an outpouring of lava, and to regard its junction with the andesite-tuffs as a break in the history of the volcanic activity represented by the Pontesford rocks.[2]

After leaving the Northern Rhyolite, the whole of the tuffs and lavas, including the acid breccias and rhyolite at the south-eastern end, form a continuous bedded series, despite the great difference in the average silica-percentage of the Andesite-Group and the Rhyolite-Breccias near the South-Eastern Rhyolite. Commencing with a silica-percentage of nearly 60, these andesite-tuffs (together with their associated lavas) become practically basic, with a little over 50 per cent., and end with tuff and lava of a pronounced acid type, with a percentage of about 75.

Thus, even if the Northern Rhyolite should be regarded as intrusive (and to determine this finally, evidence from adjacent Uriconian areas may have to be considered), the South-Eastern Rhyolite must be regarded as bedded.

It is impossible to point definitely to the source of these bedded volcanic rocks, but from the thinning of the tuffs towards the north-east, and the diminution of the size of their lapilli, together with their more gritty and washed appearance, when followed in this direction, it might be inferred that they had their origin in some vent or vents to the west of the present site of Pontesford Hill.

## (7) The Intrusive Basic Rocks.

The basaltic rocks that make up the higher ground of the hill vary considerably in colour and texture from point to point. Typically, the rock is a dark or purplish-red, coarsely-amygdaloidal dolerite or diabase, well shown along the eastern side, where it has weathered into bare, bold cliffs. But in other places it is iron-grey, very hard, fine-grained, and compact (60), or again somewhat coarsely crystalline, and showing to the naked eye a marked ophitic structure (35, 514, etc.). In places along the Camp at the top of the hill, and elsewhere, the rock has an intense red colour, due to the large amount of hæmatite contained in it. Specimens may be collected showing a breccia-like appearance, the angular fragments differing slightly in texture and colour from the surrounding material, as if a partly-consolidated mass had been broken up by subsequent intrusion. In other places the rock exhibits a spheroidal structure (424), the spheroids measuring sometimes a foot across.

[1] If the 'inlier' of rhyolite-rock (559), described on pp. 455–56, be a true tuff, the evidence for the extrusive origin of the rhyolite would seem fairly complete.

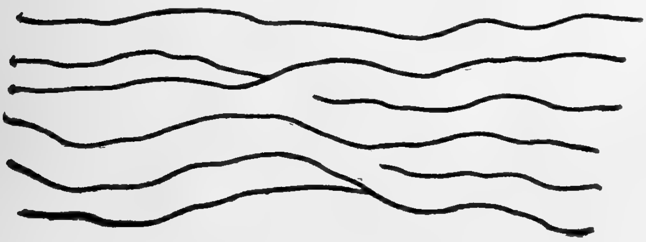
[2] For a description of an ancient, bedded, volcanic group, with sudden and marked changes in chemical composition, see Sir Archibald Geikie's 'Ancient Volcanoes of Great Britain' vol. i (1897) pp. 145 *et seqq.*, and Quart. Journ. Geol. Soc. vol. xxxix (1883) pp. 300 *et seqq.*

The amygdaloidal type shows vesicles generally elongated in a direction parallel to the strike of the bedded tuffs, sometimes 2 or more inches long, and filled with calcite and other secondary minerals, which, however, have in some cases been dissolved out, giving to the rock a very vesicular, slaggy appearance.

In a small quarry at the extreme south-western end of the hill (431),[1] very fine specimens of the amygdaloidal rock may be seen. The vesicles, up to 2 inches across, which are here quite round, have been filled with small spherulitic growths of red iron-oxide and chalcedony with pronounced concentric rings, the clearer siliceous portions showing a dark cross in polarized light. These bodies generally line the wall of the vesicle, while the intervening spaces have been filled mostly with calcite, but also with chalcedony, chlorite, and, in some cases, further spherulitic aggregates of iron-oxide. The rock is here much veined, showing slickensides, and calcite has been deposited in large quantities.

Microscopic sections of the rock often show the felspars orientated in the direction of strike of the andesite-tuffs, and at one place in the basalt of the Camp (53), curious roughly-parallel and wavy lines, about one-eighth of an inch apart, are visible on the weathered surface, and have the same direction. They stand out as thin ribs, as if made of harder material than the rest of the rock (fig. 5).[2]

Fig. 5.—*Roughly-parallel wavy ridges on a weathered surface of basalt.* (*Natural size.*)



Prof. Bonney has described a specimen from the Camp. He says:—

'The groundmass is full of elongated microliths of felspar with a slightly-parallel grouping, generally plagioclase, but possibly in one or two cases orthoclase, with dark granules, probably in many cases hæmatite, and numerous grains (generally rather irregular in outline) of augite. One of more definite form is a compound crystal, about 0·02 inch in diameter. The rock is a basalt, and more resembles that of a flow than of a dyke.'[3]

It may be added that the rock is a type of the finely-granular dolerite or basalt, and that very little of the original material of the felspars or augite remains, although the outlines of the crystals are perfectly preserved. Silica-percentage = 47·62; specific gravity = 2·84.

[1] This is the opening referred to by Murchison: see p. 451.

[2] A thin slice, taken across a selected specimen of the rock, did not reveal any difference in structure or composition such as might account for these curious ribs. The same structure, but on a larger scale, is to be seen in some of the igneous rocks of Llanvawr, in the Ordovician of the Corndon district.

[3] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 124.

A typical specimen of the granulitic dolerite (28) is from the northern slope of the hill. It contains laths of felspar measuring up to 0·05 inch in length, showing simple, but generally lamellar twinning, and a tendency to a parallel arrangement, with extinction-angles as high as 40°, indicating a felspar of the basic labradorite-series; plates of yellowish-brown augite measuring 0·04 inch across, sometimes enclosing felspar-laths, and in one or two places surrounding phenocrysts of olivine. Numerous large crystals of olivine, 0·06 inch long, showing the typical crystal-outlines and cracking, are now converted into pale-green, faintly-polarizing serpentine, with the characteristic hæmatite-rods and plates along the edges and cracks. Frequently the phenocrysts are aggregated, so as to approach the 'glomeroporphyritic' structure of Prof. Judd. The groundmass is made up of a fine mesh of felspar-laths having very low extinction-angles, surrounded by much light-brown and greenish augite in a finely-granular condition, and possibly some minute olivine-crystals, together with grains of magnetite and ilmenite, forming the pilotaxitic structure of Rosenbusch.

The rock appears to be a typical example of a granulitic augite-olivine-dolerite with two generations of felspar, the earlier consisting of phenocrysts of labradorite, the later, forming the matrix, a more acid felspar allied to oligoclase (Pl. XLIII, fig. 6). For the full analysis and the specific gravity see p. 481.

No. 60, at the extreme southern end of the hill, may be taken as a type of the ophitic dolerite. It is made up of plates of yellowish-brown, almost colourless augite nearly 0·1 inch across, enclosing laths of labradorite measuring up to 0·08 inch in length. Olivine-phenocrysts are abundant, but are all converted into pale-green serpentine, in some cases with a distinct spherulitic or fibrous structure, and with the usual separation of magnetite and hæmatite along the borders and cracks. The felspars have been largely replaced by secondary substances, while the augite is relatively fresh; but this, too, in places has degenerated into a serpentine-product. Silica-percentage=45·64; specific gravity=2·84.

No. 569, from the edge of the dolerite-mass on the western slope, shows pronounced ophitic structure, and the olivine, which is plentiful, has completely degenerated; much green serpentine, with pale-yellow granules, white by reflected light, and plates and rods of hæmatite and magnetite resulting from its decomposition. Specific gravity=2·85.

No. 514, from the north-western slope, near the gritty tuffs of the Andesite-Group, shows the ophitic structure to the naked eye, with much green material, little laths of felspar, and occasional round vesicles filled with a dark-green substance. Microscopic examination reveals large plates of augite, of a deeper brown than usual, enclosing felspar-laths measuring up to nearly 0·1 inch in length. No recognizable olivine occurs, but much greenish-yellow serpentine-material, often minutely spherulitic, and containing small pale-brown granules, white by reflected light, as well as grains iron-ore. A good deal of ilmenite with leucoxene occurs in this rock. Specific gravity=2·86.

The following table gives the percentage of silica and specific gravity of varieties of the intrusive dolerite, taken from different parts of the mass:—

| *No. of specimen.* | *Percentage of silica.* | *Specific gravity.* |
|---|---|---|
| 28 | 48·30 | 2·88 |
| 60 | 45·64 | 2·84 |
| 211 | 47·62 | 2·84 |
| 35 | 45·81 | 2·84 |
| 17 | 50·13 | 2·83 |
| 569 | ...... | 2·85 |
| 54 | ...... | 2·86 |
| 514 | ...... | 2·86 |
| Average | 47·50 | 2·85 |

The following complete analysis of a compact, relatively-fresh-looking sample of the granulitic dolerite (28) was kindly made for me by Dr. C. F. Baker, to whom I am also indebted for the determination of the silica-percentages in the foregoing table:—

| | I. | II. | III. |
|---|---|---|---|
| $SiO_2$ | 48·30 | 49·860 | 48·8 |
| $TiO_2$ | not est. | 1·330 | not est. |
| $Al_2O_3$ | 19·00 | 12·750 | 18·1 |
| $Fe_2O_3$ | 6·72 | 3·360 | 3·5 |
| FeO | 3·97 | 11·380 | 7·2 |
| CaO | 8·93 | 8·710 | 8·4 |
| MgO | 3·53 | 4·395 | 4·9 |
| $Na_2O$ | 5·01 | 5·250 | 3·7 |
| $K_2O$ | 2·38 | 0·570 | 1·9 |
| $P_2O_5$ | — | 0·580 | — |
| $H_2O$ | 2·05 (ignit.) | 2·560 | 3·6 (ignit.) |
| Totals | 99·89 | 100·745 | 100·1 |
| Specific gravity | 2·88 | 2·907 | 2·79 |

I. Compact granulitic dolerite, Pontesford Hill.
II. Dolerite, Rowley. (See J. J. H. Teall 'Brit. Petrogr.' 1888, p. 213.)
III. Dolerite, Hailstone Hill, Rowley. (Do.)

By the side of this analysis I have placed two analyses of the dolerite, intrusive in the Coal-Measures of Rowley (Staffordshire), with which the Pontesford rock seems to show some points of resemblance. It will be noted, however, that the iron is mainly in the ferric state in the case of the Pontesford dolerite, and the minerals in the latter rock are not nearly so fresh, in general, as in the Rowley rock. This is particularly the case with the olivine and the felspars, while the augite has not the deep purplish-brown colour that characterizes that mineral in most of the Rowley rocks.[1] In this connection it should be borne in mind that the Rowley specimens, especially those collected by Allport, were obtained from

[1] Probably due to an absence of titanic acid in the Pontesford rock. Unfortunately, in the above analysis, titanic acid was not looked for.

a relatively-fresh and unaltered portion of the rock, whereas, owing to the absence of quarries or other deep openings, those from Pontesford were taken from near the surface. The general resemblance in chemical composition, mineral contents, and structures of the Pontesford rock and that of Rowley would apply also to the dolerites of the Clee Hills, Kinlet, and the east of the Wrekin, and applies almost equally well to some of the Tertiary dolerites of Scotland, described by Prof. Judd.[1] On the other hand, it differs from most of the intrusive dolerites of North Wales, mainly in the absence of olivine in these latter rocks; while the olivine-diabase or basalt-lava, associated with the Pebidian rocks of St. David's (Pembrokeshire), described by Sir Archibald Geikie,[2] differs from the Pontesford rock, mainly in the much greater amount of magnesia and smaller quantity of potash in the Pembrokeshire rock.

### (8) Relation of the Intrusive Basic Rocks to the Bedded Rocks.

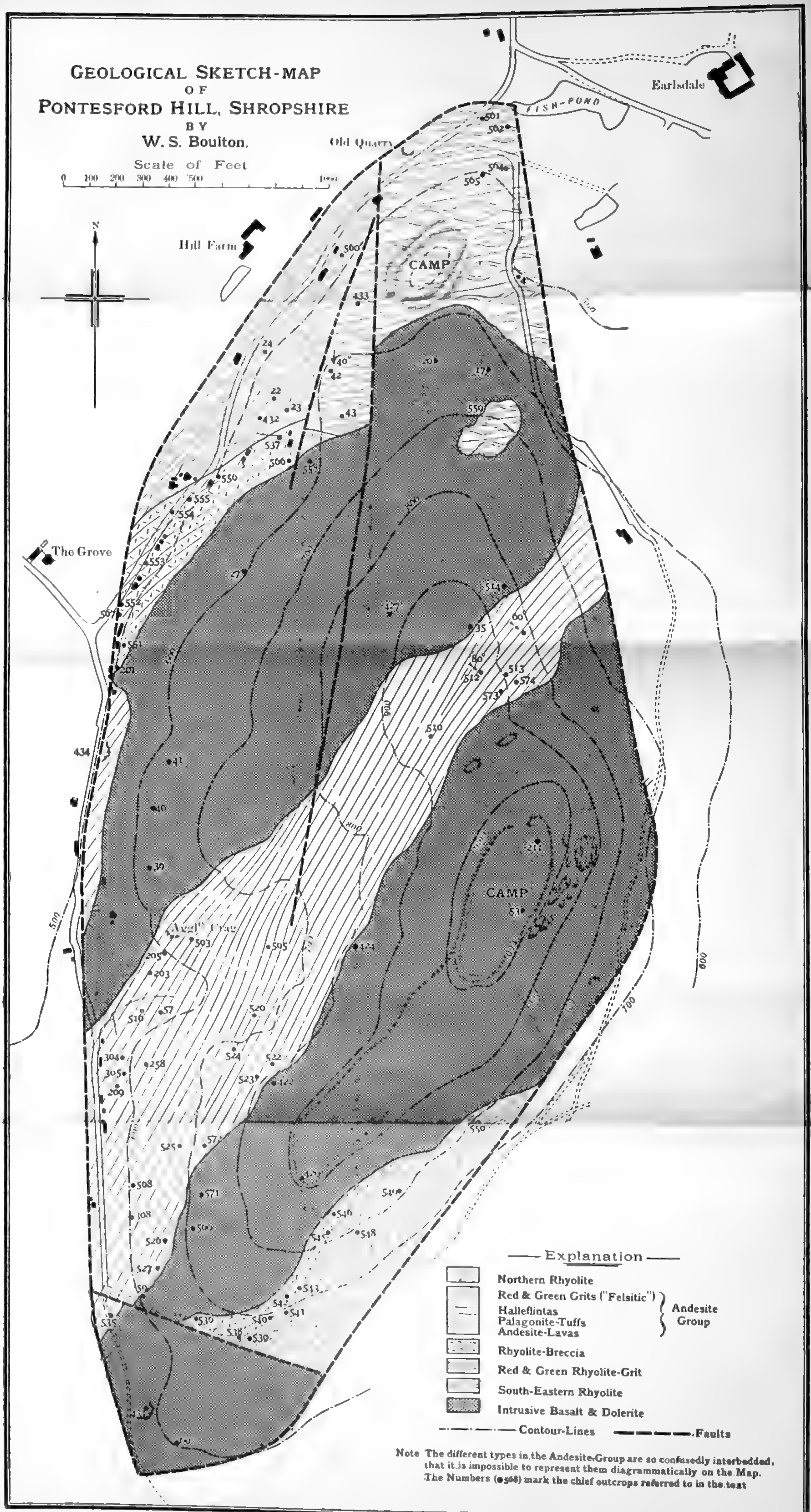
Although the general trend of the dolerite-masses of the hill is with the bedding of the tuffs, there can be no doubt that the dolerite is intrusive in the latter, notwithstanding that some of the characters, such as the coarsely-vesicular structure and the parallel arrangement of vesicles and felspar-crystals, are those generally associated with bedded lava-flows. In some places (516 *d*, 201) the dolerite can be seen penetrating, and enclosing masses of, the andesite-tuffs and lava, while the irregular junction of the dolerite and the bedded rocks (see map, Pl. XXXVIII) would preclude the possibility of its being interbedded with the latter.

It is highly probable that the dolerite forced its way into the underlying tuffs and lavas, mainly along two lines of weakness, near the south-eastern margins of the two dolerite-masses shown on the map, and, with relief of pressure, spread out among the bedded rocks. But whether the dolerite actually came out at the surface, or formed a laccolitic mass between the tuff-series and newer beds now removed (possibly Cambrian or Bala, both of which are in the immediate vicinity), there is no direct evidence to show. It would seem more probable, however, that the dolerite invaded the bedded rocks during the disturbance of the latter, which resulted in their present high inclination (see map and sections, Pls. XXXVIII & XXXIX).

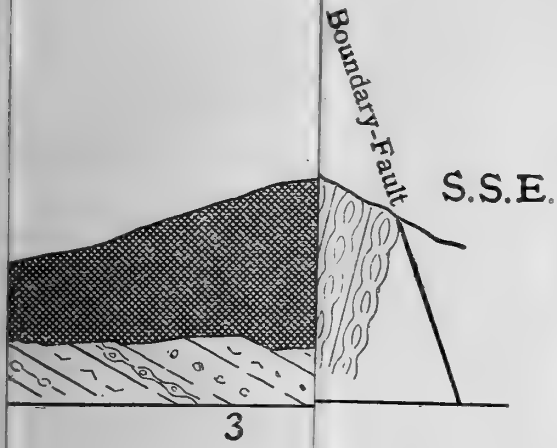
## IV. General Summary of Conclusions.

The present paper is confined to a description of the characters and sequence of the rocks within the limits of Pontesford Hill, and no attempt is here made to correlate them with those of other Uriconian areas.

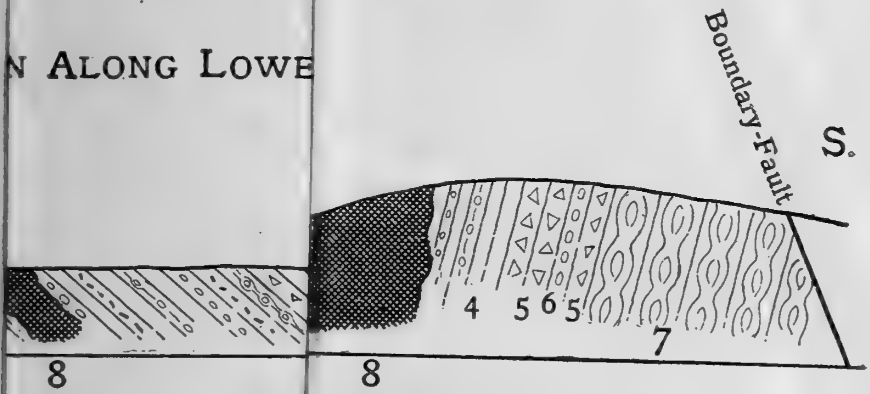
[1] Quart. Journ. Geol. Soc. vol. xlii (1886).
[2] *Ibid.* vol. xxxix (1883) p. 293.


GEOLOGICAL SKETCH-MAP
OF
PONTESFORD HILL, SHROPSHIRE
BY
W. S. Boulton.
Scale of Feet
0 100 200 300 400 500 1000
Earlsdale
FISH-POND
Old Quarry
Hill Farm
CAMP
The Grove
Ang^{ls} Crag
CAMP
Explanation
Northern Rhyolite
Red & Green Grits ("Felsitic")
Halleflintas
Palagonite-Tuffs
Andesite-Lavas
Andesite Group
Rhyolite-Breccia
Red & Green Rhyolite-Grit
South-Eastern Rhyolite
Intrusive Basalt & Dolerite
Contour-Lines
Faults
Note The different types in the Andesite-Group are so confusedly interbedded, that it is impossible to represent them diagrammatically on the Map. The Numbers (●568) mark the chief outcrops referred to in the text

RALIZED SECTI




N ALONG LOWE



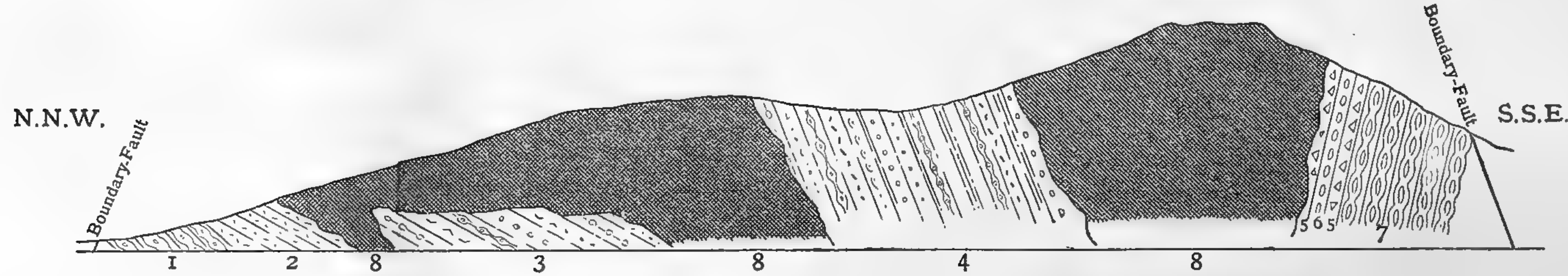

'Felsitic-Looking') Grit

Green Rhyolite-Grit.

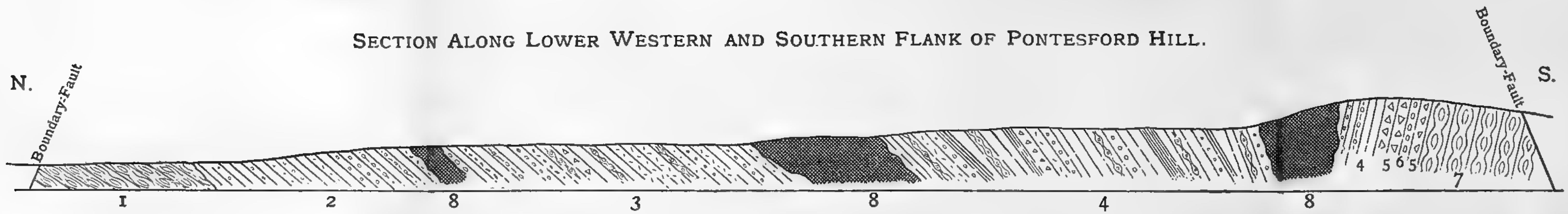
& Vertical Scale

00 300 400 500 feet

GENERALIZED SECTION THROUGH PONTESFORD HILL FROM N.N.W. TO S.S.E.




SECTION ALONG LOWER WESTERN AND SOUTHERN FLANK OF PONTESFORD HILL.




1. Northern Rhyolite. 2. Red and Green ('Felsitic-Looking') Grits. 3. Red Andesite-Tuff. 4. Palagonite-Tuff, Red and Green Grits, Hälleflintas and Andesite-Lava.
5. Pink Rhyolite-Breccia. 6. Red and Green Rhyolite-Grit. 7. South-Eastern Rhyolite. 8. Intrusive Basalt and Dolerite.

Horizontal & Vertical Scale
0 100 200 300 400 500 feet

Pontesford Hill is a 'plagioclinal ridge', bounded on all sides by faults, consisting entirely of igneous rocks, though some of the fine tuffs and volcanic grits show unmistakable signs of deposition in water.

Two distinct groups of igneous rocks are found:—

1. A Bedded Group, consisting of the Northern and South-Eastern Rhyolite respectively, differing in composition and structural characters. Of these, the Northern Rhyolite, of Uriconian type, is probably bedded, but may be intrusive in the Andesite-Group, while the South-Eastern Rhyolite, which is associated with breccias and grits of the same composition, is certainly bedded. Between these acid rocks intervenes a thick series of basic andesite-tuffs (palagonite, hälleflinta, crystal, and gritty), interbedded with basic augite-andesite lava.

Leaving out of account the highly-siliceous Northern Rhyolite, the bedded tuffs and lavas begin with a silica-percentage of about 56 and pass gradually into rocks, which form the bulk of the Andesite-Group, with a little over 50 per cent.; these again become somewhat more acid, and then pass up abruptly into true rhyolite-grits and breccias and rhyolite-lava, with about 75 per cent. of silica.

The general strike of these bedded rocks is north-north-east and south-south-west, parallel to that of the neighbouring Longmynd rocks, with an average dip of about 80° east-south-eastward; while, at the extreme south-east of the hill, the rhyolite and associated breccias dip in the opposite direction (west-north-westward) at about the same angle.

2. Olivine-Augite Dolerites (granulitic, ophitic, or coarsely amygdaloidal), having a chemical composition and mineralogical characters similar to those of the dolerites of the Carboniferous districts of Staffordshire and Shropshire, are intruded among the bedded rocks in laccolite-like masses.

I have to express my gratitude to Prof. Lapworth for the encouragement and assistance which he has so readily accorded to me during the progress of this work, and also to Prof. Sollas for his kindness in allowing the micro-photographs for the plates to be taken in the Geological Laboratory at the University Museum, Oxford.

## EXPLANATION OF PLATES XXXVIII–XLIII.

### Plate XXXVIII.

Geological sketch-map of Pontesford Hill, on the scale of 400 feet to the inch.

### Plate XXXIX.

Generalized section through Pontesford Hill, from north-north-west to south-south-east; and section along the lower western and southern flank of Pontesford Hill.

PLATE XL.

Fig. 1. Northern Rhyolite (15), showing part of a nodule with mushroom-growths and fibrous matter traversing small spherulitic spaces. The matrix exhibits a perlitic structure with 'micro-lithophyses.' × 17. (See pp. 457–58.)

2. Northern Rhyolite, showing part of the fibrous wall of a nodule (in the upper part of the figure), enclosing felspar-phenocrysts, with angular portions of the wall in the quartz-amygdaloid (to the right of the figure). Bands of chalcedony and spherulitic felsitic matter surround the fibrous wall and detached angular portions, the rest of the amygdaloid consisting of quartz and brown spherulites. × 17. (See pp. 459–60.)

PLATE XLI.

Fig. 1. Northern Rhyolite, showing part of the double wall of a nodule, in which felspar-phenocrysts and radiating tufted growths are visible. The light space between the brown fibrous walls is filled with a quartz-mosaic, enclosing small brown spherulites. × 17. (See p. 459.)

2. South-Eastern Rhyolite. Definite spherulitic growths are seen, but the radial structure is only faintly visible in polarized light. Secondary quartz has largely replaced the substance in the spaces between the spherulites. × 17. (See p. 477.)

PLATE XLII.

Fig. 1. Andesitic gritty tuff (205), with lapilli of andesite-glass filled with felspar-microlites, vesicles, etc. × 25. (See p. 467.)

2. Palagonite-tuff (Agg. Crag, *b*). At the top of the figure is a fragment of palagonite of a bright orange-yellow colour, enclosing felspar-microlites and vesicles with well-marked zonary banding. The dark border round this glass-fragment is made up of a mass of small fragments of the same palagonite. The rest of the field consists of small fragments of palagonite, in a light-grey matrix of secondary zeolitic matter. × 25. (See p. 467.)

3. Palagonite-tuff (308), showing abundant, green, vesicular palagonite-fragments, in which decomposed felspars are embedded; zeolites fill the vesicles, and make up the bulk of the groundmass. × 25. (See p. 469.)

4. Coarsely-laminated hälleflinta (574), showing finer bands of glassy dust and coarser bands of yellowish-green palagonite-tuff. (× 25.)

PLATE XLIII.

Fig. 1. Palagonite-tuff (518), with characteristically-shaped glassy fragments turned into green palagonite and filled with microlites of felspar and round vesicles, showing zonary banding, and now filled with zeolites. (× 24.)

2. The same, showing in the lower half of the figure a portion of a large lapillus of very vesicular light-brown glass. (× 25.)

3. Finely-laminated hälleflinta, with grey (coarser) and yellow (finer) bands of fine-grained glassy and crystal-dust. The glassy particles are all converted into palagonite. × 25. (See pp. 467–68.)

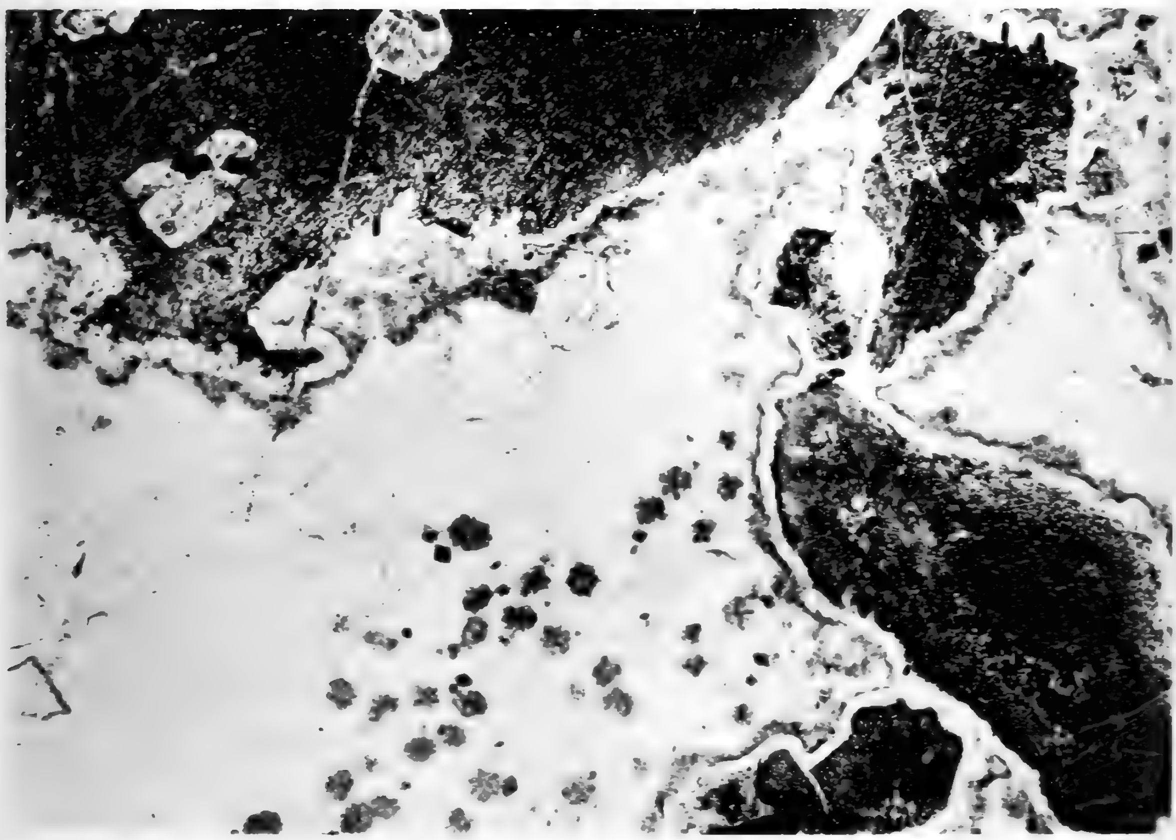
4. Red-and-green grit (539), associated with the South-Eastern Rhyolite, showing cloudy felspars, rounded grains of quartz, and dark curvilinear splinters of altered glass, which are yellow, green, or red in colour. × 23½. (See pp. 458, 475.)

5. Andesite-lava (516 *c*) showing a mesh of felspar-laths in a matrix which is now largely converted into orange-yellow palagonite (the nearly-black portions in the figure). In the centre is a group of pale-yellow augite-crystals. × 24. (See p. 471.)

6. Granulitic olivine-dolerite (28). There is a cluster of labradorite- and olivine-crystals, the latter converted into pale-green serpentine, with hæmatite-rods and fibres along the cracks and borders. The matrix consists of a 'granulitic' aggregate of felspar and augite. × 23½. (See p. 480.)

FIG. 1. × 17.

FIG. 2. × 17.



THE IGNEOUS ROCKS OF PONTESFORD HILL (SHROPSHIRE).

*Photomicro, W. S. Boulton* *Bemrose, Collo.*

Fig. 1. × 17.

Fig. 2. × 17.

THE IGNEOUS ROCKS OF PONTESFORD HILL (SHROPSHIRE).

*Photomicro, W. S. Boulton.* *Bemrose, Collo.*

FIG. 1. × 25.

FIG. 2. × 25.

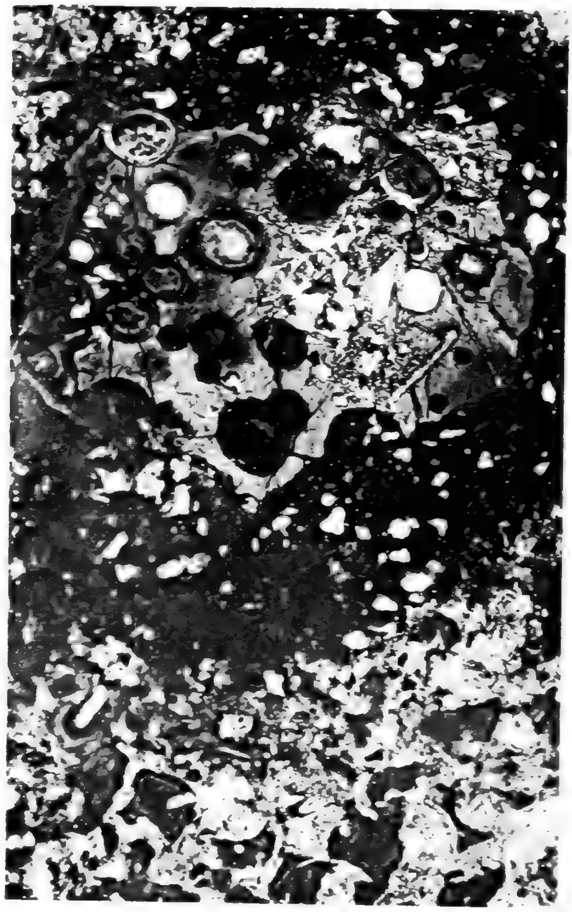


FIG. 3. × 25.

FIG. 4. × 25.

THE IGNEOUS ROCKS OF PONTESFORD HILL (SHROPSHIRE).

*Photomicro, W. S. Boulton.*

*Bemrose, Collo.*

Fig. 1. × 24.

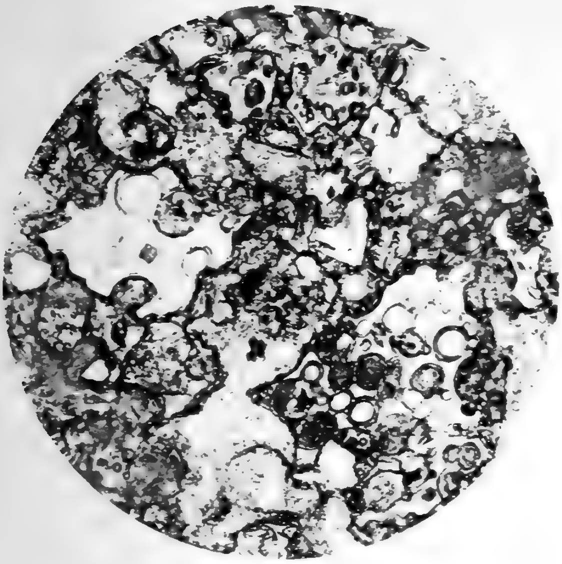


Fig. 2. × 25.

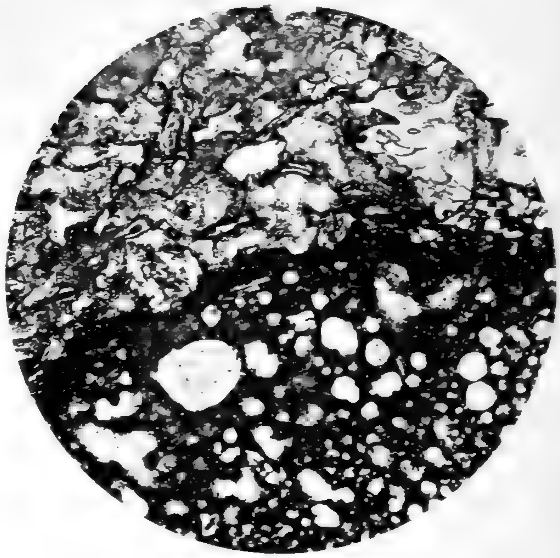


Fig. 3. × 25.

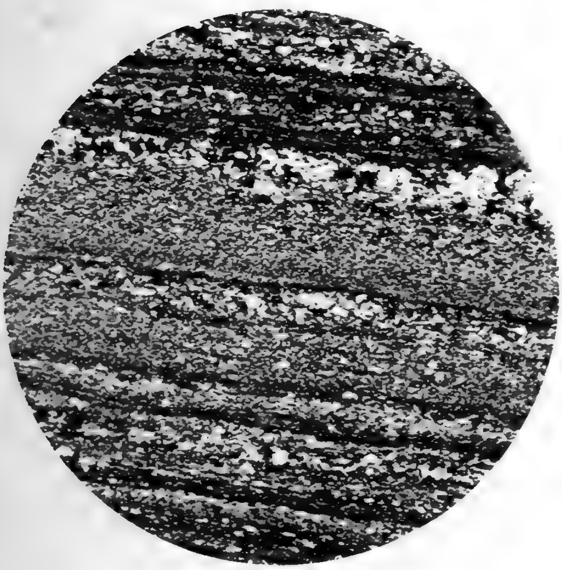


Fig. 4. × 23½.

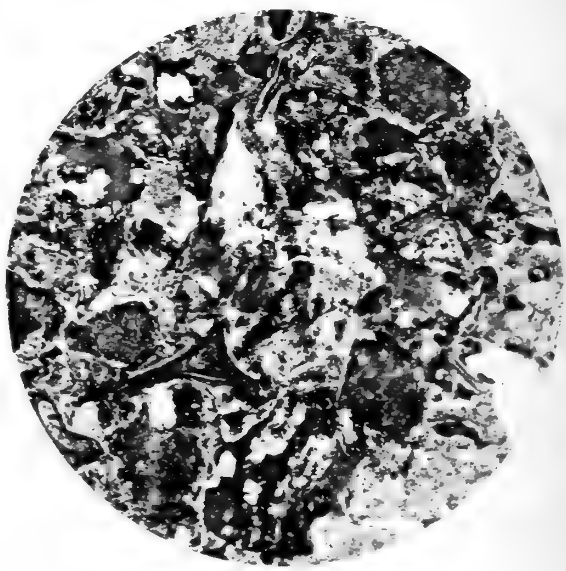
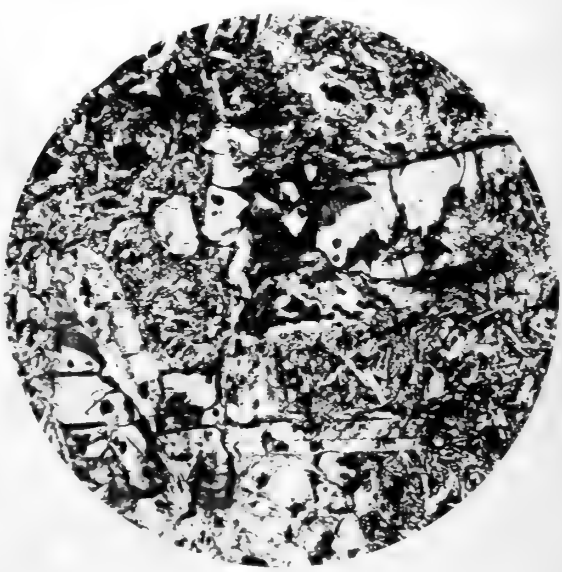


Fig. 5. × 24.

Fig. 6. × 23½.



THE IGNEOUS ROCKS OF PONTESFORD HILL (SHROPSHIRE).

*Photomicro, W. S. Boulton.* *Bemrose, Collo.*

## Discussion.

The President said that he felt that the detailed petrographical descriptions given by the Author were of much value. He stated that hopes had been held out that Prof. Lapworth would come to the Meeting, and he felt sure that all the Fellows present would regret his absence and the cause of it. In these circumstances, he asked the Secretary to read some remarks which Prof. Lapworth had kindly contributed to the discussion.

Prof. Watts said that Prof. Lapworth had hoped to attend the Meeting, and to speak upon the stratigraphical aspect of the question, but unfortunately he was not well enough to be present. He had, however, asked him to say that

'the tuffs and lavas of Pontesford were clearly faulted against Cambrian strata on the western side of the hill, while Bala Beds were exposed at several points in the valley running practically all along its eastern side. These Pontesford rocks, however, were merely a portion of a broken band of Uriconian rocks occurring at intervals from Plealey on the north to Linley on the south, and following at once in contact with Upper Longmyndian strata near both ends of this line, inverted in position, however (like the Longmynd generally), in the northern half. Uriconian volcanic rocks also occurred on the eastern side of the Longmynd, as at Ragleth, Caradoc, and elsewhere, where, however, they rested transgressively upon the Lower Longmyndian and began with the so-called Helmeth Grits.

'The Longmyndian formation itself (which was made up of a Lower division of grey, green, and red shales and grits, reminiscent of the Charnian of Leicestershire; and an Upper division of red sandstones, grits, and conglomerates, reminiscent of the Torridonian of Scotland, with an intermediate zone—the Bayston Group—combining characteristics of both) was certainly sedimentary throughout. But the materials of which the beds were made up appeared to have been largely pyroclastic in origin, and were often suggestive of simultaneous volcanic action at no great distance outside the Longmyndian area. Broadly speaking, the amount of this ashy or felspathic material increased as the succession was ascended, and the typical volcanic rocks of the so-called Uriconian marked apparently the local incoming or culminating phase of this volcanic action, connected perhaps with the movements which brought the Longmyndian to a close and prepared the way for the Cambrian.

'The igneous rocks of Pontesford Hill, both bedded and intrusive, although perhaps not more varied, were less involved than those of the other Uriconian areas; and now that the Author had so admirably cleared up their character and inter-relations, he hoped that he would carry on his researches into the more complicated Uriconian areas in other parts of Shropshire.'

The Rev. J. F. Blake said that he had not been able to follow the details so rapidly given by the Author, but he hoped to read them more at leisure. Although he (the speaker) had referred to the relations of Pontesford Hill, he had not attempted any complete account of it, and he would only venture the remark that volcanic tuffs and ashes appeared to him in many cases to be somewhat too freely quoted, considering the difference that they showed when compared with those exposed among recent volcanoes.

Mr. Parkinson, referring to the great difficulty, from a petrographical point of view, of the Pontesford rhyolites, said that he felt that all students of this group of rocks would be grateful to the Author for the able paper which he had submitted to the Society.

The Author had mentioned that the spherulitic type of devitrification was not all of the same age, and the speaker asked whether this, in part, might be connected with intrusion, as in the well-known instance described by Prof. Bonney. The possibility that these lithophysal rhyolites might be intrusive was a point of considerable interest.

Prof. Groom drew attention to the apparent resemblance between the rocks described by the Author and those occurring as pebbles in the Cambrian and Silurian Series of the Malvern Hills.

The Author, in reply, said that he was not aware that the spherulitic structure in the South-Eastern Rhyolite was due to the intrusion of the dolerite. He agreed with Mr. Parkinson that the presence of spherulitic and pyromeridal structures in the Northern Rhyolite would be additionally interesting, if the latter turned out to be intrusive; but the weight of evidence was in favour of its bedded origin. Some years ago the Author collected, and had sliced, a large number of specimens from the 'Warren-House' rocks, on the eastern flank of the Malverns, and he could endorse what Prof. Groom had said with regard to the points in common between them and some of the Pontesford rocks. He thanked the Fellows present for their reception of his paper.

# GENERAL INDEX

TO

## THE QUARTERLY JOURNAL

AND

## PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

---

END OF VOL. LX.

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

**Vol. LX.** FEBRUARY 15th, 1904. **No. 237.**
Part 1.

C. A. White

THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

[With Fourteen Plates, illustrating Papers by Mr. E. T. Newton, Mr. Cunningham-Craig, Mr. Acland, Prof. Gregory, Miss Healey, and the late Mr. E. E. Walker.]

LONDON:

LONGMANS, GREEN, AND CO.

PARIS:—CHARLES KLINCKSIECK, 11 RUE DE LILLE.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

*Price Five Shillings.*

# LIST OF THE OFFICERS OF THE GEOLOGICAL SOCIETY OF LONDON.

Elected February 20th, 1903.

## President.

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

## Vice-Presidents.

Sir Archibald Geikie, D.C.L., D.Sc., LL.D., Sec.R.S.
Prof. Henry Alexander Miers, M.A., F.R.S.
Edwin Tulley Newton, Esq., F.R.S.
J. J. Harris Teall, Esq., M.A., F.R.S.

## Secretaries.

Robert Stansfield Herries, Esq., M.A.
Prof. W. W. Watts, M.A., M.Sc.

## Foreign Secretary.

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

## Treasurer.

William Thomas Blanford, C.I.E., LL.D., F.R.S.

## COUNCIL.

The Rt. Hon. the Lord Avebury, P.C., D.C.L., LL.D., F.R.S., F.S.A., F.L.S.
Francis Arthur Bather, M.A., D.Sc.
William Thomas Blanford, C.I.E., LL.D., F.R.S.
Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S., F.S.A., F.L.S.
Prof. Edmund Johnstone Garwood, M.A.
Sir Archibald Geikie, D.C.L., D.Sc., LL.D., Sec.R.S.
Prof. Theodore Groom, M.A., D.Sc.
Alfred Harker, Esq., M.A., F.R.S.
Robert Stansfield Herries, Esq., M.A.
Robert Logan Jack, LL.D.
Prof. John W. Judd, C.B., LL.D., F.R.S.
Percy Fry Kendall, Esq.
Prof. Charles Lapworth, LL.D., F.R.S.
Lieut.-General Charles Alexander McMahon, F.R.S.
John Edward Marr, M.A., Sc.D., F.R.S.
Prof. Henry Alexander Miers, M.A., F.R.S.
Horace Woollaston Monckton, Esq., F.L.S.
Edwin Tulley Newton, Esq., F.R.S.
George Thurland Prior, Esq., M.A.
Prof. Harry Govier Seeley, F.R.S., F.L.S.
Prof. William Johnson Sollas, M.A., D.Sc., LL.D., F.R.S. L. & E.
J. J. Harris Teall, Esq., M.A., F.R.S.
Prof. W. W. Watts, M.A., M.Sc.

---

## Assistant-Secretary, Clerk, Librarian, and Curator.

L. L. Belinfante, M.Sc.

## Assistants in Office, Library, and Museum.

W. Rupert Jones. Clyde H. Black.
Alec Field.

---

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

SESSION 1903–1904.

1904.

| | | |
|---|---|---|
| Wednesday, | February (*Anniversary*, Friday, Feb. 19th)... | 24* |
| ,, | March ........................................ | 9*—23 |
| ,, | April ........................................ | 13*—27 |
| ,, | May ........................................ | 11*—25 |
| ,, | June ........................................ | 8*—22* |

[*Business will commence at Eight o'Clock precisely each Evening.*]

The dates marked with an asterisk are those on which the Council will meet.

# ADMISSION AND PRIVILEGES

OF

# FELLOWS OF THE GEOLOGICAL SOCIETY OF LONDON.

EVERY Candidate for admission as a Fellow must be proposed by three or more Fellows, who must sign a Certificate in his favour. The Proposer whose name stands first upon the Certificate must have a personal knowledge of the Candidate.

Fellows on election pay an Admission-Fee of Six Guineas. The Annual Contribution paid by Fellows is Two Guineas, due on the 1st of January in every year, and payable in advance; but Fellows elected after the month of February are subject only to a proportionate part of the Contribution for the year in which they are elected, and Fellows elected in November or December pay no Contribution for the current year. The Annual Contribution may at any time be compounded for by a payment of Thirty-Five Pounds.

The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling-prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

---

# CONTENTS.



**[No. 238 will be published next May.]**

**[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]**

***** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.**

The Library and Museum at the Apartments of the Society are open every Weekday from Ten o'clock until Five, except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.

**Vol. LX.** MAY 14th, 1904. **No. 238.**
PART 2.

# THE QUARTERLY JOURNAL OF THE GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

[With Five Plates, illustrating Papers by Dr. A. Smith Woodward, Prof. Lloyd Morgan & Prof. Reynolds, Prof. Reynolds & Mr. Vaughan, and Dr. Davison.]



LONDON:

LONGMANS, GREEN, AND CO.

PARIS:—CHARLES KLINCKSIECK, 11 RUE DE LILLE.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

*Price Five Shillings.*

LIST OF THE OFFICERS OF THE

# GEOLOGICAL SOCIETY OF LONDON.

Elected February 19th, 1904.

### President.

John Edward Marr, Sc.D., F.R.S.

### Vice-Presidents.

Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Edwin Tulley Newton, Esq., F.R.S.
Horace Bolingbroke Woodward, Esq., F.R.S.

### Secretaries.

Robert Stansfield Herries, Esq., M.A.
Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.

### Foreign Secretary.

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

### Treasurer.

William Thomas Blanford, C.I.E., LL.D., F.R.S.

### COUNCIL.

The Rt. Hon. the Lord Avebury, P.C., D.C.L., LL.D., F.R.S., F.L.S.
Francis Arthur Bather, M.A., D.Sc.
William Thomas Blanford, C.I.E., LL.D., F.R.S.
Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S.
Prof. Edmund Johnstone Garwood, M.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Prof. Theodore Groom, M.A., D.Sc.
Alfred Harker, Esq., M.A., F.R.S.
Robert Stansfield Herries, Esq., M.A.
Prof. John W. Judd, C.B., LL.D., F.R.S.
Percy Fry Kendall, Esq.
Philip Lake, Esq., M.A.
Prof. Charles Lapworth, LL.D., F.R.S.
Bedford McNeill, Esq., Assoc. R.S.M.
John Edward Marr, Sc.D., F.R.S.
Prof. Henry Alexander Miers, M.A., F.R.S.
Horace Woollaston Monckton, Esq., F.L.S.
Edwin Tulley Newton, Esq., F.R.S.
George Thurland Prior, Esq., M.A.
Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.
The Rev. Henry Hoyte Winwood, M.A.
Horace Bolingbroke Woodward, Esq., F.R.S.

---

### Assistant-Secretary, Clerk, Librarian, and Curator.

L. L. Belinfante, M.Sc.

### Assistants in Office, Library, and Museum.

W. Rupert Jones. Clyde H. Black.
Alec Field.

---

## EVENING MEETINGS OF THE GEOLOGICAL SOCIETY

TO BE HELD AT BURLINGTON HOUSE.

SESSION 1903–1904.

1904.

Wednesday, May ........ 25
,, June ........ 8*—22*

[*Business will commence at Eight o'Clock precisely each Evening.*]

The dates marked with an asterisk are those on which the Council will meet.

# ADMISSION AND PRIVILEGES

OF

# FELLOWS OF THE GEOLOGICAL SOCIETY OF LONDON.

EVERY Candidate for admission as a Fellow must be proposed by three or more Fellows, who must sign a Certificate in his favour. The Proposer whose name stands first upon the Certificate must have a personal knowledge of the Candidate.

Fellows on election pay an Admission-Fee of Six Guineas. The Annual Contribution paid by Fellows is Two Guineas, due on the 1st of January in every year, and payable in advance; but Fellows elected after the month of February are subject only to a proportionate part of the Contribution for the year in which they are elected, and Fellows elected in November or December pay no Contribution for the current year. The Annual Contribution may at any time be compounded for by a payment of Thirty-Five Pounds.

The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling-prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

---

## Publications to be had of the Geological Society, Burlington House.

| TRANSACTIONS. | Reduced Price to the Fellows. £ s. d. |
|---|---|
| Vol. I, Part 2 | 1 8 0 |
| Vol. III, Part 2 | 0 4 0 |
| „ Part 3 | 0 4 0 |
| Vol. VI, Part 2 | 0 10 0 |
| Vol. VII, Part 4 | 0 10 0 |

**QUARTERLY JOURNAL.** (Vols. III to LIX, inclusive.)

Price to Fellows, 13*s.* 6*d.* each (Vols. XV, XXIII, XXX, and XXXIV to LIX, 16*s.* 6*d.*), in cloth.

**CLASSIFIED INDEX TO THE TRANSACTIONS, JOURNAL,** &c., by G. W. ORMEROD, Esq. New Edition, to the end of 1868, with First, Second, and Third Supplements to the end of 1889. Price 8*s.* 6*d.* To Fellows, 5*s.* 6*d.* [Postage 5*d.*]—The First, Second, and Third Supplements may be purchased separately.

**GENERAL INDEX TO THE FIRST FIFTY VOLUMES OF THE QUARTERLY JOURNAL** (1845–1894). Part I (A–La). Part II (La–Z). Price 5*s.* each. To Fellows 3*s.* 9*d.* each. [Postage 3*d.*]

**CATALOGUE OF THE LIBRARY,** 1880. (620 pages 8vo.) Price 8*s.* To Fellows 5*s.* [Postage 6*d.*]

**GEOLOGICAL LITERATURE** added to the Geological Society's Library during the years ended December 31st, 1894–1902. Price 2*s.* each. To Fellows 1*s.* 6*d.* each. [Postage 2½*d.*]

**LIST OF THE TYPE- AND FIGURED SPECIMENS RECOGNIZED BY C. D. SHERBORN IN THE COLLECTION OF THE GEOLOGICAL SOCIETY,** verified and arranged, with additions, by the Rev. J. F. BLAKE. 1902. Price 3*s.* 6*d.* (bound in cloth), 3*s.* 0*d.* (in paper wrappers). To Fellows 2*s.* 6*d.* and 2*s.* 0*d.* [Postage 3*d.*]

**HUTTON'S 'THEORY OF THE EARTH,'** Vol. III., edited by Sir ARCHIBALD GEIKIE, D.C.L., F.R.S. Price 3*s.* 6*d.* To Fellows 2*s.* [Postage 4*d.*]

**THE GEOLOGY OF NEW ZEALAND.** Translated by Dr. C. F. FISCHER, from the works of MM. HOCHSTETTER & PETERMANN. With an Atlas of Six Maps.

Fellows may purchase One Copy of this book at 2*s.*; additional copies will be charged 4*s.* [Postage 5*d.*]

# CONTENTS.



## PAPERS READ.



**[The List of Geological Literature for 1903 will be issued shortly.—No. 239 of the Quarterly Journal will be published next August.]**

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library and Museum at the Apartments of the Society are open every Weekday from Ten o'clock until Five, except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.

**Vol. LX.** Part 3. AUGUST 15th, 1904. **No. 239.**

C. A. White

THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

**[With Thirteen Plates, illustrating Papers by Dr. Davison, Col. English, Mr. R. B. Newton, Mr. R. Holland, Prof. G. de Lorenzo, Mr. H. N. Davies, Mr. Arnold-Bemrose, and Mr. J. V. Elsden.]**

LONDON:

LONGMANS, GREEN, AND CO.

PARIS:—CHARLES KLINCKSIECK, 11 RUE DE LILLE.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

*Price Five Shillings.*

LIST OF THE OFFICERS AND COUNCIL OF THE

# GEOLOGICAL SOCIETY OF LONDON.

Elected February 19th, 1904.

## President.

John Edward Marr, Sc.D., F.R.S.

## Vice-Presidents.

Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Edwin Tulley Newton, Esq., F.R.S.
Horace Bolingbroke Woodward, Esq., F.R.S.

## Secretaries.

Robert Stansfield Herries, Esq., M.A.
Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.

## Foreign Secretary.

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

## Treasurer.

William Thomas Blanford, C.I.E., LL.D., F.R.S.

## COUNCIL.

The Rt. Hon. the Lord Avebury, P.C., D.C.L., LL.D., F.R.S., F.L.S.
Francis Arthur Bather, M.A., D.Sc.
William Thomas Blanford, C.I.E., LL.D., F.R.S.
Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S.
Prof. Edmund Johnstone Garwood, M.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Prof. Theodore Groom, M.A., D.Sc.
Alfred Harker, Esq., M.A., F.R.S.
Robert Stansfield Herries, Esq., M.A.
Prof. John W. Judd, C.B., LL.D., F.R.S.
Prof. Percy Fry Kendall.
Philip Lake, Esq., M.A.
Prof. Charles Lapworth, LL.D., F.R.S.
Bedford McNeill, Esq., Assoc. R.S.M.
John Edward Marr, Sc.D., F.R.S.
Prof. Henry Alexander Miers, M.A., F.R.S.
Horace Woollaston Monckton, Esq., F.L.S.
Edwin Tulley Newton, Esq., F.R.S.
George Thurland Prior, Esq., M.A.
Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.
The Rev. Henry Hoyte Winwood, M.A.
Horace Bolingbroke Woodward, Esq., F.R.S.

---

## Assistant-Secretary, Clerk, Librarian, and Curator.

L. L. Belinfante, M.Sc.

## Assistants in Office, Library, and Museum.

W. Rupert Jones.
Clyde H. Black.
Alec Field.

---

## STANDING REFERENCE COMMITTEE.

Dr. J. E. Marr, *President*.

R. S. Herries, Esq.
Prof. W. W. Watts. } *Secretaries.*

Dr. F. A. Bather.
Dr. W. T. Blanford.
Prof. T. G. Bonney.
Prof. E. J. Garwood.
Sir Archibald Geikie.
Prof. J. W. Judd.
Prof. H. A. Miers.
Mr. E. T. Newton.
Mr. A. C. Seward.
Mr. H. B. Woodward.

---

## EVENING MEETINGS OF THE GEOLOGICAL SOCIETY

### TO BE HELD AT BURLINGTON HOUSE.

SESSION 1904–1905.

1904.

| | | |
|---|---|---|
| Wednesday, | November | 9*—23* |
| „ | December | 7*—21 |

1905.

| | | |
|---|---|---|
| Wednesday, | January | 4*—18* |
| „ | Feb. (*Anniversary*, Friday, Feb. 17th) | 1*—22* |
| Wednesday, | March | 8*—22 |
| „ | April | 5*—19 |
| „ | May | 10*—24 |
| „ | June | 7*—21* |

[*Business will commence at Eight o'Clock precisely each Evening.*]

The dates marked with an asterisk are those on which the Council will meet.

# ADMISSION AND PRIVILEGES

OF

# FELLOWS OF THE GEOLOGICAL SOCIETY OF LONDON.

EVERY Candidate for admission as a Fellow must be proposed by three or more Fellows, who must sign a Certificate in his favour. The Proposer whose name stands first upon the Certificate must have a personal knowledge of the Candidate.

Fellows on election pay an Admission-Fee of Six Guineas. The Annual Contribution paid by Fellows is Two Guineas, due on the 1st of January in every year, and payable in advance; but Fellows elected after the month of February are subject only to a proportionate part of the Contribution for the year in which they are elected, and Fellows elected in November or December pay no Contribution for the current year. The Annual Contribution may at any time be compounded for by a payment of Thirty-Five Pounds.

The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling-prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

---

## Publications to be had of the Geological Society, Burlington House.

| TRANSACTIONS. | Reduced Price to the Fellows. £ s. d. |
|---|---|
| Vol. I, Part 2 | 1 8 0 |
| Vol. III, Part 2 | 0 4 0 |
| „ Part 3 | 0 4 0 |
| Vol. VI, Part 2 | 0 10 0 |
| Vol. VII, Part 4 | 0 10 0 |

**QUARTERLY JOURNAL.** (Vols. III to LIX, inclusive.)

Price to Fellows, 13*s*. 6*d*. each (Vols. XV, XXIII, XXX, and XXXIV to LIX, 16*s*. 6*d*.), in cloth.

**CLASSIFIED INDEX TO THE TRANSACTIONS, JOURNAL,** &c., by G. W. ORMEROD, Esq. New Edition, to the end of 1868, with First, Second, and Third Supplements to the end of 1889. Price 8*s*. 6*d*. To Fellows, 5*s*. 6*d*. [Postage 5*d*.]—The First, Second, and Third Supplements may be purchased separately.

**GENERAL INDEX TO THE FIRST FIFTY VOLUMES OF THE QUARTERLY JOURNAL** (1845–1894). Part I (A–La). Part II (La–Z). Price 5*s*. each. To Fellows 3*s*. 9*d*. each. [Postage 3*d*.]

**CATALOGUE OF THE LIBRARY,** 1880. (620 pages 8vo.) Price 8*s*. To Fellows 5*s*. [Postage 6*d*.]

**GEOLOGICAL LITERATURE** added to the Geological Society's Library during the years ended December 31st, 1894–1903. Price 2*s*. each. To Fellows 1*s*. 6*d*. each. [Postage 2½*d*.]

**LIST OF THE TYPE- AND FIGURED SPECIMENS RECOGNIZED BY C. D. SHERBORN IN THE COLLECTION OF THE GEOLOGICAL SOCIETY,** verified and arranged, with additions, by the Rev. J. F. BLAKE. 1902. Price 3*s*. 6*d*. (bound in cloth), 3*s*. 0*d*. (in paper wrappers). To Fellows 2*s*. 6*d*. and 2*s*. 0*d*. [Postage 3*d*.]

**HUTTON'S 'THEORY OF THE EARTH,'** Vol. III., edited by Sir ARCHIBALD GEIKIE, D.C.L., F.R.S. Price 3*s*. 6*d*. To Fellows 2*s*. [Postage 4*d*.]

**THE GEOLOGY OF NEW ZEALAND.** Translated by Dr. C. F. FISCHER, from the works of MM. HOCHSTETTER & PETERMANN. With an Atlas of Six Maps.
Fellows may purchase One Copy of this book at 2*s*.; additional copies will be charged 4*s*. [Postage 5*d*.]

# CONTENTS.



PAPERS READ.




**[No. 240 of the Quarterly Journal will be published next November.]**

**Vol. LX.** NOVEMBER 23rd, 1904. **No. 240.**
PART 4.

C. A. White

THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

**[With Eleven Plates, illustrating Papers by Mr. Barrow and Prof. Boulton.]**

LONDON:

LONGMANS, GREEN, AND CO.

PARIS:—CHARLES KLINCKSIECK, 11 RUE DE LILLE.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

*Price Five Shillings.*

LIST OF THE OFFICERS AND COUNCIL OF THE

# GEOLOGICAL SOCIETY OF LONDON.

Elected February 19th, 1904.

## President.

John Edward Marr, Sc.D., F.R.S.

## Vice-Presidents.

Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Edwin Tulley Newton, F.R.S.
Horace Bolingbroke Woodward, F.R.S.

## Secretaries.

Robert Stansfield Herries, M.A.
Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.

## Foreign Secretary.

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

## Treasurer.

William Thomas Blanford, C.I.E., LL.D., F.R.S.

## COUNCIL.

The Rt. Hon. the Lord Avebury, P.C., D.C.L., LL.D., F.R.S., F.L.S.
Francis Arthur Bather, M.A., D.Sc.
William Thomas Blanford, C.I.E., LL.D., F.R.S.
Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.
Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S.
Prof. Edmund Johnstone Garwood, M.A.
Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.
Prof. Theodore Groom, M.A., D.Sc.
Alfred Harker, M.A., F.R.S.
Robert Stansfield Herries, M.A.
Prof. John W. Judd, C.B., LL.D., F.R.S.
Prof. Percy Fry Kendall.
Philip Lake, M.A.
Prof. Charles Lapworth, LL.D., F.R.S.
Bedford McNeill, Assoc. R.S.M.
John Edward Marr, Sc.D., F.R.S.
Prof. Henry Alexander Miers, M.A., F.R.S.
Horace Woollaston Monckton, F.L.S.
Edwin Tulley Newton, F.R.S.
George Thurland Prior, M.A.
Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.
The Rev. Henry Hoyte Winwood, M.A.
Horace Bolingbroke Woodward, F.R.S.

---

## Assistant-Secretary, Clerk, Librarian, and Curator.

L. L. Belinfante, M.Sc.

## Assistants in Office, Library, and Museum.

W. Rupert Jones. Clyde H. Black.
Alec Field.

---

## STANDING REFERENCE COMMITTEE.

Dr. J. E. Marr, *President*.

Mr. R. S. Herries.
Prof. W. W. Watts. } *Secretaries.*

Dr. F. A. Bather.
Dr. W. T. Blanford.
Prof. T. G. Bonney.
Prof. E. J. Garwood.
Sir Archibald Geikie.
Prof. J. W. Judd.
Prof. H. A. Miers.
Mr. E. T. Newton.
Mr. A. C. Seward.
Mr. H. B. Woodward.

---

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

SESSION 1904–1905.

1904.

Wednesday, November ......... 23*
" December ......... 7*—21

1905.

Wednesday, January ............ 4*—18*
" Feb. (*Anniversary*, Friday, Feb. 17th) 1*—22*

1905.

Wednesday, March ............ 8*—22
" April ............... 5*—19
" May ............... 10*—24
" June ............... 7*—21*

[*Business will commence at Eight o'Clock precisely each Evening.*]

The dates marked with an asterisk are those on which the Council will meet.

## ADMISSION AND PRIVILEGES

OF

## FELLOWS OF THE GEOLOGICAL SOCIETY OF LONDON.

EVERY Candidate for admission as a Fellow must be proposed by three or more Fellows, who must sign a Certificate in his favour. The Proposer whose name stands first upon the Certificate must have a personal knowledge of the Candidate.

Fellows on election pay an Admission-Fee of Six Guineas. The Annual Contribution paid by Fellows is Two Guineas, due on the 1st of January in every year, and payable in advance; but Fellows elected after the month of February are subject only to a proportionate part of the Contribution for the year in which they are elected, and Fellows elected in November or December pay no Contribution for the current year. The Annual Contribution may at any time be compounded for by a payment of Thirty-Five Pounds.

The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling-prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

---

### Publications to be had of the Geological Society, Burlington House.

| TRANSACTIONS. | Reduced Price to the Fellows. £ s. d. |
|---|---|
| Vol. I, Part 2 | 1 8 0 |
| Vol. III, Part 2 | 0 4 0 |
| „ Part 3 | 0 4 0 |
| Vol. VI, Part 2 | 0 10 0 |
| Vol. VII, Part 4 | 0 10 0 |

**QUARTERLY JOURNAL.** (Vols. III to LX, inclusive.)

Price to Fellows, 13*s.* 6*d.* each (Vols. XV, XXIII, XXX, and XXXIV to LX, 16*s.* 6*d.*), in cloth.

**CLASSIFIED INDEX TO THE TRANSACTIONS, JOURNAL,** &c., by G. W. ORMEROD. New Edition, to the end of 1868, with First, Second, and Third Supplements to the end of 1889. Price 8*s.* 6*d.* To Fellows, 5*s.* 6*d.* [Postage 5*d.*]—The First, Second, and Third Supplements may be purchased separately.

**GENERAL INDEX TO THE FIRST FIFTY VOLUMES OF THE QUARTERLY JOURNAL** (1845–1894). Part I (A–La). Part II (La–Z). Price 5*s.* each. To Fellows 3*s.* 9*d.* each. [Postage 3*d.*]

**CATALOGUE OF THE LIBRARY,** 1880. (620 pages 8vo.) Price 8*s.* To Fellows 5*s.* [Postage 6*d.*]

**GEOLOGICAL LITERATURE** added to the Geological Society's Library during the years ended December 31st, 1894–1903. Price 2*s.* each. To Fellows 1*s.* 6*d.* each. [Postage 2½*d.*]

**LIST OF THE TYPE- AND FIGURED SPECIMENS RECOGNIZED BY C. D. SHERBORN IN THE COLLECTION OF THE GEOLOGICAL SOCIETY,** verified and arranged, with additions, by the Rev. J. F. BLAKE. 1902. Price 3*s.* 6*d.* (bound in cloth), 3*s.* 0*d.* (in paper wrappers). To Fellows 2*s.* 6*d.* and 2*s.* 0*d.* [Postage 3*d.*]

**HUTTON'S 'THEORY OF THE EARTH,'** Vol. III., edited by Sir ARCHIBALD GEIKIE, D.C.L., F.R.S. Price 3*s.* 6*d.* To Fellows 2*s.* [Postage 4*d.*]

**THE GEOLOGY OF NEW ZEALAND.** Translated by Dr. C. F. FISCHER, from the works of MM. HOCHSTETTER & PETERMANN. With an Atlas of Six Maps.
Fellows may purchase One Copy of this book at 2*s.*; additional copies will be charged 4*s.* [Postage 5*d.*]

# CONTENTS.

PAPERS READ.



**[No. 241 of the Quarterly Journal will be published next February.]**

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library and Museum at the Apartments of the Society are open every Weekday from Ten o'clock until Five, except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.