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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 FORTY-NINTH.

1893.

LONDON:

LONGMANS, GREEN, AND CO.

PARIS: FRIED. KLINCKSIECK, 11 RUE DE LILLE; F. SAVY, 77 BOULEVARD ST. GERMAIN;
LEIPZIG: T. O. WEIGEL.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

MDCCCXCIII.

List

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OF THE

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Elected February 17th, 1893.

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CORRIGENDA.

Page 13, line 10 [text] from bottom, *for* 'Botzeu' *read* 'Botzen.'
Page 187, line 7 from top, *for* '60 centimetres' *read* '62·5 millimetres.'
Page 189, line 3 from top, *for* '60 centimetres' *read* '62·5 millimetres.'

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1892–93.

November 9th, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

William Gregson, Esq., Baldersby, Thirsk, Yorkshire, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. "A Sketch of the Geology of the Iron, Gold, and Copper Districts of Michigan." By Prof. M. E. Wadsworth, Ph.D., A.M., F.G.S.[1]

2. "The Gold-quartz Deposits of Pahang (Malay Peninsula)." By H. M. Becher, Esq., F.G.S., Assoc.R.S.M.

3. "The Pambula Gold-deposits." By F. D. Power, Esq., F.G.S.

The following specimens were exhibited :—

Auriferous Rock from the Pambula Gold Deposits, exhibited by F. D. Power, Esq., F.G.S., in illustration of his paper.

Specimens from the Michigan Ore Deposits, exhibited by H. Bauerman, Esq., F.G.S.

A series of Restorations of Extinct Animals, drawn by Mr. J. Smit, exhibited by the Rev. H. N. Hutchinson, B.A., F.G.S.

Plant-remains from the Old Red Sandstone of the Auchendoir (Rhynie) Quarries, near Gartly (Aberdeenshire), exhibited by Major R. T. W. Lambart Brickenden, F.G.S.

[1] This paper has been withdrawn by permission of the Council.

November 23rd, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

John Walker Stather, Esq., 16 Louis Street, Hull, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. "Outline of the Geological Features of Arabia Petræa and Palestine." By Prof. Edward Hull, LL.D., F.R.S., F.G.S.

[Abstract.]

The region may be considered as physically divisible into five sections, viz. :—(i) The mountainous part of the Sinaitic peninsula; (ii) the table-land of Badiet-el-Tîh and Central Palestine; (iii) the Jordan-Arabah valley; (iv) the table-land of Edom, Moab, and the volcanic district of Jaulân and Haurân; and (v) the maritime plain bordering the Mediterranean.

The most ancient rocks (of Archæan age) are found in the southern portion of the region; they consist of gneissose and schistose masses penetrated by numerous intrusive igneous rocks. They are succeeded by the Lower Carboniferous beds of the Sinaitic peninsula and Moabite table-land, consisting of a bluish limestone, with fossils which have their counterparts chiefly in the Carboniferous Limestone of Belgium, and of a purple and reddish sandstone (called by the Author 'the Desert Sandstone,' to distinguish it from the Nubian Sandstone of Cretaceous age), lying below the limestone. The Nubian Sandstone, separated from the Carboniferous by an enormous hiatus in the succession of the formations, is probably of Neocomian or Cenomanian age, and is succeeded by white and grey marls, and limestones-with-flint, with fossils of Turonian and Senonian ages.

The Middle Eocene (Nummulitic Limestone) beds appear to follow on those of Cretaceous age without a discordance; but there is a real hiatus notwithstanding the apparent conformity, as shown by the complete change of fauna. In Philistia a calcareous sandstone, in which no fossils have been observed, is referred to the Upper Eocene; for the Miocene period was a continental one, when faulting and flexuring was taking place, and the main physical features were developed—*e. g.*, the formation of the Jordan-Arabah depression is referable to this period.

In Pliocene times a general depression of land took place to about 200–300 feet below the present sea-level, and littoral deposits were formed on the coasts and in the valleys. To this period belong the higher terraces of the Jordan-Arabah valley. The Pliocene deposits consist of shelly gravels. Later terraces were formed at the epoch of the glaciation of the Lebanon Mountains, when the rainfall was excessive in Palestine and Arabia.

The volcanoes of the Jaulân, Haurân, and Arabian Desert are considered to have been in active operation during the Miocene, Pliocene, and Pluvial periods; but the date of their final extinction has not been satisfactorily determined.

Discussion.

The President remarked on the interest of the geology of an area which was that of the Bible. Many authors had recorded their observations on this district, one of the latest being the Author of this paper. Some years ago Mr. Holland had read a paper before the Society, and he (the speaker) believed that that writer was actually the first to prove the existence of Carboniferous fossils in the Sinaitic peninsula. He remarked that *Lepidodendron mosaicum*, described by Salter, was somewhere preserved in the Society's museum, so that the Society had long ago had evidence of Carboniferous rocks. Mr. Bauerman's paper, which was a reconnaissance in a comparatively unknown district, created great interest; and when that paper was read, doubt was expressed as to whether the fossils then exhibited were Carboniferous or Triassic. After the researches of Prof. Hull, there was no doubt that Carboniferous rocks do occur in the region. As regards the granitic rocks (extending far up the Nile Valley, in the Sinaitic peninsula, and elsewhere), they were all of much the same character, and, according to Sir William Dawson, occurred at two horizons—the lower rocks being granitoid and gneissic, the upper more or less volcanic, but still pre-Carboniferous. He asked the Author whether the 'Poudingues de Jebel Haroûn' of Lartet were or were not ancient volcanic rocks.

The Nubian Sandstone of older writers included many things, but the age of the various sandstones was now satisfactorily determined by the Author. Some were Carboniferous, others (in the speaker's opinion) Cenomanian. The calcareous formations of Judæa were well known from the writings of Lartet, Fraas, and others; but the exact line of demarcation between the Nummulitic Limestone and the true Cretaceous had never been determined. It was a curious fact, as stated by Zittel, that not one fossil was common to the two deposits, which were nevertheless quite conformable.

Miocene beds appeared to be absent, for, as noted by Lartet and confirmed by the Author, this was a period of movement, when the great valley and the great fault were initiated. He (the speaker) felt that there were many difficulties connected with the depression which had not yet been cleared up. Lartet, Hitchcock, and others had traced the general direction of the fault; but the Author had determined its exact site at more than one point.

The most interesting point in this connexion was the question of the age of the 700-foot saddle separating the Akabah watershed from the Jordan-Arabah depression. This saddle, in fact, separates the Jordan-Arabah depression from the Red Sea basin. Was it probable that this saddle was contemporaneous with the longitudinal fracture? Much depended on the determination of this question. Canon Tristram had shown that the fishes of the Jordan waters presented some curious analogies with the fish fauna of those of Africa, and Günther, after studying his specimens, had confirmed this view. He (the speaker) believed that this connexion was not over the saddle of the Arabah, but might have been the 285-foot pass of the gorge of Jezreel. If the Pliocene depression, which the Author thought was at least 200 feet, was a little greater, it would at least cause an outflow in this direction.

As to the date of the basaltic eruptions, he thought the Author's explanation was not unreasonable. He remarked that the Jordan-Arabah valley must have been of considerable antiquity, and had many lateral valleys of erosion more or less pointing towards the central hollow of the Dead Sea, whether from the Jordan or the Arabah end. Whither had the material thus eroded gone? It could not have passed over the saddle into the Red Sea, for the drainage had evidently been towards the Dead Sea for ages. He allowed that much was soluble limestone; but that must be precipitated somewhere, and the only conclusion he could come to was the somewhat heretical belief that the bottom of the Dead Sea had been an unsound one.

Dr. Irving referred to the characterless facies of the Nubian Sandstone in the Wady Halfa region as recently observed by Capt. H. G. Lyons, F.G.S.; also to the remarkable density of the waters of the Dead Sea, as showing evaporation to be the true cause of the low level of its waters, while the non-felspathic character of the volcanic rocks of the Jordan basin, and the consequent deficiency of alkaline carbonates in the surface-waters, seemed fully to account for the abnormally large amount of chlorides of lime and magnesia which the Dead Sea waters hold in solution, salts which by reactions with alkaline carbonates would otherwise be precipitated as dolomite. He agreed with the President that the former connexion of the Jordan basin with the sea was probably by the valley and plain of Jezreel. He thought the unmetamorphosed condition of the pre-Carboniferous volcanic rocks described by the Author of great interest, as bearing upon theories as to metamorphism. He also thought that students of Biblical literature owed a debt of gratitude to the Author for his researches.

Mr. J. Bridges Lee said that in the North-western Himalayas he had traced extensive deposits of volcanic trap, of undoubtedly pre-Carboniferous age, the whole way from the neighbourhood of the Baralacha Pass, at the north-western corner of Spiti, through Zanskar, Suru, Dras, and a large part of Cashmere. Every appearance would seem to indicate that these volcanic rocks extended originally in continuous sheets over immense tracts of country. On the south side of the great central chain of the Himalayas they are found now in more or less scattered and detached masses; but on the north, throughout the whole length of Zanskar and Suru (where there has been less denudation than to the south), there is an almost continuous outcrop visible. It might be interesting to ascertain whether the pre-Carboniferous rocks of Palestine are contemporaneous with and generally similar to the Himalayan rocks. It is a remarkable fact that some of the most notable of the Buddhist monasteries of Zanskar and Suru are built on the line of outcrop of these rocks. Pooktal, Thonde, and Ringdom monasteries are examples; and while the trap forms one of the best geological landmarks throughout a large part of the North-western Himalayas, it would also seem to have some especial interest for large numbers of Buddhist priests, who have elected to build their monasteries and to live upon it.

Messrs. Topley, Hinde, and Whitaker also spoke.

The Author accounted for the change of species between the Cretaceous and Eocene Limestones, as determined by Zittel, by supposing that at the close of the Cretaceous period the sea-bed had been elevated into a land-surface—but without flexuring—owing to which the life-forms of the Cretaceous ocean were destroyed, and upon resubmergence new forms entered from the outer ocean: in this way there would be no appreciable discordance of stratification, but complete change of species. As regards the origin of the saddle in the Arabah Valley, he believed it was formed during the formation of the valley itself, not subsequently; the valley contracted very much at the saddle.

In reply to Mr. Topley's question, the Author stated he had been informed that there was a very distinct terrace of gravel near the Lake of Huleh, corresponding in level with that in the Arabah Valley; about 1200 feet above the Dead Sea surface the intermediate representatives of this terrace may be found, but doubtless had been to a large extent swept away by floods and rains.

In attempting to account for the difference between the faunas of the Red Sea and Mediterranean, it would be clear that once the Isthmus of Suez had been converted into land, and the seas dissevered, differentiation would begin and proceed till all the forms unsuited to each had disappeared: difference in the temperature of the waters of the two seas would be the chief cause of differentiation.

2. "The Base of the Keuper Formation in Devon." By the Rev. A. Irving, B.A., D.Sc., F.G.S.

3. "The Marls and Clays of the Maltese Islands." By John H. Cooke, Esq., B.Sc., F.G.S.

Specimens of breccia were exhibited by the Rev. A. Irving, B.A., D.Sc., F.G.S., in illustration of his paper.

December 7th, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Robert Aird, Esq., M.A., Killean Place, Campbeltown, N.B.; Charles Anthony Benn, Esq., B.A., Inner Temple, E.C., and Pudleston Court, Leominster; Arthur Launcelot Collins, Esq., Kabul, Afghanistan; John Dixon, Esq., Government Inspector of Collieries, Merewether, near Newcastle, New South Wales; John Fraser, M.D., M.A., Chapel Ash, Wolverhampton; Horace Broughton Nash, Esq., 23 Victoria Road, Barnsley; William Charles Northcott, M.A., LL.D., Rochester House, Ealing, W.; Frederick Richard Cowper Reed, Esq., B.A., Trinity College, Cambridge; Edmund Spargo, Esq., Artido House, Kensington, W., and 3 Cable Street, Liverpool; E. Kemper-Voss, Esq., Kimberley, South Africa; and Richard Henry Walcott, Esq., London Street, Dunedin, Otago, New Zealand, were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT announced that the American Philosophical Society will celebrate the one hundred and fiftieth anniversary of its foundation at Philadelphia, from May 22nd to May 26th, 1893. Fellows of the Geological Society who propose to be in Philadelphia during that week, and who may wish to participate in the celebration as representatives of the Society, are requested to communicate with the Assistant Secretary, Burlington House, W.

The following communications were read:—

1. "Note on the Nufenenstock (Lepontine Alps)." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

2. "On some Schistose 'Greenstones' and allied Hornblendic Schists from the Pennine Alps, as illustrative of the Effects of Pressure-Metamorphism." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

3. "On a Secondary Development of Biotite and of Hornblende in Crystalline Schists from the Binnenthal." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

4. "Geological Notes on the Bridgewater District in Eastern Ontario." By J. H. Collins, Esq., F.G.S.

[Abstract.]

The plateau of the Bridgewater district consists chiefly of gneiss and mica-schist, with subordinate beds of white marble, quartz-conglomerate and quartzite, and some veins of 'giant-granite.' The general dip of the gneissose series is eastward.

The Author notes the effect of frost in splitting off flakes of the gneissose rocks and conglomerates, especially on the bare glaciated surfaces, and suggests that many of the smaller and shallower lakelets may have originated by this process.

The conglomerates are described as gneisses and mica-schists, with subordinate pebble-beds.

The occurrence of gold in quartz-veins near Flinders and at Madoc is noted; and amongst other economic products are the micas of the

granites, asbestiform actinolite, and marble. The Author discusses the mode of origin of the granite, marble, and actinolite-rock.

Discussion.

The President remarked that the Author seldom failed to make good use of his time when travelling. The conditions displayed in his principal section might possibly be explained on the shearing theory, two different sets of beds being sandwiched into one another. But this could scarcely account for the peculiar relations of the quartz-conglomerates to the Author's gneisses and mica-schists. We might believe almost anything of these very ancient (Archæan) rocks.

Dr. Hicks asked what was the evidence to show that the gneiss was of the same age as the conglomerates and shales? Were there not evidences of faults such as would cause two distinct series to be brought together in apparent sequence?

Dr. Hinde did not think the Author was right in attributing the origin of the lakelets and basin-like rock-depressions in the districts referred to, to the action of frost in exfoliating the rock-surfaces; for in this case they would not show the glacial striæ and polishing now present, not only in the raised bosses but in the hollows as well. The débris resulting from exfoliation, if such had taken place to any extent, would also have prevented the frost from penetrating deep enough to form the hollows.

Mr. Monckton also spoke.

The Author, in reply to the President and to Dr. Hicks, said that he thought the shale-actinolite series might be of different age from that of the gneiss-conglomerate series; the strike was perhaps not precisely the same, and the junction was concealed by a stream. But the stratigraphic relations of the conglomerate-beds were perfectly clear, and he had no doubt whatever as to their forming part of the gneissic series. He applied the term 'gneiss,' as it was generally used in Canada, to a more or less foliated crystalline rock consisting of quartz, felspar, and mica in varying proportions. He did not really think the marbles were segregations, but the suggestion had been made and he thought it worthy of some consideration. In reply to Dr. Hinde, he said that only the smaller lakelets could be formed by frost-flaking, and perhaps he ought to have spoken of these as rock-pools rather than lakelets. The flakes did not accumulate, because they were soon split up into minute fragments by succeeding frosts and removed by the winds.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., in illustration of his papers.

Rock-specimens and photographs, exhibited by J. H. Collins, Esq., F.G.S., in illustration of his paper.

December 21st, 1892.

Prof. J. W. Judd, F.R.S., Vice-President, in the Chair.

Basil Wilfred Bowdler, Esq., 2nd Lieutenant R.E., Chatham; Edward Power, Esq., 12 Bolton Gardens, South Kensington, S.W.; and William Frederick Smeeth, Esq., B.A., Assoc.R.S.M., Demonstrator in Geology in the University of Sydney, N.S.W., 8 Mall Road, Hammersmith, W., were elected Fellows of the Society.

The List of Donations to the Library was read.

Two documents, which had belonged to the late Sir Richard Owen, were presented by C. Davies Sherborn, Esq., F.G.S.

The Chairman gave expression to the Society's deep sense of the loss which it had just sustained by the death of so distinguished a Fellow as Sir Richard Owen, who had been associated with the Society for no less than fifty-five years. He further announced that the Council, in causing a resolution of condolence to be forwarded to the bereaved family, had deputed Dr. Hicks and himself to represent the Society at Sir Richard's funeral.

In explanation of certain specimens of fossils exhibited by J. V. Parkes, Esq., F.G.S., and found in limestones about 11 miles north of Beltana Township, South Australia, Dr. G. J. Hinde said that the limestone-slabs forwarded by Mr. Parkes were filled with the peculiar fossils belonging to the family Archæocyathinæ, which had been considered as probably allied to Perforate Corals. These fossils were widely distributed in rocks of Cambrian age in various parts of the world, having been found in Nevada, Labrador, Spain, and Sardinia, and they had lately been recognized in the same district in South Australia as that whence Mr. Parkes's specimens had been obtained, and an excellent description and figures of them were given by Mr. R. Etheridge, jun., in the 'Transactions of the Royal Society of South Australia,' 1890, pp. 10–22, pls. ii., iii.

The following communications were read:—

1. "On a Sauropodous Dinosaurian Vertebra from the Wealden of Hastings." By R. Lydekker, Esq., B.A., F.G.S.

2. "On some additional Remains of Cestraciont and other Fishes in the Green Gritty Marls, immediately overlying the Red Marls of the Upper Keuper in Warwickshire." By the Rev. P. B. Brodie, M.A., F.G.S.

3. "*Calamostachys Binneyana*, Schimp." By Thomas Hick, Esq., B.A., B.Sc. Communicated by J. W. Davis, Esq., F.G.S., F.L.S.[1]

[1] This paper has been withdrawn by permission of the Council.

4. "Notes on some Pennsylvanian Calamites." By W. S. Gresley, Esq., F.G.S.

[Abstract.]

The Author believes that a group of specimens from the Pottsville conglomerate series demonstrates that the so-called Calamite-casts in sandstone are not always to be regarded as casts of pith-cavity only, but are often casts of the vascular cylinder as well; also that these specimens show that some Calamites, at all events, possessed furrowed exteriors or barks. A specimen from the Pittston bed of anthracite in the Wyoming basin also seems to suggest that the true bark had not always a smooth exterior.

A specimen from the same geological horizon as the last specimen, and from a neighbouring locality, indicates a Calamite of gigantic proportions. Another specimen, from the Pittsburgh bed, is remarkable as showing two branch-scars not on, but below the nodes of the Calamite.

5. "Scandinavian Boulders at Cromer." By Herr Victor Madsen, of the Danish Geological Survey. Communicated by J. W. Hulke, Esq., F.R.S., For.Sec.G.S.

The following specimens, in addition to those above mentioned sent by Mr. Parkes, were exhibited:—

Specimen and cast of Dinosaurian Vertebræ, exhibited by R. Lydekker, Esq., B.A., F.G.S., in illustration of his paper.

Specimens of a 'Bone-bed' with Fish-remains, from the Green Marls below the *Avicula contorta*-shales at Gold Cliff, Monmouthshire. Collected by H. B. Woodward, Esq., F.G.S., and A. Strahan, Esq., M.A., F.G.S. Exhibited by permission of the Director-General of the Geological Survey.

'Rhomben-Porphyr,' Christiania District, found at Cromer by J. J. H. Teall, Esq., M.A., F.R.S., F.G.S., and Clement Reid, Esq., F.L.S., F.G.S. Exhibited by permission of the Director-General of the Geological Survey.

January 11th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

George William Card, Esq., Assoc.R.C.S., Assoc.R.S.M., Curator and Geologist to the Geological Survey of New South Wales, Sydney, New South Wales; and William Morris, Esq., M.Inst.C.E., Kent Waterworks, Deptford, S.E., were elected Fellows of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's accounts for the preceding year:—T. V. Holmes, Esq.; H. W. Monckton, Esq., F.L.S.

The List of Donations to the Library was read.

The following communications were read:—

1. "Variolite of the Lleyn, and associated Volcanic Rocks." By Catherine A. Raisin, B.Sc. Communicated by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

2. "On the Petrography of the Island of Capraja." By Hamilton Emmons, Esq. Communicated by Sir Archibald Geikie, D.Sc., LL.D., For.Sec.R.S., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Miss Catherine A. Raisin in illustration of her paper.

Photographs of the Island of Capraja, exhibited by Hamilton Emmons, Esq., in illustration of his paper.

At a Special General Meeting, held at 7.55 P.M., before the Ordinary Meeting, the appointment of Henry Franklin and his wife to the respective posts of House-Porter and Upper-Housemaid to the Society was confirmed by the Fellows.

January 25th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

George Bastable Laffan, Esq., B.Sc., Assoc.M.Inst.C.E., 4 Walpole Road, Twickenham, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On Inclusions of Tertiary Granite in the Gabbro of the Cuillin Hills, Skye; and on the Products resulting from the Partial Fusion of the Acid by the Basic Rock." By Prof. J. W. Judd, F.R.S., V.P.G.S.

2. "Anthracite and Bituminous Coal-beds. An Attempt to throw some light upon the manner in which Anthracite was formed; or Contributions towards the Controversy regarding the Formation of Anthracite." By W. S. Gresley, Esq., F.G.S.

[Abstract.]

The Author does not seek to advance any new theory in this communication, nor to proclaim new facts of any importance, but to put old facts in something of a new light, in order to aid the investigations of others. His main object is to establish two facts, viz.:—that the associated strata of anthracite-beds are more arenaceous than those containing so-called bituminous coal-beds, and that the prevailing colours of the sandstones, grits, etc., of anthracite regions are greyer and darker than those of regions of bituminous coal. To these facts may perhaps be added a third, that the more anthracitic the coal-beds, and the more siliceous the enclosing strata, the harder and tougher these associated strata are.

While recognizing that the rocks of many anthracite regions have undergone great disturbance, he cites other areas where coal-basins have been much folded, without any corresponding production of anthracite in considerable quantity.

The modes of occurrence of anthracite are illustrated by many instances observed by the Author in the Old and New Worlds.

Discussion.

The President observed that the apparently greater abundance of anthracite in arenaceous rocks may be due to chemical causes. Perhaps the gases escaped from the coal through these porous strata, whereas they were 'bottled up' in argillaceous strata and so preserved the bituminous character of the coals.

Prof. Hull remarked that the question whether the anthracitic condition of coal-seams depended on the predominance of sandstones amongst the associated strata, as he understood the Author to suggest, would require careful observation of the sections of particular coalfields, but was one which deserved attention. If we were to take, for example, the South Wales Coal-basin, it would be interesting to ascertain whether sandstones predominated in the western parts of that basin where anthracite was found, and shales in the eastern parts where the coal was bituminous. This might be done by a comparison of vertical sections of the strata, and if found to be the case, the argument would have some weight that, owing to the greater porosity of the sandstones over the shales, the escape of the gaseous products had been easier where these were in excess than where the less porous shales predominated. But this would not wholly account for the production of anthracite, which probably depended for its origin on a variety of conditions.

The following specimens were exhibited:—

Rock-specimens exhibited by Prof. J. W. Judd, F.R.S., V.P.G.S., in illustration of his paper.

Rock-specimens and microscope-slides exhibited by W. S. Gresley, Esq., F.G.S., in illustration of his paper.

Rock-specimens sent by Herr Victor Madsen to illustrate his paper on "Scandinavian Boulders at Cromer," read on Dec. 21st, 1892.

February 8th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Harry George Mantle, Esq., Melrose House, near Lichfield, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "Notes on some Coast-Sections at the Lizard." By Howard Fox, Esq., F.G.S., and J. J. H. Teall, Esq., M.A., F.R.S., F.G.S.

2. "On a Radiolarian Chert from Mullion Island." By Howard Fox, Esq., F.G.S., and J. J. H. Teall, Esq., M.A., F.R.S., F.G.S.

3. "Note on a Radiolarian Rock from Fanny Bay, Port Darwin, Australia." By G. J. Hinde, Ph.D., V.P.G.S.

4. "Notes on the Geology of the District west of Caermarthen." Compiled from the Notes of the late T. Roberts, Esq., M.A., F.G.S. (Communicated by Prof. T. McKenny Hughes, M.A., F.R.S., F.G.S.)

The following specimens were exhibited:—

Rock-specimens and microscopic sections exhibited by Howard Fox, Esq., F.G.S., and J. J. H. Teall, Esq., M.A., F.R.S., F.G.S., in illustration of their papers.

Microscopic preparations of Radiolarian Chert from Mullion Island, exhibited by Dr. G. J. Hinde, V.P.G.S., in illustration of his Appendix to Messrs. Fox and Teall's paper on that chert.

Microscopic preparations of a Radiolarian Rock from Fanny Bay, Port Darwin, exhibited by Dr. G. J. Hinde, V.P.G.S., in illustration of his paper.

Specimens of the Radiolarian Rock from Fanny Bay described by Dr. G. J. Hinde, V.P.G.S., exhibited by Sir Archibald Geikie, LL.D., For. Sec.R.S., F.G.S.

Specimens of Graptolites exhibited by J. E. Marr, Esq., M.A., F.R.S., Sec.G.S., in illustration of the paper compiled from the Notes of the late T. Roberts, Esq., M.A., F.G.S.

ANNUAL GENERAL MEETING,

February 17th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Report of the Council for 1892.

While the Council are once more in a position to congratulate the Fellows on the very satisfactory condition of the Society's finances, they feel it is their duty to point out that, for the first time since 1888, the number of Fellows, instead of increasing, has slightly diminished.

The number of Fellows elected during the past year was 40, of whom 33 paid their fees before the end of the year, making, with 18 previously elected Fellows who paid their fees in 1892, a total accession in the course of the twelvemonth of 51 Fellows.

During the same period, however, there was a total loss of 70 Fellows—38 by death, 15 by resignation, 14 removed from the list for non-payment of their Annual Contributions, and 3 (2 of whom were non-Contributors and 1 was a Compounder) removed from the list after having remained thereon for many years without any known address.

The actual decrease in the number of Fellows is, therefore, 19.

Of the 38 Fellows deceased, 6 were Compounders, 24 were Contributing Fellows, and 8 were non-Contributing Fellows.

On the other hand, in 1892, 6 Fellows compounded for their Annual Contributions.

From the above figures it will be seen that, in the number of Contributing Fellows, the actual decrease is 8, making a total of 896 Contributing Fellows, as compared with 904 at the end of the previous year.

The total number of Fellows, Foreign Members, and Foreign Correspondents, which, on December 31st, 1891, had been 1418, stood at 1400 on the last day of 1892.

At the end of 1891, there was 1 vacancy in the list of Foreign Members, and also 1 vacancy in the list of Foreign Correspondents. During the year which has just elapsed, 1 Foreign Member and 1 Foreign Correspondent died.

These vacancies were partly filled during 1892 by the election of 1 Foreign Member and 3 Foreign Correspondents, but there was still 1 vacancy in the list of Foreign Members at the end of the year.

With regard to the Society's Income and Expenditure in 1892, they may be briefly summarized as follows:—

The total Receipts on account of Income amounted to £2927 14*s.* 9*d.*, being £234 12*s.* 5*d.* more than the estimated Income for 1892. On the other hand, the Expenditure during that year (leaving out of account the sum of £528 3*s.* expended in the purchase of £400 London and South Western Railway 4% Preference Stock) amounted to £2358 11*s.* 3*d.*, being £263 15*s.* 9*d.* less than the estimated Expenditure for 1892. The actual excess of Receipts over current Expenditure amounted to £569 3*s.* 6*d.*

In recording this extremely satisfactory result, it should be mentioned that some portion, at least, of the excess of Receipts is accounted for by the successful claim and recovery from the Inland Revenue of a sum of £96 9*s.* 8*d.*, representing four years' taxes under Schedules A and C (viz. £54 and £42 9*s.* 8*d.* respectively). It is, moreover, anticipated that in future years a saving of about £13 and £11 per annum respectively will be effected under those headings. Of the sum reimbursed to the Society, £16 10*s.* 1*d.* belongs to the various Trust Accounts, and these have been duly credited with the corresponding amounts.

The Council have pleasure in announcing the completion of Volume XLVIII. and the commencement of Volume XLIX. of the Society's Journal.

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

The Wollaston Medal is awarded to Prof. Nevil Story Maskelyne, M.A., F.R.S., in recognition of his eminent services in those branches of geological science in which Wollaston himself was especially proficient; and further, in token of appreciation of his valuable additions to our knowledge of the mineral constitution of meteorites.

The Murchison Medal, with a sum of Twenty Guineas from the Proceeds of the Fund, is awarded to the Rev. Osmond Fisher, M.A., F.G.S., in recognition of his valuable and long-continued researches in the stratigraphical geology of the Eastern Counties and the South-east of England, and more especially his admirable contributions to the physical history of the earth's crust.

The Lyell Medal, with a sum of Twenty-five Pounds from the Proceeds of the Fund, is awarded to Mr. E. Tulley Newton, F.G.S., as a token of appreciation of his important and fruitful researches in various branches of palæontology.

The Bigsby Medal is awarded to Prof. W. J. Sollas, D.Sc., F.R.S., in testimony of appreciation of his valuable and varied contributions to many departments of geological science.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. J. G. Goodchild, F.G.S., in recognition of his geological researches in the North-west of England, and of his untiring efforts in the promotion of the science generally.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. G. J. Williams, F.G.S., as a token of appreciation of his laborious researches among the rocks of North Wales, and to aid him in his future investigations.

One moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Miss C. A. Raisin, B.Sc., in recognition of her researches in petrology and other branches of geological science.

The other moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Alfred N. Leeds, in appreciation of his long-continued and successful endeavours to collect and reconstitute the Fossil Vertebrata of the Oxford Clay of the neighbourhood of Peterborough.

Report of the Library and Museum Committee for 1892.

Library.

During the year which has elapsed since the presentation of your Committee's previous report, the Library has acquired, partly through the kindness of various donors and partly by purchase, a large number of valuable works and serials.

Turning first of all to the Donations, we find that the Library has received about 84 Volumes of separately published works and Survey Reports, and 235 Pamphlets, besides about 117 Volumes and 50 detached Parts of the publications of various Societies. Moreover, 16 Volumes of Newspapers have been received. The total addition, by gift, to the Society's Library is therefore about 217 Volumes and 235 Pamphlets.

By donation also the Library has received 18 sheets of Maps.

The Books and Maps which have just been enumerated were the gift of 96 Personal Donors, of the Editors or Publishers of 21 Periodicals, of 88 Societies, and of 25 Surveys and other Public Bodies—in all, 230 Donors.

By Purchase, on the recommendation of the Standing Library and Museum Committee, the following additions have been made to the Library:—41 Volumes of separately published works, and 95 Volumes and 33 Parts of works published serially.

The cost of Books and Periodicals purchased during the year 1892 was £116 1*s.* 11*d.*, and the cost of Binding amounted to £81 14*s.* 11*d.*, making a total expenditure on the Library of £197 16*s.* 10*d.*

The work of making good the deficiencies existing in many sets of scientific serials in the Society's Library has further progressed during the past twelvemonth, 22 sets previously imperfect having now been completed. Worthy, perhaps, of particular mention among these are the 'Comptes Rendus de l'Académie des Sciences' and the 'Bulletins et Mémoires de la Société Géologique de France.'

As the result of an application made by the Assistant Secretary to the Netherlands Minister for the Colonies, 25 volumes of the 'Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië,' which in the course of the past seventeen years had been sent by the Dutch Government to the Foreign Office (for transmission, it is believed, to this Society), but had been retained in error and distributed among various Government departments, were collected by the Foreign Office and handed over to this Society's Library.

The Society's collection of historically interesting mementoes of the earlier generation of illustrious geologists has been enriched during the past year by the gift of a bust of Sir Charles Lyell, and a reproduction of a portrait in crayons of Leonard Horner, from Mrs. Catherine Lyell; a copy of Macculloch's Geological Map of Scotland, from Professor Judd, F.R.S.; and a framed portrait of Dr. Samuel P. Woodward, from H. B. Woodward, Esq. An early portrait in oils of Sir Charles Lyell, believed to have been painted about the year 1832, was purchased at a cost of £1.

Such of the six-inch Ordnance Survey Maps as are in the Society's possession have now all been placed in suitable cases.

Museum.

No additions have been made to the collections during the past year. The work of labelling in a distinctive manner and registering the type-specimens, unfortunately interrupted during several months by the serious illness of Mr. C. Davies Sherborn, was actively resumed by him on his recovery. He has now gone through nearly 26 Cabinets or 523 Drawers of specimens.

The total expenditure on the Museum in the year 1892 amounts to £20 5*s*. 6*d*., and includes the following items:—

	£	*s*.	*d*.
Special work at the Museum	20	0	0
Sundries	0	5	6
	£20	5	6

Comparative Statement of the Number of the Society at the close of the years 1891 and 1892.

	Dec. 31, 1891.		Dec. 31, 1892.
Compounders	312	......	311
Contributing Fellows	904	......	896
Non-contributing Fellows	124	......	114
	1340		1321
Foreign Members	39	......	39
Foreign Correspondents	39	......	40
	1418		1400

Comparative Statement explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1891 *and* 1892.

Number of Compounders, Contributing and Non-contributing Fellows, 31st December, 1891		1340
Add Fellows elected during former year and paid in 1892		18
Add Fellows elected and paid in 1892		33
		1391
Deduct Compounders deceased	6	
Contributing Fellows deceased	24	
Non-contributing Fellows deceased	8	
Contributing Fellows resigned	15	
Compounder removed	1	
Contributing Fellows removed	14	
Non-contributing Fellows removed	2	
	—	70
		1321

Number of Foreign Members and Foreign Correspondents, 31st December, 1891		78	
Deduct Foreign Member deceased	1		
Foreign Correspondent deceased	1		
Foreign Correspondent elected Foreign Member	1		
	—	3	
		75	
Add Foreign Member elected		1	
Foreign Correspondents elected		3	
		—	79
			1400

Deceased Fellows.

Compounders (6).

Allen, E., Esq.
Burnand, G., Esq.
Freeland, H. W., Esq.
Gervis, Dr. W. S.
Owen, Sir R.
Spence, J. B., Esq.

Resident and other Contributing Fellows (24).

Abbott, Rev. A. R.
Betley, R., Esq.
Bevington, J. B., Esq.
Brunlees, Sir J.
Dairon, J., Esq.
Davies, T., Esq.
De Laune, C. De L. F., Esq.
Dover, W. K., Esq.
Fawkes, Major F. H.
Floyd, T., Esq.
Glen, D. C., Esq.
Guest, Rev. W.
Harrison, J. T., Esq.
Hart, T., Esq.
Homersham, C., Esq.
Lindon, E. B., Esq.
Marten, H. J., Esq.
Murray, J., Esq.
Norton, H., Esq.
Peace, M. W., Esq.
Roberts, T., Esq.
Talman, J. J., Esq.
Tate, A. N., Esq.
Woolcock, H., Esq.

Non-contributing Fellows (8).

Bright, Dr. J.
Clay, J. T., Esq.
Dillwyn, L. L., Esq.
Hargreaves, E. H., Esq.
Henry, Dr. W. C.
Hunt, R., Esq.
Reed, W., Esq.
Wynne, T., Esq.

Foreign Member (1).

Newberry, Dr. J. S.

Foreign Correspondent (1).

Zigno, Baron A. de.

Fellows Resigned (15).

Blows, S., Esq.
Brunton, J., Esq.
Cowham, J. H., Esq.
Dysart, Earl.
Edridge-Green, Dr. F. W.
Gardner, J. S., Esq.
Giles, G. F. L., Esq.
Lemon, W. G., Esq.
Loveday, W. T., Esq.
Noble, T. S., Esq.
Pattison, S. R., Esq.
Rose, Rev. A.
Spalding, H. A., Esq.
Thuey, A., Esq.
Wood, W. H., Esq.

FELLOWS REMOVED (17).

Boyd, R. N., Esq.
Crawford, J. S., Esq.
*Earle, C., Esq.
Easton, E., Esq.
*Elwin, H., Esq.
Ffolkes, M. W. B., Esq.
Glenny, H., Esq.
Gordon, D. G. H., Esq.
James, Rev. G. W.
Lane, C., Esq.
Martin, J., Esq.
*Meyer, C. P., Esq.
Mirza Mehdy Khan.
Seaver, J. C. B. P., Esq.
Simons, A., Esq.
Stirling, J., Esq.
Stopes, H., Esq.

* Removed from list after having remained thereon for many years without any known address.

The following Personage was elected from the List of Foreign Correspondents to fill the vacancy in the List of Foreign Members during the year 1892.

Professor Gustav Lindström, of Stockholm.

The following Personages were elected Foreign Correspondents during the year 1892.

Professor Johann Lehmann, of Kiel.
Major John W. Powell, of Washington, D.C., U.S.A.
Professor George H. Williams, of Baltimore, U.S.A.

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. T. G. Bonney and L. Fletcher, Esq., retiring from the office of Vice-Presidents.

That the thanks of the Society be given to Dr. H. Hicks, retiring from the office of Secretary.

That the thanks of the Society be given to J. W. Davis, Esq., L. Fletcher, Esq., Prof. C. Le Neve Foster, Prof. T. McKenny Hughes, and W. Topley, Esq., retiring from the Council.

After the Balloting-glasses had been duly 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.

PRESIDENT.

W. H. Hudleston, Esq., M.A., F.R.S., F.L.S.

VICE-PRESIDENTS.

Sir Archibald Geikie, D.Sc., LL.D., For. Sec. R.S.
G. J. Hinde, Ph.D.
Prof. J. W. Judd, F.R.S.
Henry Woodward, LL.D., F.R.S.

SECRETARIES.

J. E. Marr, Esq., M.A., F.R.S.
J. J. H. Teall, Esq., M.A., F.R.S.

FOREIGN SECRETARY.

J. W. Hulke, Esq., F.R.S.

TREASURER.

Prof. T. Wiltshire, M.A., F.L.S.

COUNCIL.

Prof. J. F. Blake, M.A.
Prof. T. G. Bonney, D.Sc., LL.D., F.R.S.
R. Etheridge, Esq., F.R.S.
Sir Archibald Geikie, D.Sc., LL.D., For. Sec. R.S.
Prof. A. H. Green, M.A., F.R.S.
Alfred Harker, Esq., M.A.
H. Hicks, M.D., F.R.S.
G. J. Hinde, Ph.D.
T. V. Holmes, Esq.
W. H. Hudleston, Esq., M.A., F.R.S., F.L.S.
J. W. Hulke, Esq., F.R.S.
Prof. J. W. Judd, F.R.S.
R. Lydekker, Esq., B.A.
Lieut.-General C. A. McMahon.
J. E. Marr, Esq., M.A., F.R.S.
H. W. Monckton, Esq., F.L.S.
Clement Reid, Esq., F.L.S.
F. Rutley, Esq.
J. J. H. Teall, Esq., M.A., F.R.S.
Prof. T. Wiltshire, M.A., F.L.S.
Rev. H. H. Winwood, M.A.
Henry Woodward, LL.D., F.R.S.
H. B. Woodward, Esq.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1892.

Date of Election.

1848. James Hall, Esq., *Albany, State of New York, U.S.A.*
1851. Professor James D. Dana, *New Haven, Connecticut, U.S.A.*
1853. Count Alexander von Keyserling, *Raykül, Russia.*
1856. Professor Robert Bunsen, For. Mem. R.S., *Heidelberg.*
1857. Professor H. B. Geinitz, *Dresden.*
1867. Professor A. Daubrée, For. Mem. R.S., *Paris.*
1871. Dr. Franz Ritter von Hauer, *Vienna.*
1874. Professor Albert Gaudry, *Paris.*
1875. Professor Fridolin Sandberger, *Würzburg.*
1876. Professor E. Beyrich, *Berlin.*
1877. Dr. Carl Wilhelm Gümbel, *Munich.*
1877. Dr. Eduard Suess, *Vienna.*
1879. Major-General N. von Kokscharow, *St. Petersburg.* (*Deceased.*)
1879. M. Jules Marcou, *Cambridge, U.S.A.*
1879. Dr. J. J. S. Steenstrup, For. Mem. R.S., *Copenhagen.*
1880. Professor Gustave Dewalque, *Liége.*
1880. Baron Adolf Erik Nordenskiöld, *Stockholm.*
1880. Professor Ferdinand Zirkel, *Leipzig.*
1882. Professor Sven Lovén, *Stockholm.*
1882. Professor Ludwig Rütimeyer, *Basel.*
1883. Professor J. S. Newberry, *New York, U.S.A.* (*Deceased.*)
1883. Professor Otto Martin Torell, *Stockholm.*
1884. Professor G. Capellini, *Bologna.*
1884. Professor A. L. O. Des Cloizeaux, For. Mem. R.S., *Paris.*
1884. Professor J. Szabó, *Pesth.*
1885. Professor Jules Gosselet, *Lille.*
1886. Professor Gustav Tschermak, *Vienna.*
1887. Professor J. P. Lesley, *Philadelphia, U.S.A.*
1887. Professor J. D. Whitney, *Cambridge, U.S.A.*
1888. Professor Pierre J. van Beneden, *Louvain.*
1888. Professor Eugène Renevier, *Lausanne.*
1888. Baron Ferdinand von Richthofen, *Berlin.*
1889. Professor Ferdinand Fouqué, *Paris.*
1889. Marquis Gaston de Saporta, *Aix-en-Provence.*
1889. Professor Karl Alfred von Zittel, *Munich.*
1890. Professor Heinrich Rosenbusch, *Heidelberg.*
1890. Herr Dionys Stur, *Vienna.*
1891. Dr. Charles Barrois, *Lille.*
1891. M. Gustave H. Cotteau, *Auxerre.*
1892. Professor Gustav Lindström, *Stockholm.*

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1892.

Date of Election.

1863. Dr. F. Senft, *Eisenach.*
1866. Professor Victor Raulin, *Montfaucon d'Argonne.*
1866. Baron Achille de Zigno, *Padua.* (*Deceased.*)
1874. Professor Igino Cocchi, *Florence.*
1874. Dr. T. C. Winkler, *Haarlem.*
1877. Professor George J. Brush, *New Haven, U.S.A.*
1879. M. Édouard Dupont, *Brussels.*
1879. Dr. Émile Sauvage, *Boulogne-sur-Mer.*
1880. Professor Alphonse Renard, *Ghent.*
1881. Professor E. D. Cope, *Philadelphia, U.S.A.*
1882. Professor Louis Lartet, *Toulouse.*
1882. Professor Alphonse Milne-Edwards, *Paris.*
1884. M. Alphonse Briart, *Morlanwelz.*
1884. Professor Hermann Credner, *Leipzig.*
1884. Baron C. von Ettingshausen, *Grätz.*
1884. Dr. E. Mojsisovics von Mojsvár, *Vienna.*
1885. Dr. A. G. Nathorst, *Stockholm.*
1886. Professor J. Vilanova y Piera, *Madrid.*
1887. Senhor J. F. N. Delgado, *Lisbon.*
1887. Professor A. Heim, *Zürich.*
1887. Professor A. de Lapparent, *Paris.*
1888. Professor W. C. Brögger, *Christiania.*
1888. M. Charles Brongniart, *Paris.*
1888. Professor Edward Salisbury Dana, *New Haven, U.S.A.*
1888. Professor Anton Fritsch, *Prague.*
1888. M. Ernest Van den Broeck, *Brussels.*
1889. Professor G. K. Gilbert, *Washington, U.S.A.*
1889. M. A. Michel-Lévy, *Paris.*
1889. Dr. Hans Reusch, *Christiania.*
1889. M. R. D. M. Verbeek, *Padang, Sumatra.*
1890. M. Gustave F. Dollfus, *Paris.*
1890. Herr Felix Karrer, *Vienna.*
1890. Professor Adolph von Könen, *Göttingen.*
1890. M. Friedrich Schmidt, *St. Petersburg.*
1891. Señor Don Antonio del Castillo, *Mexico.*
1891. Professor W. Dames, *Berlin.*
1891. Professor Emanuel Kayser, *Marburg.*
1891. Professor Karl August Lossen, *Berlin.* (*Deceased.*)
1892. Professor Johann Lehmann, *Kiel.*
1892. Major John W. Powell, *Washington, D.C., U.S.A.*
1892. Professor George H. Williams, *Baltimore, U.S.A.*

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE "DONATION FUND"

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., &c.

"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. Professor C. G. Ehrenberg.
1840. Professor A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron L. von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy. }
1844. Rev. W. D. Conybeare.
1845. Professor John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. Rev. Dr. W. Buckland.
1849. Professor Joseph Prestwich.
1850. Mr. William Hopkins.
1851. Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil. }
1854. Sir Richard Griffith.
1855. Sir H. T. De la Beche.
1856. Sir W. E. Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Mr. James Hall. }
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Professor Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Professor Gustav Bischof.
1864. Sir R. I. Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Professor Carl F. Naumann.
1869. Dr. H. C. Sorby.
1870. Professor G. P. Deshayes.
1871. Sir A. C. Ramsay.
1872. Professor J. D. Dana.
1873. Sir P. de M. Grey-Egerton.
1874. Professor Oswald Heer.
1875. Professor L. G. de Koninck.
1876. Professor T. H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Professor Bernhard Studer.
1880. Professor Auguste Daubrée.
1881. Professor P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. W. T. Blanford.
1884. Professor Albert Gaudry.
1885. Mr. George Busk.
1886. Professor A. L. O. Des Cloizeaux.
1887. Mr. J. Whitaker Hulke.
1888. Mr. H. B. Medlicott.
1889. Professor T. G. Bonney.
1890. Professor W. C. Williamson.
1891. Professor J. W. Judd.
1892. Baron Ferdinand von Richthofen.
1893. Professor N. S. Maskelyne.

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. Professor G. P. Deshayes.
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Professor Edward Forbes.
1842. Professor John Morris.
1843. Professor 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. Professor John Morris.
1851. M. Joachim Barrande.
1852. Professor John Morris.
1853. Professor L. G. de Koninck.
1854. Dr. S. P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Professor G. P. Deshayes.
1857. Dr. S. P. Woodward.
1858. Mr. James Hall.
1859. Mr. Charles Peach.
1860. { Professor T. Rupert Jones. Mr. W. K. Parker.
1861. Professor A. Daubrée.
1862. Professor Oswald Heer.
1863. Professor Ferdinand Senft.
1864. Professor G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Mr. W. Carruthers.
1870. M. Marie Rouault.
1871. Mr. R. Etheridge.
1872. Dr. James Croll.
1873. Professor J. W. Judd.
1874. Dr. Henri Nyst.
1875. Mr. L. C. Miall.
1876. Professor Giuseppe Seguenza.
1877. Mr. R. Etheridge, Jun.
1878. Professor W. J. Sollas.
1879. Mr. S. Allport.
1880. Mr. Thomas Davies.
1881. Dr. R. H. Traquair.
1882. Dr. G. J. Hinde.
1883. Mr. John Milne.
1884. Mr. E. Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. S. Gardner.
1887. Mr. B. N. Peach.
1888. Mr. J. Horne.
1889. Mr. A. Smith Woodward.
1890. Mr. W. A. E. Ussher.
1891. Mr. R. Lydekker.
1892. Mr. O. A. Derby.
1893. Mr. J. G. Goodchild.

AWARDS OF THE MURCHISON MEDAL

AND OF THE

PROCEEDS 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 inquiries 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. *Medal.*
1873. Professor Oswald Heer.
1874. Dr. J. J. Bigsby. *Medal.*
1874. Mr. Alfred Bell.
1874. Professor Ralph Tate.
1875. Mr. W. J. Henwood. *Medal.*
1875. Professor H. G. Seeley.
1876. Mr. A. R. C. Selwyn. *Medal.*
1876. Dr. James Croll.
1877. Rev. W. B. Clarke. *Medal.*
1877. Professor J. F. Blake.
1878. Dr. H. B. Geinitz. *Medal.*
1878. Professor Charles Lapworth.
1879. Professor F. M'Coy. *Medal.*
1879. Mr. J. W. Kirkby.
1880. Mr. R. Etheridge. *Medal.*
1881. Professor A. Geikie. *Medal.*
1881. Mr. F. Rutley.
1882. Professor J. Gosselet. *Medal.*
1882. Professor T. Rupert Jones.
1883. Professor H. R. Göppert. *Medal.*
1883. Mr. John Young.
1884. Dr. H. Woodward. *Medal.*
1884. Mr. Martin Simpson.
1885. Dr. Ferdinand von Römer. *Medal.*
1885. Mr. Horace B. Woodward.
1886. Mr. W. Whitaker. *Medal.*
1886. Mr. Clement Reid.
1887. Rev. P. B. Brodie. *Medal.*
1887. Mr. Robert Kidston.
1888. Professor J. S. Newberry. *Medal.*
1888. Mr. E. Wilson.
1889. Professor James Geikie. *Medal.*
1889. Mr. Grenville A. J. Cole.
1890. Professor Edward Hull. *Medal.*
1890. Mr. E. Wethered.
1891. Professor W. C. Brögger. *Medal.*
1891. Rev. R. Baron.
1892. Professor A. H. Green. *Medal.*
1892. Mr. Beeby Thompson.
1893. Rev. O. Fisher. *Medal.*
1893. Mr. G. J. Williams.

AWARDS OF THE LYELL MEDAL

AND OF THE

PROCEEDS 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. Professor John Morris. *Medal.*
1877. Dr. James Hector. *Medal.*
1877. Mr. W. Pengelly.
1878. Mr. G. Busk. *Medal.*
1878. Dr. W. Waagen.
1879. Professor Edmond Hébert. *Medal.*
1879. Professor H. A. Nicholson.
1879. Dr. Henry Woodward.
1880. Mr. John Evans. *Medal.*
1880. Professor F. A. von Quenstedt.
1881. Sir J. W. Dawson. *Medal.*
1881. Dr. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. Dr. J. Lycett. *Medal.*
1882. Rev. Norman Glass.
1882. Professor Charles Lapworth.
1883. Dr. W. B. Carpenter. *Medal.*
1883. Mr. P. H. Carpenter.
1883. M. E. Rigaux.
1884. Dr. Joseph Leidy. *Medal.*
1884. Professor Charles Lapworth.
1885. Professor H. G. Seeley. *Medal.*
1885. Mr. A. J. Jukes-Browne.
1886. Mr. W. Pengelly. *Medal.*
1886. Mr. D. Mackintosh.
1887. Mr. Samuel Allport. *Medal.*
1887. Rev. Osmond Fisher.
1888. Professor H. A. Nicholson. *Medal.*
1888. Mr. A. H. Foord.
1888. Mr. T. Roberts.
1889. Professor W. Boyd Dawkins. *Medal.*
1889. M. Louis Dollo.
1890. Professor T. Rupert Jones. *Medal.*
1890. Mr. C. Davies Sherborn.
1891. Professor T. McKenny Hughes. *Medal.*
1891. Dr. C. J. Forsyth-Major.
1891. Mr. G. W. Lamplugh.
1892. Mr. G. H. Morton. *Medal.*
1892. Mr. J. W. Gregory.
1892. Mr. E. A. Walford.
1893. Mr. E. T. Newton. *Medal.*
1893. Miss C. A. Raisin.
1893. Mr. A. N. Leeds.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially "as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much."

1877. Professor O. C. Marsh.
1879. Professor E. D. Cope.
1881. Dr. C. Barrois.
1883. Dr. Henry Hicks.
1885. Professor Alphonse Renard.
1887. Professor Charles Lapworth.
1889. Mr. J. J. Harris Teall.
1891. Dr. G. M. Dawson.
1893. Professor W. J. Sollas.

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."

1880. Purchase of microscope.
1881. Purchase of microscope lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Professor Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Professor Charles Mayer-Eymar.

Estimates *for*

INCOME EXPECTED.

	£ s. d.	£ s. d.
Compositions		105 0 0
Due for Arrears of Admission-fees	25 4 0	
Admission-fees, 1893	157 10 0	
		182 14 0
Due for Arrears of Annual Contributions		63 0 0
Annual Contributions, 1893, from Resident Fellows, and Non-residents, 1859 to 1861		1680 0 0
Annual Contributions in advance		35 0 0
Dividends on Consolidated $2\frac{3}{4}$ per Cents.		101 1 4
Dividends on London and North-Western Railway 4 per cent. Consolidated Preference Stock		87 15 0
Dividends on London and South-Western Railway 4 per cent. Consolidated Preference Stock		109 4 0
Sale of Quarterly Journal, including Longman's account	165 0 0	
Sale of Geological Map, including Stanford's account	12 0 0	
Sale of Transactions, Library-catalogue, Ormerod's Index, Hochstetter's 'New Zealand,' and List of Fellows	5 0 0	
		182 0 0
		£2545 14 4

THOMAS WILTSHIRE, Treasurer.

28th January, 1893.

the Year 1893.

EXPENDITURE ESTIMATED.

	£ s. d.	£ s. d.
House Expenditure:		
Taxes	4 4 6	
Fire-insurance	15 0 0	
Gas	35 0 0	
Fuel	30 0 0	
Furniture and Repairs	30 0 0	
House-repairs and Maintenance	35 0 0	
Annual Cleaning	15 0 0	
Washing and Sundries	25 0 0	
Tea at Meetings	14 0 0	
		203 4 6
Salaries and Wages, &c.:		
Assistant Secretary	250 0 0	
„ Half premium of Life Insurance	10 15 0	
Assistant Librarian and Assistant Clerk	270 0 0	
House Porter and Upper-Housemaid, including Uniform and Allowance for Washing	91 12 0	
Under-Housemaid, including Allowance for Washing	42 12 0	
Errand Boy	23 8 0	
Charwoman and Occasional Assistance	16 0 0	
Accountant's Fee	10 10 0	
		714 17 0
Official Expenditure:		
Stationery	25 0 0	
Miscellaneous Printing	30 0 0	
Postages and other Expenses	90 0 0	
		145 0 0
Library (Books and Binding)		200 0 0
Museum		50 0 0
Publications:		
Geological Map	5 0 0	
Quarterly Journal	900 0 0	
„ „ Commission, Postage, and Addressing	100 0 0	
List of Fellows	35 0 0	
Abstracts, including Postage	110 0 0	
		1150 0 0
Balance in favour of the Society		82 12 10
		£2545 14 4

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
Balance in Bankers' hands, 1 January, 1892 .	264	17	11			
Balance in Clerk's hands, 1 January, 1892 .	22	1	5			
				286	19	4
Compositions				189	0	0
Arrears of Admission-fees..............	113	8	0			
Admission-fees, 1892	207	18	0			
				321	6	0
Arrears of Annual Contributions				109	17	2
Annual Contributions for 1892, viz.:						
Resident Fellows	1684	4	0			
Non-Resident Fellows ...	12	14	6			
				1696	18	6
Annual Contributions in advance				37	16	0
Dividends on $2\frac{3}{4}$ p. c. Consolidated Stock. .	101	1	4			
,, L. & N. W. Railway Stock . .	87	15	0			
,, L. & S. W. Railway Stock . .	97	10	0			
				286	6	4
Taylor & Francis: Advertisements in Journal, Vol. 47. .				4	4	2
Publications:						
Sale of Journal, Vols. 1–47	109	2	9			
,, Vol. 48 *	76	4	3			
Sale of Library Catalogue	1	10	0			
Sale of Geological Map	12	2	8			
Sale of Ormerod's Index.........................	2	10	10			
Sale of Hochstetter's 'New Zealand'	0	4	0			
Sale of Transactions	0	11	0			
Sale of List of Fellows	0	1	6			
				202	7	0
Repayment of Income Tax under						
Schedule A for four years 1888–92 . .	54	0	0			
Schedule C for four years 1888–92 . .	25	19	7			
				79	19	7
*Due from Messrs. Longmans, in addition to the above, on Journal, Vol. 48, &c......................	65	12	10			
Due from Stanford on account of Geological Map...	12	1	3			

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

(Signed) T. V. HOLMES, HORACE W. MONCKTON, } *Auditors.*

28th January, 1893.

£3214 14 1

Year ending 31*st December*, 1892.

EXPENDITURE.

		£	s.	d.	£	s.	d.
House Expenditure:							
Taxes		18	5	0			
Fire-insurance		15	0	0			
Gas		34	2	0			
Fuel		28	0	10			
Furniture and Repairs		52	4	2			
House-repairs		35	5	3			
Annual Cleaning		15	7	2			
Washing and Sundries		24	10	0			
Tea at Meetings		13	12	0			
					236	6	5
Salaries and Wages, &c.:							
Assistant Secretary		250	0	0			
" Half premium of Life Insurance		10	15	0			
Assistant Librarian and Assistant Clerk		260	0	0			
House Porter and Upper-Housemaid, including Uniform and Allowance for Washing		93	19	5			
Under-Housemaid, including Allowance for Washing		43	17	3			
Errand Boy		18	10	0			
Charwoman and Occasional Assistance		15	11	4			
Accountant's Fee		10	10	0			
Late House-Steward (three months' pension)		17	10	0			
					720	13	0
Official Expenditure:							
Stationery		21	4	5			
Miscellaneous Printing		28	14	7			
Postages and other Expenses		86	12	6			
					136	11	6
Library (Books and Binding)					197	16	10
Museum					20	5	6
Publications:							
Geological Map		4	3	10			
Journal, Vols. 1–47		10	1	1			
" Vol. 48	805 1 11						
" " Commission, Postage, and Addressing	86 4 10						
		891	6	9			
List of Fellows		35	1	1			
Abstracts, including Postage		105	1	6			
Ormerod's Index		1	3	9			
					1046	18	0
Investment in £200 L. & S. W. Railway 4 per cent. Consolidated Pref. Stock, @ 128¼		259	6	0			
Investment in £200 L. & S. W. Railway 4 per cent. Consolidated Pref. Stock, @ 133		268	17	0			
					528	3	0
Balance in Bankers' hands, 31 Dec. 1892		311	1	9			
Balance in Clerk's hands, 31 Dec. 1892		16	18	1			
					327	19	10
THOMAS WILTSHIRE, *Treasurer.*					£3214	14	1

"Wollaston Donation Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1892	21	16	0	Cost of striking Gold Medal awarded to Baron F. von Richthofen	10	10	0
Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock	29	1	4	Award to Mr. O. A. Derby	18	11	4
Repayment of Income Tax under Schedule C for four years 1888–92	3	6	9	Balance at Bankers', 31 December, 1892	25	2	9
	£54	4	1		£54	4	1

"Murchison Geological Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1892	19	10	0	Award to Prof. A. H. Green, with Medal	10	10	0
Dividends on the Fund invested in London and North-Western Railway 4 per cent. Debenture Stock	39	0	0	" Mr. B. Thompson	27	13	0
Repayment of Income Tax under Schedule C for four years 1888–92	4	0	10	Cost of Medal	0	17	0
				Balance at Bankers', 31 December, 1892	23	10	10
	£62	10	10		£62	10	10

"Lyell Geological Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1892	51	9	0	Award to Mr. G. H. Morton, with Medal	25	0	0
Dividends on the Fund invested in Metropolitan $3\frac{1}{2}$ per cent. Stock	68	12	0	" Mr. J. W. Gregory	21	5	6
Repayment of Income Tax under Schedule C for four years 1888–92	7	1	6	" Mr. E. A. Walford	21	5	6
				Cost of Medal	1	1	0
				Balance at Bankers', 31 December, 1892	58	10	6
	£127	2	6		£127	2	6

"Barlow-Jameson Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1892	44	13	10	Award to Prof. C. Mayer-Eymar	21	0	0
Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock	13	8	4	Balance at Bankers', 31 December, 1892	38	10	3
Repayment of Income Tax under Schedule C for four years 1888–92	1	8	1				
	£59	10	3		£59	10	3

"Bigsby Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1892	4	4	0	Balance at Bankers', 31 December, 1892	10	8	11
Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock	5	12					
Repayment of Income Tax under Schedule C for four years 1888–92	0	12	11				
	£10	8	11		£10	8	11

Valuation of the Society's Property; 31st December, 1892.

Property.	£	s.	d.	£	s.	d.		£	s.	d.
Due from Longman & Co., on account of Journal, vol. xlviii. &c.				65	12	10	Balance in favour of the Society	10,737	8	11
Due from Stanford, on account of Map				12	1	3				
Balance in Bankers' hands, 31 Dec. 1892				311	1	9				
Balance in Clerk's hands, 31 Dec. 1892				16	18	1				
Funded Property:—										
Consolidated $2\frac{3}{4}$ per Cents. at 97	3769	2	6	3656	1	0				
London & North-Western Railway 4 per cent. Consolidated Pref. Stock at 131.	2250	0	0	2947	10	0				
London & South-Western Railway 4 per cent. Consolidated Pref. Stock at 130.	2800	0	0	3640	0	0				
Arrears of Admission-fees (considered good)				25	4	0				
Arrears of Annual Contributions (considered good)				63	0	0				
				£10,737	8	11		£10,737	8	11

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

THOMAS WILTSHIRE, *Treasurer*.

28*th January*, 1893.

Award of the Wollaston Medal.

In presenting the Wollaston Medal to Prof. Nevil Story Maskelyne, M.A., F.R.S., F.G.S., the President addressed him in the following words:—

Professor Maskelyne,—

The Council of the Geological Society have this year awarded to you the Wollaston Medal, in recognition of your researches in those branches of science which the Founder himself cultivated with so much success. We do not forget that Wollaston invented the reflecting goniometer, and that no one has been more skilful in the use of that instrument than yourself. Thirty years ago you were enabled, in this way, to make an exact determination of the form of the minute crystals of Connellite; and the later discovery of larger crystals of that mineral has only served to confirm the accuracy of your original determination. During the thirty-five years that you have occupied the Chair of Mineralogy at Oxford you have ever insisted on symmetry as being the essential feature of the crystalline systems. Contemporaneously with your professorial duties you devoted twenty-three years of your life to the development of the mineral collections at the British Museum. These collections had for some years previously been without a mineralogist in charge. With the co-operation of the late Mr. Thomas Davies, your apt pupil and assistant, the collection was rearranged; and when you left the Museum to enter Parliament, in 1880, the classification of the entire collection had reached a high pitch of perfection, while the collection itself had been in many respects enriched.

The investigation of extra-telluric bodies has long since attracted your attention, though the want of a chemical laboratory must have been felt by one who had already proved, from his numerous chemical papers, the interest he took in that science. Failing this, you sought to recognize the individual minerals by the aid of the microscope, working on thin sections—a method now universally adopted in the study of terrestrial rocks. In this way, thirty years ago, you were enabled to determine many of the most important ingredients of meteorites, by means of the relation of the axes of optic elasticity to known crystallographic lines. The microscope was further applied to the mechanical separation of the different mineral ingredients of a meteorite, and the existence of such minerals as enstatite and bronzite demonstrated. Your research on the mineral constituents of the Busti meteorite will long remain an example to future workers. Further, in conjunction with the late Dr. Flight, you described the minerals of the diamantiferous rock of South Africa, suggesting that an enstatite-rock, at points of contact with carbonaceous shales, was probably the original home of the diamond—an explanation which is now generally accepted.

Although for several years past your energies have found employment in another direction, we may venture to hope that your interest in those branches of science which Wollaston was desirous of promoting is in no wise lessened; and we trust that you may yet achieve results such as shall even further justify the Council in the selection they have made.

Professor Maskelyne, in reply, said:—

Mr. President,—

In receiving at your hands the Wollaston Medal, I beg to thank the Council for the great honour they confer on me, and you, Sir, for the generous review in which you have sketched my past scientific life. When my first surprise at the Award gave way to other thoughts, the first of them was one of gratification at the Council having this year determined to give the Medal for studies so nearly connected with Wollaston's work, and to furthering which he rendered such distinguished services. To these you have alluded; and, in the kindly view you have taken of my work, I thank you for associating with it the names of some of those to whom I was much indebted in its achievement.

You have alluded, Sir, to the period—nearly a quarter of a century—that I was working at the British Museum as head of the Mineral Department. I am proud of the work done in those years, and it was done, as most good work is done, by few hands—mostly by those of Mr. Thomas Davies and myself. Davies came to me a young man, fresh from the sea, and absolutely innocent of any scientific knowledge. He died a few weeks ago, in many ways an accomplished man—the best judge of a mineral in this country, and an admirable petrologist—a worthy son of William Davies, and a worthy recipient of the Wollaston Fund, which was awarded him some years ago. And, Sir, I have to thank you for naming another of the helpers in my work—Dr. Walter Flight. He, too, is no more; and there died in him one of the finest of laboratory manipulators and a very accomplished chemist.

But one name I must supply, of a man who more than thirty years ago came to London for a visit, and remained to work in the Museum for some time. I allude to Viktor von Lang, the partner of Joseph Grailich in the splendid work done by the Vienna school of crystallography and physics, and who had already then a European name. That period of my life, in the continual companionship of so finely trained a physicist and crystallographer, was like a second education.

Then, Sir, you have alluded to the little school, if I may call it so, of Crystallography connected with my Chair at Oxford, and to the results of my teaching. The deduction of the laws of morphological and physical symmetry in crystals from the fundamental law of rational indices lay as a germ, though entirely undeveloped, in the Treatise and tracts of my late friend and master in the study of the science, Prof. Miller, of Cambridge. Modern Crystallography has grown from that germ, and if I have helped in promulgating it in England through my lectures, I owe more to the students who attended those lectures than they owe to me in guiding them; for they have always kept high the standard of crystallographic work in their investigations as in their teaching. Among these I must mention my old friend, W. J. Lewis, now Professor at Cambridge; and I need only allude to the remarkable memoirs on 'Thermic Dilatation in Crystals' and on the 'Optical Indicatrix' by the able mathematician who succeeded me at the British Museum, Mr. Fletcher, and to the fine work of his first assistant, Mr. Miers, to justify me in saying that if I have had any merit in directing such men upon their way, it is to their own qualities that the success of that little Oxford school is due. Gladly, if it were possible, would I divide that Medal among those who have so contributed to the winning of it, and retain as my own share the grateful remembrance that you, Sir, and the Council have thought me worthy to receive it, with the features stamped on it of that distinguished Englishman its Founder, the man to whom we owe the instrument—so simple, so accurate, and so indispensable—the reflection-goniometer; the instrument which made it possible for Crystallography to become an exact science.

Finally, in respect to the last part of your observations, I may say that of the many duties imposed on me by my county during the past few years, I am relieved now of one of the weightiest, and shall be able, I trust, to devote much of the leisure of what may be left to me of life to the subjects which were heretofore my chief interest; and in cordially thanking you, Mr. President, and the Council for this, the greatest honour you can confer, I may assure you that it will be a great incentive to me still to strive to be worthy of it.

AWARD OF THE WOLLASTON DONATION FUND.

The PRESIDENT then handed the Balance of the Proceeds of the Wollaston Fund, awarded to Mr. J. G. GOODCHILD, F.G.S., to Prof. T. MCKENNY HUGHES, M.A., F.R.S., F.G.S., for transmission to the recipient, addressing him as follows:—

Professor HUGHES,—

The Council, in awarding the Balance of the Proceeds of the Wollaston Donation Fund to Mr. Goodchild, have been desirous of expressing their sense of the value of his geological work in the North-west of England, and more especially of his description of the Glacial phenomena of the Eden Valley, as recorded in the Quarterly Journal of the Society. They also recognize his services in aid of Science generally for many years past, as Editor of the Transactions of the Cumberland and Westmoreland Association, and as the Author of many interesting papers on local Geology which have appeared in those Transactions. The Council hope that his appointment in Edinburgh will not prevent him from still carrying on investigations in the field.

Professor HUGHES, in reply, said:—

Mr. PRESIDENT,—

I have, as the oldest friend of Mr. Goodchild in this Society, been asked to receive and transmit to him the Proceeds of the Wollaston Fund. I feel more inclined to dilate upon my friend's deserts than upon the kindness of the Council in making the Award to him.

I will try to compromise the matter by saying only that there is no man who will so keenly appreciate this recognition of his work, and no case in which the Society may reckon on a better return for this wholesome stimulus of encouragement.

AWARD OF THE MURCHISON MEDAL.

In presenting the Murchison Medal to the Rev. OSMOND FISHER, M.A., F.G.S., the PRESIDENT addressed him as follows:—

Mr. FISHER,—

The Council have this year awarded to you the Murchison Medal, together with a sum of Twenty Guineas, in consideration of the work you have done in the general advancement of Geological Science. They recognize the importance of your work, at once as a stratigraphical geologist and as a physicist who has devoted his attention to problems in connexion with the Earth's crust. It is now nearly forty years since your paper on the Purbeck strata of Dorsetshire made its appearance, worked out while you had charge of a parish in Dorchester, your connexion with this part of the world arising from the fact that your father was formerly Vicar of Osmington. During the last 30 or 35 years a very great number of works have emanated from your pen, and have been published either separately or in the Proceedings of our own or of some other Society.

These works attest the wide range of the subjects in which you have taken an interest and the extent of your scientific research. The subjects may be classified under four principal heads:—1. Earth sculpture and its results; 2. The discrimination of the various superficial deposits collectively spoken of as Drifts; 3. Description of the stratigraphy and palæontology of the later Jurassics of Dorsetshire and the Older Tertiaries of the Isle of Wight; 4. Investigations into the conditions of the Earth's crust, and speculations as to the causes of the great operations which take place therein, either observed in action or inferred from their results.

Whether dealing with denudation in Norfolk, with the Bracklesham Beds on the coasts of the Channel, or making use of mathematical analysis to determine what must be the resultant form and status of the Earth (on the hypothesis of a certain not improbable combination of forces, brought to bear upon certain possible conditions of the crust), you have given evidence of that philosophic spirit which has ever been your characteristic. And we have also seen how suggestive your work has been, from the large series of similar investigations which have often followed the publication of your results.

The Rev. Osmond Fisher, in reply, said:—

Mr. President,—

I regard the award of this Medal to me as to some extent a token that my efforts to find a *modus vivendi* between geologists and physicists have been appreciated by the Geological Society. I regret to say that the leading physicists, at least in this country, make no sign at present either of accepting or of rejecting my conclusions; but the important questions at issue seem on the point of receiving recognition from American mathematicians.

It is with peculiar pleasure that I shall treasure the Murchison Medal. I had the honour many years ago of a slight acquaintance with the distinguished Founder of this endowment, and I recollect still how, at the reading of the first paper which I offered to this Society, Sir Roderick expressed approbation of my views, which were somewhat opposed to the strictly uniformitarian theories then chiefly in vogue. Words of encouragement falling from so great a man could not fail to be valuable to an amateur at his first venture before a learned Society; and that the same Society should after many years endorse in so appropriate a manner the favourable opinion which he expressed of my early effort affords me the greatest satisfaction.

Award of the Murchison Geological Fund.

The President then handed the Balance of the Proceeds of the Murchison Geological Fund to Mr. G. J. Williams, F.G.S., addressing him as follows:—

Mr. Williams,—

The Balance of the Proceeds of the Murchison Geological Fund has been awarded to you by the Council in token of appreciation of your active researches amongst the Cambrian and Ordovician rocks of Ffestiniog and Harlech. You have done good petrological and palæontological work, both in the selection of rocks for thin sections and in amassing a fine series of fossils. The exhibition of a portion of your collection at Chester, on the occasion of the International Congress Excursion in 1888, proved to be of great interest. The Council hope that this Award may be fruitful, in inducing you to persevere on the lines which you have already adopted with so much success.

Mr. Williams, in reply, said :—

Mr. President,—

I beg to thank the Council of the Geological Society for the wholly unexpected honour they have conferred on me in awarding me the Balance of the Proceeds of the Murchison Geological Fund. I have been able to do but little work in the past, and I look upon this Award as an aid to further research rather than a recognition of work already accomplished. If anything is needed as an incentive to further work, in addition to the pleasure derived from the work itself, I shall be able to look back on this Award as a "spur to prick the sides of my intent."

Award of the Lyell Medal.

In presenting the Lyell Medal to Mr. E. Tulley Newton, F.G.S., the President addressed him as follows :—

Mr. Newton,—

The Council have awarded to you the Lyell Medal, with a sum of Twenty-five Pounds, in recognition of the valuable services you have rendered to British Palæontology. In addition to your well-known memoirs, 'On the Chimæroid Fishes of the Cretaceous Rocks' and 'On the Vertebrata of the Forest-bed Series,' published by the Geological Survey, you continue to contribute important papers to the Royal, Geological, and Zoological Societies, to the 'Geological Magazine,' and to the Geologists' Association. Nor must we forget the very valuable synopsis of the Animal Kingdom brought out by you in 1887.

Your knowledge of the fossil Mollusca has been made available by way of joint contribution to more than one paper, while you have further increased our knowledge of the Vertebrata of the British Isles in almost every class. The Fishes have always constituted one of your favourite subjects, and lately you have brought to notice a new species of *Clupea* from the Oligocene of the Isle of Wight, and a form of *Semionotus* from the Keuper of Warwick, besides contributing to the history of Eocene Siluroids. Your recent papers in the Proceedings of the Royal Society prove that you have not neglected the Reptilia, while your 'Further Contribution to the History of the Norfolk Forest-bed' and your Notice of some new Mammals from the Crags show that the Mammalia have not been forgotten. Even in the class Aves you have indicated the presence of the Red-throated Diver in Pleistocene Beds at Mundesley, and more recently you have described *Gastornis Klaasseni* from the Lower Eocene of Croydon.

In presenting you with this token of their appreciation of your work, the Council feel sure that you are by no means likely to relax those efforts in descriptive palæontology which have already borne such excellent fruit.

Mr. Newton, in reply, said:—

Mr. President,—

I am deeply sensible of the honour which the Geological Society has conferred upon me to-day, by the Award of the Lyell Medal, and regret that the work, of which you, Sir, have spoken so kindly, bears so small a proportion to the reward bestowed upon it; for the Medal of Sir Charles Lyell is in my estimation one of the highest honours which a geologist can hope to receive.

It has been my good fortune to be placed in a position which has brought me valuable specimens to work out, and if the results of my labour are in any way of scientific value, it is due to training, in years gone by, under my esteemed master in science, the Rt. Hon. Professor Huxley.

I receive this Award with the greater pleasure, because it is to me a further evidence of the kindly feeling existing between this Society and the members of the Geological Survey, who are to-day rejoicing and participating in the honours conferred upon two of their colleagues.

I desire to express my warmest thanks to the Council for their much valued Award, and to you, Sir, for the kind words with which it has been accompanied.

Award of the Lyell Geological Fund.

The President then handed one moiety of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Miss Catherine A. Raisin, B.Sc., to Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., for transmission to the recipient, addressing him as follows :—

Professor Bonney,—

In asking you to forward to Miss Raisin one moiety of the Balance of the Proceeds of the Lyell Geological Fund, I am performing a very pleasing duty. Miss Raisin's excellent work, both in the field and with the microscope, so far commends itself to the Council that they have readily made this Award to a pupil of whom you may be justly proud. The considerable number of papers which that lady has contributed, both to the Quarterly Journal of the Society and also to the 'Geological Magazine'—all within the last six years—is a proof of her industry, while the papers themselves indicate an excellent knowledge of Petrology and a good eye for country. The Council, in making this Award, wish it to be regarded as an acknowledgment of past work, and at the same time as an encouragement for the future.

Professor Bonney, in reply, said :—

Mr. President,—

I have been requested by Miss Raisin to offer her thanks to the Council and Society in the following terms :—

"It is difficult for me to express the gratification which I feel at the honour that has been conferred upon me by the Council of the Geological Society. It gives me also peculiar pleasure to receive an award associated with the name of Sir Charles Lyell, whose 'Principles of Geology' was one of the earliest books to arouse my enthusiasm in that subject, and who by the terms of his Bequest gave evidence of his interest in the intellectual work of women, and even anticipated that they might in the future take part in scientific investigations. In addition to the personal honour, I welcome this recognition as an encouragement, not to myself only, but also to other women who are working at Geology and at different branches of Natural Science. I can assure the Society that their generous appreciation of the little which I have done will not be thrown away, but that I shall use my best endeavours in the future to carry on work worthy of their kind encouragement, worthy also of the instruction and guidance received at University College, the benefit of which I rejoice to have this opportunity of acknowledging."

Here I might sit down, but I cannot forbear from expressing my personal gratification at being chosen to represent so earnest and conscientious a worker. It brings me a further gratification. As life is in its afternoon we become conscious, often painfully, that we have failed in fulfilling our earlier ideals. My own work has been smaller in quantity and inferior in quality to what I had hoped, but, when one former pupil receives an Award and another a Medal, when the Secretaries designated for the coming year are two other old pupils, one feels that one has not wholly laboured in vain.

The President then presented the other half of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Alfred N. Leeds, addressing him as follows:—

Mr. Leeds,—

The Council have awarded to you the second moiety of the Balance of the Proceeds of the Lyell Geological Fund, in appreciation of your long-continued and successful endeavours to collect and reconstruct the fossil Vertebrata of the Oxford Clay of the neighbourhood of Peterborough. In making this Award the Council bear in mind the readiness which you have at all times shown to place the materials in your possession at the service of palæontologists desirous of availing themselves of your treasures. The Fund now awarded, besides being a recognition of past services, may help to encourage you to work in the same direction.

Mr. Leeds, in reply, said:—

Mr. President,—

In returning thanks to yourself and the Council for this Award, I must say how astonished and pleased I was at so unexpected a recognition. It is more than twenty years since my brother (who now resides in New Zealand) and I began to collect fossils from the Oxford Clay. The late Prof. Phillips, of Oxford, was the first geologist to describe some of our specimens, which are also figured in his 'Geology of Oxford.' In 1874 Prof. Seeley described the remains of *Murænosaurus*, and since then he, Mr. J. W. Hulke, Mr. R. Lydekker, and Mr. A. Smith Woodward have written many papers for your Society upon other specimens of Saurians and Fishes which we had collected. From all these friends, and especially from Dr. H. Woodward, we have received the very greatest encouragement in our work.

You, Sir, have crowned our labours to-day, by your generous approval and the stamp of the 'Lyell Award.'

Award of the Bigsby Medal.

In handing the Bigsby Medal, awarded to Prof. W. J. Sollas, D.Sc., LL.D., M.A., F.R.S., F.G.S., to Mr. J. J. H. Teall, M.A., F.R.S., F.G.S., for transmission to the recipient, the President addressed him in the following words:—

Mr. Teall,—

The Council have awarded to Prof. Sollas the Bigsby Medal in acknowledgment of his continued researches on the morphology and mineral constitution of the Fossil Sponges. Fifteen years have elapsed since a President of this Society, in presenting him with the balance of the proceeds of the Wollaston Donation Fund, expressed a belief that he would continue to benefit Palæontological Science by his researches on these obscure forms of life. That those anticipations have been fully realized the important character of Prof. Sollas's subsequent work in this direction most clearly proves.

But it is not in Palæontology alone that he has evinced his interest in Geological Science, as his paper on the Silurian district of Rhymney and other contributions to the geology of the neighbourhood of Bristol serve to demonstrate. Nor have his efforts relaxed since he became Professor of Geology and Mineralogy in the University of Dublin, as the Transactions of the Royal Dublin Society and the Royal Irish Academy can testify. We recognize the philosophical biologist in his memoir on the Origin of Freshwater Faunas, and the mineralogist and chemist in his contributions to a knowledge of the Granites of Leinster. It is satisfactory to reflect that one who has done so much and in so many ways for science is still sufficiently young to receive the Bigsby Medal, and, should he happily be spared, it is not unreasonable to suppose that still higher honours may await his efforts.

Mr. Teall, in reply, said :—

Mr. President,—

I have been requested by my friend Prof. Sollas to express his thanks to the Council of the Geological Society for the honour which they have conferred upon him. Had he been present in person I feel sure that he would also have thanked you, Sir, for the kind words with which you have accompanied the Award. He desires me to read the following communication :—

"If the first impulse in the study of science arise from a longing for deeper insight into Nature, a second, at once powerful and innocent, is a desire for the approbation of elders. Thus I gratefully receive this Bigsby Medal awarded me by the Council, finding in it both reward, too little deserved, and stimulus to fresh endeavour.

"My old friend and whilom fellow-student, Mr. Teall, who, by the indulgence of the Society, represents me to-day, was its recipient in 1889, and he concluded his expression of thanks with an eloquent tribute to our revered teacher, Prof. Bonney. Here I can gladly follow where I fain would lead; for if any success has attended my studies, I owe it to the encouragement of our old Tutor, who has never treated the designation 'in loco parentis' as a harmless College fiction, but has made of it through life a veritable truth."

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

W. H. Hudleston, Esq., M.A., F.R.S., F.L.S.

Gentlemen,—

Our losses by death since the last Anniversary Meeting have been considerable, although there were but few of the Fellows deceased who participated to any great extent in the work of the Society. No more than five, so far as I can ascertain, contributed to its publications.

Sir Richard Owen, K.C.B., F.R.S., youngest son of Mr. Richard Owen, of Fulmer Place, near Slough, was born at Lancaster on the 20th July, 1804. He was educated at the grammar school of his native town, where he made the acquaintance, amongst others, of Whewell, afterwards Master of Trinity, a firm friend of his for many years. Having evinced an anxiety for a seafaring life, young Owen is stated to have served for a short time as midshipman. Ultimately he returned home, was articled to a surgeon in Lancaster, and about 1823 matriculated in the University of Edinburgh. Two years afterwards he removed to London, where he joined the medical school of St. Bartholomew's Hospital, and in the following year entered himself as a member of the Royal College of Surgeons. On the completion of his medical studies, Mr. Owen settled down to practise in Serle Street, Lincoln's Inn Fields.

It must often have occurred to those who are fond of tracing the early history of a celebrity that opportunity seems to have been the making of most men. We need not, however, suppose that if Owen had continued to apply himself exclusively to private practice, or had joined the medical department of the Navy, he might not afterwards have become a distinguished anatomist. Indeed, we know of one who did actually, at the outset of life, make choice of the latter profession, and who ultimately rivalled Owen himself in the very branch of science he had chosen to make his own. The year 1828 witnessed the turning-point in Owen's career. There can be no doubt that the rising talent and skill of his pupil had been duly noted by Abernethy, at whose suggestion he was employed by the College of Surgeons to assist in making a catalogue of the Hunterian Collection. From that day onwards his long public life was, with possibly one exception, an uninterrupted success.

It is by no means necessary on the present occasion to enumerate all the steps in this remarkable career, which, indeed, has already formed the subject of many a chronicle. With reference to this period of his life it may be sufficient to say that in 1830 an instalment of the Catalogue was published. In the same year Mr. Owen read a paper on the Anatomy of the Orang-utan at the very first meeting of the Zoological Society's Committee of Science. He afterwards made several important contributions to that Society's publications, and was in fact for many years their unpaid prosector. In 1832 he wrote his well-known memoir on the Pearly Nautilus, and in 1834 was appointed to the newly-established Chair of Comparative Anatomy at St. Bartholomew's. In 1835 he married the daughter of Mr. Clift.

It is in this latter year that we find the first allusion to Owen in the publications of the Geological Society. Dr. Mantell, it appears, had read a paper with reference to the discovery of bird-bones in the Tilgate Forest Beds, and, as doubts had been expressed, he placed his specimens in the hands of 'Mr. Owen, of the College of Surgeons,' who pointed out one bone as decidedly belonging to a wader. In April 1837 the first paper of the Hunterian Professor of Anatomy was read before the Geological Society. It contained a description of *Toxodon platensis*, an extinct Mammal of gigantic size, referable by its dentition to the Rodentia, but with affinities towards the Pachydermata and the herbivorous Cetacea. Charles Lyell and Charles Darwin were then Secretaries of the Society. On May 31st in the same year Prof. Owen was elected a Fellow of the Society (F.R.S. in 1836) in company with Mr. James Heywood, of Manchester, whose name still remains upon our books. Owen's certificate on that occasion was signed, amongst others, by R. Hutton, R. I. Murchison, C. Darwin, L. Horner, and J. Phillips.

As an instance of the way in which honours came thick upon him, Prof. Owen, when only 34 years of age (in 1838), received the Wollaston Medal, awarded, as his friend Dr. Whewell remarked, for his services to 'Fossil Zoology' in general, and in particular for the description of the Fossil Mammalia collected by Mr. Darwin. The President further expressed a hope that this early recognition of the Medallist's services might be regarded as a token of interest in future investigations. Owen, in reply, confessed that since he had pursued anatomical investigations in connexion with fossil remains he had been rewarded by new and extrinsic pleasures. To this source he traced his connexion with the Geological Society and the possession of some most valued friendships. He received this testimony as a strong stimulus to future endeavours, and pledged himself to lose no available time in furthering that branch of Geological Science which deals with extinct animals. Thus it was that the comparative anatomist of the College of Surgeons was induced to become a palæontologist. That the Wollaston Medallist of 1838 amply redeemed his promises the publications of our own Society and of the Palæontographical Society, to mention no others, bear most convincing testimony.

As regards Prof. Owen's further connexion with this Society, other than as a contributor to its publications, he appears to have been on the Council at different times between the years 1838 and 1857 inclusive, acting as Vice-President in 1845, 1847, and 1853. It is said that the Presidency of the Society was offered to him and that he declined it, but no authority can be given for the statement, neither is anything known as to the period when this supposed offer was made. The only thing we can say for certain is that since 1857, being the year he was elected President of the British Association, he took no active part in the administration of the affairs of this Society.

It would be no easy task to enumerate all the honours and appointments which fell to the lot of Prof. Owen during a career which we may regard as having been fully established in the pre-Victorian era, though attaining its zenith during the present reign. Six years after the award of the Wollaston Medal he received the Royal Medal from the Royal Society for his descriptive memoir on the Belemnites of the Oxford Clay, and he was further awarded the Copley Medal from the same Society in 1851. Rarely has a *savant* met with such an amount of recognition from nearly all quarters. He received (1858) the appointment of Fullerian Professor of Physiology in the Royal Institution, was made LL.D. of Cambridge and D.C.L. of Oxford. About the same time, in accordance with the wish of the late Prince Consort, Prof. Owen was requested by Her Majesty to deliver at Buckingham Palace a course of lectures on the elements of natural history, including zoology and geology. From the late Emperor of the French he received the insignia of the Legion of Honour, from the King of Italy the order of St. Maurice and St. Lazarus, and from the King of Prussia the Star of the Order of Merit; whilst in the 'Prix Cuvier,' awarded by the Institute of France, he obtained a recognition from that body which was peculiarly appropriate.

Prof. Owen's connexion with the College of Surgeons terminated in 1856, when he was appointed Superintendent of the Natural History Department in the British Museum, a post which he was the first to occupy and which he filled with so much ability for twenty-eight years. The great event of his reign was the transfer of the collections from Bloomsbury to South Kensington. His efforts to obtain more accommodation for the accumulating material, and how he was thwarted by one set of politicians and encouraged by another, are matters of history. Suffice it to say that the money was ultimately voted and the plans drawn out, though his biographer will probably repudiate responsibility on Owen's part for the peculiarities of that remarkable building. On Easter Monday, 1881, the new Museum of Natural History was opened for the first time to the public.

Prof. Owen received the Knight-Commandership of the Bath on resigning the post of Director in 1884, and thereafter he lived more or less in retirement at his prettily situated residence in Richmond Park, which had been assigned to him by Her Majesty in 1852. There, we are told, it was his pleasure to receive his numerous friends and such foreign visitors as were desirous of enjoying the society and reminiscences of the clever and entertaining old *savant*. And thus was spent the evening of his long and useful life, in fairly robust health and in the full possession of his faculties. When the last days came, his strong constitution delayed for long the inevitable hour, and he finally passed away on December 18th, 1892, in the 89th year of his age.

The Council at the ensuing meeting deputed Prof. Judd and Dr. Hicks to represent the Society at the funeral, and a resolution of condolence was likewise passed and communicated to the late Professor's grandson. Sir Richard Owen having expressed a desire to be buried in Ham churchyard, the funeral took place there on the 23rd December. Amongst those present was the Duke of Teck, who placed on the coffin a wreath in token of sincere admiration and affection on his own part and that of the Duchess. The scientific societies and many other public institutions were represented by officers specially deputed to attend. A few days afterwards a preliminary meeting was held at the house of Sir James Paget to consider what steps should be taken with regard to a suitable memorial, when it was decided that a committee should be formed to make the necessary preparations. Subsequently the Prince of Wales consented to become Chairman of the Committee, and a meeting was held at the rooms of the Royal Society on the 21st January, 1893, when it was decided that the memorial should consist primarily of a marble statue to be placed in the hall of the Natural History Museum. It was also determined that a Memorial Catalogue of Owen's works should be issued.

Whatever memorial may ultimately be raised in his honour, it must be confessed that Sir Richard Owen's publications are of themselves a monument of his talent and industry. On looking over the Royal Society's Catalogue one is tempted to exclaim 'Prodigious!' No less than 368 memoirs and papers of his are enumerated down to the end of 1872, and he has been credited with some 60 after that date; of these 28 were printed in the Quarterly Journal of this Society. We ourselves are chiefly concerned with his palæontological work, and especially with those portions of it which appeared in our own publications and in those of the Palæontographical Society.

With the latter Society Owen may be said to have established the most intimate relations. It was in 1848 that he first offered a Monograph on the British Fossil Reptiles, and in the following year he became a member of their Council, being re-elected on many occasions in succeeding years. In 1867 he was elected a Vice-President, and he retained that office until 1877, when he was elected the fourth President of the Society on the death of Dr. Bowerbank. It is almost needless to remind you that he continued to be President until the day of his death, although the last time he occupied the Chair was at a Council meeting in June 1887. Meanwhile his promised Monograph had expanded into a series of monographs, on which he continued to work for a period of over thirty years. The 'Reptilia of the London Clay,' commenced in 1848, was completed in 1880: this includes the Bracklesham and other Tertiary beds. The 'Reptilia of the Cretaceous Formations,' commenced in 1851, was completed in 1862. The 'Reptilia of the Wealden and Purbeck Formations,' commenced in 1853, was completed in 1879. This is an immense work, running into thirteen separate numbers. The 'Reptilia of the Kimeridge Clay Formation' was commenced in 1859 and concluded in 1868. The 'Reptilia of the Liassic Formations,' begun in 1859, was concluded in 1869. The 'Reptilia of the Mesozoic Formations,' the 'Red Crag Cetacea,' and the 'Mammalia of the Mesozoic Formations' must also be added to this list. A 'History of British Fossil Reptiles,' in three volumes, was published in 1884, with abundant illustrations, in which the memoirs already mentioned, with some others, were collected.

Other societies and institutions were also favoured by Prof. Owen; as examples I may mention 'Researches on Fossil Remains of the Extinct Mammals of Australia, with a notice of the Extinct Marsupials of England,' published by the Zoological Society, and 'Fossil Reptilia of South Africa in the Collection of the British Museum,' published by order of the Trustees. Besides these, we must not forget to enumerate his 'Classification and Distribution of Mammals' (1859), his 'Manual of Palæontology' (1861), and, to go very far back indeed, his 'Odontography,' published between 1840–45.

His communications to the Geological Society vary much in length; but, taking great and small together, 85 papers are set down to his name. Vols. vi. and vii. of the second series of the Transactions are especially rich in communications from this author, the quarto plates offering advantages for illustration. He clears up doubts as to the marsupial character of *Thylacotherium* and *Phascolotherium* from the Stonesfield Slate, and combats the notion that the so-called *Basilosaurus* was a reptile possessing teeth with double fangs. Five quarto plates are devoted to the illustration of a species of *Glyptodon* from South America, whilst three classes of Vertebrates are noticed from the London Clay, and descriptions given of five species of *Labyrinthodon* from Warwickshire. Of course, all this is ancient history, but it may serve to direct attention for a moment to what was going on at the Geological Society fifty years ago. Several years later he writes largely on *Dicynodon*. His description of *Hyopotamus* from the Isle of Wight is also of this period. In our Quarterly Journal his papers have been numerous, but many of them are rather short. The Vertebrates of South Africa have always held an important place in these communications.

Referring to Owen's work generally, none but an expert must presume to venture an opinion. Criticisms on his numerous speculative treatises would nowadays be somewhat out of date. His opposition to what was once called Darwinism is a curious episode in his career. At the celebrated meeting of the British Association at Oxford in 1860 his assistance was of use in enabling the anti-Darwinians to maintain a good defensive position; but two years later, at Cambridge, even Owen's powers of persuasion could not avert defeat. His attitude has been attributed to various causes, such as a predilection for bishops, or to jealousy that others should have forestalled him in interpreting the great riddle of the succession of life. Whatever may have been the cause, it is admitted that the researches of Owen himself paved the way for the reception of the doctrine of Evolution, nor was his attitude in later years one of active hostility.

When all is summed up, we recognize in Owen a man highly gifted by Nature, and who knew how to make use of his talents—a rare faculty in a genius, as Owen most undoubtedly was. His very presence had in it something remarkable, and that he possessed the power of fascinating his hearers is amply testified by what fell from the Prince of Wales on a recent occasion. Some people may fancy that cataloguing museum specimens and describing the remains of extinct animals is necessarily associated with a peculiarity of character in unison with the subject. But the whole history of Owen contradicts such a supposition. Skilled beyond others in the science of comparative anatomy, an eloquent lecturer, a courteous and sympathetic official, an indefatigable writer, Owen also presented a bright social side, as those who had the pleasure of knowing him have ever testified. Surely we cannot be far wrong in ranking him among the Great Men of the Nineteenth Century.

Henry Francis Blanford, F.R.S., was born in 1834 in Bouverie Street, Whitefriars, where his father had a manufactory, on the site of the 'Daily News' printing-office. His early education was obtained at private schools in Brighton and Brussels, and after studying for some time at the old School of Design in Somerset House, he joined the Royal School of Mines at its commencement in 1851, and a life that might otherwise very possibly have been devoted to art, for he was an admirable draughtsman, was thenceforward gained to science. At the Royal School of Mines he took the first place in his year, and received the Duke of Cornwall's Scholarship, then the only prize. After a year's study in Freiberg and another year in London, which he employed in preparing a translation of v. Kobell's work on the Blowpipe, his first publication, he was appointed to the staff of the Geological Survey of India, together with his brother, Mr. W. T. Blanford, and landed in Calcutta at the end of September, 1855.

Almost immediately after their arrival in India, the two brothers and Mr. W. Theobald were despatched to examine and report upon an almost unknown coal-field around Talchir in Orissa. The work done was chiefly memorable geologically for one discovery, that of the Talchir boulder-bed, and for the circumstance that, chiefly through Mr. H. F. Blanford's observations, the first step was taken towards the classification of the remarkable series of beds associated with the Indian coal-bearing rocks, for both the underlying Talchir division and an overlying mass were separated from the Damuda or true coal-bearing beds. For some time after this Mr. H. F. Blanford was engaged in Calcutta in charge of the Survey Office, and was occupied with palæontological work in the Museum, but in 1857 he was placed at the head of a strong Survey party that was despatched to Madras, and he was chiefly engaged for the next three or four years in examining the Cretaceous beds near Trichinopoly and Pondicherry, some fossils from which, described by Prof. E. Forbes and Sir P. Egerton, had attracted much attention in Europe. The stratigraphical work on the Indian Cretaceous beds was mainly palæontological, but the classification established by Mr. Blanford was fully confirmed by Dr. F. Stoliczka's well-known description of the fauna. A commencement of this description was made by Mr. Blanford himself, who published an account of the Nautilidæ and Belemnitidæ in the 'Palæontologia Indica' before he left the Survey in 1862. The geology of the area was described in a report published in the fourth volume of the Memoirs of the Geological Survey of India. An account of the geology of the Nilghiri Hills in the first volume of the same Memoirs was the only other report on the Madras Presidency by Mr. Blanford that was published by the Survey.

The causes of Mr. Blanford's retirement from the Survey were partly injury to his health produced by exposure to the climate, partly strained personal relations with the Superintendent of the Survey, the late Dr. T. Oldham. After staying for a short time in Europe and recovering his health, Mr. Blanford was appointed to the Science Professorship at the Presidency College, Calcutta, and was from 1864 to 1872 on the staff of the Bengal Educational Department. He became in 1864 one of the Hon. Secretaries of the Asiatic Society of Bengal, and about this time took up the subject of Indian meteorology, at first in connexion with cyclonic storms, of which a very severe one visited Calcutta in 1864. He was for some years a member of a Meteorological Committee appointed by the Government; in 1867 he became Meteorological Reporter to the Government of Bengal; and finally, in 1874, a new department having been formed by the Government of India, he was placed at its head. This post of Meteorological Reporter to the Government of India he held until his retirement from the Indian Service in 1888. After his retirement he resided at Folkestone until his death on January 23rd, 1893.

Besides a number of important reports and works on meteorology, Mr. Blanford was author of several papers on fossil and recent mollusca and of two treatises on the geography of India. One of these has been used for many years as a text-book by schools and colleges in India; the other is a recent publication, and forms one of Macmillan's Geographical Series, published under the editorship of Sir Archibald Geikie. Another recent publication of Mr. Blanford's is 'A Practical Guide to the Climates and Weather of India, Ceylon, and Burma, and the Storms of Indian Seas.' He also wrote, in conjunction with the late Mr. J. W. Salter, the Palæontology of Niti. His only contribution to the Quarterly Journal of this Society was an important paper published in 1875 on 'The Age and Correlation of the Plant-bearing Series of India, and the former existence of an Indo-Oceanic Continent.'

Mr. H. F. Blanford became a Fellow of the Geological Society in 1862 and of the Royal Society in 1880. He was President of the Asiatic Society of Bengal in 1884–85.

Thomas William Fletcher, M.A., F.R.S., F.S.A., late Colonel in the Staffordshire Militia, was born at Darlaston, Staffordshire, on the 25th May, 1808. He was educated at Dublin, and took his M.A. at that University, being also an M.A. of Oxford. For some years he practised as a solicitor at Dudley, and in 1860 became a barrister of the Inner Temple. At one time he was much interested in the fossils of his native county, and in 1850 contributed two short papers on Dudley Trilobites to our Quarterly Journal. When the meeting of the British Association took place at Dudley in 1849 his collection attracted the attention of several notabilities, among whom were Prince Charles Lucien Bonaparte, Sir R. Murchison, Drouyn de Lhuys, Joachim Barrande, Edward Forbes, etc. Subsequently Colonel Fletcher parted with his collection to the Woodwardian Museum, and apparently ceased to collect fossils. Nevertheless, he is said to have taken an interest in geology to the last, and often attended the field meetings of the Dudley Geological Society. He died at Launeswood House, near Stourbridge, on the 1st February, 1893, within a few months of completing his 85th year.

Thomas Davies was born on the 29th December, 1837, in the neighbourhood of London. He was the son of Mr. William Davies, F.G.S., of the Geological Department of the British Museum. Having somewhat of a roving disposition, he went to sea at the age of 14, and during the four years that he was afloat visited India, Singapore, China, South America, and other countries. In 1858 he was appointed a third-class assistant in the Mineral Department of the British Museum under Prof. Maskelyne, and became a junior assistant in 1863. For nine years he was Prof. Maskelyne's only assistant, and it was in the arrangement and labelling of the immense mass of specimens under that gentleman's supervision that he acquired an eye-knowledge of minerals which has rarely been surpassed. Subsequently, under the same tuition, he obtained a knowledge of the microscopic characters of rock-forming minerals, which rendered him a very practical petrologist.

In 1880 Mr. Davies was promoted to the grade of first-class assistant, and by a singular coincidence his father, Mr. William Davies, obtained similar promotion in another department of the British Museum on the very same day. In that year also Mr. T. Davies was awarded the Balance of the Proceeds of the Wollaston Fund, the then President specially commenting upon the generous assistance he was so ready to afford to others. He became a Fellow of this Society in 1870, served on the Council during 1886–87, and contributed appendices on the microscopical structure of rocks to papers written by Dr. Hicks.

His publications were not numerous, although he contributed articles on mineralogy and petrology to more than one Magazine. Of late years, however, he took a deep interest in the Mineralogical Society, of which he was one of the original members, and for a long time was Foreign Secretary and practically Editor of their Journal, his very considerable knowledge of French and German being of material service to him in this connexion. One feature was particularly conspicuous in Mr. Davies, viz. his readiness to oblige. Thus he earned the goodwill of his colleagues, and of those numerous friends and acquaintances who were so ready to avail themselves of his practical knowledge in the judging of minerals. About two and a half years ago he was attacked by serious illness, and though he recovered for a time, his constitution was too severely shaken, and he died at East Acton on December 21st, 1892, within a few days of completing his 55th year.

Henry John Marten, M.Inst.C.E., was born in 1827. He was a well-known hydraulic engineer, and had been adviser to the Board of Agriculture, the Severn Commissioners, and the Staffordshire and Worcestershire Canal Company. He became a Fellow of this

Society in 1888, and two years afterwards read a paper 'On some Water-worn and Pebble-worn Stones taken from the Apron of the Holt-Fleet Weir on the River Severn.' Quite recently, Mr. Marten gave evidence before the Royal Commissioners on Water Supply as to the practicability of constructing storage-reservoirs in the Upper Thames Valley. He died on November 3rd, 1892, in his 66th year.

Edward Hammond Hargraves, late of Sydney, New South Wales, was born at Gosport on October 7th, 1816, being the third son of John Edwards Hargraves, then a Lieutenant in the Sussex Militia. E. H. Hargraves was educated at Brighton Grammar School, and afterwards at Lewes. When 14 years of age he went to sea and had to 'rough it' on board a merchant-vessel for nearly three years, ultimately landing in Australia in 1832. After a few more years devoted to a roving life, we find him engaged as a rearer of stock in Eastern Australia, where he appears to have been not unmindful of the geological features of that district, which was afterwards to become the scene of his celebrated discovery of gold.

Not being very successful in business, he sailed for California in 1849, in the hope of making a fortune by gold-mining. His experiences in that region quickly convinced him of the similarity in structure that existed between the auriferous rocks of California and certain districts in New South Wales with which he was well acquainted. Mr. Hargraves accordingly returned to the country of his adoption, and on the 4th February, 1851, set out from Sydney for the region where he expected to find gold. On the 12th of that month, having arrived at Lewis Ponds Creek, he succeeded in proving to his companion that they had been walking on gold, since, after a few washings on a small scale, it was clearly demonstrated that the alluvium was auriferous, and subsequently a considerable quantity of gold was obtained by the party. Ultimately, Mr. Hargraves was instructed to point out the gold-field to the Government Geologist, whom he accompanied to Ophir, a place since then well-known in the annals of Australian gold-mining. Not many weeks elapsed before the usual rush of prospectors ensued, and the once lonely spot suddenly became populous.

Some of us, perhaps, are old enough to remember the controversies which took place forty years ago with reference to the first discovery of gold in Australia. The disputed claims of Sir Roderick Murchison and the Rev. W. B. Clarke to the honour of the *scientific* discovery are matters of history. Although there had been accidental discoveries of small samples of gold at various times, it is a singular circumstance that Count Strzelecki's work on New South Wales, published in 1845, contains no allusion to the presence of gold in the rocks of that country. However, it cannot be doubted that the subject of the present notice was the first practical discoverer of gold in Australia, and as such received many valuable gifts and testimonials. He was made Commissioner of Crown Lands in New South Wales, and on his vacating that office the Legislative Council awarded him £10,000, a sum which he considered scarcely adequate, bearing in mind the enormous amount of wealth that his discovery had brought to that colony.

In 1854 we find Mr. Hargraves in England, and in the following year he brought out his work on Australia and its Gold Fields, which was published in London. In that year also he became a Fellow of the Geological Society, though we do not appear to have received any papers at his hands. Nevertheless, he was evidently a man with considerable powers of observation, a geologist by instinct, as it were, and the chapter which treats of the scientific and practical discoveries of gold in Australia is an interesting geological disquisition.

We do not know much of his later life, though it is said that throughout his career he was more remarkable for generosity than prudence. The 25th anniversary of the great gold discovery was duly kept at Sydney in 1876, shortly before which event the Parliament of New South Wales granted him a pension for his services. In the Queen's Jubilee year, being the 36th since the discovery of gold in New South Wales, then comprising the Colony of Victoria, he made a last appeal to the Legislature of the latter colony to fulfil their obligations towards him, obligations which they had admitted but never discharged. Whether or no he was successful in this application is unknown to me.

He died, presumably at Sydney, on October 30th, 1891, at the age of 75. The announcement of his death did not reach this Society until the autumn of the following year.

John Murray, the third of that name, was born in London on the 16th April, 1808. He received his early education at Charterhouse, and proceeded thence to the University of Edinburgh, where his attention was much drawn to Natural Science. In 1828, at the early age of 20, he joined his father's business, as one of the firm of well-known publishers in Albemarle Street, and in the same year he appears to have become a Fellow of this Society, before he was 21 years of age. Consequently, although not the oldest Fellow at the time of his death, he was the Father of the Society when that event occurred, having been a contributing Fellow for 64 years.

In early life John Murray developed a taste for travelling, and when 21 years of age visited Belgium, and in the following year France and Italy. We are told that he travelled, note-book in hand, preserving an ample record of places and events; so that, in this way, at a comparatively early stage of his career, he originated the famous series of handbooks, which for many years enjoyed almost a monopoly amongst the travelling public—before, in fact, he succeeded to his father's business in 1843.

John Murray was one of the original Fellows of the Royal Geographical Society; he sat on the Council of that Society as long ago as 1850 and subsequently. He was of frequent assistance to Murchison, who in his later years almost made that Society his home. Murray had also been associated with the Royal Agricultural Society from its commencement, and had arranged with Mr. Philip Pusey, fifty-four years ago, the terms on which their Journal was originally published.

He does not appear ever to have taken an active part in the affairs of this Society, and from the fact that no cross is attached to his name in our List I conclude that he never contributed to its publications. Nevertheless he was a man of letters, a scholar as well as a publisher, and was especially interested in physiographical problems. An anonymous brochure entitled 'Scepticism in Geology,' published in 1877, is attributed to his pen. This work to a certain extent seems to have reflected the views of Murchison, since it was a kind of protest against the ultra-uniformitarianism which then prevailed. The Author more especially opposed the fashion of attributing all the features of the earth's surface to denudation, and protested strongly against Ramsay's theory of lake-basins.

Mr. Murray died in London on the 2nd April, 1892, aged 84 years. At his funeral, to meet the convenience of personal friends, among whom was Mr. Gladstone, the first part of the burial service was read at St. James's Church, Piccadilly, whence his remains were finally transferred to Wimbledon.

William Reed was born at Malton, in Yorkshire, on the 21st December, 1810. He was educated at Monkman's School in York, and afterwards at Thornton, near Pickering. After having been duly articled to a local surgeon, he studied Medicine and Surgery both in Leeds and in London, and in 1838 became a Member of the Royal College of Surgeons. From 1839 to 1842 he was House-Surgeon of the York County Hospital, and towards the close of the latter year he proceeded to Paris and attended lectures in the Faculté de Médecine. Returning to England in 1843 he commenced a country practice at Whitwell, a village on the Oolites a few miles west of his native Malton. Thence he ultimately removed to York, where for upwards of 30 years he applied himself with much success to the work of a general practitioner. In his later years he relinquished practice, and continued to devote a great part of his time to the increase of his already large collection of fossils.

There can be very little doubt that Mr. Reed strengthened, if he did not imbibe, his taste for fossils in the pleasant valley of Derwent, where he first settled down to practise after his return from France. His collection of the Inferior Oolite fossils of that district, carefully separated from those of the Coralline Oolite of Malton itself, is a fairly good one and was of much use in assisting geologists to discriminate between the two formations. It gives me great pleasure to record the assistance that I have myself received from him in that respect. In early days, Mr. Reed's specimens were mainly the spoils of his own hammer, but as time went on his attention was largely devoted to the purchase of collections, and year after year he kept adding to the stock until the house in Blake Street was full to overflowing. Indeed his work in Geology seems to have been chiefly in this direction, for there is no record of his having written anything except a short note on a boring at Masham. Fortunately, as Honorary Curator in Geology to the Yorkshire Philosophical Society, this king of collectors found a legitimate outlet for his accumulating treasures. In their excellent Museum at York, Mr. Reed had the pleasure of arranging the different collections which from time to time he had presented to them, and almost to the day of his death found a congenial occupation in making good any deficiencies which might happen to be noticed.

He died at York on May 9th, 1892, after a short illness, in his 82nd year.

Sir James Brunlees, M.Inst.C.E., F.R.S.E., was born at Kelso on the 5th January, 1816. After leaving school he was put by his father to gardening and farm work, with the intention of his being trained as a landscape gardener. Having a desire for a higher education he went to the University of Edinburgh for two sessions, and there made the acquaintance of Mr. Alexander Adie, by whom he was engaged in 1838 as his assistant on the Bolton and Preston Railway. This engagement seems to have fixed his career in life, and subsequently he had an important share in the construction of many railways both in this country and abroad. He became a Fellow of this Society in 1862. In May 1886 he received the honour of Knighthood in connexion with the Mersey Tunnel Railway. He was a Past-President of the Institution of Civil Engineers and a Fellow of the Royal Society of Edinburgh.

He died at Wimbledon on the 2nd June, 1892, at the age of 76.

Lewis Llewellyn Dillwyn was born at Swansea in 1814, being the second son of Mr. Lewis Weston Dillwyn, of Sketty Hall, a well-known botanist and student of Natural History. The Dillwyn family originated in the county of Hereford, but migrated with William Penn in 1699; and thus it happened that the grandfather of our deceased Fellow was born in Pennsylvania. The Dillwyns were first associated with Swansea in connexion with the Cambrian Pottery Works. Mr. L. L. Dillwyn married in 1838 the daughter and heiress of Sir Henry de la Beche. He was a magistrate and deputy-lieutenant of the county of Glamorgan, and Lieutenant-Colonel Commandant of the Glamorganshire Rifle Volunteers. Although a Fellow of this Society and also of the Linnean, his energies seem to have been mainly directed to politics. He was elected member for Swansea in 1855 and continued to represent that borough in each successive Parliament until his death, which occurred very suddenly on June 19th, 1892, during the excitement of the last general election, when he was in the 79th year of his age.

Alexander Norman Tate was born in 1837, at Wells in Somerset, and educated at the Chapter Grammar School of that city. He early evinced a taste for chemistry, and having entered the laboratory of the late Dr. Muspratt at Liverpool, he ultimately became one of the principal consulting chemists in that neighbourhood, being especially recognized as a leading authority on petroleum.

His public educational work commenced soon after he settled in Liverpool, and both by teaching and lecturing he did much to popularize science. Besides having initiated, in conjunction with Mr. James Samuelson, the Liverpool Science and Art Classes, he established the Liverpool Science and Art Teachers' Association and took a strong interest also in the geological work of that city and neighbourhood. Although his special subjects were chemistry, physiology, botany, and general biology, he did good service to Geology by analysing many of the rocks in the neighbourhood of Liverpool. Thus he discovered the presence of *iserine* in the decomposed greenstones of the Boulder-clay in the valley of the Mersey, and showed that the colour of certain black bands in the local Triassic sandstones was due to the presence of manganese. The Proceedings of the Liverpool Geological Society contain many of his memoirs. About five years ago Mr. Tate became a Fellow of this Society, and although he never contributed anything to our Proceedings, we may well believe that, had he been spared, so promising a recruit would have enriched the Quarterly Journal with more than one valuable paper.

He died, after a long illness, on July 22nd, 1892, at the comparatively early age of 55, leaving a distinct void, we are told, in the intellectual life of Liverpool.

David Corse Glen was born at Hawkhead, near Glasgow, in 1823. He received his early education in Paisley and at Glasgow Grammar School, and having turned his attention to engineering, ultimately became partner in the firm of Glen and Ross. Prospering in business, he had the opportunity of indulging his scientific tastes, which were in the direction of Geology and especially of Mineralogy. From the year 1860, Mr. Glen was an active member of the Glasgow Geological Society, frequently representing that Society at the meetings of the British Association. He became a Fellow of this Society in 1876 and occasionally attended the meetings till within two or three years ago. He is said to have possessed one of the finest private collections of minerals in Scotland, which he was always glad to show to strangers interested in the subject; indeed, for many years, his scientific friends were entertained annually at his own house, where his collections were exhibited and explained.

Mr. Glen, who, in addition to his scientific qualifications, was a public-spirited citizen of Glasgow, died in November, 1892, at the age of 68.

John Hooke Taunton, M.Inst.C.E., was born in April, 1820, at Totnes, in Devonshire. For many years he was engineer to the Thames and Severn Canal. Having always paid great attention to the Springs and Water Supply of the Cotteswold area, he was regarded as an authority on the water question, and contributed valuable information to the Report of the Royal Commission on Water Supply in 1869.

As an old Member of the Cotteswold Naturalists' Field Club, he contributed papers on the Hydrology of the Cotteswolds, on the Geology of the Sapperton Tunnel, and other subjects. Less than a twelvemonth has elapsed since he made an interesting communication to that Club on the Dynamic Geology of Palestine, in which the salient features of that remarkable region were well described.

Mr. Taunton resided latterly at Stuart House, near Stroud, where he died on the 31st January, 1893, aged 73.

Thomas Wynne, M.Inst.C.E., was born at Tenbury on the 7th February, 1807, and was educated at Ledbury. About the year 1830 he removed into Staffordshire, where he turned his attention to the study of mine-engineering, became managing partner in a Colliery Company, and practised as a consulting engineer. Mr. Wynne was appointed one of H.M. Inspectors of Mines in 1852, and two years afterwards became a Fellow of this Society. Throughout life he took an active and intelligent interest in all engineering and mining discoveries, and there were few subjects of this nature with which he was not practically conversant. He resided at the Manor House, near Gnosall in Staffordshire, where he died on June 4th, 1891, in the 85th year of his age. The announcement of his death did not reach this Society until the autumn of the following year.

John Strong Newberry, Professor of Geology in Columbia University, New York City, was born on the 22nd of December, 1822, at Windsor, Connecticut. He graduated at Western Reserve College in 1846, and at the Cleveland Medical School in 1848, and began the practice of medicine at Cleveland, Ohio, in 1851. In 1855 he commenced his labours in Geology, the science to which, in connexion with its fellow-science, Palæontology, he devoted the chief part of his remaining years. He received in that year an appointment as geologist and botanist of the expedition sent out by the U.S. Government under Lieutenant Williamson to explore the region on the Pacific between San Francisco and the Columbia River; and the 6th volume of the Government Reports on a 'Practical Route for a Railroad to the Pacific,' published in 1857, contains the results of his work.

In 1857 and 1858 he was engaged in exploring the Colorado

River on the expedition under Lieutenant Ives. The party ascended the river in a steamer for 500 miles from its mouth, and brought back grand views of the wonderful scenery of the cañon, then for the first time explored, for the illustration of his excellent Geological Report, as well as for that of the Commander of the Expedition. Again in 1859 he was geologist of the Government expedition under Captain Macomb, which explored the country of the San Juan and Upper Colorado, and thus had an opportunity for the geological study of part of Utah, Northern Arizona, and New Mexico. His report appeared, after much delay, in 1876, in connexion with the Report of an Expedition from Santa Fé to the junction of the Grand and Green Rivers. The volume contains, besides a general report on the geology of the regions visited, descriptions by F. B. Meek of his Cretaceous fossils, and by himself of the other fossils, including Carboniferous Brachiopods and Fishes, and Triassic plants from Abiquiu, New Mexico, and Sonora, Mexico, the figures of the plants occupying five of the eight plates.

During the Civil War, Dr. Newberry was a member of the Sanitary Commission for the five years following September 1861, and had charge of the work of the Commission in the valley of the Mississippi.

In 1866 Dr. Newberry received the appointment of Professor of Geology at the Columbia College School of Mines. In 1869 he was made State Geologist of Ohio; and the volumes published on Geology and Palæontology contain much written by him on the stratigraphy of the various parts of the State, but still more on the wonderful collections of Devonian and Carboniferous Fishes which the rocks afforded him, and on numerous fossil plants.

In 1888 Dr. Newberry published, in connexion with the United States Geological Survey, a quarto volume of 95 pages and 26 plates on the Fossil Fishes and Fossil Plants of the Triassic rocks of New Jersey and the Connecticut Valley; and in 1889 a similar volume of 228 pages and 53 plates on the Palæozoic Fishes of North America. A report of like completeness on the Amboy Clays (Cretaceous) of New Jersey was nearly ready for publication two years ago, when a stroke of paralysis put an end to his long and most fruitful scientific labours. Besides his larger reports above mentioned, he published many shorter papers connected with all departments of Geology.

Dr. Newberry was one of the corporate members of the U.S. National Academy of Sciences. He was elected a Foreign Member of our Society in 1883, and received the Murchison Medal in 1888. From 1867 until recently he was President of the New York Academy of Sciences. He was a man of great excellence of character. While deeply devoted to science and an earnest worker, he was yet willing to give up several years to the superintendence of soldiers' hospitals at the time of his country's need.

Dr. Newberry died on the 7th December, 1892, within a few days of completing his 70th year.

Nicolai J. von Kokscharow, Major-General in the Russian Army, was born in Siberia on the 5th December, 1818, and at the age of 12 was sent to St. Petersburg to be educated at the Military School of Mines. When only 22 years of age he had the good fortune to be selected to accompany Murchison and De Verneuil during three successive summers, and afterwards De Keyserling, in their extensive journeys through different parts of Russia. Subsequently Kokscharow spent some years in foreign countries, where he had good opportunities for making the acquaintance of distinguished men of science, but always with a leaning towards the mineralogists, of whom, in England, Miller was his chief correspondent.

On his return to Russia he received important appointments in connexion with scientific institutions, all more or less under the government of that country, and ultimately he was appointed to the Directorship of the Institute of Mines, a post which he occupied for 13 years. In 1865 he was made an Honorary Member and Director of the Imperial St. Petersburg Mineralogical Society, afterwards becoming Honorary Director in 1891. Such was the esteem in which he was held by men of science that, when his jubilee was celebrated in 1887, addresses of congratulation from all parts of the world poured in upon the Russian *savant*.

Of his works, which were numerous, the most important is the 'Materialen zur Mineralogie Russlands,' the publication of which, in ten volumes, ranged from 1853 to 1891. We can well believe that a country so rich in minerals as Russia, both European and Asiatic, must have afforded a congenial field for the exercise of Kokscharow's talents, but the Author ultimately included the minerals of other countries in his *magnum opus*. The publications of the Imperial St. Petersburg Mineralogical Society are full of papers by him. A collection of topaz, on which he worked, is now in the British Museum; whilst our own Quarterly Journal contains abstracts of two of his papers furnished by Count Marschall, 'On Clinochlore and Mica' and 'On Crystallized Euclase in the Ural.' He contributed papers largely to Poggendorf's Annalen, to Silliman's Journal, to Leonhard and Bronn's Jahrbuch, and to the St. Petersburg and Vienna Academies of Science.

He continued to work to the very last, dying at St. Petersburg on the 2nd January, 1893, at the age of 75, and the esteem in which he was held by all classes was amply shown at his funeral in the environs of that city.

ON SOME RECENT WORK OF THE GEOLOGICAL SOCIETY.

Bearing in mind that several of the later occupants of this Chair have selected special subjects for the Anniversary Address, it has occurred to me that some notice of a portion of the work brought before the Society during a limited period might not be without interest to the Fellows. The Quarterly Journal is a rich mine to exploit, and although some portions of it may be rather stiff reading, yet there is a large amount of material which will repay close attention. The limitation which I propose in this case covers a period of about seven years, during which time I have had the honour of serving the Society in one official capacity or another, and consequently have had my attention specially drawn to many of the papers which have been read.

It would of course be out of the question to attempt to deal comprehensively with all the subjects which have been brought before the Society; but as the Fellows might like to be reminded of what we have been doing during this septennial period, it will be convenient to offer a rough classification and enumeration of the communications which have been made. Strict numerical accuracy is not attempted, nor is it claimed that the classification is the best that could be devised. My object is simply to draw your attention to what has been going on, and afterwards to select some one or more subjects for further consideration. In so doing it may be necessary briefly to allude to works outside the publications of the Society.

Certainly one of the most popular subjects has been *Pleistocene Geology*. Many of these papers, as possibly some of you may remember, attracted considerable audiences and were provocative of interesting and prolonged discussions. Upwards of thirty papers have been read dealing with the Pleistocene Geology of the British

Isles, besides one or two referring to foreign localities. With these may be grouped about half a dozen papers which deal with theoretical questions in connexion with glaciation. It is scarcely necessary to remind you that the Nestor of British Geology, Prof. Prestwich, has been one of the chief contributors to this branch of our science. As the subject is a popular one, I have dwelt upon it at some length, always with the express reservation that I have no special qualifications for the task.

In *Tertiary Geology* there was an important paper by Messrs. P. F. Kendall and R. G. Bell on the Pliocene Beds of St. Erth, and about a dozen papers on various members of the Eocene, especially on the Bagshots of the western part of the London Basin; Dr. Irving and Messrs. Monckton and Herries distinguished themselves in this connexion. Prof. Prestwich contributed an important paper on the correlation of the Eocene strata in England, Belgium, and the North of France, and Mr. Starkie Gardner, with the assistance of Messrs. Keeping and Monckton, contributed a very useful paper on the Upper Eocene, comprising the Barton and Upper Bagshot formations.

Under the heading of Tertiary Geology it will be convenient also to consider certain oceanic deposits in the West Indies and elsewhere, with more particular reference to the island of Barbados.

The papers on *Cretaceous Geology*, including some specially devoted to palæontological subjects, are about nine in number, and among these are memoirs by Messrs. Jukes-Browne, William Hill, and Lamplugh, which will require to be considered in some detail.

There have been about fifteen papers on *Jurassic Geology*, including the *Rhætic*. Most of these relate to English localities, and a few are purely palæontological. The correlation of the Upper Jurassic strata of the Swiss Jura with those of England was a valuable contribution from the late Thomas Roberts, of the Woodwardian Museum. There is also an important paper by Mr. S. S. Buckman on the Cotteswold, Midford, and Yeovil Sands, and contributions from other well-known authors, to some of which I hope to be able to draw your attention with more detail subsequently.

It might have been surmised that there was not much left to say on the *Triassic* and *Permian* formations. Yet we have had eight papers, including one by Mr. Wilson on the Durham Salt district, and a very interesting paper by Mr. Horace T. Brown on the Permian rocks of the Leicestershire Coal-field; while Messrs. Irving and Hull have given us their views on the Red Rocks of

Devon. Perhaps I may find time to expand this subject a little and therewith conclude the present Address.

Of the other subjects brought before the Society there is one of considerable importance with which I shall not venture to meddle, viz. *Vertebrate Palæontology*. In this branch of science there have been between fifty and sixty papers published in the Quarterly Journal, some of which are rather short. Messrs. Seeley and Lydekker have been the most prolific authors, although Messrs. Huxley, Hulke, and Smith Woodward have also contributed valuable papers. It is interesting to bear in mind that Sir Richard Owen sent his last contribution to the Society in November 1886. The President on that occasion expressed his regret that the Author, owing to his illness, could not attend the Meeting, and thus reply to criticisms on the systematic position of *Galesaurus* and the geological age of the beds in which it occurs.

The subjects, then, for special consideration on the present occasion include *Pleistocene*, *Tertiary*, *Cretaceous*, *Jurassic*, and possibly *Triassic* and *Permian Geology*.

Pleistocene Geology.

Some of the papers placed in this category might perhaps have been grouped under Vertebrate Palæontology, such as that by Mr. Fisher on '*Elephas meridionalis* at Dewlish' and a few others; but these papers are certainly required to illustrate the subject of Pleistocene Geology. On the other hand, seeing that the most important factor in Pleistocene Geology was the Glacial Period or Great Ice Age, it will be convenient to consider by way of an appendix to this heading a certain number of papers dealing with the question of glacial climates, etc., from a more or less theoretical point of view.

When these additions are made, there will have been upwards of forty papers on the subjects now under consideration. Of these the most important, perhaps, was the memoir by Prof. Prestwich 'On the Westleton Beds,' which the Author found it convenient to divide into three parts. Prof. Prestwich has also contributed other papers of considerable magnitude in connexion with Pleistocene Geology. A large proportion of the papers read by authors relate to the South-east and the South of England; and in the latter case especially the phenomena of districts not themselves glaciated have received considerable attention. Approaching nearer the sources of glaciation, we have a useful paper by Mr. Deeley on the Pleistocene succession in the Trent basin, and several authors have written on North Wales and the Border districts. The north has yielded few papers, but we have one of considerable importance on the Drifts of Flamborough Head by Mr. Lamplugh, and there is a paper by Mr. Kilroe on the direction of the ice-flow in the North of Ireland. Lastly, Mr. Jamieson has contributed some supplementary remarks on the Parallel Roads of Glen Roy.

In making a division of the subject, the South-east and South of England are naturally the first areas to claim our attention. Owing to the number of communications and the varied character of the phenomena described, the arrangement of this large amount of matter is by no means an easy task. To attempt anything in the nature of a chronological classification would seem to be like offering the Apple of Discord at the very outset, since few are agreed as to the precise value of the words 'post-glacial,' 'glacial,' and 'pre-glacial.' We may indeed adopt a common-sense interpretation, partly suggested by Prof. Prestwich, that 'post-glacial' means the time during which the cold was diminishing, 'glacial' the time when it was at its height, and 'pre-glacial' the time during which the cold was increasing. It must be obvious to all that no sound chronological arrangement can be based on these divisions, since 'glacial' conditions may easily have prevailed in some parts of our island and 'post-glacial' in others, more or less contemporaneously.

The divisions then which I propose to adopt are in the main topographical, and include the South-east of England, the South of England, Central England and North Wales, East Yorkshire, and the North of England and Scotland.

South-east of England.—In many parts of this district the Chalky Boulder-clay acts as a guide to a certain extent, and we can at least say in these cases whether a deposit is above or below the Boulder-clay. With this proviso I would draw attention to a paper by Mr. Candler on the Lacustrine Deposits of St. Cross. This place is situated within the drainage of the Waveney, the beds lying in a hollow of the Boulder-clay towards the northern edge of the plateau of Suffolk. The lacustrine beds themselves now occupy a ridge between two depressions, the valleys having been deeply eroded since the filling-up of the lake. The fauna and flora of such a deposit are interesting from the fact that there can be no doubt whatever of their marking a period subsequent to the deposition of the Boulder-clay of East Anglia, and though somewhat remote in time from that deposit, a considerable amount of denudation has been effected subsequently. Hence we may call it 'post-glacial' as far as that district is concerned, although glacial conditions most likely still prevailed in the mountainous regions of the north and north-west. The uppermost beds were found to contain *Elephas* (? *primigenius*), *Equus caballus*, *Bos taurus*, var. *primigenius*, *Cervus*, sp., and *Arvicola*, sp. Below this was a loam with seeds and shells. There was nothing especially Arctic in the plants, which were mainly of marsh- and aquatic species; but the discovery, due to Mr. Clement Reid, of the hawthorn as a fossil for the first time in Britain was a fact of considerable interest.

Of approximately the same age as the St. Cross beds are those now celebrated deposits in Endsleigh Street, where Dr. Hicks last year discovered the remains of Mammoth, associated, as at St. Cross, with the bones of Deer, Horse, and Vole. In this case also the accompanying flora contained no typically Arctic plants, but such as extend at the present time from the Arctic Circle to the South of Europe. That the climate, even in the Thames Valley, was then cold the Author had no doubt, and he observed that farther north the conditions were such as are considered, in part at least, characteristic of the Glacial period. The most natural inference from these statements and from the known facts of the case is that the Endsleigh Street deposits are of early 'post-glacial' age. Dr. Hicks, however, felt sure that the beds above the mammaliferous loam cannot be classed as post-glacial river-deposits, and he rather favoured the notion that they might be an extension of the Chalky Boulder-clay of the higher grounds, an opinion not justified by any marked lithological similarity.

There are about half a dozen papers which deal with the Boulder-clay and Northern Drift of South-eastern England, north of the Thames. Mr. Rowe, in describing the rocks of the Essex Drift, comments on the absence of granite, while quartz-porphyrites and felspar-porphyrites, as he calls them, are abundant; but the most plentiful rocks are the dolerites, some of which resemble the whin-sill, whereas the basalts are stated to be like those of Scandinavia. The sandstones are chiefly of Carboniferous age, but there are some from the Spilsby Beds of South Lincolnshire, such as are known to be abundant in the Boulder-clay of West Norfolk. Most of the limestones belong to the Jurassic Series.

How far this Author is correct in assuming the basalts of the Essex Drift to be like those of Scandinavia may be regarded as an open question. There has been a laudable desire for some years past to find boulders of Scandinavian origin in Eastern England. The Rhomben-porphyr of the neighbourhood of Christiania, for instance, has been fairly identified as an erratic on the coast near Cromer. Very recently a member of the Danish Geological Survey obtained three specimens of boulders in the same district, of which one was thought to have come from the south of Norway and the other two from so remote a district as Dalecarlia : they were either felspar- or felsite-porphyries. The subject of Scandinavian boulders has been likewise discussed by Mr. Lamplugh in his paper on the Drifts of Flamborough Head, where he quotes Mr. Harker to the effect that the bulk of the granitic and gneissic specimens might have been derived from Scandinavia or from the Scottish Highlands. Among them are some undoubted Norwegian rocks, while none can be pointed out as certainly brought from Scotland : it may well be, then, that the whole of the doubtful rocks are also of Norwegian origin. The granite-and-gneiss group of Flamborough, according to Mr. Lamplugh, amounts to between 3 and 4 per cent. of the boulders at that spot. If one might venture to make a remark on this subject, it would seem that the felspar- and felsite-porphyries, rather than the granites and the gneisses, are the most likely rocks to survive the long journey across the North Sea.

One of the most curious facts in connexion with Northern Drift is the discovery, narrated by Mr. Whitaker, of a deep channel of Drift in the valley of the Cam, also in Essex. The Drift here is said to consist mostly of loam or sand more or less bedded, together with clay (sometimes apparently a Boulder-clay full of pieces of chalk) and gravel. At Newport occurs the greatest thickness of Drift hitherto recorded in the South-east of England. In one case a boring of 340 feet, being 140 feet below the level of the sea, failed to reach the bottom of this curious rift in the Chalk. In this case we seem to be dealing mainly with beds below the great sheet of Boulder-clay, and thus the chief interest in these singular discoveries centres in a period anterior to the deposition of that formation.

The Rev. Edwin Hill drew attention to some features of the Boulder-clay of the adjoining district of West Suffolk, inferring that it must contain within its mass pervious beds or seams of some different material, and consequently that it is not a uniform or homogeneous mass. From the above considerations he argued that this Boulder-clay could not be the product of the attrition between an ice-sheet and its bed—a conclusion on the part of the Author apparently not shared by the majority of those present at the reading of his paper.

Coming nearer home, there are two papers relating to Glacial deposits in the Thames basin, which raise questions of considerable interest. That by Dr. Hicks on some recently-exposed sections in the Glacial deposits at Hendon relates mainly to beds below the Chalky Boulder-clay. But he observes that recently, on the Finchley and Hendon side of the Brent Valley, there is good evidence that Boulder-clay extends considerably below the 200-feet contour-line, and it sometimes reaches downwards through the underlying Drifts until it has completely penetrated them and touched the London Clay floor. It is these underlying Drifts which are of such extreme interest in that district. The view originally expressed by Dr. Hicks that the sands and gravels at and near Hendon should be classed with the so-called Middle Sands and Gravels of the Eastern Counties is now, the Author says, generally adopted. It is well within the recollection of many of the Fellows that our Secretary successfully conducted a large party of geologists over these sections in April last. The singular appearance of a mass, consisting mainly of reconstructed London Clay, sandwiched, as it were, between an upper and a lower gravelly series, will not be readily forgotten by those who were able to verify the sequence. These deposits reach downwards on the slopes below the 200-feet contour, and it is thought that they may be traced on other heights in N.W. Middlesex. The Author also considers that the implement-bearing deposits on the higher horizons in the Thames Valley should be classed as of contemporaneous age with these undoubted Glacial deposits at Hendon and Finchley, which they so closely resemble. It would be more to the point, however, to find palæolithic implements in these latter.

Still more conclusive evidence as to the existence of low ground in what is now the basin of the Thames was adduced by Mr. Holmes in his paper on the new railway from Grays Thurrock to Romford. In the Hornchurch cutting 15 feet of Boulder-clay was seen to rest directly upon the London Clay near the 100-feet contour-line. This Boulder-clay is overlain by about 12 feet of sands and gravels, which, if we take the Boulder-clay as the time test, are locally post-glacial. It is in all respects a typical deposit, such as commonly occurs in Essex. Except in this cutting, we are told, Boulder-clay has never been seen in conjunction with the overlying deposits of the Thames Valley, either north of Romford or in the neighbourhood of Finchley and Hendon, the most southerly spots where it has hitherto been known to occur.

The great series of papers by Prof. Prestwich on the Westleton

Beds relates to deposits below the East Anglian Boulder-clay. The first part deals more especially with the sections on the coasts of Norfolk and Suffolk, and the second with the range inland of the Westleton Beds or their presumed equivalents; the third part, relating chiefly to the Southern Drift, belongs to another category.

It is well known to students of geology that the classification of the variable series of beds which lie between the undoubted Pliocene and the Chalky Boulder-clay in Norfolk and Suffolk has exercised the faculties of observers in East Anglia for a long period of time. There are few subjects, indeed, which have been more fruitful of divergent opinion. No one can doubt the importance of these beds, for they contain the key to the history of the first half of Pleistocene time in this country. Prof. Prestwich, in describing the relationship of this group to the Crag Series below and the Glacial Series above, while he admits the value of the distinction drawn by Messrs. Wood and Harmer between the Norwich Crag and the Bure Valley Pebble-beds, does not think that either the palæontological or stratigraphical proofs respecting the position of these Pebbly Sands are so well defined in the Bure Valley district as they are in the Westleton and Southwold districts, or so fitted to be taken as the type of a widespread geological zone.

It is not very easy to understand the duplicate character of the 'Westleton Beds.' However, we learn that on Westleton Common a general section shows about 50 feet of sandy shingle or pebbly sands without fossils. At Mundesley about half that thickness of variable gravels, sands, and clays occasionally fossiliferous, represents the series, which on the Norfolk coast is held to consist of the Arctic Freshwater Bed of Reid, the *Leda myalis*-bed of King and Reid, and the Upper Freshwater Bed of Reid.

Since the Pebbly Sands at Westleton are themselves unfossiliferous, a difficulty occurs at the outset. It was, in fact, pointed out that although the name Mundesley Beds might be a useful local term for the series immediately above the Forest-bed, yet, if the term Westleton Beds was associated with them, it might turn out in the end that there were no 'Westleton Beds' at Westleton. As regards the above grouping, Mr. Reid objected to his Upper Freshwater Bed being merged in the Westleton or Mundesley Series, giving reasons for his having included it with the Forest-bed group. As to classing the Arctic Freshwater Bed with this one, he noted that the floras showed a difference of climate amounting to 20° F., and thus he considered the grouping of the two unadvisable.

The Westleton Beds, as above defined, were found to rest unconformably on various underlying beds: in places on the Forest-bed Series, elsewhere on the Chillesford Clay, while occasionally the latter had been partly or entirely eroded before the deposition of the Westleton Beds. A similar discordance has been noted between the Westleton Beds and the overlying Glacial deposits, so that the former mark a distinct period, characterized by a definite fauna and by particular physical conditions. In spite of the discordance above mentioned, Prof. Prestwich is prepared to claim the Forest-bed as part of the Westleton Series, if the former should prove to be newer than the Chillesford Beds. The Westleton Beds being marine, and the Mundesley Beds estuarine and freshwater, that author proposed to use the double term to indicate the two facies. But these two facies were found to be local, and the most persistent feature of the beds is the presence of a shingle of precisely the same character over a very wide area. By means of this shingle the Westleton Beds may be identified far beyond East Anglia. Moreover, unlike the Glacial deposits, they contain pebbles of southern origin.

In tracing the Westleton Beds, or their presumed equivalents, from the East Coast to the Berkshire Downs, they are seen to rise from sea-level to heights of 600 feet, in the first instance underlying all the Glacial deposits, and in the second rising high above them, so that their seeming subordination to the Glacial Series altogether disappears. At Braintree, for instance, where the Westleton Beds are largely developed, they stand up through the Boulder-clay and gravel which wraps round their base; while farther west, where they become diminished to mere shingle-beds, they attain heights of 350 to 400 feet, capping London Clay hills, where the Boulder-clay lies from 80 to 100 feet lower down the slope, the difference in level between the two deposits becoming still greater in a westerly direction, until finally the Boulder-clay disappears. A plate of diagram-sections serves to illustrate these views, and we thus see how the Pebbly Series of East Anglia, for the most part at slight elevations and covered by Boulder-clay in Essex, gets higher and thinner and more widely separated until it becomes a mere hill-gravel. As such it is found capping isolated eminences, 370 feet above Ordnance datum at Highbeach, 400 feet at Totteridge on the opposite side of the Lea, and 600 feet on more than one point of the Chilterns, where this Pebbly Series has been the means of preserving small outliers of the Tertiaries.

Since the identification of the Westleton shingle at points so wide apart seems mainly based on lithological grounds, it is important to notice its distinctive features. Prof. Prestwich states that this shingle consists of drifts from the south and south-east. The flint-pebbles were derived from shingle-beds of Tertiary age in Belgium, the North of France, and Kent; the quartz-pebbles directly or indirectly from the Ardennes; the subangular flints directly from the Chalk or from an older Drift; chert and ragstone from the Lower Greensand of Kent and Surrey, or indirectly from the Southern Drift. The marine nature of the beds is inferred from the included fossils of the type-area, and the absence of these elsewhere is accounted for by decalcification. With reference to this point, it may be as well to remember that the Westleton Beds on Westleton Common are unfossiliferous, and that the Mundesley facies of this series is mainly freshwater.

In conclusion, Prof. Prestwich states his belief that the Westleton shingle must have been formed on a comparatively level sea-floo throughout the area over which its outliers extend, and that the irregularities in distribution have been produced by subsequent differential elevatory movements. He gave a diagram-section across the Thames at Goring, which yields a means for estimating the amount of earth-sculpture effected there since the presumed equivalents of the Westleton shingle were continuous from side to side of the valley. He thus arrives at the conclusion that the deepening of the gorge amounted to about 160 feet during the early Glacial Period, to 220 feet during the later Glacial Period, and to 70 feet during the post-Glacial Period. Surely this amount of work is scarcely in accordance with the moderate limits which, in another paper, he is disposed to assign to the entire Glacial Period.

The last paper which it seems necessary to notice in connexion with the Pleistocene Geology of the South-east of England is one by Mr. E. T. Newton on the Cetacea of the Norfolk Forest-bed. He identified the Sperm Whale and a species of *Balæna* which is most probably *B. biscayensis*. Of other vertebræ from the Forest-bed one was referred to *Balæna* and another to *Balænoptera*. This collection was regarded as a fair epitome of the Cetaceans now inhabiting British seas, since it contained examples of all the leading types, while curiously enough the large land Mammals of the Forest-bed are said to be extinct. Under these circumstances, and bearing in mind how differently the Cetacea are represented in the true Crags, it seems only natural to regard the Forest-bed as a local phase of the

Pleistocene succession. Indeed, as we have already seen, Prof. Prestwich under a certain contingency threatens to incorporate it with his Westleton Beds.

The South of England.—After we cross the Thames there is no longer a Boulder-clay of northern origin to supply a sort of rough chronology to the various drifts of this region, which we speak of as not having been glaciated in the ordinary sense of the term. Hence the problems connected with these various drifts, mostly perhaps of Pleistocene age, but some possibly yet more ancient, are especially difficult of solution.

Here again we follow Prof. Prestwich, who, in the third part of his great paper on the Westleton Beds, discusses the subject of a Southern Drift. The character and composition of this Drift have long been known to geologists through the writings of Prof. Rupert Jones, and, more recently, of Dr. Irving and others. It is satisfactory to find that on these points there is but little difference of opinion. The Southern Drift is said to differ from the Westleton Beds in a deficiency of pebbles of old-rock origin, while on the other hand it is characterized by a large proportion of chert and ragstone—not that these are wanting in the Westleton shingle, but they are in less abundance, more reduced in size, and hold a more subordinate position. The materials common to both, but present in different proportions, are subangular flints and flint-pebbles.

The Southern Drift or Hill-gravels are then traced from Kent into Berkshire; in the east they repose mainly on the Chalk, in the west on the Tertiaries. Owing to the absence of organic remains we are without a clue as to whether their origin was fluviatile or marine. Prof. Prestwich thinks it not improbable that they are of subaerial origin, possibly 'fans' such as are carried down by torrents. It is also possible that the cone may have discharged under water, thus spreading out to a greater extent and more uniformly, and with the rough sort of bedding this gravel sometimes shows. Such an origin implies something like a mountain-range in the direction of the Weald, the consideration of which might take us too far outside the limits of Pleistocene Geology. It is sufficient to say that the Author believes the Southern Drift to be somewhat older than the Westleton shingle, but that the two must at one time have proceeded synchronously. Hence the Southern Drift may range from late Tertiary to early Pleistocene times. This is as much as to say that they are pre-glacial in a certain sense. Dr. Irving thinks that the chief evidence of glaciation occurs at lower levels, and that the deposition of the Plateau-gravels covers most of the geological time represented by the Pliocene.

Stimulated by the example of Prof. Prestwich, Mr. Monckton has lately studied with much attention the gravels on the south side of the Thames from Guildford to Newbury. He concludes that the greater part of the hill-gravels belongs to the Southern Drift of Prestwich, and that the valley-gravels mostly consist of material derived from the Southern Drift. Small patches of what he identifies as Westleton shingle and Glacial gravel occur near Reading and Twyford. He divides the Southern Drift into three classes, of which the oldest is probably the Upper Hale type, characterized by the abundance of small quartz-pebbles and the scarcity of chert. The gravels of Chobham Ridges and Silchester, though differing as o the amount of quartz-pebbles and chert, were probably nearly contemporaneous. He rejects the theory of marine action.

The entire subject of the hill- or plateau-gravels south of the Thames is indeed full of difficulty, but there does seem a preponderance of opinion in favour of their freshwater origin, including ice to a certain extent in that category. These gravels may or may not have been continuous, though the elongated shape of many of the patches is thought to afford an indication, in some cases, of fluviatile origin. Such patches are certainly answerable for many of the existing hills in the soft Tertiary districts of West Surrey and East Berks. Of course, as the valleys were excavated or deepened, much of the gravelly material originally on the plateau would remain on the flanks, either as irregular deposits or imperfect terraces. This is an almost self-evident proposition, and the principal question for decision relates to the period when these events occurred.

Some answer to this question may be sought in another paper by the indefatigable Prof. Prestwich on the Drift stages of the Darent Valley, where he observes that the first indent of that valley must have been subsequent to the deposition of the Lenham Sands (earliest Pliocene) and even of the Red Clay-with-flints. In early Pliocene times a plain of marine denudation was shown to extend over the valley of Holmesdale, and in pre-glacial times the valley was scored by streams flowing from the high, central Wealden ranges. The streams centred in the Darent and the excavation of the present valley then commenced. The Author believes there is a gap between the pre-glacial drifts of that district and the earliest post-glacial drifts of the valley, a gap which might perhaps be covered by the epoch of extreme glaciation. The paper last quoted was to a certain extent supplementary to that on the Palæolithic Flint-implements at Ightham. The anthropological questions raised in this remarkable paper I do not venture to discuss, but there also the Author insists that the high-level deposits were formed anteriorly to what he calls the post-glacial drifts of the Thames and Medway, the deposits on the Chalk-plateau being abruptly cut off by the river-valleys.

Shifting the venue now to the south side of the Weald, comprising the basins of the Arun, Adur, Ouse, and Cuckmere, we have the testimony of Mr. Elsden, who observes that the angular-flint drift occurs mainly on the higher parts of the district and is wanting in the river-valleys, where river-gravels derived from the denudation of older deposits are abundantly developed. Not only in the Wealden area, he continues, but in many of the neighbouring districts, the angular-flint drift consists of the undenuded remnants of a deposit formed before the present river-valleys were excavated: many of the river-gravels, though newer than the angular drift, were deposited when the valleys were less deep. He considered that Mr. Searles Wood's marine theory of the origin of these gravels was refuted by their mode of occurrence.

If time and the necessity of dealing with other subjects permitted, it would be interesting to touch on some of the questions raised by Prof. Prestwich's last paper 'On the Head or Rubble Drift of the South of England.' There are also two papers by Mr. Clement Reid relating to the Pleistocene Geology of Sussex. His suggestion as to the origin of Coombe Rock seems very natural. It is quite possible that the cold *in winter* during all three phases of the Glacial epoch may have been as severe in the South of England as in the most glaciated regions of the northern part of these islands. Such being the case, the ground would be frozen to a considerable depth, and the drainage-system of the Chalk more or less modified. The summer rains would run off any steep slope, tearing up the layer of rubble already loosened by frost, and carrying down masses of Chalk too rapidly for solvents to have much effect. A similar suggestion with reference to certain deposits in connexion with the Yorkshire Wolds has been made by the Rev. E. M. Cole and Mr. Lamplugh. The submergence shown by the marine beach at Goodwood, 130 feet above sea-level, is stated to have occurred before the deposit of Coombe Rock. Mr. Reid's investigations, as narrated in a second paper, tended also to show that erratics on the Sussex coast have, in some cases, travelled from the west or south.

Dorsetshire is the next county which claims our attention in considering the Pleistocene history of the South of England. It so happened that as long ago as 1813 some Elephant's teeth were discovered near Dewlish, a village in the hilly Chalk country which lies between Blandford and Dorchester. These found their way into the Blackmore Museum at Salisbury, and were generally regarded as the teeth of *Elephas meridionalis*. It is a somewhat curious instance of prejudice on the part of an eminent palæontologist that the late Dr. Leith Adams could not bring himself to allow that these remains belonged to the Cromer Forest-bed species, simply because that species had never been found so far to the westward. Accepting the general palæontological determination as the true one, Mr. Fisher and Mr. Mansel-Pleydell set to work, two or three years ago, to investigate the locality, and their efforts were rewarded by finding further traces of *Elephas meridionalis* on the same spot.

Inferences of considerable geological interest may possibly be drawn from this discovery, if we admit that the species is rightly determined. Whether we regard the Forest-bed series as Pliocene or Pleistocene is merely a question of detail, as to where a line should be drawn. But it seems only reasonable to suppose that the deposit at Dewlish is approximately of the same age, though no doubt the confirmation of an associated fauna would be desirable. Such being the case, the history of a deposit like this, if successfully worked out, might yield important evidence in relation to the sculpture of the district and to the period during or since which it has been effected. In this way also we might find some means for testing the conclusions of Prestwich with regard to the presumed inland equivalents of his Westleton Beds, and the events which he believes to have happened since they were laid down.

The Authors in the first instance concluded that the deposit at Dewlish had been water-borne, and that it had been undercut into the face of the escarpment, which is very steep at that spot, rising about 100 feet above the bottom of the valley. Had this been the correct inference, it was evident that the valley had been deepened to the extent of some 90 feet since the Elephant-remains were deposited. But further investigation has convinced Mr. Mansel-Pleydell that this reading, as represented in the section accompanying the paper, is not the true one. The deposit, in fact, lies in a kind of narrow fissure, which is situated on the brow of the escarpment, almost at right angles to the trend of the valley itself. It would seem, therefore, that the deposit is altogether independent of the present gorge, and may possibly be older than its initiation, though the evidence on this point requires further working out. Altogether, since the new reading, the evidence as to the amount of sculpture effected in the immediate neighbourhood posterior to the deposit of the Elephant-remains is not of so decided a character as under the old hypothesis.[1]

Central England and North Wales.—We must now turn from the Pleistocene Geology of the southern counties to the more certain evidences of glacial action in the North Midlands. In this connexion we have a paper by Mr. Deeley on the Pleistocene succession in the Trent basin, more especially in the vicinity of the junction of the Derwent with that river. As the outcome of seven years of careful observation from 1879 to 1886, this paper should carry some weight with it. The Pleistocene deposits of the Trent basin are, he says, chiefly remarkable for the great development which the Glacial beds attain; these consist of Boulder-clays, gravels, and sands of various kinds and ages. The distribution of Boulder-clay varies much, both as regards age and thickness, for in some localities it occurs in great masses occupying small areas, and in others it covers considerable districts with a tolerably uniform mantle.

In the Trent basin, as in that of the Thames, the Older Pleistocene deposits are distinguished from those of later age by their freedom from Cretaceous rock-débris. This Older Pleistocene consists of two Boulder-clays separated by a quartzose sand. These Pennine Boulder-clays, as Mr. Deeley calls them, are composed of materials derived almost entirely from the Derbyshire highlands, with a slight admixture to the westward of erratics from Scotland and elsewhere. The bulk of the materials were transported from the Pennine chain by glaciers, and deposited in what he regards as the partially submerged valley of the Trent. "The conditions of climate which gave rise to the formation of the early Pennine glaciers, and which passed away with the increasing submergence of the Quartzose-sand sea, again returned; for upon the Quartzose sand there are thick deposits of Boulder-clay, giving evidence of intense glacial conditions." I have quoted this last passage *verbatim*, as it shows the

[1] The following is an extract from a letter written to me by Mr. Mansel-Pleydell on this subject last autumn:—'Perhaps you will kindly add a note to your remarks upon the Dewlish bed, namely, that my paper in the Proceedings of the Dorset Field Club was written before I had traced it from end to end. Instead of its being a pocket at a higher level than that of the present stream, as I supposed, it is a fissure in the Chalk into which the Elephant-remains, flints, etc., fell in as the Pliocene (?) stream passed over it, and of which no other evidence is left.'

impression of the Author that the Quartzose sand is marine, and that it indicates an intermittence of the cold—suppositions which seem to be due to ideas then prevailing rather than to any positive proof, since there is no mention of any fossils.

Coming next to the Middle Pleistocene deposits, he regards the Great Chalky Boulder-clay in the Trent basin as chiefly a ground-moraine, though in places it presents indications of an aqueous origin. This also is underlain by a sand known as the Melton Sand, in which detritus of Cretaceous age first appears in abundance, and here again, according to the views of the Author, there is a suspicion of a milder climate. The Pennine rocks in this Boulder-clay he thinks were derived from the Older Pleistocene deposits over which the ice passed. This view necessitates an extraordinary want of activity on the part of the Pennine glaciers, during the very culmination of the Glacial Period, which is not easy to account for. Consequently he calls in the aid of a depression in the Pennine axis, which would admit the approach of Continental ice without interference from local English glaciers. In a recent communication to the 'Geological Magazine' for 1893, p. 33, he appears to hold the same view; for he considers that the only way of accounting for this absence of local glaciers, while the Scandinavian ice-sheet advanced over the country, must be based on the assumption that it occurred during a period of submergence. He admits that the present opposition to such a view is very strong, though possibly based on inadequate grounds. In West Staffordshire, Mr. Deeley considers that the entire Middle Pleistocene deposits are probably represented by gravels and sands, and it is noteworthy that in this area fragments of marine mollusca are stated to be of frequent occurrence.

In the Newer Pleistocene, according to Mr. Deeley, there was a re-elevation of the Pennine chain and of the Trent Valley, thus apparently producing a change in the direction from which the materials of the deposits were derived; and a river-gravel which he regards as interglacial now occupies terraces at various heights along the valley of the Trent and its tributaries. This was succeeded by the later Pennine Boulder-clay stage, which marks the return of local ice-action. He observes that whilst the Older Pleistocene Boulder-clays are partly sedimentary, these later deposits are almost entirely unstratified, and when pebbles and boulders occur a fair proportion of them are flint. In many cases, he says, it is scarcely correct to call this moraine a Boulder-clay, for it is occasionally quite free from clay, consisting of gravel and sand so disturbed that all traces of original stratification, if ever they existed, have been destroyed. All the Boulder-clays and gravels from the early Pennine down to the 'Interglacial River-gravel' have been crushed at the surface, or even partially converted into newer Boulder-clay.

Crossing the Cheshire plain, we must now follow Messrs. Strahan, Hughes, and Hicks in their descriptions of some of the Pleistocene phenomena of North Wales and its borders. The first-named Author tells us that in the neighbourhood of Liverpool the materials of the Drift have travelled from the N.W., and that the edges of the strata have in many cases been bent back also from the N.W., the same agent which distributed the Boulder-clay having presumably striated the rock-surface. On the Welsh border the striations are said to show a general parallelism, as though the direction of the movement of the Drift was from the W.S.W., and the transportation of much of this Drift has taken place across the lines of the principal hill-ranges and valleys. It would seem that in a valley such as that of the Dee, which is in part conformable to the mean direction of the movement, this is less evident than in the valley of the Clwyd, which seems to have been crossed almost at right angles to its axis. The line of demarcation of these two partly opposing Drifts is shown on a map.

When Mr. Strahan discussed the merits of the rival hypotheses, firstly of two ice-sheets moving in different directions, and secondly the agency of floating ice, he was (at that time) in favour of the latter view, concluding that the marine drifts and their striations were produced by floating ice during a period of submergence. Amongst his reasons for thus deciding, he pointed out that the rock-surface is not 'moutonnée' on a large scale, and that the striæ and terminal curvature are far from being universal; and he further observes that the marine origin of the drifts is indicated by their well-marked stratification, as a whole, and by the occurrence throughout all the beds of marine shells. Some of these arguments may be good, but it has always seemed to me that anything approaching to parallelism in a system of striations could only be effected by an agent moving more or less in one direction, which is hardly what we should expect of floating ice, subject to the irregularities of winds and currents, even supposing that floating ice is capable of rock-grooving on a large scale. I venture to make these comments, because the views then advocated by Mr. Strahan seem to represent the belief of that school of geologists which seeks in submergence and the direct action of the sea for a true explanation of these phenomena.

But whatever theories as to origin we may adopt, the leading factor in the Pleistocene history of this region is the existence of two drifts, viz. the Welsh or Arenig Drift, and the Northern or Irish Sea Drift. Prof. Hughes has traced the Arenig or Great Ice Drift, as he calls it, from the Snowdon and Arenig ranges by the striæ on the solid rocks and by the included fragments. It is described as consisting of Boulder-clay and striated boulders, all of indigenous origin, and contains no shells. In his classification of the drifts of the Vale of Clwyd, this drift is placed at the base of the system, but Dr. Hicks was of opinion that the Welsh or Arenig Drift is not necessarily the oldest. In some places it may even be the newest, as it is known from well-sinkings to be underlain by sands and gravels in which bones of animals similar to those found in the caverns were discovered. The explanation of this divergence of opinion seems to be that the indigenous Drift both underlies and overlies the Drift of the Irish Sea, as might very well be the case where the two inosculate, just as in Derbyshire there is a local Boulder-clay both older and newer than the Middle Pleistocene Chalky Boulder-clay.

The following is an abstract of the views expressed by the late Prof. Carvill Lewis when the paper on the Drifts of the Vale of Clwyd was read. He maintained that there had been "three main areas of local glacial dispersion in Wales, the glaciers from each of these being defined by terminal moraines. But there was also satisfactory evidence that an ice-lobe coming from Scotland [reinforced by Cumbrian and North Irish ice] and filling the Irish Sea had impinged upon the extreme northern border of Wales, and passing over Anglesey and along the west of the Snowdonian mountains on the one side, and into Cheshire and along the east of the mountains on the other side, had pushed its terminal moraine against the highlands and in the teeth of the opposing local glaciers. The latter were both earlier and later than the northern ice-lobe, and the two Drifts were therefore often commingled. The line dividing the northern ice-lobe from the Snowdonian glaciers was close to the Cae Gwyn cave, and the massive deposits near St. Asaph were probably washed out of the common terminal moraine." "The undoubted marine deposits," he continued, "full of shells, which cover the lowlands of Lancashire up to 150 feet above the sea, also extended up the Vale of Clwyd to the same level; but much of the stratified material in that valley was remanié." He spoke of "torrential freshwater action, operating during the melting of the ice, as an important factor not to be omitted in studying valley-gravel."

One of the chief points in dispute on this as on a subsequent occasion, when Dr. Hicks read a paper on the Cae Gwyn cave, referred to the precise age of the bone-earth at the bottom of that cave, the mouth of which is 400 feet above sea-level. Dr. Hick maintained there was no foundation for the view that the drift, which covered up the entrance and extended into the cavern, was remanié. He claimed that the deposits which lay over the bone-earth were *in situ* and were identical with the normal Glacial deposits of the area, and that the cavern had been completely buried in them. These drifts Mr. Strahan believed were part of the Northern Drift which he had mapped over a large portion of Denbighshire, Flintshire, and Cheshire. On the whole, it must be admitted that the testimony of the majority of geologists was in favour of the view that this bone-earth, with its peculiar fauna, so different from that of the post-Glacial fauna of the vicinity (Morton), and bearing a certain resemblance to the Forest-bed fauna, has been sealed up by a Drift, which is most probably that derived from the Irish Sea, and which, if we accept its glacial origin, represents in all probability the most severe period of the Great Ice Age. How much older the bone-earth may be than this Drift it is not easy to say, but appearances are certainly in favour of its being early Glacial. The point is one of considerable interest, because of the associated Palæolithic implements; but into this part of the controversy I do not venture to enter.

The question of the glacial origin of the Drift of the Irish Sea is one of more importance from a geological point of view, and it bears also on some of the points brought forwards in the Cae Gwyn discussion. It was alleged, for instance, that the sea during the great submergence would have washed all the bone-earth and its contents out of the cave, on the supposition that those contents were of early Glacial age. But if the sea never reached the mouth of the cavern, as the opponents of the Great Submergence hypothesis might allege, this difficulty at once disappears.

In this connexion there is a paper by Mr. A. C. Nicholson, 'On the high-level Glacial Gravels at Gloppa, near Oswestry,' which raises the same questions that have been so often discussed with reference to Moel Tryfaen. These gravels occur on the eastern slope of the ridge of Carboniferous rocks, here represented by Millstone Grit, which forms the western boundary of the Shropshire and Cheshire plain. The main mass of the gravels at Gloppa is comprised in a ridge of eskers, about 1000 yards long and ranging from 900 to 1160 feet above sea-level. The beds present the appearance of having been abruptly cut off on the north-eastern slope, the greatest depth exposed being about 60 feet. The upper layers seem to be sufficiently argillaceous to have prevented the percolation of water, and the gravels themselves are in places much contorted and current-bedded. Among the boulders are granites like those of Eskdale, Criffel, etc., felspathic traps, Silurian grits and argillites, Carboniferous rocks, Liassic shale, and Chalk flints. England, Ireland, Scotland, and Wales seem to have been requisitioned in order to find materials for this curious deposit. The shells are often broken, rolled, and striated, but the bulk of them are in fairly good condition, so that many species of varying bathymetrical range have been determined. The fauna is like that of Moel Tryfaen, and, as there is a considerable mixture of species belonging to various depths, such an assemblage cannot be regarded as having lived contemporaneously on the spot where the deposit occurs. A large proportion of the shells belong to species frequenting a sandy bottom, and different from those which might be expected on a steep, rocky coast such as would here be exposed to the sea by submergence. The highest point for marine shells at Gloppa is 1120 feet. A similar gravel occurs on Selattyn Hill, two miles to the north along the Millstone Grit ridge, at a height reaching to 1300 feet, but hitherto no shells have been found here, the exposure being small.

More recently Mr. Mellard Reade has again drawn attention to some facts in connexion with the shell-sands on Moel Tryfaen, which have evidently been sorted by water. He points out that they are in fact overlain by typical 'till' composed of local rocks with a small percentage of clay; whereas the sands and gravels are full of erratics, including rocks from Scotland and elsewhere. He still adheres apparently to the hypothesis of submergence to an extent of at least 1400 feet.

There are other geologists of eminence who likewise maintain these views, though in the case of the high-level shell-gravels it is now generally admitted that these are not original marine deposits. The believers in the Great Submergence would ascribe such accumulations to the action of floating ice transported by the waves and currents of the sea. A younger and more numerous school of geologists consider that they are the result of the action of glacier-ice, which has actually thrust a portion of the bed of the sea uphill, into positions where the materials have been roughly assorted in the streams and lakelets resulting at various times from the thawing of such ice. This is a considerable demand upon the credence of the older race of geologists, essentially and rightly a conservative body of men. One may venture to say that it is the dynamical question which has been the chief obstacle to the general acceptance of this view; if that part of the problem could be satisfactorily solved, we should accept with thankfulness an explanation which does away with the necessity for belief in the Great Submergence and all the incongruities which that belief involves. Certainly, there is yet a third explanation to which I may make a passing allusion, viz. the possibility of that Great Flood which is to relieve us from the Glacial Nightmare, and thus enable us to get rid of our difficulties. Lyell, in one of his letters,[1] as some of you may remember, speaks of a tour in Wales, where "a certain Trimmer" had found near Snowdon 'crag' shells at the height of 1000 feet, "which Buckland and he convey thither by the Deluge." This, I presume, alludes to Moel Tryfaen, and it is significant that the writers spoke of these remains as 'crag' shells. The Great Flood seems to be a kind of revival of the Noachian Deluge.

In order to satisfy ourselves as to the necessary *vis-a-tergo* required by the ice-thrust hypothesis, we must take into consideration the possible condition of the Irish Sea towards the period of intense glaciation. Some notion of this state of things may be furnished by studying Mr. Kilroe's paper on the direction of the ice-flow in the North of Ireland and the accompanying map. It may be objected that the conclusions of this paper are based mainly on the direction of the striæ, and especially that portions of the map represent what may possibly be regarded as an exaggerated aspect of the case, more particularly in the direction of the Atlantic. Messrs. Peach and Horne, whom the Author follows, extend the margin of their Atlantic ice-sheet to the edge of the 200-fathom line, a distance of about 80 miles from North-western Ireland and the Hebrides, although this is a moderate distance compared with Dr. Croll's estimate. As we are frequently told that if we want to study the phenomena of the Glacial Period we should go to Greenland, I would merely remark that there is nothing taking place in that country at the present

[1] 'Life of Sir Charles Lyell,' vol. i. p. 319.

day to justify Messrs. Peach and Horne's conception of the west coast of Scotland during the extreme glaciation of our islands. In modern Greenland there is a strip of ice-free land, broader on the west than on the east coast, and possessed of a fairly abundant fauna and flora; and this strip is continuous, except where glaciers actually enter the sea. The recent researches of Lieut. Peary tend to show that such a strip of ice-free land extends even to the hitherto unknown shores of North-eastern Greenland.

But I have been digressing. The point for present consideration is the condition of the shallow Irish Sea and of the glaciers that flowed into it during the great glaciation. If we accept the main conclusions of Mr. Kilroe, we may readily admit that the North Channel leading into the Irish Sea was blocked by the Scottish ice-flow passing over Ulster and Northern Connaught, and that this flow even controlled for a time the glacial system of North-western Ireland. This central snow-field of Ireland is represented as having its axis on the confines of the northern and the western province in a district which is elevated, but by no means lofty; from this axis the striæ indicate a regular movement of the ice in a south-easterly direction towards the Irish Sea. The most direct flow into the Irish Sea would arise out of the glaciers that descended from the southern uplands of Scotland in Galloway and Dumfries-shire, a limited area certainly, and only of moderate elevation, but possibly overridden at times by more northern ice. Lastly there was the Lake District ice streaming in from the north-east. The outlet for these masses of ice must have been in a southerly direction.

Granting these premises, which do not seem unreasonable in the light of modern investigation, although a few years ago we might have hesitated to accept them, there must have been a stupendous crush, the result of contending glaciers, in the shallow basin of the Irish Sea. Some authors assert that this sea was filled from side to side by an ice-stream fully 2000 feet thick, and the heights at which striæ occur in the Isle of Man are adduced in favour of this hypothesis. The power of ice to thrust rocks uphill is also said to be exemplified in that island, where boulders of granite from Granite Mountain have been carried to the summit of South Barule, a rise of over 800 feet in a mile and a half. The comparatively low watershed of the Irish and South Scottish glacier-systems, which are supposed mainly to have fed this mass, appears to be the principal difficulty in assigning such a thickness as 2000 feet to the ice of the Irish Sea. We may, however, believe that in an area of excessive precipitation a very considerable thickness of ice did accumulate on these low watersheds, and thus helped to supply the impetus or *vis-a-tergo* which the actually existing watersheds seem barely sufficient to explain.

According to this hypothesis, then, the ice of Ireland, Scotland, and England in combination essayed to force a portion of the bed of the Irish Sea up the flanks of the Welsh highlands, and this attack was to a certain extent parried by the native ice-streams, since it has been remarked that the shell-bearing High-level Glacial Sands have as yet only been found upon the outskirts of the mountainous areas, such as Moel Tryfaen on the west and Gloppa on the east. In its progress southwards there were only two channels for the escape and melting of the ice, viz. St. George's Channel, and the depression represented by the plain of Cheshire and Shropshire. If this be the true explanation, it would seem that this plain must have been filled with ice for some distance up the western flank of the Pennine Chain, since the deposits above Macclesfield in all probability originated in a manner similar to those at Gloppa.

East Yorkshire.—The history of the drifts in this part of England, though sufficiently obscure, does not make quite so large a demand upon our faith, mainly perhaps because the heights traversed by the presumed glacier of the North Sea are not so lofty as in the cases just quoted from the west side of our island. Mr. Lamplugh, after pointing out the importance of the Flamborough promontory as a locality where the connexion between the drift of the hills and that of the plains may be traced, states that he finds himself compelled to dissent from the views expressed a quarter of a century ago in the Quarterly Journal by Messrs. Wood and Rome. In opposition to their hitherto accepted correlation he concludes that the triple division of Hessle Clay, Purple Clay, and Basement Clay may be recognized to a certain extent farther north than Holderness. Moreover, he declares that he no longer has faith in the occurrence of the so-called 'Interglacial Periods.' He claims that in East Yorkshire the glacial deposits attain their greatest development near the coastline, and that inland from Flamborough they thin away so rapidly that the Chalk often carries nothing more than a scanty covering of clay within a few hundred yards of the edge of the cliff.

Into the details of this remarkable paper we cannot of course enter, but if we accept his main conclusions as deduced from a study of the sections, the following are some of the results at which he arrives. These results constitute a sort of epitome of the history of Pleistocene time within the district.

Starting with the lowest beds, Mr. Lamplugh observes that we are met at the very outset by a question of the highest importance. This refers to the so-called 'infra-Glacial' Beds of Sewerby and Speeton. At the former place occurs a buried cliff of Chalk, with fossiliferous beds (containing Mammalia and land and marine Mollusca) banked against it, the whole being surmounted by a more or less complete series of the Glacial Beds. Are these beds, which underlie the Basement Boulder-clay, to be considered as older than the Glacial Period, or are they of inter-Glacial age, formed during an interval between the periods of glaciation? The fauna is rather meagre, though the Elephant-remains hitherto found at Sewerby have been determined as *E. antiquus*. One of the most curious features in connexion with this old beach at Sewerby relates to the pebbles it contains. There is no trace of Mountain Limestone or other recognizable Carboniferous rock, and the inference seems fair that no glaciers from the Pennine Chain reached the east coast at this period. Though there can be little doubt of the ice-borne character of these pebbles, it is not clear whether they have been carried to this beach by floating ice, or have been derived at second hand from an older glacial deposit. The Author is inclined to adopt the former view, and generally contests, throughout the whole of his paper, the notion of an inter-Glacial period. As regards the correlation of his 'infra-Glacial' beds, while admitting that they may not be strictly pre-Glacial, since the district was not likely to be invaded by land-ice until long after the commencement of glacial conditions, he thinks they contain the record of a period anterior to the first glaciation of the east coast, and may be as old as the *Leda myalis*-bed in Norfolk.

Owing to the physical character of the district and its distance from lofty mountains, it may be inferred that a long interval of severe climate ensued before anything like an ice-sheet reached this area. This period would naturally be indicated on the Wolds by subaerial deposits of the nature of disintegrated rock, which would be swept down into the hollows, the action being intensified by the frozen condition of the upper layers of the Chalk. Within the area invaded by the ice-sheet this surface-deposit was not likely to remain undisturbed, but in the inner recesses of the Wolds, never reached by the North Sea ice-sheet, such a deposit has accumulated in high-lying depressions and also in the upper reaches of some of the Wold valleys, where it has remained unmodified. The analogy between such deposits and the Coombe Rock, already referred to, is obvious, though this formation may have been going on throughout a great portion of the Glacial Period.

We now come to the Basement Boulder-clay, and this, in the Author's opinion, represents the earliest glaciation affecting the eastern side of England. That which is known as the Lower Clay of Flamborough is the northward continuation of the Basement Clay of Holderness. It is now quite clear that, although it includes the scrapings of a boulder-strewn sea-bottom, the clay cannot on this account be reckoned marine. It is essentially the product of land-ice which seems to have crept in upon the land from the north-east. Besides other evidence for the non-existence of earlier glacial beds, Mr. Lamplugh refers to the repeated occurrence of transported masses of Secondary rocks in the Basement Clay, showing that the marine deposits torn up by the ice of that particular period rested upon a platform of Secondary rocks and not upon older glacial beds. Neither transported Secondary rocks nor shelly masses of sea-bottom have yet been observed in any of the higher Boulder-clays. He therefore concurs in the later results of Mr. Wood with respect to the Basement Clay, and regards it as the product of the earlier ('major') glaciation and roughly equivalent to the Cromer Till.

The origin and correlation of the beds between the Upper and Lower Boulder-clays on Flamborough Head constitute at once the most difficult and most important of the problems presented by the sections. It is here that Mr. Lamplugh differs so materially from previous writers, and since he concludes that the 'Intermediate Series' of Flamborough passes laterally into the Purple Boulder-clay of Holderness, the proofs will be strictly challenged when we bear in mind how little these have in common. The sections north of Bridlington Quay show clearly, he says, that in spite of the apparent difference, the stratified beds are really equivalent to the Purple Boulder-clay, since we can trace the greater portion of the clay until it is shredded out and merged with the bedded loam and gravel. Although this equivalence only holds good in a general way, yet, broadly speaking, the great mass of the Purple Clay may be said to resolve itself, in the Flamborough sections, into stratified deposits. That portion of the 'Intermediate Series' on the crest of the escarpment at Speeton, described by Messrs. Wood and Rome as denudation-gravels of post-Glacial age and supposed by them to have been formed during a great submergence, is really due to the melting on the spot of the Purple Clay ice. This was Mr. Wood's final opinion, essentially the same as that of the late Prof. Carvill Lewis.

With the ice filling up the bed of the North Sea to the extent indicated by the Basement Clay, and this ice not of local origin (for it is clear that the Yorkshire Wolds added nothing to it, and were not entirely submerged by it), there must have been a time when the great ice-sheet rested with its flank upon this coast-line while the main current swept southwards, following the deepest part of the sea-bottom. At the time of its greatest extension the ice seems to have been 500 or 600 feet thick at Speeton, and a thin flange from the top of the glacier probably passed over the edge of the cliff there during the deposition of the Basement Clay. So long as the edge of the ice was advancing no very great accumulation of material could well take place at its margin, but as soon as its growth was arrested and it began to decline there must have been a considerable deposition in this quarter. It is to the washings of such morainic material at the margin of the ice that Mr. Lamplugh ascribes the origin of the 'Intermediate Series' of Flamborough and of the northern part of Holderness. In the neighbourhood of the Humber there may have been some difference of origin, and possibly the sea was not entirely excluded from the old bay, where in some places it might have laved the edge of the glacier. Whilst the 'Intermediate Series' was being formed at the edge of the ice during a period of slow recession, following a long pause, the formation of Boulder-clay was still being carried on over the area covered by the glacier, and thus, he says, originated the Purple Clay of Holderness. These beds he is inclined to correlate with the Contorted Drift and Middle Glacial gravels of Norfolk.

With regard to the Upper Boulder-clay, he considers that as the ice in the North Sea gradually diminished in volume, so the products of the Teesdale glacier were able to make themselves more and more felt. When the ice, from want of renewal, gradually melted away, there resulted a stony and earthy residuum, and the Upper Boulder-clay is in part the result of this action. The Hessle Clay of Messrs. Wood and Rome, which they describe as a mantle covering everything, had a similar origin in Holderness.

Such is a brief outline of Mr. Lamplugh's views on the Glacial deposits of East Yorkshire. We seem to recognize in this Upper Boulder-clay, charged as it is with débris of Carboniferous origin, something analogous to the Upper Pennine Boulder-clay of Deeley, where the indigenous glaciers were beginning to re-assert themselves. If this is so, the Author can scarcely be correct in regarding the

Chalky Boulder-clay as even roughly equivalent to the Upper Boulder-clay of Yorkshire, at least in a chronological sense.

We may naturally suppose that the Chalky Boulder-clay of the South-east of England in its march towards the Thames Valley represents the most intense period of the Great Ice Age—a period when the *vis-a-tergo* was at its maximum. Hence there does not seem to be much chronological value in the tripartite division of the Glacial deposits of East Yorkshire, but merely the physical history of a great glacier-movement. We learn, however, the important lesson that the origin of interglacial gravels may be explained on other and perhaps more probable grounds than those of subsidence and interglacial warm periods.

North-western England and Scottish Highlands.—Lastly we have to consider those portions of our island where glaciers originated, and in this case we naturally turn towards the North-west of England and, farther still, the Highlands of Scotland, regions where for the most part the land is mountainous and the precipitation excessive. The glaciology of these districts had perhaps to a great extent been worked out in previous years; at least there have been no more than two communications to the Society in the past seven years, and these relate to such well-known subjects as the perched blocks at Norber and the Parallel Roads of Glen Roy.

The phenomenon of boulders on pedestals is one that lends itself to illustration. The subject was well handled by Prof. Hughes in connexion with boulders, chiefly Silurian, resting on pedestals of Mountain Limestone in the Kendal district and also at Norber Brow in Craven. He assigned their origin, not to icebergs nor to the stony residuum of a washed-out Boulder-clay, but to certain conditions which arose during the recession of the great ice-sheet. There must have been, as he remarks, oscillations during the general recession, and he thought that the glacier in its last advance might have picked up the boulders due to the weathering of massive beds, which had been exposed when it had receded somewhat. Nor was this all, for the ice had been able to carry these boulders up and over the brow of a hill. On Norber Brow, he says, this pushing uphill of the boulders is well marked, for here the blocking of the mouth of the valley by a ridge of grit forced the ice to higher levels. We here perceive the effects of an obstruction in the path of the ice, though on a small scale compared with those gigantic results which have been claimed for the ice of the Irish Sea.

As regards Scotland, Mr. Jamieson has contributed some Supplementary Remarks on Glen Roy, and this is the only paper on Pleistocene Geology that we have received from the other side of the Border. The history of this controversy is familiar to all, and most geologists are acquainted with the general principles, if not with the details, of Mr. Jamieson's explanation of the origin of the famous Parallel Roads.

Since there had been objections to his hypothesis on the grounds that it seemed strange for one set of valleys to be filled with ice and another set, in close proximity, with water, the Author points out that, as the rainfall on the west side of Scotland is quite double of that on the east side, so also in the Glacial Period must have been the snowfall. He indicates on a map, to which meteorologists are by no means strangers, those portions of the country which, from excessive precipitation, were likely to have been the most strongly glaciated. The wettest part of the country nowadays lies along a line extending from the mouth of the Clyde to the island of Skye, passing right across the western entrance of the Great Glen of Scotland through which runs the Caledonian Canal. The two great ice-fields which must have resulted from the immense snowfall over this district would coalesce hereabouts, and there must have been a great congestion, especially towards the head of Loch Linnhe.

He concludes that the quantity of ice filling the Great Glen and the mouth of Glen Spean was such that it eventually overflowed the passes leading eastwards into the valleys of the Nairn and the Spey, notwithstanding that many of these passes are higher than those on the west which lead out into the Atlantic. Consequently, before the era of the lakes which produced the Parallel Roads of Glen Roy, the western ice actually discharged itself through the very *cols* over which the water from the lakes flowed at a subsequent period. He further points out that during the maximum glaciation it was the cumulative effect of such storage of the surplus snow and ice, continuing through so many ages, which gave rise to similar remarkable results not only in Scotland, but in Ireland, Scandinavia, and North America.

The state of preservation of the Parallel Roads is such that it is quite clear no glaciers can have gone over them since their formation: hence their origin must be referred to a comparatively late stage of the Glacial Period. Mr. Jamieson supposes that the thinner ice towards the north-east was the first to disappear, so that the ground became clear a long time before the ice gave way in the western glens. Such a state of things it was which produced the glacial lakes of Lochaber, and he quotes the authority of Hansen, who maintains that it was the great decaying mass of the 'inland-ice,' and no mere local glaciers, which constituted the barriers of the lakes. The thinner ice towards the north-east having melted, the watershed at the head of the Spey became sufficiently open to admit of water passing out, and a lake resting on the surface of the decaying glacier would in the first instance discharge over this *col.* The several stages are thus explained and the corresponding points of escapement indicated. The alluvium of Bohuntine is considered to be the gravel and mud that fell into the lake from the front of the ice when it stood at the mouth of Glen Roy during the formation of the two upper lines. It also serves to show, in opposition to the opinion of Prestwich, that the lake must have existed for a considerable length of time. During the last stage of the lake the ice-dam retreated gradually from the entrance of Glen Roy until it finally stood across the mouth of Glen Spean. The Author then refers to the ultimate subsidence of the lake and to the traces of a débâcle.

Theories in connexion with Glaciation.

In addition to the mass of papers dealing with what is usually known as the Great Ice Age of Pleistocene time, there have been a few papers in which subjects connected with glaciation have been discussed from a more or less theoretical point of view. These may be grouped as follows:—(1) The evidence of glacial conditions in the Palæozoic era; (2) Date and duration of the [Pleistocene] Glacial and post-Glacial Periods; (3) Misconceptions regarding the evidence of former Glacial Periods.

Evidence of Glacial Conditions in the Palæozoic Era.—Dr. Blanford is of opinion that the existence of boulder-beds over areas so extensive and so widely separated as the Karoo Beds of South Africa, the Gondwána of India, and the Coal-measures of Eastern Australia, all of which boulder-beds might probably be of the same age, renders it likely that these were really contemporaneous and due to one great Glacial Period, occurring towards the close of the Palæozoic era. He even goes so far as to speculate on the possibility of this presumed Glacial Period having terminated the Palæozoic era by destroying many of the principal forms of life. How far the floras of these beds justify such a supposition must be decided by those well versed in palæobotany, but at least it is not claimed that either fauna or flora presents any modifications due to severe cold. In other words, nothing analogous to an Arctic or sub-Arctic fauna or flora, such as we find in Pleistocene times, is presented to us from these Upper Carboniferous beds. The evidence in favour of glaciation appears to be of a purely physical nature, and rests mainly on the frequent presence of smoothed and striated boulders in the midst of a matrix of fine silt.

Mr. David is equally certain that in New South Wales there are glacial beds of Carboniferous age; and as some of these are marine, the glaciation would seem to have extended to the sea-level, since we are told that nothing but ice-action could have brought these boulders into their present position. There can be no doubt that many persons in New South Wales, as elsewhere, are content to accept these appearances as evidence of glacial action, but that is not quite the same thing as the establishment of a Glacial Period at the time in question. Admitting for argument's sake that ice-action alone could have produced these striations and distributed large stones in the midst of fine silt, it must at least be shown that the glaciation was something more than what may be expected to occur in the vicinity of lofty ranges of mountains which have been recently elevated.

As a supplement to Mr. David's paper I would draw attention to a Special Report issued by the Colony of Victoria and compiled by Mr. Dunn, with reference to the celebrated 'Glacial Conglomerate' at Wild Duck Creek.[1] The chief feature of this remarkable publication is the number of striking photographs showing striated boulders, and most remarkable of all are the photographs of the striated bed-rock, which is stated to be of Silurian age. Dr. Wallace brought this publication to the notice of English geologists a few weeks ago.[2] He considered that the whole of the phenomena of Wild Duck Creek point unmistakably to glacial action. Referring subsequently to a list of localities in Eastern Australia where similar conglomerates have been found, though the indications of glacial action are not specially mentioned, Dr. Wallace remarks that "if these deposits are really all glacial and contemporaneous, they indicate an extent of glaciated country that would imply either a very lofty mountain range or the occurrence of a real glacial epoch in the southern hemisphere."

[1] 'Notes on the Glacial Conglomerate, Wild Duck Creek.' By E. J. Dunn, F.G.S. Melbourne, 1892.

[2] 'Nature,' Nov. 17th, 1892, vol. xlvii. pp. 55, 56.

From the original discoveries of the Blanfords in India, and from the further evidence of the Dwyka Conglomerate in Africa, there can hardly be any doubt that similar deposits, approximately contemporaneous, extend over a very wide area. Indeed, one cannot help calling to mind that even in Britain the Permian conglomerates and breccias have often been and still are quoted as evidences of a Palæozoic ice-age. That something very remarkable occurred in the physical history of the earth's crust about this period (Permo-Carboniferous interval) is perfectly certain, and the results of this action may be traced over widely separated regions. It is quite legitimate to seek for an explanation of the cause, but geologists especially should be careful how they accept theories which require the earth's axis of rotation to be shifted, or which profess to account for general climatic conditions, which perhaps never existed, during the period in question.

Date and Duration of the Glacial (and 'post-Glacial') Period.—Two well-known authors have ventured to place an approximate chronological value on the whole or on a portion of Pleistocene time, viz. Prof. Prestwich and Mr. Mellard Reade.

Prof. Prestwich commenced by stating his belief that there is no valid evidence of the recurrence of Glacial epochs; and he pointed out the divergence in the late Dr. Croll's estimates as to the beginning of what is usually known as the Glacial Epoch, these estimates having ranged from nearly a million years ago to something less than a quarter of a million years ago. Prof. Prestwich is inclined to believe that a much smaller figure than the lowest of these will suffice, basing his calculations, in part, on a study of the laws affecting the growth of ice and the motion of glaciers. The observations made by Steenstrup, Rink, and others in Greenland tend to show that there is a general movement of the 'inland ice' towards the sea, and that it concentrates its force upon comparatively few points, which are represented by the so-called ice-fields, through which the annual surplus of ice is carried off. The velocity of the ice was noted in seventeen glaciers, and it was calculated that these move at rates varying from 30 to 50 feet *per diem* throughout the year, the rate of movement not being materially influenced by the seasons. The precipitation in Greenland is thought to be less than 20 inches per annum. From the above data, and bearing in mind the ratio of ice-front to rock-front along the whole coast, the total annual discharge is equal to a fringe of ice one-eighth of a mile in breadth, or one mile of ice in eight years.

Taking as the known quantity the results supplied by the observations in Greenland, the equation, he says, will be as follows:—A surplus-ice overflow equal to one mile advance in eight or twelve years, *minus* (1) the retardation due to friction and irregularities of the surface, and (2) to seasonal changes of temperature (the so-called interglacial periods): *plus* (1) the increase of discharge due to progressive secular refrigeration and (2) further to increased precipitation. The known quantity, he says, gives us from 4000 to 6000 years. He allows that of the unknown quantities we can at present form but a distant idea, although he thinks it will be found that the time required for the formation and spread of the great ice-sheets in Europe and America need not be extended beyond 25,000 years at the utmost, including in this estimate the time during which the cold was increasing, or pre-glacial time, and that during which the cold was diminishing, or post-glacial time. The close of the Glacial Period, *i. e.* the final melting of the ice-sheet, might have taken place from 8000 to 10,000 years ago.

We must all admit the interest which attaches to calculations based on the rate of motion in the Greenland ice-sheet, yet the unknown elements, and especially the uncertainty as to the duration of the period of refrigeration, seem to cast a shadow upon this attempt to estimate the duration of the Glacial Period. However, the Author himself explains that he does not attempt to fix actual terms of years, but only wishes to show that we must not unhesitatingly accept such large measures of time as have in some instances been required.

It is curious to note how different a view Mr. Mellard Reade takes of the duration of what is usually termed post-glacial time. While Prof. Prestwich thinks that the final melting of the Great Ice Sheet is not likely to have occurred more than 10,000 years ago, Mr. Reade claims for events succeeding the deposition of the low-level Boulder-clay of Lancashire a period of 57,500 years, which is made up as follows:—He assigns a period of 40,000 years to the elevation and erosion of the Boulder-clay, one of 15,000 years for the deposition of the post-glacial beds, such as estuarine silt and *Scrobicularia*-clay succeeded by peat and forest-beds, and a further 2500 years for the blown sand which covers these in many places.

It seems tolerably certain that, when an author is bold enough to attempt a chronological scheme of this nature, the arguments of most of the speakers aim at demonstrating the impossibility of reducing geological time to years. Such was conspicuously the case when Mr. Reade's paper was brought before the Society. Undoubtedly, when the slopes were steeper, the rate of denudation and consequently of deposition would be more rapid, and this fact is held by some to invalidate any calculations based on the present rate of deposition of silt.

Misconceptions regarding the Evidence of former Glacial Periods.—Lastly, we possess in the paper which bears the above title a legacy which the late Dr. Croll may be almost said to have bequeathed to the Geological Society. His cardinal point was that the evidences of glaciation are to be found principally on land-surfaces, and that the transformation of a land-surface into a sea-bottom would probably obliterate every trace of glaciation.

He even went so far as to assert that the absence of large erratic blocks in the stratified beds may indicate, in some cases, a period of extreme glaciation. The more complete the glaciation, says Dr. Croll, the less probability of the ice-sheet containing any blocks, since the rocks would be covered up. This assertion was especially aimed at Nordenskjöld's statement that there is no evidence of glacial conditions in the strata of Greenland and Spitzbergen down to the termination of the Miocene period, the absence of large boulders being conspicuous in beds of that or earlier date. It suited Dr. Croll wholly to ignore the character of the faunas and floras which have been discovered in these high latitudes. Moreover, he seems to have been unaware that, by adopting this line of argument, he was claiming for pre-Miocene times a greater amount of glaciation than that which prevails in Greenland and Spitzbergen at the present day. Neither of these countries now presents the phase which marks the complete glaciation imagined by Dr. Croll, since there is abundance of morainic matter and rock-detritus at the margins of the inland ice.

The real state of the case seems to have been that Dr. Croll, as an astronomer and mathematician, was perpetually calling upon geologists to find evidence of the truth of his favourite hypothesis, viz. the recurrence of glacial epochs. These latter for the most part have been wholly unable to respond to the call, and, except in the doubtful cases previously mentioned, it can hardly be said that there is any positive evidence in support of Dr. Croll's cardinal point, although we cannot help admiring the dexterity with which he contrived to fire a Parthian shot into the camp of the enemy.

Tertiary Geology.

Having spent so much time over papers relating to Pleistocene Geology, it will be necessary to touch but briefly on matters which otherwise might well have occupied our attention at greater length. The Tertiary Geology of West Surrey and East Berks, taken *per se*, is mainly of local interest, but any attempt based on palæontological data to correlate portions of the London and Hampshire Basins, and so pave the way, if possible, for a more uniform nomenclature, must be regarded from a wider standpoint.

Upper Eocene.—Such a paper was presented to the Society by Messrs. Gardner, Keeping, and Monckton, entitled 'On the Upper Eocene, comprising the Barton and Upper Bagshot Formations.' The primary object which the Authors had in view was to effect a partial revision of the grouping of the older British Tertiaries, in consequence of the introduction of the Oligocene into our classification. Unless, as they observe, the considerable literature relating to the Bracklesham, the Calcaire Grossier, and the Nummulitic is to be rendered obsolete, their classification as Middle Eocene must be preserved, and a modified Upper Eocene constructed out of the Barton Series. Secondly, then, the Barton Series, as developed in Hampshire, is to a certain extent remodelled, with an adequate notice of its very abundant fauna: and thirdly, it is shown by way of correlation that, in all probability, the beds hitherto known as the Upper Bagshot Sands in the London area correspond to the lower portion of this series, *i. e.* to the Lower Bartons.

It is admitted that the base of the Barton Series is not sharply defined, since there is no boundary-line of importance, palæontological or lithological. Indeed, if the section at Whitecliff Bay, which the Authors regard as the most perfect in all the Eocene formation in England, had been the original or type-section, a different arrangement, we are told, from that which now exists might have been entertained. Here the fauna of the Lower Brackleshams, with its giant Nummulites, Bullas, and Cowries, and its wealth of Corals, differs far more from that of the Upper Brackleshams than the latter does from that of the Bartons. Had the Barton Series been in the first instance described from the Highcliff section in Christchurch Bay, and then followed from west to east, taking first Alum Bay and then Whitecliff Bay, the entire Upper Bracklesham Series would have found a place in it, and the base-line would have been drawn where a decided physical change is manifest. However, the division as now made coincides with the final disappearance of several subtropical Mollusca, and almost with the extinction of Nummulites in our area. There is less difficulty about the upper limit of the Barton Series, which is drawn at the base of the Lower Headon, where the brackish-water fauna gives place to one of freshwater origin.

A considerable portion of the paper is then devoted to a detailed description of the Barton Series as developed in Christchurch Bay, an ascending section being given, and the measurements compared with those of previous observers, such as Prestwich, Bristow, and Wright. The zone of *Nummulites elegans* is taken to be somewhere about the base of the Lower Barton Beds. I may mention, by the way, that a paper was read before the Society by Prof. Rupert Jones in 1886, where it was shown that Sowerby's labelled specimens of '*Nummularia*' *elegans* are really the same as the var. *Prestwichiana* of *Nummulites planulatus*. We may believe, then, that the *Nummulina Prestwichiana*, auct., is really the same thing as *Nummulites elegans*, Sow. Since this line is to be taken as the base of the Upper Eocene, it is at least important that the synonymy of the name-giving Nummulite should be settled.

The Lower Barton or Highcliff Beds are estimated at about 50 feet, consisting mainly in their lower parts of stiff drab-coloured clay, which higher up becomes filled with sand drifts full of fossils, the uppermost portion being known as the Highcliff Sands; this part of the series terminates with the *Pholadomya*-bed. Its fauna comprises many Bracklesham species, which range no higher up, and it also contains a large number of peculiar species. The base-line fixed for the Middle Barton, or Barton Clay proper, is the lowest of several bands of septaria, which distinguish the 50 feet of drab-coloured clays comprised in it, and this last division terminates in a very remarkable formation, known as the Shell-bed, which, although only a foot or two thick at Highcliff, increases towards the east. The fauna of the middle division of the Bartons is nearly as rich as that of the lower, and far more characteristic. Some of the grandest species, such as *Rostellaria ampla*, *Fusus longævus*, and *Murex minax*, range from the Bracklesham right through the Barton, but attain their finest development here. Others, such as *Cassidaria nodosa*, *Ficula nexilis*, *Triton argutum*, and *Fusus regularis*, pass upwards from the Bracklesham, but do not range beyond the limit of this division. The finest specimens of the strictly Barton fossils, *Voluta luctatrix*, *Crassatella sulcata*, and *Limopsis scalaris*, are obtained here, while others, such as *Voluta ambigua* and *Pleurotoma* *rostrata*, cannot be collected at all above this zone. Finally, several small but well-known species, such as *Conus dormitor* and *Buccinum desertum*, here make their first appearance.

The Upper Barton division is represented as having a development of 90 feet, and is far more variable both in its fauna and lithology; in fact it comprises within itself a triplicate subdivision, of which the upper portion contains the Hampshire Upper Bagshots, which are also known as the Headon Hill Sands (the Long-Mead-End Sands of the Authors). This Upper Barton as thus constituted is, in fact, a somewhat artificial division, its base being the *Chama*-bed. The fauna of the *Chama*-bed numbers altogether 170 known species, and differs, as a whole, more from that of the Lower and even Middle Barton than does that of the Lower Barton from the Upper Bracklesham. The greater number of what may be considered the typical Barton species have disappeared. It is difficult to say positively whether the change was from deeper to shallower water, or the reverse; but the shell-bed preceding the *Chama*-bed plainly indicates a long period when no mud was being deposited, and the *Chama*-bed itself was formed in clear water. It serves to show, like so many other abrupt transitions in the Eocene, that a relatively slight change in physical conditions makes a far greater impression on the succession of life in a formation than would be occasioned by an enormous lapse of time without such a change. This is the last appearance of *Chama* in England.

An analysis of the entire Barton fauna is given towards the end of the paper, with a table enumerating also those species which ascended from below, and those which continued into the Headon Series. A somewhat critical examination of the Edwards collection shows about 527 varieties of Mollusca from the Barton Beds entitled to specific rank, and the Authors are not of opinion that this number will ever be greatly exceeded. Fossils belonging to other groups bring the fauna to a possible total of 600. The list comprises 23 Vertebrates, 47 Invertebrates other than Mollusca, 257 Gasteropods, and 150 Bivalves, exclusive of over 120 undetermined species.

The Barton Series in Hampshire is now separated from its representative in the London Basin by an interval of about 60 miles—a break in all probability due to post-Eocene denudation. There can be no doubt that exact correlation in this case must be attended with much difficulty; still the Authors roundly assert that the fauna precludes the idea of any correspondence between the Upper Bagshot Sands of Surrey and the sandy beds of the Upper Barton, heretofore known as the Upper Bagshot Sands of the Hampshire Basin. The Surrey Upper Bagshots they consider to be such as might have been accumulated in a bay of the open sea, while in Hampshire the Barton Series was evidently laid down within the influence of a considerable river.

Accepting as the dividing-line between the Middle and Upper Bagshots of Surrey the bed of pebbles which is stated to occur persistently over the London Basin, the greatest proved thickness of the Upper Bagshots is about 230 feet. The various levels at which the pebble-bed is found are considered to show that the formation rests on a syncline of Bracklesham Beds, and is probably conformable with them. There seems to have been just a suspicion in the minds of the Authors, or of one of them, as to whether the Upper Bagshots of the London Basin are not partly or even mainly of Upper Bracklesham age; but if they are to be regarded as Barton at all, there can be no doubt whatever as to their being Lower Barton. Subsequently the Authors appear to conclude that it would be unreasonable to put the whole of the 230 feet of Upper Bagshot Sand into the Bracklesham Series.

The fossils on which these correlations are based were mainly obtained about the middle of the Fox Hills, on the Woking-Aldershot line, by Messrs. Monckton and Herries. The Authors indeed consider it certain that the Upper Bagshots of the London area were once at least as fossiliferous as their equivalents in Hampshire, and the remarkable condition of some of the Hampshire beds when not protected by clays gives some colour to this supposition. The list contains 52 species of Mollusca, of which 43 could be determined specifically. Thirty-one are common to the Upper Bracklesham and the Barton, and there are nine Barton species unknown in the Bracklesham. Making allowance for the effects of more sandy conditions, the palæontological evidence agrees with the stratigraphy, the presence of the few Bracklesham forms leading the Authors to place the Tunnel-Hill horizon of the Woking-Aldershot line a little below that of Highcliff in Christchurch Bay.

Should exact correlation betwixt beds of the London and Hampshire Basins be ultimately possible, it would seem almost unnecessary to perpetuate a double nomenclature. It might, indeed, simplify the problem if we abolished the so-called Middle and Upper Bagshots, and replaced these names by those of the richly fossiliferous Hampshire equivalents. There would still remain the variable and extensive underlying series of clays and sands, for the most part devoid of molluscan remains, but locally rich in fossil wood, leaves, and fruits, to perpetuate the name of Bagshot in the list of British formations.

Deep-sea Deposits.—Under the heading of Tertiary Geology it will be convenient to consider this subject, since certain deposits in Barbados, described by Messrs. Jukes-Browne and Harrison, are believed to be of late Tertiary age. In the same connexion also is a paper by Mr. Lechmere Guppy on the Tertiary Microzoic formations of Trinidad. The late Mr. Brady, likewise, made an interesting communication to the Society on the so-called Soapstone of Fiji, which, although post-Tertiary in age and not precisely a deep-sea formation as the term is now understood, clearly belongs to the category of Oceanic deposits. The interest attaching to the proofs that deep-sea deposits have actually been raised above sea-level so as to form recognizable geological formations must be my excuse for venturing to deal, however briefly, with matters which do not relate strictly to our own islands. The venue then for the moment is shifted from the coast of Hampshire to the islands of the Caribbean Sea, and more especially to Barbados, whose geology has been described in considerable detail by Messrs. Jukes-Browne and Harrison. These authors were in correspondence with Dr. John Murray, whose conclusions in the main are stated to coincide with their own, and they were further indebted to Mr. William Hill and Miss Raisin for reports on the minute structure of the rocks submitted to them.

The geology of Barbados turns out to be, on the whole, tolerably simple, and one cannot help feeling surprised at such statements as that of Alexander Agassiz, who assumed the island to be a volcanic cone, entirely surrounded by coral terraces which completely hide the cone.[1] This statement may possibly have had its origin in the conventional idea that an insular coral-formation ought to be on the summit of a volcanic peak. On the other hand, Haeckel[2] asserts that the Island of Barbados consists for the most part of fossil Radiolarian ooze, and he proceeds to speculate on the probability that in certain parts of the tropical Atlantic true Radiolarian ooze, like that of the Pacific and Indian Oceans, will eventually be found in depths between 2000 and 3000 fathoms, perhaps over a considerable area. As a matter of fact, the Island of Barbados is composed of three formations. The fundamental rock is a terrigenous series (Scotland Beds) consisting of grits,

[1] 'Cruise of the *Blake*,' vol. i. p. xix.

[2] 'Challenger' Rep., Zool. vol. xviii. pt. 1, p. cli.

sandstones, and clays, which have been thrown into a succession of folds and flexures. From comparison with rocks in Trinidad, this series is thought to be of Eocene age, and must have been laid down when there was a large land-area in the vicinity. The Oceanic deposits, which rest unconformably on this series, consist chiefly of fine white earths, much resembling soft chalk in general appearance, together with subordinate beds of pink and yellow clay, and occasional layers of grey pumiceous sand or silt. The raised reefs or coral-rocks which cover six-sevenths of the surface of Barbados constitute the third formation. A section across the island from east to west serves to show the mutual relations of these three formations, and exhibits faulting to the extent of a few hundred feet, while the coral-rock is sometimes seen to rest directly on the fundamental series.

The area and volume of the Oceanic Series does not appear to be large; the most complete succession yields an estimated thickness of a little over 300 feet, which is made up as follows:—Resting unconformably on the fundamental rocks are calcareous earths, gradually becoming more siliceous, and succeeded by a great thickness of pure siliceous Radiolarian earths, which again become more calcareous, and are topped by a moderate thickness of chalky earths and marls. All these are, in the main, organic deposits, but above them come very fine-grained argillaceous deposits, and above this, in one place, some 25 feet of grey volcanic mudstones, with a few Radiolaria, but no calcareous matter. We perceive, then, that the first phase was one of calcareous deposits containing from 60 to 80 per cent. of carbonate of lime, with many *Globigerinæ* and other oceanic Foraminifera. Presently siliceous organisms are found in increasing numbers, and at length we arrive at the central part of the series, which is essentially siliceous, some beds containing 77 per cent. of organic silica, with less than ·5 per cent. of calcareous matter, made up principally of Radiolaria, Diatoms, Sponge-spicules, and occasionally associated with layers of pumiceous sand. Higher up, calcareous organisms again make their appearance, and the sequence of organic rocks closes with a second zone of calcareous material, the quantity of carbonate of lime varying from 44 to 80 per cent. Above the last beds there is a rapid change into fine-grained argillaceous earths.

When we come to compare the Barbados rocks, as above detailed, with modern Oceanic deposits we can hardly fail to recognize, more or less completely, the *Globigerina*-ooze, the Radiolarian ooze, and possibly the Red Clay of deep-sea investigation, to say nothing of deposits which partake of the nature of mixtures of the above. It must be accounted as a somewhat singular coincidence that this paper on the Oceanic Deposits of Barbados should have been brought before the Society within a few weeks of the publication of the 'Challenger' Report, which deals *in extenso* with the Deep-sea Deposits collected by the staff of that vessel from 16 to 20 years ago.[1] Fortunately many of the results had been given to the world in previous publications, though it must have been a satisfaction to our Authors to have been able to test their conclusions by the more perfected report. Dr. John Murray, on the other hand, has been able to refer to the similarity between the Barbadian deposits and the modern oceanic oozes. But he still expresses doubts whether the deposits of the abysmal areas have in the past taken any part in the formation of the existing continental masses.[2] Again he says that, with some doubtful exceptions, it has been impossible to recognize in the rocks of the continents any formations identical with the pelagic deposits.[3]

We may, however, take it for granted that in more than one island of the Caribbean Sea pelagic deposits are now to be found as rock-masses of considerable importance, some modified in structure, others but little altered. Such being the case, it remains to consider their age, and the inferences connected with their upheaval from the bed of the sea. If we may trust to the scientific imagination the story runs somewhat as follows :—After the earth-movements which resulted in the plication of the fundamental series of 'continental' origin, the area subsided into depths appropriate for the deposition of *Globigerina*-ooze, and so continued to subside until the relative numbers of the calcareous and siliceous organisms became reversed, when finally such depths were attained that siliceous organisms alone remained in the ooze, which now became exclusively Radiolarian. The comparative thickness of the Radiolarian portion of the earths is held to indicate a long period of extreme depth ; but presently a reverse action commenced, and the organic series ended, as it began, with a calcareous deposit. When the area again began to subside, and the calcareous matter to diminish in amount, a fine argillaceous substance, believed to be analogous to the Red Clay of the deep sea, was deposited in lieu of the Radiolarian ooze of the first great depression.

[1] 'Challenger' Reports, Deep-sea Deposits, Murray and Renard, 1891.
[2] *Ibid.* p. xxix.
[3] *Ibid.* p. 189.

Beyond this point there is no very clear evidence of the sequence of events, nor indeed are we to expect that every chapter in this geological record should be complete. But, among the many questions which this interesting speculation raises, there are two which seem to call for special attention: firstly, whether the Authors are right in referring the origin of the Red and Mottled Argillaceous Earths to a deep-sea Red Clay, seeing that this theory requires a second great depression of the area. This latter supposition, unless supported by corroborative evidence, seems to be rather a weak point in the argument, though it certainly fits in fairly well with the present condition of the adjacent Atlantic. Here, as we know, in depths from 2500 to 3000 fathoms, Red Clay with but few traces of organisms, siliceous or calcareous, is the predominating deposit. It is evident, however, from the analyses published in the 'Challenger' Report that the term 'Red Clay' is made to cover a great variety of deposits, so much so indeed that it can scarcely be said to possess any definite meaning whatever; and it is necessary to refer to the Synoptical Table in each case, where very interesting details as to the percentage composition of particular samples of Red Clay are available for the student. The chemical analyses are somewhat perplexing, owing to the methods adopted, but Dr. Murray gives us the average composition of the 'Challenger' samples of Red Clay as follows[1]:

	Per cent.
Calcareous organisms	$6\frac{1}{2}$
Siliceous organisms	$2\frac{1}{2}$
Minerals	$5\frac{1}{2}$
Fine washings	$85\frac{1}{2}$

Messrs. Jukes-Browne and Harrison are sanguine enough to consider that if the 'Challenger' samples of Red Clay containing only small amounts of carbonate of lime and the samples of the Barbados Argillaceous Earths had been analysed by similar methods, a close resemblance in composition would have been found in them, and that the differences would have been such only as might arise from the action of organic acids percolating through the rock.

A more important question is presented by the undoubted fact of so large a development of Radiolarian earths, and the inferences which the Authors are disposed to draw respecting the great depths in which these deposits originated. It is a curious circumstance that no Radiolarian ooze is known to occur on the floor of the Atlantic at the present day. Haeckel, as we have seen, predicated the

[1] *Op. cit.* p. 197.

existence of considerable areas of Radiolarian ooze in the tropical portions of the North Atlantic, but Dr. Murray is less sanguine on this point.[1] Of course, there are plenty of Radiolaria in the Atlantic, but their remains do not collect in sufficient quantities to form a Radiolarian ooze, which according to Murray's definition should contain not less than 20 per cent. of Radiolaria and siliceous organisms other than Diatoms.[2] Such deposits occur sparingly in parts of the Indian Ocean and in the central and western regions of the Pacific. Dr. Murray goes on to remark that even Radiolaria, like the calcareous Foraminifera, are slowly dissolved by sea-water, after the death of the organisms.

There is a general idea, evidently shared by Jukes-Browne and Harrison, that Radiolarian ooze in existing seas indicates excessive depths. Murray himself states that Radiolarian ooze has a greater average depth than even the Red Clay. But it is evident that causes other than bathymetrical influence in a remarkable manner all kinds of oceanic deposits. Attention to the following 'Challenger' soundings will easily show this to be the case. At station No. 116, between Fernando Noronha and Pernambuco, the surface-temperature being 78° F. and the depth 2275 fathoms, the bottom was found to be what is called *Globigerina*-ooze, containing 65 per cent. of carbonate of lime; while at station No. 259, between Yokohama and the Sandwich Islands, the surface-temperature being 77° F. and the depth 2225 fathoms, the bottom was found to consist of what is called Red Clay with only a trace of carbonate of lime. On comparing these two stations, one in the Atlantic and the other in the Pacific, we perceive that, while the surface-temperatures and depths are almost identical, in the one case carbonate of lime, arising principally from calcareous organisms, amounts to 65 per cent. of the whole, whereas in the other case there is scarcely a trace of it.

Again, with regard to Radiolarian ooze, which we have seen defined as a Red Clay with 20 per cent. and upwards of siliceous organisms other than Diatoms, some curious facts may be gathered from a careful perusal of the Synoptical Table in the 'Challenger' Report. It so happened that at station No. 225, between the Admiralty Islands and Yokohama, in the Western Pacific, the enormous depth of 4475 fathoms was reached, the deepest sounding from which a deposit is known to have been procured, and this was found to contain 80 per cent. of Radiolaria and siliceous organisms. Even in this case one or two *Globigerinæ* were observed.

[1] *Op. cit.* p. 208. [2] *Ibid.* p. 203.

But the chief discoveries of Radiolarian ooze were made in the Central Pacific, within the tropics, between the Sandwich Islands and Tahiti. Considerable depths exist here also, though Dr. Murray's Synoptical Table reveals some curious, one might almost say anomalous, results with reference to the distribution of *Globigerina*-ooze and Radiolarian ooze in this area. For instance, at station No. 270, which is situated about $2\frac{1}{2}°$ north of the Equator, the surface-temperature being $79\frac{1}{2}°$ F. and the depth 2925 fathoms, a *Globigerina*-ooze containing 65 per cent. of calcareous Foraminifera and only 5 per cent. of Radiolaria occurs; while at station No. 273, which is about 5° south of the Equator, the surface-temperature being $80\frac{1}{2}°$ F. and the depth only 2350 fathoms, the floor of the ocean was found to consist of Radiolarian ooze containing no more than 1 per cent. of calcareous Foraminifera, 30 per cent. of Radiolaria and Diatoms, and a large amount of amorphous matter. This is certainly reversing the ordinary conditions in a remarkable manner, when we find in the same part of the ocean, at points separated by only 7° of latitude, two deposits, of which the one, composed principally of calcareous organisms, lies deeper by nearly 600 fathoms than the Radiolarian ooze of the other station. Furthermore, throughout this great area of Radiolarian ooze, while the general depth may be about 2700 fathoms, the very deepest sounding taken is just the one which is represented as containing 71 per cent. of carbonate of lime.

To take an example from the Indian Ocean, there is the case of the Radiolarian ooze between Zanzibar and the Seychelles, a sample of which was brought up from a depth of 2200 fathoms by Capt. Pullen of the 'Cyclops' many years ago. This was stated by Ehrenberg to be a mass of almost pure *Polycystinæ*, such as no sample of a deep-sea deposit had hitherto shown, and it was particularly noticeable that in the whole of this mass of living forms no calcareous tests were to be seen.[1] Unless, therefore, any doubt attaches to the accuracy of these results, we are entitled to quote this as an instance where calcareous organisms are entirely excluded by siliceous ones at the comparatively moderate depth of 2200 fathoms.

With these recent cases before them it would seem unsafe for geologists to indulge too freely in bathymetrical speculations where they happen to discover fossil Radiolarian ooze raised above the level of the sea, as is the case in Barbados, and also apparently in Trinidad. It is plain that causes other than bathymetrical operate now, and probably did so formerly with still greater force, in the

[1] Quoted by Haeckel, 'Challenger' Rep., Zool. vol. xviii. pt. 1, p. cl.

accumulation of Radiolarian oozes. Consequently, we are not bound to believe that the Tripoli or Polycystine marls of the Mediterranean coasts and islands, for instance, were upheaved from any very extraordinary depths. As a case in point, I may mention the deposit of Oran, stated by Haeckel to be a pure Radiolarian ooze very similar to that now found in the Central Pacific.[1] Without doubt both the Mediterranean and the Caribbean Sea have been in times past, and still are, regions subject to a considerable amount of vertical oscillation. Indeed, the analogies which these two seas present are very remarkable. Each of them is a deep and irregular depression enclosed within a continental area. The Caribbean Sea, it is true, lies more open to the ocean, which possesses many superficial entrances through the submarine continental slope connecting the two Americas. Barbados is on the very edge of this slope, perched like an outwork on the top of a gigantic wall, the greater part of which is submerged. Thus its position perhaps renders it liable to vertical movements of considerable intensity.

As regards the age of the Barbadian Earths, the evidence from organic remains seems to be somewhat contradictory. According to Haeckel, as quoted by the Authors, about 25 per cent. of the Radiolaria found in the Barbadian Earths are likewise known from the recent ooze. Even supposing that the investigation of the recent Radiolaria is somewhat incomplete, such a percentage almost points to a Miocene age, and this seems to have been the view of Haeckel himself. It is also Mr. Lechmere Guppy's view as to the age of the Radiolarian Beds of Trinidad. On the other hand, the evidence as regards the Foraminifera is somewhat uncertain. The late Mr. H. B. Brady remarked that there was still much to learn respecting the Rhizopod fauna of these deposits, before any very satisfactory conclusion could be drawn as to their geological age or the depth of water at which they were formed. Still, he had little hesitation in concluding that of the 81 species of Foraminifera enumerated about 72 are certainly recent forms, and half the remainder probably so. He further adds that an investigation of the Microzoa of a large series of soft deposits from various islands of the South Pacific has yielded a very similar result, and he agrees with Dr. H. B. Guppy, who has assigned to them a post-Tertiary date.

It may be as well to mention here, by way of parenthesis, that the 'Soapstone' of Fiji, described by Mr. Brady in the Quarterly Journal, rests on a sort of Coral-limestone instead of being covered

[1] *Op. cit.* p. clxvi.

by Coral-rock, as is the case with the Microzoan formations of Barbados. The Fiji deposit is described as a post-Tertiary volcanic mud, formed at a moderate depth, judging from the character of the Foraminifera, and such as might be expected to occur in the neighbourhood of any of the volcanic islands of the Pacific. This, then, would seem to be a more recent formation than any of the Barbadian Earths, and a similar remark may possibly apply to a large proportion of the soft deposits in the Pacific spoken of by Dr. H. B. Guppy.

Referring once more to the Oceanic Deposits of Barbados, the Authors, after balancing the evidence, are led to conclude that they were most probably formed during the period we call Pliocene; and it is possible that, together with the still later Deep-water Deposits, they cover not only the whole of Pliocene time, but so much of the post-Pliocene as elapsed before the rising island reached the level at which reef-corals could build.

Cretaceous Geology.

The communications on the subject of Cretaceous Geology are most conveniently arranged under the headings Upper Cretaceous and Lower Cretaceous.

Upper Cretaceous.—The bulk of the papers relate to this division, and if we are to proceed from above downwards, the first which demands notice is that by Monsieur Cornet, dealing with the Brown Phosphatic Chalk of Ciply in the zone of *Belemnitella mucronata.* Although this relates to Belgian geology, the comparison is of interest, in consequence of a recent discovery at Taplow by Mr. Strahan of a Phosphatic Chalk on a somewhat lower horizon, viz. the zone of *Belemnitella quadrata*, which is stated to be somewhere about the level of the Margate Chalk.

The bed at Ciply which contains the phosphatic matter is about 70 feet thick, but it is only in the central portion that the main phosphatic mass appears, along with many fossils, in the form of brown granules. In these beds, as a rule, the amount of dry phosphoric acid is about 12 per cent., and where no further concentration from natural causes has taken place it is possible to separate the chalk from the phosphate by mechanical processes. Chemical analysis revealed some interesting facts, amongst others the existence of a considerable quantity of nitrogenized organic matter, causing the emission of a peculiar odour on treatment with acid. The Author speculates on the origin of the phosphate in this formation, which he believes was deposited in a sea that nourished a numerous Molluscan fauna, and in which Fishes and great marine Saurians abounded, and he seemed to think that there had been no previous discovery of phosphatic beds analogous to those of Ciply.

However this may be, Mr. Strahan's discovery at Taplow, though not of much economic importance in consequence of the limited extent of the deposit, is strictly analogous from a chemico-geological point of view. Here also we have the brown phosphatic grains in a chalky matrix, and it is interesting to learn that these grains are almost entirely of organic origin, Foraminifera and shell-prisms forming the bulk of them. The tests, as well as the contents, of the Foraminifera seem to have been phosphatized, the phosphate appearing as a translucent film in the former case, and as an opaque mass in the latter. In the case of the prisms of Molluscan shells the whole of the phosphate appears in the opaque form. Fragments of fish-bone also are observed to occur in the granular portion, and such, Dr. Hinde remarked, are also present in the Ciply material, but their osseous nature had not previously been recognized. As bearing on the question of the nitrogenized organic substance suggested by M. Cornet, the brown colour of this rock at Taplow is attributed to a substance very near to, if not identical with, humic acid, but stated to contain between 3 and 4 per cent. of nitrogen. Everything seems to point to the remains of Fishes as having been the principal source of the phosphate, although other organisms may have contributed thereto. In the very extensive replacement of carbonate of lime by phosphate of lime which has taken place, it is possible that organic acids, remains of which are still traceable in these rocks, may have played an important part.

Quitting the horizons of the Higher Chalk we will now proceed to consider the lower beds of the Upper Cretaceous, more especially in the East of England, where these beds have undergone a most important revision, principally at the hands of Messrs. Jukes-Browne and William Hill. It must be premised that these Authors had already laid the foundation for their subsequent work by their joint contribution on the 'Melbourn Rock and the zone of *Belemnitella plena* from Cambridge to the Chiltern Hills.' That paper lies beyond the limits of the present Address, though it may be as well to remind you that the *Belemnitella*-marls were therein regarded as forming the summit of the Lower Chalk, while the Melbourn Rock, which rests upon these marls, is taken to be the base of the Middle Chalk, commencing with the zone of *Rhynchonella Cuvieri*.

Similarly the Totternhoe Stone, a tough grey chalk, often containing phosphatic nodules, which occurs towards the middle of the Lower Chalk Series, is held to separate the Grey Chalk from the Chalk Marl. Thus these old-established divisions and subdivisions of the Upper Cretaceous are shown to be defined by hard beds, possessed of a peculiar lithology and capable of influencing the features of the country. This no doubt has been a great boon to surveyors, who are naturally not too well disposed towards mere palæontological horizons.

Previous to the work of Messrs. Jukes-Browne and Hill on the lower beds of the Upper Cretaceous in West Suffolk and West Norfolk, no one had attempted to trace the zonal divisions which are found in the neighbourhood of Cambridge, through the tract of country which lies between Newmarket and Hunstanton. In this somewhat difficult region lies the clue to the mystery which has so long enshrouded the true relations between the basal beds of the Upper Cretaceous in the South and the North-east of England. The interest which attaches to such a piece of work must be my excuse for treating this matter with somewhat more attention to local details. The results may be said to be of a twofold character; for not only have the relations of the Red Rock of Hunstanton to the Gault been re-established on a more satisfactory footing, but the remarkable diminution in the volume of the Lower Chalk Series within the area has been demonstrated, though the subdivisions remain mostly the same.

Let us for a moment consider the Red Rock of Hunstanton and its equivalents to the southward. This is an old story. Years ago Mr. Wiltshire remarked, in the Quarterly Journal, that the blue Gault with its characteristic Belemnite had been observed to rest on the Carstone at Flitcham, 10 miles south of Hunstanton; but that, rather nearer the latter place, a red clay occurs immediately under the white Chalk, thus connecting the blue Gault with the Red Chalk. It is scarcely necessary to state that the general fauna of the Hunstanton Red Rock was also shown to be that of the Upper Gault. Such in the main had been Mr. Wiltshire's original views, and the objections arising from lithological differences had long ago been surmounted.

Bearing in mind that the existence of Gault in Norfolk had since then been disputed, the Authors paid particular attention to this point. They found that in the Stoke Ferry and West Dereham district the Gault is about 60 feet thick, while in an adjoining outlier *Ammonites interruptus* occurs plentifully in the form of clay casts with the inner whorls phosphatized. Mr. Teall had previously noted the occurrence of Gault at West Dereham. From this point the Gault rapidly diminishes southward. At Roydon, which is about halfway between Stoke Ferry and Hunstanton, a boring yielded very remarkable results. Resting on the Carstone we there have 20 feet of Gault, the lower portion blue and argillaceous, the upper portion grey and marly; towards the centre occur buff sub-calcareous rocks, blotched and stained with red, which in a neighbouring section are shown to contain well-known Gault Ammonites and *Inocerami*. In the grey, marly, upper portion Belemnites are abundant. Dersingham is the point where the lithological change becomes more marked. In our Authors' map the Gault, regarded lithologically, is represented as ceasing at this village, and the beds between the Carstone and the base of the Chalk Marl are reduced to some 7 feet in all, as proved by a boring: these beds are marls, greyish white above, yellowish towards the centre, and more argillaceous below, with a tendency to redness in colour.

The next point is to connect the 3 feet of Red Rock at Hunstanton with the 7 feet of Norfolk Gault, which seems to end off in the manner above stated at Dersingham. First of all, there is the evidence of identity of position between the Carstone below and the equivalents of the so-called 'Sponge-bed' above. There is no question as to the identity of the Carstone; the only doubt which could possibly arise relates to the upward limit, and here the Authors admit that their case largely depends upon the exact correlation of the presumed equivalents of the Hunstanton 'Sponge-bed,' which is for them the base of the Chalk Marl, though so unlike the base of the Chalk Marl in other districts. On the whole, the argument from stratigraphical position seems to point to a lithological passage between the Gault and the Red Chalk. It may indeed seem strange to those, who have never recognized the marly character of much of the Upper Gault, that this mainly argillaceous formation should shrink to 3 feet of Red Chalk on the eastern shores of the Wash, nor is it exactly clear through what causes the iron in the Red Chalk appears in the state of sesquioxide, while the iron in the Gault is mainly in the state of protoxide.

The fossils hitherto found in the Norfolk Gault are not very numerous, but nearly all are of species which occur in the Red Rock of Hunstanton, and this fact, coupled with the stratigraphical evidence, seems conclusive as to their being mainly on the same geological horizon. Undoubtedly the Cephalopoda are the best guides in correlating strata of Mesozoic age, and the Authors claim that eight species of Ammonites characteristic of the Gault have been recorded from the Hunstanton Red Rock, while those of the higher horizon are not known to have occurred in it. As regards bivalves, there certainly is in the Upper Gault a mixture of Cenomanian forms, and these seem to become proportionally more numerous as the Norfolk area is reached—a circumstance which the Authors attribute to the effect of deeper water.

While dealing with the subject of the fauna of the Hunstanton Red Rock, I should here take the opportunity of mentioning that Mr. Vine has recently contributed a paper on the Polyzoa of that formation. This Author dealt with over a thousand fossil specimens, principally Cephalopoda, Monomyaria, and *Terebratulæ*, on most of which encrusting forms of Polyzoa were found. As a result he recognized 43 species, mostly forms described by foreign authors, but some new. A few of these species have been noted from the Cambridge Greensand. The Polyzoan fauna of the Gault and Chalk Marl, he says, still awaits special attention.

The extraordinary diminution in the thickness of the Gault and its equivalents in North-west Norfolk applies in a less degree to all the subdivisions of the Lower Chalk, which also are said to become more calcareous on being followed northwards. The Totternhoe Stone is traced through Norfolk, being about 2 feet thick at Hunstanton, and its existence enables the limits of the Chalk Marl to be defined. Including the Sponge-bed and the *Inoceramus*-beds of Hunstanton, this thickness is somewhat under 20 feet. The Grey Chalk also thins towards the Wash, being about 30 feet thick at Hunstanton.

Mr. William Hill, in a subsequent paper, carried these investigations on the Lower Beds of the Upper Cretaceous Series into Lincolnshire and Yorkshire, where the character of the strata partakes somewhat of the North-west Norfolk type, though their thickness is usually somewhat greater, except at one place on the western escarpment of the Yorkshire Wolds. His discovery of Gault Ammonites tends to strengthen the view that the equivalents of the Hunstanton Red Rock in the two more northern counties are really on that horizon. Near its most north-westerly exposure on the Yorkshire Wolds the peculiar colour of the Red Rock is lost, but such characteristic fossils as *Inoceramus sulcatus* and *Belemnites minimus* were found associated with a conglomeratic bed of slight thickness.

The base of the Chalk Marl throughout Lincolnshire continues to be marked by a bed of compact limestone, which the Author regards as the representative of the 'Sponge-bed' of Hunstanton. This can also be traced in Yorkshire as far as the north-western extremity of the Wolds. Above this bed a few feet of grey gritty chalk retain the character of the Hunstanton '*Inoceramus*-bed' throughout the area above mentioned. In the same district also a well-known rock called the 'Grey Bed' is shown to be on the horizon of the Totternhoe Stone, and thus to determine the upper limit of the Chalk Marl; this bed is characterized by much comminuted shelly matter and by numerous Pectens amongst other fossils. The Author notes, moreover, the red coloration of portions of the Grey Chalk in Lincolnshire, the principal horizons for this coloration being just above the Grey Bed and a little below the Lincolnshire equivalent of the Melbourn Rock.

When the basement-beds of the Upper Cretaceous are traced from their most attenuated outcrop, 600 feet above sea-level, at the north-western extremity of the Wolds, towards the sea, there is every reason to believe that they rapidly thicken again, and when the coast at Speeton is attained the whole series is found to be expanded to a thickness nearly four times greater than at Leavening on the Wolds, and more than twice as great as at Hunstanton. The thickening is shared by all the series below the zone of *Rhynchonella Cuvieri* (at the base of the Middle Chalk), where flints, as a rule, first make their appearance. This classical section is described with much care by Mr. Hill, and many new points of interest are brought out, though time will not allow me to do justice to them. I will only quote one passage for the benefit of those who place their faith in flints as a means of determining horizons in the Chalk. He says:—"The gradual approach of the Chalk-with-flints to the Lower Chalk should be noted, and the value of flints for stratigraphical purposes may be estimated from the following facts:—at Dover they are 120 feet above the zone of *Belemnitella plena*; at Hitchin the first line of flints, followed by others at distant intervals, occurs about 45 feet above the base of the Middle Chalk. In Lincolnshire flints occur in regular lines . . . . only 15 feet above the Belemnite-marls, and this is reduced by nearly one half at Speeton, where flints come on 8 feet above the Marls." Moreover, at Speeton, beds of flints, some yards in extent, occur in the higher portion of the Chalk Marl itself.

Mr. Hill, as is well known, has paid much attention to the minute structure of the various chalks. With reference to the composition of the Red Chalk or Hunstanton Limestone in Lincolnshire and along the western escarpment of the Yorkshire Wolds, he observes that disunited or primordial cells of Foraminifera form a very large part of the mass, shell-fragments are few, and the finer amorphous material appears to be made up entirely of calcareous particles. In Lincolnshire mineral-fragments, probably derived from the underlying Neocomian sands, are found in the lower part of the Red Chalk, while in Yorkshire these fragments are much coarser; in fact, the rock is almost conglomeratic in places, sometimes even when resting on Jurassic clays. This character becomes most marked towards the elevated outcrop near the north-western corner of the Wolds, where coarse shell-fragments, large Foraminifera, detached Sponge-spicules, and glauconitic grains of large size are observed to be abundant. With the thickening of the beds towards Speeton a change comes over the character of the deposit; shelly fragments of small size are abundant and Foraminiferal tests common, but there is a large quantity of fine inorganic material, and it is only in the upper portion that the deposit becomes more purely calcareous.

It may be as well to state here that the topmost beds of the Speeton Clay, on which the Red Chalk reposes, have been shown by Mr. Lamplugh to contain a fauna very closely allied to that of the Red Chalk. He considers that these beds are too thick to be explained as the result of the working up of the underlying clays into the base of the Red Chalk, as supposed by Mr. Hill. It is not a little curious to note how the Gault once more, if only for a few feet, assumes an argillaceous aspect. Mr. Lamplugh suggests that in these beds we have probably a representative of the Lower Gault, while the Red Chalk itself may represent the upper division of the formation—an idea which, no doubt, he shares with other geologists. How far he is correct in correlating this horizon, designated by him as the *Belemnites minimus*-marls, with the Lincolnshire Carstone,[1] is a point which I should not venture to discuss on the present occasion. Clearly, however, he is of opinion that at Speeton the Upper Cretaceous succeeds the Lower without any break of importance.

Before attempting to deal with Lower Cretaceous Geology, we may pause for a moment to consider what may have been the physical history of part of the area covered by the Red Chalk. Starting from Hunstanton, we have seen that the minimum of deposition occurs at two points, viz. at Hunstanton itself and at the north-western corner of the Yorkshire Wolds, the subdivisions of the Lower Chalk being proportionally affected. One of the questions

[1] Rep. Brit. Assoc. (Leeds Meeting), 1890, p. 808.

which present themselves for solution is to ascertain the meaning of this attenuation, and also the meaning of the attenuation of the Red Chalk, as a whole, by comparison with the synchronous Gault. Messrs. Jukes-Browne and Hill are rather disposed to explain these facts on the assumption of deeper water. Undoubtedly there is less terrigenous sediment, which would at first sight seem to imply greater distance from land. This, however, will not altogether explain the great diminution in the *actual* amount of calcareous matter; for we should bear in mind that there is many more times the amount of carbonate of lime in such a formation as the Upper Gault of Folkestone than exists in the whole of the Red Chalk of Hunstanton. The phenomena in connexion with the equivalent of the Red Chalk at the north-western corner of the Yorkshire Wolds, where its outcrop reposes on a denuded ridge of Jurassic rocks 600 feet above sea-level, seem to supply a clue. Even according to the views of Messrs. Jukes-Browne and Hill there was an approximation to the western margin of the Cretaceous sea at that spot. With this approximation to land we have a minimum of deposit, yet we are asked to believe that the scanty deposit at Hunstanton was due to distance from land and deepening water.

I would venture to suggest that the Red Chalk, as a whole, is not a deep-water deposit, but that it was formed where powerful currents limited the amount of sediment thrown down. The number of small siliceous stones found in it serves to bear out this view. There can be no doubt that such was the case throughout the major part of what is now the Wold outcrop; less so, perhaps, in Lincolnshire, but likely enough at Hunstanton, where some irregularity in the sea-bottom, of the nature of an old ridge, may have caused currents unfavourable to a bulky deposit. Clearly, this must have been the case at the north-western corner of the Wolds. At Speeton, on the other hand, materials swept from the shallower and more troubled portions of the sea, possibly in part from the old Jurassic ridge before it was completely covered up, were deposited in calmer and perhaps rather deeper water.

Lower Cretaceous.—The relations of the Lincolnshire Carstone were described by Mr. Strahan in a paper where he showed that this formation rests on different members of the Tealby group, presenting a strong contrast to them in lithological character, and in being, except for the derived fauna, entirely unfossiliferous. He seemed disposed to associate it more or less with the Red Chalk, remarking that where the Carstone thins out to nothing in the north the Red Chalk becomes increasingly conglomeratic in character. This is certainly the case in the outcrops on the western escarpment of the Yorkshire Wolds. We have already seen that Mr. Lamplugh places the Carstone on the horizon of the *Belemnites minimus*-marls of the Speeton section. If these views are correct, the Carstone would seem to belong almost as much to the Upper as to the Lower Cretaceous.

The last paper which remains for consideration in connexion with Lower Cretaceous Geology is that by Mr. Lamplugh, already quoted, 'On the Subdivisions of the Speeton Clay.' There are so many issues involved in this paper, which almost opens up a new history for the Lower Cretaceous Series in England, that it is quite impossible, with due regard to other subjects, to do it full justice. The importance of the Speeton Clay as the fullest development of marine beds of this age in England had been thoroughly realized by Prof. Judd, who pointed out that the section at this place furnished the key by means of which might be identified the more or less isolated and fragmentary exposures of beds of Lower Cretaceous age scattered over the whole of Northern Europe.

Many years of careful attention to these clays, as they are from time to time exposed on the sea-shore, has enabled Mr. Lamplugh to effect considerable alterations in the interpretation of the details of the section. Moreover, in his grouping he has selected Belemnites, always abundant at Speeton, rather than Ammonites, as a means for defining his zones. Subsequently, in association with Prof. Pavlow, of Moscow, who inspected this section under Mr. Lamplugh's guidance in the autumn of 1888, the Speeton Clays have been duly correlated with an important series of deposits in the interior of Russia, and the rich palæontology of their Cephalopoda largely worked out.[1] On this point Prof. Pavlow remarks that the Belemnite fauna is less rapidly modified than that of the Ammonites, thus enabling us to establish larger and more generalized subdivisions in the manner already indicated by his colleague. On the other hand, Ammonites are more sensitive indicators of the lapse of geological time.

Mr. Lamplugh considers that there is a more or less continuous sequence from the clays of the Upper Jurassic, through the Lower Cretaceous into the Upper, where at length the argillaceous

[1] 'Les Argiles de Speeton et leurs Équivalents,' par A. Pavlow et G. W. Lamplugh. Bull. Soc. Imp. des Naturalistes, Moscou, 1892, vol. v. pp. 181–276, 455–570.

sediments give way to those of a calcareous nature. Hence this had been an area of marine deposition throughout a long period of Mesozoic time, although at no great distance to the westward there must have been an axis of upheaval in the interval of time between the Kimeridge Clay and the Red Chalk. In point of fact, he considers that part of the material removed from this area of denudation to the westward may possibly have contributed to the formation of the Speeton Clays themselves. However this may be, he justly regards the series of beds collectively known as the 'Speeton Clay,' though probably not more than 300 feet thick, as by far the most important exposure of marine beds of Lower Cretaceous age in England, and possibly in Europe.

Accepting Mr. Lamplugh as our guide, we may venture to consider the Speeton section somewhat in detail, proceeding from higher to lower horizons. The zone of *Belemnites minimus* and its allies has already been referred to in dealing with the Upper Cretaceous.

The second zone is somewhat obscured towards its upper part, and it is only the lower part of the zone which the Author ventures to describe with any degree of certainty. *Belemnites brunsvicensis*, Stromb. (*semicanaliculatus*?), is the distinguishing Belemnite. Ammonites are said to be rare in this portion of the section, the most characteristic being *Hoplites Deshayesii*. The fauna generally tends to prove that this portion of the section corresponds with the Lower Greensand and Atherfield Clay of the South of England, which may be regarded as of Aptian age. In Lincolnshire the Tealby Limestone is stated to represent this zone, which has also been recognized in Central Russia. It is quite possible that the correlation of this zone at Speeton with beds in the South of England can only be approximate, since it scarcely seems fair to associate *Hoplites Deshayesii* with the whole of a zone, in so large a portion of which that Ammonite has not yet been discovered.

The third zone may be regarded as the backbone of the Speeton section, and it is on the whole perhaps the most interesting and apparently the most fossiliferous, since the more typical Speeton forms, such as *Ammonites speetonensis*, *Am. regalis* (*noricus*), *Crioceras ? Duvalii*, *Meyeria ornata*, etc., occur more or less abundantly throughout certain horizons of this zone. Moreover, the measurements are complete, showing a thickness of about 120 feet. Belemnites which may be grouped under the collective title of *Bel. jaculum*, in which Prof. Pavlow recognizes at least 3 species, predominate throughout this series of clays. Among the Ammonites we find in the central, and to a certain extent in the upper portions, great numbers of the section *Simbirskites* of the genus *Olcostephanus*, of which *Ol.* (*Simbirskites*) *speetonensis*, Young and Bird, may be regarded as the most characteristic. The lower part of the zone, on the other hand, is occupied by representatives of the genus *Hoplites*, better known to English readers under the collective title of *Am. regalis* (*noricus*). In this portion of the Speeton section, therefore, *Am. speetonensis* characterizes the upper sub-zone and *Am. regalis* the lower sub-zone, the Tealby Clay being correlated with the former and a portion of the ferruginous rocks of Claxby with the latter. In the clays of this zone at Speeton it is noticeable that many species appear and disappear; but still it is principally throughout this horizon that a Neocomian fauna is encountered. This zone of *Bel. jaculum* seems to be partially represented at two localities in Central Russia.

The fourth zone is one about whose precise age and relations there seems to have been considerable difference of opinion. At Speeton this zone consists of about 35 feet of clays lying between two thin nodular bands, the upper of which is called the 'Compound Nodular Band,' whilst the lower is known as the 'Coprolite-bed.' This is the zone characterized by *Belemnites lateralis*, a group which is held to include five species, viz. *B. lateralis*, Phil., *B. subquadratus*, Röm., *B. russiensis*, D'Orb., *B. explanatus*, Phil., and *B. explanatoides*, Pavl. In the 'Compound Nodular Band' there are still considerable traces of the fauna of the third zone, such as *Hoplites regalis* (*noricus*), *Crioceras*, etc., so much so that it must be regarded to some extent as a kind of blend of the two zones, such as is found to be the case with so many bands in which rolled and transported nodules occur. The Ammonites of this fourth zone are frequently of great size and belong to the section *Polyptychites* of the genus *Olcostephanus*, regarding which Prof. Pavlow writes that representatives of this group are most varied and most numerous in Northern Russia (the region of the Petchora), in Eastern Russia (government of Simbirsk), in Yorkshire, and in Northern Germany. Amongst these forms are the Ammonites referred by Mr. Leckenby to the *Coronati*, and regarded by him as Portlandian, about whose actual position in the Speeton section there has existed a certain amount of doubt.

Mr. Lamplugh admits that the fauna accompanying *Bel. lateralis*, both at Speeton and in Lincolnshire, is peculiar. It includes forms very near to those which attain their complete development in the

Neocomian beds by the side of those which are developed in the underlying Jurassics. It is this fauna, especially as noted in the upper beds of the zone, which characterizes a deposit of intermediate age. He thinks, however, that a detailed study of the entire fauna will show that its affinities incline to the Jurassic rather than to the Cretaceous. Moreover, he observes that perhaps the *lateralis*-zone naturally divides into two parts. The upper portion in all probability is that which contains the large and numerous species of *Polyptychites*, referred by Leckenby to the *Coronati*; in Lincolnshire this is represented by the Claxby Ironstone. On the other hand, some very fragmentary specimens of smaller forms of *Olcostephanus*, belonging to the section *Craspedites*, are held to mark the lower division, which is correlated with the Spilsby Sandstone. This twofold division of the *lateralis*-zone seems to be more obvious in Lincolnshire than at Speeton, supposing the above correlations to be correct, and it may have been partly suggested in order to bring the sequence into harmony with that which appears to obtain in Eastern Europe. When we come to consider the Russian equivalents *en bloc*, the upper division of the *lateralis*-zone is said to correspond with the 'Petchorien,' and the lower division with the 'Étage supérieur de Rouillier,' the latter being a sort of provisional arrangement for beds of the Russian Jura situated immediately above the undoubted Portlandian. In the Alpine region the whole might be held to correspond with the Upper Tithonian, and, as regards period of deposition, with the Purbecks of the South of England [1] and possibly somewhat higher beds.

The remainder of Mr. Lamplugh's paper deals with beds which are undoubtedly Jurassic, and are therefore only indirectly connected with the subject of Lower Cretaceous geology. Considering for a moment the Speeton section as a whole, the bituminous shales of the Upper Kimeridge call for no especial remark, the first point of interest being the 'Coprolite-bed,' which our Author regards as the base of the overlying clays of the *lateralis*-zone. This 'Coprolite-bed,' he says, is undoubtedly a most important horizon in the series, both stratigraphically and palæontologically. There is a marked change in the character of the deposits almost immediately above it, and also in the fauna. Of the few Jurassic forms that pass it, the doubtful *Lingula ovalis* is the only species yet found in the bituminous shales. Here then is a well-recognized break in the great argillaceous series of Speeton, and it is not easy to say how long a

[1] Pavlow, *op. cit.* pp. 213 and 546 (sep. cop. pp. 35, 188).

period of time may be represented by these four inches of phosphatic nodules. The list of recognizable fossils is a very small one; but there are those phantom forms, so characteristic of nodule-beds, which most probably represent the defaced casts and other hard parts of an elutriated formation. This, then, was an area of submarine erosion, which apparently lasted so long that when deposition again set in the fauna was no longer the same. There seems to have been something of the sort, though less marked, in connexion with the 'Compound Nodular Band,' which separates the *lateralis*-zone from the zone of *Bel. jaculum*. Here, as we have seen, a great mixture of forms occurs; but the presence of *Crioceras*, for the first time in the Speeton section, seems to show that this bed should be regarded as the base of the series of clays which succeed, and which the Author regards as marking the commencement of the Neocomian in this part of Yorkshire.

Jurassic Geology, including Rhætic.

Upper Jurassic.—In Lincolnshire the late Mr. Roberts endeavoured to make a triple division of the Upper Jurassic Clays. He called to mind that Prof. Seeley had previously divided the Fen clays of Cambridgeshire into Kimeridge Clay, Ampthill Clay (regarded as of Corallian age), and Oxford Clay. The task Mr. Roberts imposed upon himself was certainly a very difficult one, seeing that the region in question is largely obscured by Drift, and the only places where sections can be observed are in the various clay-pits or an occasional railway-cutting. His paper is in some sort a supplement to the Sedgwick Prize Essay, which, though written six or seven years ago, has only lately been published.[1] From this essay we gather that, in Cambridgeshire and the parts immediately adjacent, it is not so difficult to trace the results of the Corallian episode even in the clays. In Lincolnshire, on the other hand, muddy sediments appear to have been deposited without a break, and there are neither limestones nor grits to help in defining the horizon.

The several zones recognized by authors in the Oxford Clay of this portion of England need not detain us on the present occasion: it is enough for our purpose that the clays with Ammonites of the *cordatus*-group are regarded as occupying the uppermost zone.

[1] 'The Jurassic Rocks of the Neighbourhood of Cambridge,' Univ. Press, Camb. 1892.

The chief interest of this paper centres in the clays above the Oxford Clay, and especially in the possibility of tracing a Corallian Clay between it and the Kimeridge.

The clays which extend to the top of what has been mapped as Lower Kimeridge in Lincolnshire may, he says, be conveniently divided into four zones. The lowest of these is a series of black selenitiferous clays, which he regarded as Corallian for the following reasons:—(1) They occur between the Oxford Clay and what he regards as the basement-bed of the Kimeridge; (2) out of 23 species of fossils collected from this zone 22 are recognized as Corallian; (3) the two characteristic oysters of the Oxford and Kimeridge Clays respectively occur together in this series of clays and in the Corallian, but in no other formation.

If we endeavour to test the value of the first conclusion, it would seem that the black clays are nowhere observed immediately overlying the Oxford Clay, but they are found in several places immediately eastward of what is regarded as the uppermost zone; they are easily distinguished by their darker colours, and from the fact of the fossils never being pyritized. These indications certainly seem to separate the black selenitiferous clays from the uppermost Oxford Clay of the district, though there does not seem to be any adequate explanation of the more general oxidation of the sulphur compounds. The next point is to ascertain how far a profusion of *Ostrea deltoidea* is evidence of the basement-beds of the Kimeridge. That such is the case in the Lower Kimeridge of Ringstead Bay there can be no doubt. In Cambridgeshire the Author remarks that, immediately above a layer of phosphatic nodules, which is regarded as constituting the actual base of the Kimeridge Clay in that district, *Ostrea deltoidea* occurs in profusion. It is probable that this is also the case in Yorkshire, but good exposures of the basal Kimeridge are not very common there. On the whole we may fairly allow that Mr. Roberts has justified his first conclusion.

Turning to the evidence of the 22 recognized Corallian species, this speaks strongly in favour of Mr. Roberts's view as to the age of the black clays. The greatest number of Corallian forms occur in pits at North and South Kelsey, and on the whole the fauna inclines rather to older than to newer beds. The characteristic Corallian sea-urchin is not quoted in the list, and this may perhaps be due to distance from actual reefs, since the spines of *Cidaris florigemma* are not unknown from the Ampthill Clay. Mr. Roberts's third conclusion involves the proving of a negative, viz. that the two characteristic oysters never appear together either in the Oxford or the Kimeridge Clay. At all events such an occurrence must be extremely rare, and if there are cases quoted they may possibly be capable of some other explanation. We may therefore admit that clays which contain both these forms of oyster are likely to be of Corallian age.

It is not, perhaps, to be expected that the Geological Survey should lay down the lines of a third clay in Lincolnshire, and so separate the Oxford and Kimeridge Clays, where no beds of the usual Corallian type supervene. Nevertheless the map which illustrates Mr. Roberts's paper is a very useful piece of work, and eminently characteristic of that conscientious and painstaking geologist, whose untimely death we all so much deplore.

Turning our attention now from Lincolnshire to Wiltshire, but still dealing with the Upper Jurassic, I must remind you of an interesting account of a well-sinking at Swindon given by Messrs. H. B. Woodward and E. T. Newton. One cannot help being struck with the great development of Oxfordian beds at this spot, completely reversing the conditions which prevail, for instance, in the Weymouth district, and considerably exceeding the limits assigned to the Oxford Clay by Prestwich at the city of Oxford. There are probably not many places in England where the Oxford Clay and Kellaways Rock together attain a thickness of 572 feet.

Callovian Ammonites occur in the lowest beds, which for a moderate thickness exhibit the sandy conditions of the ordinary Kellaways Rock. These are succeeded by 220 feet of clays containing Ammonites of the *ornatus*-group, in company with many other species. The Cephalopod fauna of these beds is evidently rich, when so many species can be quoted from so limited an amount of material. The results, however, are fairly in accord with what we know of Oxfordian beds generally where the lower zones, as in the upper part of the Kelloway Rock of Scarborough, are full of Ammonites of many species. It is somewhat singular, however, that the well-known Corallian *Am. plicatilis*, should occur in these *ornatus*-clays. The Upper Oxfordian is 290 feet thick; this roughly represents the *cordatus*-zone, and it is very poor in species as compared with the lower beds, just as we see is the case in Yorkshire. The Corallian beds in the Swindon sinking were found to be feebly developed, and one wonders what has become of the massive Rag of Wootton Basset only a few miles away. There is not much to be learnt as regards the Kimeridge Clay at this point, but it was mentioned during the discussion that in a boring not far off, which had been commenced in Cretaceous beds, the Portland Sands, so well developed at Swindon, were already wanting.

Saline waters were met with in the Corallian Rocks, and again in the Forest Marble, where the amount was found to be upwards of 2000 grains per gallon, chiefly chlorides. Attention was also drawn to the occurrence of saline waters in the Jurassic rocks at other localities in the neighbourhood.

This seems to be the proper place to notice another paper by Mr. Roberts, 'On the Correlation of the Upper Jurassics of the Swiss Jura with those of England.' He commences by referring to the fact that since the days of Oppel's 'Jura-Formation' but little had been done in this direction, though many new discoveries had been made in both countries. As regards the Swiss Jura itself, it so happens that there is a considerable difference in the development of the Upper Jurassics in the northern and southern districts, and it becomes necessary to institute a comparison between these districts before a more extended correlation is possible. It is scarcely necessary to remark that the grouping is variously stated by different authors, and it is evident that many of the terms borrowed from English geology have a different value in Switzerland from that which they bear in this country.

Departing from the plan hitherto adopted, it seems convenient in this particular instance to follow Mr. Roberts in an ascending sequence, and thus to commence at the base. The importance assigned to the Callovian on the Continent is altogether out of proportion to our practice on this side of the Channel, where the Kellaways or Kelloway Rock is mainly regarded as the irregularly developed arenaceous base of the Lower Oxfordian. If regarded as a palæontological zone, it must be held to underlie that of the *ornatus*-Ammonites. Hence, whatever we may think of the Swiss zone of *Ammonites macrocephalus*, which is a kind of compound of Cornbrash and Kelloway Rock, it is evident that the so-called 'Fer sous-oxfordien' of the Northern Jura answers to a large part of our Oxford Clay. On the other hand, the Swiss Oxfordian Beds answer to the lower part of our Corallian, such as the Lower Calcareous Grit and other beds below the regular Coralline Oolite; while the 'Terrains à Chailles siliceux' and the 'Oolithe Corallienne' correspond to the main mass of our Corallian Limestones. The whole of these beds are but feebly developed in the Southern Jura.

So far the resemblance holds fairly well; but when we come to consider the equivalents of what used to be called the Upper Oolite in this country, viz. the Kimeridge Clay and Portland Beds, there is found to be a very considerable difference of development which renders correlation more difficult. Thus it is not easy to parallel the 'Calcaire à Nérinées' with anything in England. These beds are very rich, containing 192 species, of which 28 only are recognized as British. The series corresponds approximately in position with a group of beds I once ventured to name 'Upper Corallian' or 'Supra-coralline,' and of which the curious little reef in Ringstead Bay is a notable example. This 'Calcaire à Nérinées' is rich in species of corals. Indeed, one of the most striking differences between the fauna of the British Corallian reefs and those of the Jura is the large number of species of corals in the latter. I can hardly think that the difference of climate can have been so great as to account for the whole of this peculiarity, which may in part have been due to deeper and clearer water.

The next thing to consider is how far the Kimeridge Clay proper is represented in the Swiss Jura, and here we must remember that we are for the most part comparing clays with limestones. In this case also the beds are characteristically developed in the Southern as well as in the Northern Jura. We can hardly find fault with Mr. Roberts for grouping the *Ostrea deltoidea* and *Astarte supracorallina*-clays with the Swiss Astartian; at least they occupy approximately the same relative position, and contain a few of the same fossils. It is more difficult to point out the actual time-equivalents of the Pterocerian in our English beds. Mr. Roberts considered the Pterocerian to be perhaps the most important stage in the whole Upper Jurassic Series, since it forms by far the greater portion of the high ground in parts of the Jura (southern district), where it consists of limestones with some marls. It should be noted that *Pteroceras Oceani* occurs at Boulogne on a higher horizon than is usually assigned to the Pterocerian, viz. in the so-called Lower Portlandian, the Bolonian of Blake.

Next come the clays with *Exogyra virgula*, and these we have not much difficulty in correlating with the Virgulian, which, however, is somewhat irregularly developed, even in the northern district of the Swiss Jura, whilst in the southern district it has only been recognized at one or two spots. These beds take us to the top of the Lower Kimeridge, above which, on the present occasion, I do not propose to go, since the investigation of the various interpretations that have been put upon the word 'Portlandian' would occupy too much time. Something of the sort we have already seen in connexion with the Speeton Clay.

Inferior Oolite and Upper Lias.—It might have been thought that the geology of the Cotteswolds had been fairly worked out in previous years, yet there have been two or three communications of some importance dealing more especially with the lowest beds of Inferior Oolite in that region. The late Mr. Witchell, when introducing the subject of the Pea-grit, felt it necessary to preface his work by a few words of apology for venturing to write on so well-known a theme. His corrections may perhaps be regarded as only of local interest, yet the experience which comes of twenty-five years of careful observation and collecting is not to be altogether unnoticed. Mr. Witchell's conclusions were that the Pea-grit is well developed in the Cheltenham area, but thins away towards the south, and is no more than from 3 to 5 feet thick in the Stroud district, where the characteristic lithology of this peculiar formation may yet be distinctly recognized. Underlying the Pea-grit in the Stroud district are several beds of white oolitic limestone, having layers of freestone, as he describes it, alternating with shelly detritus. Attention was especially drawn to the contrast which these beds present, both lithologically and palæontologically, with the Pea-grit. Their poverty in organic remains is also very remarkable, the fauna being limited to a few, very small and ill-preserved Gasteropoda, together with fragments of Crinoids, Urchins, etc. Below this are a few feet of brown sandy limestones, very fossiliferous in the lower portion, and resting directly on the so-called 'Cephalopoda-bed.'

Witchell points out how rich and important a fauna comes in with the Pea-grit, and consequently how necessary it is to separate the Lower Limestone from it. To the substantial accuracy of these views I have myself borne witness.[1] In the Nailsworth district the Pea-grit is only 3 feet thick, but abundantly charged with *Nerinææ*, especially at Longford's Mill; it is a curious circumstance, however, that the Lower Limestone, although 25 feet thick hereabouts, hardly contains any *Nerinææ* or, indeed, any recognizable fossils: in character it rather reminds one of some beds of the Lincolnshire Limestone, and seems to be equally poor in Cephalopoda. Hence we cannot readily say whether the Lower Limestone of Witchell should be classed in the *Murchisonæ*-zone or in the *opalinus*-zone, which

[1] Pal. Soc. vol. xli. (issued 1888), 'Inferior Oolite Gasteropoda,' pp. 60 & 67.

latter is characteristically represented in the shell-bed at the base of the underlying series. Just the same difficulty occurs at Crickley Hill, near Cheltenham, where the equivalents of the Lower Limestone are almost devoid of fossils,[1] while the 33 feet of Pea-grit which succeeds contains perhaps the richest and most varied fauna, including a coral-bed, to be found anywhere in the Inferior Oolite of the Cotteswolds. Reverting to the Stroud and Nailsworth district, the series for some distance above the typical Pea-grit of that region contains here and there aggregations of brown pisolites —*Girvanella pisolitica* of Mr. Wethered—and since the fauna is practically the same as that of the typical bed, the whole may be regarded as one local series. This cannot, however, apply, as intimated by Mr. Wethered, to the Lower Limestone of Witchell.

With reference to the divisions between the *Murchisonæ*- and *opalinus*-zones, Mr. Buckman has lately found at Symondsbury Hill *Ammonites* (*Ludwigia*) *Murchisonæ* and *Am.* (*Lioceras*) *opalinus* in the same bed. This circumstance, he says, renders it difficult to draw a line of demarcation between Lias and Oolite at the top of the *opalinus*-zone. Such a rare and accidental rencontre of two zonal Ammonites would scarcely, if considered alone, substantiate this view, but in many respects it is not easy to effect a separation between these two zones. Since there has been no serious attempt, so far as I am aware, to draw a line of demarcation between Lias and Oolite at the *top* of the *opalinus*-zone, the question of defining the upward limit of that zone is one of minor importance.

But if Mr. Witchell has been able to supply a correction of some importance to the previously accepted reading of the lowest beds of the Inferior Oolite within a limited area, a more important piece of work has been effected by Mr. Buckman. His paper on the 'Cotteswold, Midford, and Yeovil Sands and on the Division between Lias and Oolite' must be regarded from a wider standpoint, as involving more extensive issues. For some time past there has been considerable doubt as to whether the Yeovil Sands and the Cotteswold Sands, although they both underlie the limestones of the Inferior Oolite, are really on the same horizon. This was a difficulty which I felt when engaged in writing the Introduction to the 'Inferior Oolite Gasteropoda,' and I then came to the conclusion that probably they were not on precisely the same horizon.

[1] *Ptygmatis xenos*, Hudl., occurs sparingly in the shell-bed below the Lower Limestone on Crickley Hill, and this position justifies us in regarding it as the oldest species of *Nerinæa* hitherto discovered in Britain.

But as these constitute an essentially transitional series, poor in fossils other than Cephalopoda, I did not pursue the subject further at that time.

No stratigraphical palæontologist can, I think, doubt that Mr. Buckman has at length succeeded in proving that the different 'Sands' are not on the same horizon. In the above-mentioned paper he described a series of sections of the typical exposures from the Cotteswolds near Frocester to the neighbourhood of Bridport Harbour. Dividing the series into seven horizons, each characterized by their distinctive Ammonites, viz.—*Am. communis*, *variabilis*, STRIATULUS, *dispansus*, the genus *Dumortieria*, *Am. Moorei*, and *opalinus*, and taking the STRIATULUS-beds as a fixed starting-point, he demonstrated how the several beds varied in regard to that horizon. Thus the Cotteswold Sands, containing a portion of the *communis*-zone together with the *variabilis*-beds, are below the fixed datum-line: the Midford Sands, having *Am. striatulus* at their base and being mainly characterized by Ammonites of the *dispansus*-horizon, are above the fixed datum-line; whilst the Yeovil Sands, containing the *Dumortieria* and *Moorei*-horizons, overlie a bed containing Ammonites of the *dispansus*-horizon and are consequently still later deposits. In South Dorset this test is productive of yet more surprising results. For instance, Mr. Buckman alleges that the Blue Clay of Down Cliff, which lies below the Yeovil or Bridport Sands, has yielded Ammonites of the genus *Dumortieria* and notably *D. radians*. This clay therefore would seem to be above the fixed datum-line. Yet, because it is a clay, it has been regarded as Upper Lias, while the undoubtedly older Cotteswold Sands, extending partly into the *communis*-beds, under recent arrangements are to be classed with the Inferior Oolite.

This is a dilemma from which there is no possible escape, except by impugning the value of the evidence. Consequently we are asked to consider what is meant by 'horizons,' or, as some would prefer to call them, 'geological zones.' There are all sorts and conditions of zónes, we are told by a very competent authority,[1] and unless one defines them simply as 'palæontological horizons' there is no definition that would apply to all that have been constituted. Now, it has been urged over and over again that the Cephalopoda, especially in the Mesozoic rocks, are the best guides to life-zones because they were less influenced by physical conditions and are therefore more reliable indicators of time than the other Mollusca.

[1] H. B. Woodward, Proc. Geol. Assoc. vol. xii. pp. 295 *et seqq.*

It seems to have made no difference to an Ammonite whether he was buried in clay, sand, or calcareous débris, and this fact is very strongly brought out by Mr. Buckman's researches on the Ammonites of the border-zones of Lias and Oolite. At the same time, one must admit that the system of zonal classification by means of Ammonites has, in some instances, been carried to excess. It is quite possible, for instance, that in the case of the old Gloucestershire Cephalopoda-bed and its associated sands there may have been a little too much subdivision; at least some of the so-called zones might be viewed as sub-zones. No doubt these names are a terrible tax upon the memory, especially when the evolution of Ammonite-genera proceeds at its present rapid pace. Furthermore, it must be admitted that zones in some cases blend both laterally and vertically, and it is quite possible that the *Ammonites epônymus*, or name-giving species, may occasionally be found straying within the jurisdiction of another chief.

These and similar points are sure to be urged by any one who is desirous of taking an *ex parte* view of any particular case; but, when all demurrers have been duly considered, there remains a considerable balance of evidence in support of the chronological value of Ammonite-zones. In the case before us, unless we dispute Mr. Buckman's facts, certain Ammonite-forms are observed to occupy definite relative positions over a considerable area. It seems quite in accordance with the maxims of stratigraphical palæontology to believe that each of these forms, or rather group of forms, was fairly synchronous over the area, and that, if we wish to know the age of any particular bed in the series, we must rely upon the Ammonites and not upon the lithology.

These considerations introduce a still larger question, viz. as to where the boundary between the Lias and the Oolites should be drawn. In this connexion I will not discuss Mr. Buckman's suggestion to take the reign of the Hildoceratidæ as indicating an intermediate series, which is to include the Upper Lias and the Lower Division of the Inferior Oolite under the name of 'Toarcian.' On purely palæontological grounds something may be said for this arrangement in those districts, such as Dorsetshire, where a Cephalopod facies predominates; but throughout the greater part of England it would not work at all. Of course, this is to a certain extent an old controversy, but we must not forget that the original divisions were made in England, nor is it likely that they will be altered to suit conditions which prevail in districts far removed from the type-area.

Reverting to a more practical view of the case, it must be admitted that previous to the appearance of the papers by Mr. Witchell and Mr. Buckman our knowledge of these boundary-beds was to a certain extent defective. This did not arise from want of discussion in former days; for the correlation of the Dorsetshire and Gloucestershire beds had been attempted so frequently that the subject became somewhat distasteful, and men shuddered at the very mention of certain Ammonite-zones. Indeed this controversy extended, at one time, to the greater part of the Inferior Oolite. However, the question before us just now is the most suitable boundary between the Lias and the Oolite.

In the International Geological Map of Europe the base of the *opalinus*-zone was adopted as the lower boundary of the Middle Jurassic. To a certain extent this is a conventional, arbitrary limit, though not without many natural advantages even in those districts where the sequence is complete. If this line were rigidly adopted in England, the bulk of the Yeovil and the whole of the Midford and Gloucestershire Sands would fall into the Lias. Hence all three groups of Sands possess one feature in common, viz. that they lie below the *opalinus*-zone, though the Sands in Gloucestershire descend to much lower horizons than either of the other two, or, in other words, they were deposited earlier. It would save trouble, perhaps, if the line adopted by the International Geological Congress were adhered to in the S.W. of England, and in this way no particular violence would be done to the lithology, as the Sands in all three districts would be relegated to the Lias. Such an arrangement would also suit very well on the Yorkshire Coast, since the lower part of the Dogger is certainly within the *opalinus*-zone, while the Sands that carry the Dogger are characterized by Ammonites of the *Dumortieria* and *dispansus*-horizons. This would be placing the Lias-line somewhat higher than it was carried by Tate and Blake.

It must not be supposed for a moment that I am advocating the adoption of this or any other line; my object is merely to show its incidence in one or two localities. In drawing a boundary, especially on a map, there are many aspects of the question to be regarded, and the resultant is partly the outcome of economic, partly of philosophical considerations. Geological surveyors must look at both sides of the question, while less responsible geologists are granted a freer hand. I must confess that, on the principle of taking all I could get, I did include these Sands within the range of my Monograph of the Inferior Oolite Gasteropoda, though merely as border or transitional beds. But there can be no doubt that the rich and characteristic fauna of the Inferior Oolite begins with the *Murchisonæ*-zone, to which the *opalinus*-zone is little more than an appendage. If I may venture to express an opinion, it is that the classification of the Gloucestershire Sands, which lie below the so-called Cephalopoda-bed, with the Inferior Oolite is scarcely to be justified without some qualification.

Miscellaneous Subjects.—So much time has been spent on stratigraphical papers that but little remains for those devoted to pure palæontology. I must not, however, fail to remind you of the recognition by Dr. Hinde of a new genus of Siliceous Sponges in the Lower Calcareous Grit of Yorkshire. The exceptional character of these fossils consists in their having the siliceous skeleton composed almost entirely of globular spicules or 'globates.' The nearest living form, he says, is *Placospongia*, in which both the axis and the dermal crust are formed of globates with an interspace built up of numerous pin-like spicules. Assuming the absence of pin-like spicules in the Scarborough fossil, the differences are more than generic. Considerable interest attaches to this discovery, because many persons had noticed the scattered globates in the Lower Calcareous Grit and also in portions of the Coral Rag, and in this condition they were a puzzle both to Sorby and to Blake. It is only right to mention that some years ago I showed a section full of similar granular bodies to Prof. Sollas, who then maintained them to be globates of a siliceous sponge such as *Geodia*. Now that the sponge itself has been described, we know that this recognition was a step in the right direction.

Mr. Carter, of Cambridge, has materially increased our knowledge of the Decapod Crustacea of the Oxford Clay. The fossils described by him occur immediately beneath the St. Ives rock, and therefore presumably, he says, in the uppermost zone. No more than three or four species had been previously recorded from the Oxford Clay of this country. Mr. Carter has been able to add at least fourteen species to that number, seven of which are identified as foreign forms, and seven are new to science.

The Polyzoa of the Inferior Oolite and Lias have received a considerable amount of attention on the part of Mr. Walford. From the first-named formation he described a series collected in the *Parkinsoni*-zone of Shipton Gorge, Dorset, and the number of forms from that one horizon and locality was stated to be equal to the whole of those described by Jules Haime from the Lias to the

Kimeridge Clay. He directed attention also to a species from the Lias of the Midlands, whose habits suggest a relationship with the Tubuliporidæ, and for which he proposed the name *Tubulipora inconstans*, in reference to its varying modes of growth.

There are two papers by Mr. Wethered devoted to rock structure and referring principally to the Inferior Oolite. His identification of *Girvanella* in the Oolitic rocks had been previously announced in the 'Geological Magazine' for 1889,[1] where it was shown that this organism was not confined to the Silurians, and that, as an agent in the formation of rocks, it is of more importance than had been previously supposed. In that communication he had established a new species, *Girvanella pisolitica*, which in his opinion was instrumental in forming the Pea-grit spherules in the well-known bed towards the base of the Inferior Oolite. He also showed that a much smaller form built up the pisolitic spherules which occur in the Coralline Oolite near Weymouth, and which he now described under the title of *Girvanella minuta*.

In referring to *G. pisolitica* he discussed the views of Brady and Nicholson as to whether the genus is most allied to the 'Challenger' Foraminifer, *Hyperammina vagans*, or to *Syringammina fragilissima*. Traces of the organism occur in the *Clypeus*-grit, but none have been discovered either in the Great Oolite or the Portland Oolite. Considerable variety is noted in connexion with the subject of *Girvanella*. For instance, there occur (1) spherules with a loosely aggregated form of *Girvanella*-tubules as a nucleus, and (2) this form also occurs in loose aggregations on surrounding foreign objects: in such specimens there can be little doubt as to the presence of the organism. Thirdly, he takes the case of a spherule or granule in which the nucleus generally consists simply of calcite, and the concentric arrangement has a granular, crystalline appearance in which occasional outlines of tubuli may be seen. Last of all is the ordinary oolitic granule, with a clear and well-defined concentric arrangement round a nucleus.

There is something very fascinating in the way the Author gradually and unconsciously, as it were, seems to lead us to the conclusion that possibly the oolitic granule itself has been fashioned by an unseen artificer. It is true he did not claim that *all* oolitic granules are derived from this one source, but his remarks regarding the last of his series plainly show the tendency of his thoughts. Viewed through a microscope, he says, spherules of this type would

[1] Dec. iii. vol. vi. p. 196.

be regarded as of concretionary origin; when photographed, however, what under the microscope are very obscure dark spots appear like the extremities of tubes which have been cut across. These objects are stated to occur throughout the concentric layers at short intervals, and it is impossible, the Author thinks, to resist the idea that the apparent concentric layers may really be layers of tubuli. On perusing these passages, it is difficult to avoid inferring that Mr. Wethered has a strong inclination to believe in the organic origin of the oolitic granule; but it should be remarked that the position of *Girvanella* as a Foraminifer was not insisted upon, and in recent communications he appears disposed to take a more lowly view of this organism.

In his second paper Mr. Wethered states the results of further examinations of the different beds of the Inferior Oolite, whereby his previous views as to the important part which *Girvanella* has taken in the formation of oolitic granules is confirmed. The precise way in which the formation of the granule was effected, he allows, is not quite so clear. Some critics suggested that the *Girvanellæ* which were found coating the nuclei of the concretions might have been derived mechanically from the calcareous mud of the sea-bed. As regards the nature of *Girvanella* itself Mr. Wethered was able to quote a high authority to the effect that the structure was certainly organic: there might be a doubt as to whether it was vegetable or animal, but the fact that the tubes occur in dense compact wefts and never appear to anastomose seems to dispose of the view that they belong to some kind of perforating *Alga*.

Rhætic.—Mr. Brodie gave an account of two sections in the Rhætics of Warwickshire. The chief point of interest related to a possible unconformity; since in one of the localities, in borings and shafts, black Rhætic shales have been found resting upon a denuded surface of New Red Marl. In answer to questions, the Author saw no reasons for believing that the beds were not in place, but the general impression of those who criticized the paper was opposed to the notion of unconformity.

More recently Mr. Wilson has had an opportunity of describing an excellent section on the south side of Bristol, exposed in a fresh cutting at Pylle Hill (Totterdown). He observes that there can scarcely be any doubt as to what is the true base of the Rhætic at this place, though it is possible there may be some difference of opinion regarding its upper limit. The total thickness of the series at this point is only 17 feet, just half what it is at Aust Cliff.

He divides the Rhætics into two groups, viz. the *Avicula contorta*-shales and the Upper Rhætic Series. The base of the *Avicula*-beds is characterized by black shales with a very thin seam and small pockets of pyritic grit, containing fish-teeth, scales, and fin-spines, coprolites, and pebbles of white quartz; there is no true 'Bone-bed' as at Aust Cliff. The contrast between this fossiliferous horizon with its Rhætic fish-fauna and the so-called 'Tea-green Marls,' containing nothing but indeterminable plant-remains, must be very strong. Indeed, unless there is evidence of a very different character forthcoming elsewhere, one cannot help expressing surprise that anyone should ever have thought of uniting them. The most natural supposition seems to be that the 'Tea-green Marls' are merely the upward continuation of the Red Marls, where the iron-oxides have undergone slight reduction in consequence of the amount of carbonaceous matter which they contain.

His Upper Rhætic Series, consisting of limestone and shales, is terminated upwards by a band of compact, light blue, concretionary limestone with conchoidal fracture and dendritic markings, which he takes to be the equivalent of the 'Cotham Marble.' This series, besides certain characteristic Rhætic fossils, yields abundance of the little freshwater plant, *Naiadita*, associated with numerous Ostracoda. These beds he regards as homotaxial with the shales and nodular limestones, containing *Estheria*, of the Midlands, which directly overlie the *Avicula contorta*-shales in that region.

Triassic and Permian Geology.

These two systems are so intimately connected in this country that, although the one is regarded as Mesozoic and the other as Palæozoic, they must perforce be taken together. There are indeed geologists who seem disposed to look upon certain developments of the Permian as simply the base of the Trias, and, as we shall perceive in the sequel, there have been wide differences of opinion as to whether certain rocks are to be regarded as Permian or Triassic. The total dissimilarity which prevails between the Permians north of Nottingham (east of the Pennine Chain) and those to the south-west of that town adds to the difficulty. The papers read before the Society relate (1) to the South-west of England; (2) to the Midlands; (3) to the Estuary of the Tees.

The South-west of England.—As regards the first district, Mr. Worth submitted evidence of the possibility of the existence of a submarine Triassic outlier off the Lizard, thus carrying the English

Trias nearly 50 miles farther to the south-west. The same Author also contributed a paper on the igneous constituents of what he regarded as the Triassic breccias and conglomerates of South Devon, which may be considered in this connexion, although the arguments are mainly petrological. His principal conclusions were that the igneous materials are of local origin; that they consist of granites, felsites, and volcanic types, ranging from andesites to basalts; and that the conditions under which the so-called 'felspathic traps' occur *in situ* lead to the inference that they are volcanic phenomena, which probably represent the final phase of the igneous activity of the Dartmoor region. Mr. Worth's contention, as to the evidence of the connexion of any of these rocks with a possible upward prolongation of the mass of Dartmoor, is hardly necessary, seeing that the origin of the materials may well be sought in the more immediate neighbourhood, where there are so many indications of volcanic activity contemporaneous with the basal conglomerate of the Red Rock Series, whether that series is of Triassic, or, as appears more probable, of Permian age.

This subject, as well as the subdivisions of the Red Rocks of South Devon generally, has been the source of a considerable amount of controversy, as must often be the case where there are few or no fossils to guide the geologist. So far as my own impressions extend, there was a time when all the Red Rocks of South Devon were regarded as of Keuper age. How far this view had any connexion with the age of the so-called Dolomitic Conglomerate of the Mendips is not for me to say. But of late years the researches of Mr. H. B. Woodward and Mr. Ussher, to mention no other names, have tended to demonstrate that the divisions of Keuper and Bunter might be recognized in the Devonshire area; and when this was once admitted it seemed difficult to exclude the Permian, since I am not aware that there are any breccias at the base of the Bunter at all like those to the south-west of the Exe. However, in spite of the resemblance of these basal breccias, in many respects, to the Permian rocks of portions of England and of Germany, it seems to have been conceded that it was better to leave the whole in the Bunter, apparently from lack of any positive evidence to the contrary.

No one can doubt that, apart from preconceived ideas, the *prima-facie* evidence in favour of the Permian age of the basal breccias is very strong. Many of these great blocks are evidently derived from the hill talus or 'screes' that once lay on the neighbouring slopes of the Palæozoic mountain-region of Damnonia. In most English districts this class of rock is of Permian age, though of course the great angular blocks that have a similar origin may find a resting-place in strata of any age, if we take the whole world into consideration. But there are several reasons why the basal breccias of South Devon are more likely to be Permian than Triassic: among others, the occurrence of contemporaneous volcanic material incidentally shown by Mr. Worth, and insisted on by Sir Archibald Geikie in his last Presidential Address. What I particularly wish to emphasize just now is the fact that Murchison, as pointed out in the same Address, thoroughly endorsed the views of Buckland and Conybeare as to the resemblance of the Heavitree conglomerate to the German Rothliegende. This appears to have been the original view of the older geologists, and one can only express surprise that the opinions of Murchison, as Director-General of the Geological Survey, were not allowed to have more weight in deciding this matter.

Let us now return to the Devon Coast-section, for the purpose of considering Dr. Irving's first paper on the Red Rock Series. He thought that at the base of the Budleigh Salterton pebble-bed there is a physical break of as much significance as that between the Trias and the Permian of the Midlands. From the pebble-bed eastwards the Triassic system is represented by a series of rocks quite comparable with the Bunter and Keuper of the Midlands, and of these rocks he proceeded to give an account. In the marls which *underlie* the Budleigh Salterton pebble-bed he recognized the equivalents of the Permian Marls of Warwickshire and Nottinghamshire. These pass by gradual transition through sandstones, becoming more and more brecciated, into the great brecciated series of Dawlish and Teignmouth, which were regarded as the equivalents of the great Permian breccias of the West of England and elsewhere.

Prof. Hull believes with Dr. Irving that the Red Rocks of Devonshire are representatives of the Permian and Trias which occupy so large a portion of the district bordering Wales and Salop, and which extend into the Midland counties. He thinks also that the breccia forming the base of the series is a representative of the Lower Permian division. But, in the first instance, he differed from Dr. Irving in assigning the red sandstones and marls of Exmouth to the Trias and not to the Permian, as that Author has done. He (Prof. Hull) compared them with the Lower Red and Mottled Sandstones, and regarded the marls as a local divergence from the normal type. Dr. Irving, in his Supplementary Note, still adhered to his contention that these sandstones and marls are really of Permian age, although such a view would necessitate the absence of the Lower Bunter of the Midlands in Devonshire. Prof. Hull has substantially acceded to this view, since he stated, in the discussion on Dr. Irving's second Supplementary Note, that he had concluded the Budleigh Salterton Conglomerate was the real base of the Trias, and that the great series of red marls, sandstones, and breccias below the Conglomerate were of Permian age.

The Upper Division of the Bunter Prof. Hull considered to be well shown at Sidmouth, and he regarded a thin calcareous breccia which occurs in the cliffs there as the basement-bed of the Keuper. In his Supplementary Note Dr. Irving accepted the breccias at Sidmouth as the base of the Keuper, and in a second Supplementary Note he states that he has obtained satisfactory data for determining a similar basement-line in the country between the valleys of the Sid and Otter, where the Keuper is repeated by a great fault.

We can scarcely doubt that the discussions raised by Dr. Irving and Prof. Hull have been useful in directing attention to the Red Rocks of South Devon. It seems pretty evident, more especially after Sir A. Geikie's last Presidential Address, that opinion is likely to swing round to the view of the older geologists that the basal breccias are of Permian age, although it might perhaps be difficult to know where to stop in considering the ascending sequence. But Prof. Hull's final adherence to the views of Dr. Irving, in relegating the Red Rocks of Exmouth to the Permian, will tend to simplify matters if the Budleigh Salterton Conglomerate should ultimately be adopted as the base of the Trias in that district. Finally, we are led to conclude that some revision of the geological maps of the Devon area may be required, though possibly the evidence on which to base the alterations is not yet sufficiently established.

Midlands.—A very interesting paper by Mr. Horace T. Brown, on the Permian rocks of the Leicestershire Coal-field, next demands our attention. This is just one of those investigations which are best carried out by persons living in the district, who have constantly-recurring opportunities which are denied to the occasional visitor. By availing himself of the use of the hand-borer and by studying the results of boring operations on a large scale, in addition to the close observation of numerous artificial sections, Mr. Brown has been able to suggest some corrections in the geological map of the district, although confirming the surmise of Prof. Hull as to the Permian age of certain beds of a brecciated character.

Intercalated between the Bunter conglomerates and the truncated edges of the Carboniferous strata at various points are thin beds of purple, marly breccias and sandstones, seldom exceeding 30 or 40 feet, but differing in lithological character from the overlying and underlying rocks. The brecciated series rests with striking unconformity upon the Carboniferous; moreover, a fault which throws the Coal-measures to the extent of nearly 1000 feet does not affect the overlying series beyond some 20 or 30 feet. The dying-out of the forces of dislocation in the Permian beds, the Author subsequently remarks, is a valuable chronological index. The disturbances affecting the lower beds can be connected with the Pennine axis, to the southerly extension of which they owe their origin, affording further proof of the pre-Permian age of that axis. On the other hand, the unconformity between the brecciated series and the Bunter is less obvious, but the Author was able to instance sections proving double unconformity. In addition, the lithological characters of the Leicestershire Permians serve to differentiate them both from the Trias and Carboniferous of that district. They consist of red and variegated marls, bands of breccia, and of fine-grained yellowish sandstone. The breccia-fragments are but little waterworn, the most abundant materials consisting of quartzo-felspathic grits with associated grey flinty slates, vein-quartz, volcanic ash, and igneous rocks, all derived from the older Palæozoics, while the Carboniferous rocks supply limestones, grits, and hæmatite.

The bulk of this material he regarded as having been derived from a sub-Triassic ridge of older rocks a few miles to the southward. Evidence was given of the probability of such a ridge in the country between Hartshill and Charnwood. Owing to certain optical characters observed in the breccia, he thought it preferable to take this view rather than to seek the origin of the fragments in the more distant Hartshill.

The Author concluded that the Permian rocks of the Leicestershire Coal-field belong to the same area of deposition as those of Warwickshire and South Staffordshire, all having formed part of the detrital deposits of the Permian lake, which extended northward from Warwickshire and Worcestershire, and the margin of which was the Pennine Chain. In Warwickshire, however, the break between the Coal-measures and the Permian is less than it is in the Leicestershire Coal-field, since in the former case there is an almost unbroken stratigraphical succession from the Upper Coal-measures, including the *Spirorbis*-limestone, into the Permian. This difference in the amount of unconformity is best explained, he thinks, by the fact that the Leicestershire Coal-field, where the greatest stratigraphical break takes place, is almost directly in the line of the Pennine-Charnwood axis, where the post-Carboniferous, yet pre-Permian, movements were at a maximum. Although not absolutely prepared to maintain the lacustrine origin of the breccia, the Author considered that it was practically the re-arranged talus and 'screes' from the harder parts—both of the older and newer Palæozoic rocks—which now form the brecciated beds in the Leicestershire Permians, and which he could no longer regard as merely the base of the Trias.

He was quite prepared to admit that the eastward overlap by higher beds of the Trias is not of itself absolute proof of the existence of a stratigraphical break, amounting to an unconformity, between the brecciated series and the Trias. There is nothing improbable in the view that the breccias might belong to the base of the Trias, representing marginal deposits which swept up the sides of the gradually submerged land, just as is the case with the Keuper breccias at Thringstone, on the borders of Charnwood Forest; these are composed of angular fragments derived from the adjacent Forest rocks. But the evidence of denudation prior to the deposition of the Bunter, coupled with the lithological character of the beds and other considerations, appears to have convinced Mr. Brown that the brecciated series described in his paper must be of Permian age. He also notes that when a bed of breccia is traced for a short distance horizontally it is never found to be very persistent, but dovetails into sandy and marly beds, just as do many of the beds of breccia 'in the fine sections at the base of the Trias on the south coast of Devonshire.' We are naturally led to ask the question—If these Leicestershire beds are of Permian age, why not the fine sections 'at the base of the Trias' on the south coast of Devon?

Estuary of the Tees.—Mr. Wilson's paper on the Durham Salt district, recently supplemented by a note from Mr. Tate, draws attention to a curious piece of Permo-Triassic Geology which would have remained unknown, because unseen, but for borings in search of salt. These were limited when Mr. Wilson's paper was read, but Mr. Tate informed us last summer that at least sixty borings had been put down, so that the extent of the basin has been pretty well defined towards the west and north, but is as yet undefined on the dip towards the south-east. The depth of the salt-bed ranges from about 1650 feet at Eston in Yorkshire to about 950 feet at Greatham in Durham, the salt averaging about 80 feet in thickness. Subsequently Mr. Tate announced that the bed, where last touched, was thickening on the dip towards the south-east.

The exact geological position of this bed of rock-salt has been the subject of much divergence of opinion. (1) There is the view, held by Sir Andrew Ramsay, that the principal bed of rock-salt belongs to the Keuper, and that the lower beds of rock-salt, marl, limestone, and gypsum belong to the upper portion of the Permian series. (2) There is the view that all the salt-beds and associated strata belong to the Permian, and that the overlying series of red sandstone and marls represents the Bunter. (3) There is the view that all the salt-beds, and the whole of the saliferous marls, sandstones, and limestones, above the continuous strata of the Magnesian Limestone, belong to the Keuper: that is to say, to the same general series as that which contains the rock-salt in the other districts of the British Isles.

Mr. Wilson is disposed to agree with this last view, which was the one taken by the older geologists; and he is of opinion that these beds of rock-salt lie near the *base* of the Upper Keuper, whereas in Cheshire the salt-beds come high up in the Keuper Marls. From a careful examination of the cores he concluded that there is a close resemblance between the beds which graduate down into the saliferous marls of the Durham salt district and the Keuper Waterstones of the Midland counties, both in general structure and mineral characters. As regards the thin and variable series below the main salt-bed, which the presence of anhydrite, marls, and a kind of limestone had induced Sir Andrew Ramsay to look upon as Permian, Mr. Wilson assures us that these show no resemblance to any known beds of the Magnesian Limestone of Durham. Consequently, he sees no difficulty in the fact that beds towards the base of the Keuper should be possessed of a dolomitic character in a region where the rocks rest on a margin of the Magnesian Limestone Series, more especially when gypsum and anhydrite are found to occur in intimate association with the dolomites of that series. This latter argument seems to cut both ways.

Irrespective of debatable matter as to the precise horizon of the rock-salt, the borings in the estuary of the Tees exhibit a considerable variety both in the Permian and Trias within a limited area. The Upper Keuper Red Marls which form the top beds, immediately below the Drifts of the country, go out on the rise towards the north. The red sandstones of the Keuper, which are supposed to represent the Waterstones of the Midlands, etc., are about 800 feet thick. The Red Marls, or Saliferous Series, immediately above the main salt-bed, range from 170 feet to about 300 feet in thickness, and there is a curious absence of the salt-rock itself in the very middle of the field. Generally speaking, according to Mr. Tate, the main salt-rock is sandwiched between two beds of anhydrite, while the underlying saliferous marls, with anhydrite, etc., held by Mr. Wilson to form the base of the Keuper in this region, are usually thin, but vary much in this respect.

The underground Permian rocks are still more variable, especially as regards thickness: ranging from 300 feet at Whitehouse, which lies beyond the salt area on the west (Tate), to nearly 900 feet at Seaton Carew, also beyond the salt district on the north-east. At the latter place the upper portion of the series consists of magnesian limestones with blue shales, gypsum, and anhydrite, preceded by a great mass consisting principally of light grey limestones (? magnesian). No mention is made throughout this great thickness of beds of the yellow sands so characteristic of the base of the Permian in other parts of Durham, and especially conspicuous at Cullercoats, in Northumberland.

In concluding this Address, so far as it has gone, a brief retrospect may not be out of place. Owing to the interest which attaches to superficial geology, this portion of the subject may perhaps be regarded as having received more than its fair share of attention. In regard to that most obscure of all subjects, the history of the drifts in the non-glaciated regions, we seem able to record some real progress. Much remains to be done in this direction, and possibly some day an effort may be made effectually to correlate the great upland gravel-sheets of the south-western counties with those farther towards the east. Coming nearer home, it will be impossible, henceforth, to maintain that there had not been a considerable amount of excavation effected in the Thames basin before the Chalky Boulder-clay reached that area.

But it is in the more obviously glaciated regions of England and Wales that the chief interest has been centred, and in this respect there can be no doubt that a young and vigorous race of geologists is inclined to attribute principally to glacier action many of the phenomena which have hitherto been explained in other ways. The picture of the Irish Sea filled with ice, over 2000 feet thick, is one which the older geologists may perhaps never be induced to contemplate.

In considering Tertiary Geology at home, I have only ventured to select one paper for special notice, while fully admitting the importance of many of the others, and particularly that by Prof. Prestwich on the Correlation of the Eocene strata in England and portions of the Continent. Deep-sea deposits, which have been considered in connexion with Tertiary Geology, are of especial interest to us islanders, and the excellent paper on deposits of this nature in Barbados has provided us with an excuse for renewing our acquaintance with the recent oceanic oozes which attracted so much attention shortly after the return of the 'Challenger.' In Cretaceous Geology considerable progress has been made during the last seven years. The basal beds of the Upper Cretaceous have proved of especial interest, while the geology and palæontology of the Lower Cretaceous in the North-east of England have undergone a considerable revolution. Jurassic Geology has not presented us with changes of similar importance, although our knowledge of the upper beds of that system has been materially increased, while the border-lands of the Lias and Oolite, like border-lands in general, afford a battle-ground between the palæontological and the lithological stratigraphist. The uncertainty as to whether the breccias west of the Exe should be classed under the Permian or the Trias raises another question of considerable interest.

One word of apology is due to the authors whose works have contributed to maintain the high standard of our Quarterly Journal. Very soon after I began to grapple with the recent work of the Geological Society, it became evident that the task of paying equal attention to all within a limited space was impossible. Already this Address has far exceeded the bounds originally contemplated, and yet many excellent papers have received but scant notice. What with the risks of omission, of misinterpretation, and of erroneous criticism, the position of a President, who ventures to review the work of the Society over which he has been called upon to preside, is not altogether unlike that of a man who tries to lift up a bee-hive. However, I trust that authors will in all cases place the most favourable interpretation upon my remarks, and that my sins, both of omission and commission, may be speedily condoned. If such should be the case, I shall enter upon the remainder, and possibly more difficult part, of this task with fewer misgivings as to the ultimate result.

February 22nd, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Frederic Lewis Bradley, Esq., Bel Air, Alderley Edge, Cheshire; Walter Thomas G. Burr, Esq., Manor House, Tapton, Chesterfield; Francis Baring Du Pre, Esq., M.A., J.P., Oakwood, Chichester; Wilfred Sessions, Esq., B.Sc. Lond., Russell House, Gloucester; and Harold J. Osborne White, Esq., 35 North Bank, Regent's Park, N.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Microscopic Structure of the Wenlock Limestone, with Remarks on the Formation generally." By Edward Wethered, Esq., F.G.S., F.R.M.S.

2. "On the Affinities (1) of *Anthracoptera*, (2) of *Anthracomya*." By Dr. Wheelton Hind, B.S., F.G.S.

3. "Geological Remarks on certain Islands in the New Hebrides." By Lieut. G. C. Frederick, R.N. (Communicated by Sir Archibald Geikie, D.Sc., For.Sec.R.S., V.P.G.S.)

The following specimens were exhibited:—

Microscopic sections and photographs, exhibited by E. Wethered, Esq., F.G.S., F.R.M.S., in illustration of his paper.

Specimens of *Anthracoptera* and *Anthracomya*, exhibited by Dr. Wheelton Hind, B.S., F.G.S., in illustration of his paper.

Rock-specimens from the New Hebrides, exhibited by Sir Archibald Geikie, D.Sc., For.Sec.R.S., V.P.G.S., in illustration of Lieut. Frederick's paper.

March 8th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Professor Waldemar Christofer Brögger, The University, Christiania; and Monsieur A. Michel-Lévy, Director of the Geological Survey of France, Paris, were elected Foreign Members of the Society.

The List of Donations to the Library was read.

Mr. Clement Reid exhibited, on behalf of Messrs. Langstaffe, Banks, and Peckover, a series of incrustations on their 'anti-incrustator,' an apparatus used to extract lime and prevent fouling in boilers. Mr. Reid said that at the last meeting he was challenged to produce artificial calcareous tubes with definite walls, the only structure visible in most of the so-called *Girvanella*. The apparatus illustrated the singular effect produced by fibres in causing the deposition of carbonate of lime. If, instead of on flat hemp-fibres, the incrustation were to take place outside *Confervæ* or other algæ, the result would be a knotted mass of cylindrical calcareous tubes, like those found so abundantly in limestones of freshwater as well as of marine origin.

Prof. T. Rupert Jones remarked that analogies are of very different values. In this case large vermiform concretions occur on the outside of fibres, while in *Girvanella* the minute body itself is composed of vermiform tubules.

The following communications were read :—

1. "On the Occurrence of Boulders and Pebbles from the Glacial Drift in Gravels south of the Thames." By Horace W. Monckton, Esq., F.L.S., F.G.S.

2. "On the Plateau-Gravel south of Reading." By O. A. Shrubsole, Esq., F.G.S.

3. "A Fossiliferous Pleistocene Deposit at Stone, on the Hampshire Coast." By Clement Reid, Esq., F.L.S., F.G.S. (Communicated by permission of the Director-General of the Geological Survey.)

The following specimens were exhibited :—

Specimens and microscopic sections, exhibited by Horace W. Monckton, Esq., F.L.S., F.G.S., in illustration of his paper.

Specimens exhibited by O. A. Shrubsole, Esq., F.G.S., in illustration of his paper.

Specimens from a Pleistocene Deposit at Stone, on the Hampshire Coast, exhibited by Clement Reid, Esq., F.L.S., F.G.S., in illustration of his paper.

Specimens from Norcot-Kiln, Tilehurst, west of Reading, exhibited by J. H. Blake, Esq., F.G.S.

Specimens of inorganic incrustations and Calcareous Algæ to illustrate the structure of *Girvanella*, exhibited by Clement Reid, Esq., F.L.S., F.G.S.

Deposit of Lime from a Kettle, exhibited by W. Topley, Esq., F.R.S., F.G.S.

New sheets of the Geological Survey Map of Sutherland, exhibited by Sir Archibald Geikie, D.Sc., For.Sec.R.S., V.P.G.S.

March 22nd, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Thomas G. Davey, Esq., Harrietville, Victoria, Australia; Morgan Williams Davies, Esq., Assoc. M. Inst. C.E., 17 Adelaide Street, Swansea, and 7 Victoria Street, Westminster, S.W.; and Joseph Pope, Esq., care of W. F. Bennetts, Esq., Roskear Safety Fuze Works, Camborne, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Jaw of a new Carnivorous Dinosaur from the Oxford Clay of Peterborough." By R. Lydekker, Esq., B.A., F.G.S.

2. "On a Mammalian Incisor from the Wealden of Hastings." By R. Lydekker, Esq., B.A., F.G.S.

3. "On an Intrusion of Muscovite-biotite Gneiss in the South-eastern Highlands of Scotland, and its accompanying Metamorphism." By George Barrow, Esq., F.G.S. (Communicated by permission of the Director-General of the Geological Survey.)

The following specimens were exhibited:—

Specimens exhibited by R. Lydekker, Esq., B.A., F.G.S., in illustration of his papers.

Rock-specimens and microscopic sections exhibited by George Barrow, Esq., F.G.S., in illustration of his paper.

April 12th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Ernest Evans, Esq., 293 Iddesleigh Terrace, Queen's Gate, Burnley, Lancashire, was elected a Fellow of the Society.

The List of Donations to the Library was read.

With reference to certain specimens on the table exhibited by himself, and collected by Mr. Ferguson in the interior of the Gold Coast Colony, Prof. Judd said :—These specimens, which are clearly referable to *Arthrophycus*, Hall (*Harlania*, Göpp.), have been found by Mr. Ferguson in the interior of the Gold Coast Colony. While agreeing in all their general characters with specimens of the same forms so abundant in the older Palæozoic of North America and other regions, they present some distinctive features. Great diversity of opinion exists as to whether these curious forms should be referred to seaweeds, or to the burrows or tracks formed by some new marine organism. While the specimens now exhibited present no features which would help to solve this curious problem, they are of very great interest as coming from an altogether unexplored district, and being the only organic structures hitherto found in that district.

In referring to the following specimens—viz.: Specimen of *Cervus Sedgwickii* (?), Falc., Norwich Crag, Bramerton, exhibited by R. W. Hinton, Esq.; Tooth of Mammoth (*Elephas primigenius*), from Witton, near Bacton, Norfolk, and a Tooth of *Elephas antiquus*, both showing glacial striæ, exhibited by James Reeve, Esq.; Boulder of Lower Carboniferous Sandstone from Hartford Bridges, near Norwich, exhibited by G. W. Page, Esq.,—Mr. H. B. Woodward drew particular attention to the glaciated tooth of Mammoth that had been obtained many years ago by Mr. John Gunn, from Witton, near Bacton, in Norfolk. He considered that the specimen was older than the Chalky Boulder Clay, and had been glaciated by the agent which brought that material. He exhibited it, through the kindness of Mr. James Reeve, Curator of the Norwich Museum, because it had lately been referred to by Sir Henry Howorth, and because hitherto no definite remains of the Mammoth had been found in East Anglia, either above or below a mass of the Chalky Boulder Clay.

Referring to a portion of a Deer's Antler, identified by Mr. E. T. Newton as *Cervus Sedgwickii* (?), Falc., Mr. Woodward said it had been found in the Norwich Crag at Bramerton by Mr. R. W. Hinton, during a recent excursion of the Geologists' Association, and that the species had not been recorded from strata older than the Cromer Forest Bed.

The following communications were read :—

1. "On some Palæozoic Ostracoda from Westmoreland." By Prof. T. Rupert Jones, F.R.S., F.G.S.

2. "On some Palæozoic Ostracoda from the District of Girvan, Ayrshire." By Prof. T. Rupert Jones, F.R.S., F.G.S.

3. "On the Dwindling and Disappearance of Limestones." By Frank Rutley, Esq., F.G.S.

4. "On some Bryozoa from the Inferior Oolite of Shipton Gorge, Dorset.—Part II." By Edwin A. Walford, Esq., F.G.S.

The following specimens, in addition to those enumerated on p. 146, were exhibited:—

Lower Silurian Ostracoda from Pusgill, Dufton, Swindale, etc., Westmoreland, collected by Messrs. Nicholson and Marr; also Lower Silurian Ostracoda from Whitehouse Bay, etc., Girvan, Ayrshire, collected by Mrs. Elizabeth Gray, exhibited by Prof. T. Rupert Jones, F.R.S., F.G.S., in illustration of his papers.

Specimens exhibited by Frank Rutley, Esq., F.G.S., in illustration of his paper.

Specimens exhibited by E. A. Walford, Esq., F.G.S., in illustration of his paper.

April 26th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Edward John Burrell, Esq., 48 Leyspring Road, Leytonstone, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "The Origin of the Crystalline Schists of the Malvern Hills." By Charles Callaway, D.Sc., M.A., F.G.S.

2. "Supplementary Notes on the Metamorphic Rocks around the Shap Granite." By Alfred Harker, Esq., M.A., F.G.S., and J. E. Marr, Esq., M.A., F.R.S., Sec.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Dr. Chas. Callaway, M.A., F.G.S., in illustration of his paper.

Rock-specimens and microscopic sections, exhibited by Messrs. Alfred Harker, M.A., F.G.S., and J. E. Marr, M.A., F.R.S., Sec.G.S., in illustration of their paper.

Specimen and microscopic section of Gneiss (Archæan) from the eastern side of the Herefordshire Beacon, Malvern, exhibited by Frank Rutley, Esq., F.G.S.

May 10th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Henry E. Ede, Esq., A.Sc., Perranporth, Truro, Cornwall; Alfred N. Leeds, Esq., Eyebury, near Peterborough; Fritz Noetling, Ph.D., Palæontologist to the Geological Survey of India, Geological Survey Office, Calcutta; and D. H. Scott, M.A., Ph.D., F.L.S. (Honorary Keeper of the Jodrell Laboratory, Royal Gardens, Kew), Old Palace, Richmond, Surrey, were elected Fellows; and Prof. Marcel Bertrand, Paris, Dr. A. Pavlow, Moscow, and Dr. C. A. White, Washington, U.S.A., Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The Secretary announced that copies of sheets Nos. 6, 12, 14, 15 of the Index Map of the Geological Survey of England and Wales (Scale 1 inch = 4 miles) had been presented by the Director-General of H.M. Geological Survey.

The following communications were read:—

1. "The Felsites and Conglomerates between Bethesda and Llanllyfni, North Wales." By Prof. J. F. Blake, M.A., F.G.S.

2. "The Llandovery and Associated Rocks of the Neighbourhood of Corwen." By Philip Lake, Esq., M.A., F.G.S., and Theo. T. Groom, Esq., B.Sc., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Prof. J. F. Blake, M.A., F.G.S., in illustration of his paper.

May 24th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

The Hon. Cecil Duncombe, The Grange, Nawton, Yorkshire John Cary Baker Hendy, Esq., Etherley, *viâ* Darlington; Frederick George Shaw, Esq., Assoc. Inst. C.E., 12 Grafton Street, W.; and John Barret Squire, Esq., Assoc. Inst. C.E., 297 Clapham Road, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "Notes on Dartmoor." By Lieut.-General C. A. McMahon, F.G.S.

2. "On some Recent Borings through the Lower Cretaceous Strata in East Lincolnshire." By A. J. Jukes-Browne, Esq., B.A., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Lieut.-General C. A. McMahon, F.G.S., in illustration of his paper.

June 7th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Robert M. W. Swan, Esq., F.C.S., 15 Walmer Crescent, Glasgow, was elected a Fellow of the Society.

The names of certain Fellows were read out for the first time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of arrears of contributions.

The List of Donations to the Library was read.

Dr. Johnston-Lavis, in referring to specimens and microscopic slides showing eozoonal structure in the ejected blocks of Monte

Somma, exhibited by him, said that all the criticisms of *Eozoon* have so far been destructive, no analogous structure having been found in other localities under conditions that could explain the origin of so curious an arrangement of different minerals. These altered limestones from Monte Somma correspond in all details with those of the original Canadian specimens, and in many cases, on account of their freshness, exhibit some of the pseudo-organic structural details, such as the stolon-tubes, in far greater perfection than does the true so-called *Eozoon canadense*. He had been working at the subject in conjunction with Mr. J. W. Gregory, F.G.S.

The following communications were read:—

1. "The Bajocian of the Sherborne District: its Relations to Subjacent and Superjacent Deposits." By S. S. Buckman, Esq., F.G.S.

2. "On Raised Beaches and Rolled Stones at High Levels in Jersey." By Andrew Dunlop, M.D., F.G.S.

In addition to the specimens exhibited by Dr. Johnston-Lavis (see p. 149), the following specimens were exhibited:—

Specimens, and a series of lithographed figures of Ammonites, exhibited by S. S. Buckman, Esq., F.G.S., in illustration of his paper.

Specimens exhibited by Dr. A. Dunlop, F.G.S., in illustration of his paper.

June 21st, 1893.

Dr. H. Woodward, F.R.S., Vice-President, in the Chair.

The following names of Fellows of the Society were read out for the second time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of arrears of contributions:—C. A. V. Butler, Esq.; E. M. Cairnes, Esq.; R. W. Cheadle, Esq.; A. W. Clarke, Esq.; W. H. Clarke, Esq.; Lt.-Col. T. Couchman; J. Diggens, Esq.; A. D. Dobson, Esq.; G. S. Griffiths, Esq.; D. W. Jones, Esq.; G. O. Kekewich, Esq.; Dr. A. C. Maybury; J. O'Donoghue, Esq.; S. B. J. Skertchly, Esq.; Dr. J. W. Stroud; G. A. H. Thureau, Esq.; J. Wonnacott, Esq.

The List of Donations to the Library was read.

The following communications were read :—

1. "On Composite Dykes in Arran." By Prof. J. W. Judd, F.R.S., V.P.G.S.

2. "Notes on an Intrusive Sheet of Diabase and Associated Rocks at Robin Hood, near Bassenthwaite." By J. Postlethwaite, Esq., F.G.S.

3. "On Two Dinosaurian Teeth from Aylesbury." By R. Lydekker, Esq., B.A., F.G.S.

4. "On a new Plesiosaur from the Waipara River, New Zealand." By Capt. F. W. Hutton, F.R.S., F.G.S.

[Abstract.]

This specimen was shortly described by Sir James Hector in 1873. The Author considers it more prudent to follow Mr. Lydekker in referring all the known New Zealand Cretaceous Sauropterygians with which he is acquainted to Leidy's genus *Cimoliosaurus*, and he therefore describes this form as a new species of that genus.

Discussion.

The Chairman remarked that the fossil described by Capt. Hutton, and referred by him to *Cimoliosaurus caudalis*, exhibits the remains of a Plesiosaur from New Zealand showing the pelvic and pectoral girdle and the vertebral column and ribs, but otherwise imperfect. Capt. Hutton had no doubt in his paper justified the proposal to constitute a new species for this Plesiosaur. One must regret that distance prevented the Author from being present to read his own communication.

5. "Observations on the Affinities of the Genus *Astrocœnia*." By Robert F. Tomes, Esq., F.G.S.

6. "Description of a new Genus of Madreporaria from the Sutton Stone of South Wales." By Robert F. Tomes, Esq., F.G.S.

7. "Study of the Dykes of Hope, Idaho." By Herbert R. Wood, Esq. (Communicated by the President.)

[Abstract.]

In this paper a description of the geographical distribution and characters of acid and basic dykes traversing slates and quartzites along the northern shore of Lake Pend'Oreille, Idaho, is accompanied

by notes on the glaciation of the area. A brief description of the microscopic features of the igneous rocks is appended.

8. "The Rise and Fall of Lake Tanganyika." By Dr. Robert Sieger. (Communicated by the President.)

9. "On Cheilostomatous Bryozoa from the Middle Lias." By Edwin A. Walford, Esq., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Prof. J. W. Judd, F.R.S., V.P.G.S., in illustration of his paper.

Rock-specimens and microscopic sections, exhibited by J. Postlethwaite, Esq., F.G.S., in illustration of his paper.

Dinosaurian Teeth from Aylesbury, exhibited by R. Lydekker, Esq., B.A., F.G.S., in illustration of his paper.

Specimen and section of *Astrocœnia gibbosa* and section from the Society's Collection, and specimens and section, exhibited by R. F. Tomes, Esq., F.G.S., in illustration of his two papers.

Specimens of *Astrocœnia*, exhibited by the Geological Survey in illustration of Mr. Tomes's papers.

A Special General Meeting was held at 7.45 p.m., before the Ordinary General Meeting, at which the following resolutions were proposed by the Chairman, seconded by Mr. Topley, and carried unanimously:—

1. That it is desirable that an Index to the first fifty volumes of the Quarterly Journal be prepared, at an expenditure not exceeding £450.

2. That it be issued, if possible, early in 1895, in two numbers in paper covers, uniform with the Quarterly Journal, and as a Supplement to Volume 50.

ADDITIONS

TO THE

LIBRARY AND MUSEUM OF THE GEOLOGICAL SOCIETY.

Session 1892–93.

ADDITIONS TO THE LIBRARY.

1. Periodicals and Publications of Learned Societies.

Presented by the respective Societies and Editors, if not otherwise stated.

Adelaide. Royal Society of South Australia. Transactions. Vol. xv. Parts 1 & 2. 1892.

P. H. Priestly. Notes on Glacial Phenomena about Mount Gambier, 123.—G. B. Pritchard. On the Cambrian Rocks at Curramulka, 179.—R. Tate. The Cambrian Fossils of South Australia, 183.—R. Tate. Critical Remarks on A. Bittner's 'Echiniden des Tertiärs von Australien,' 190.

——. ——. ——. Vol. xvi. Part 1. 1892.

Albany. University of the State of New York. New York State Museum. Forty-third Annual Report of the Regents for the year 1889. (8vo.) 1890.

——. ——. ——. Forty-fourth Annual Report of the Regents for the year 1890. (8vo.) 1892.

——. ——. ——. Ninth Report of the State Geologist for the year 1889. 8vo. 1890.

——. ——. ——. Tenth Report of the State Geologist for the year 1890. 1891. *Presented by Prof. James Hall, State Geologist, F.M.G.S.*

Alnwick. Berwickshire Naturalists' Club. History of the Berwickshire Naturalists' Club, instituted September 22, 1831. 1890–1891. 1892.

Amsterdam. Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië. Jaargang 1892. Technisch en Administratief. 2e gedeelte 1892. *Presented by the Netherlands Colonial Department.*

Austin. Texas Academy of Science. Transactions. Vol. i. No. 1. 1890.

E. T. Dumble. Sources of the Texas Drift, 11.—W. F. Cummins, The Texas Meteorites, 14.—E. T. Dumble. Volcanic Dust in Texas, 33.

Barnsley. Midland Institute of Mining, Civil, and Mechanical Engineers. Proceedings. Vol. xiii. Parts 114–119. 1892–93.

W. H. Chambers. The Pumping Appliances used in the Sinking Operations at the Cadeby New Winning, 43.

Basel. Schweizerische paläontologische Gesellschaft. Abhandlungen. Vol. xix. 1892. 1893. *Purchased.*

P. de Loriol. Etudes sur les mollusques des couches coralligènes inférieures du Jura bernois. IV.e partie.—G. Maillard et A. Locard. Monographie des mollusques tertiaires, terrestres et fluviatiles de la Suisse, II.e partie.—T. Studer. Ueber zwei fossile dekapode Krebse aus den Molasseablagerungen des Belpberges.—R. Hæusler. Notes sur la distribution des Lituolides dans les terrains jurassiques de la Suisse.

Bath. Natural History and Antiquarian Field Club. Proceedings. Vol. vii. Nos. 3 & 4. 1892 & 1893.

H. H. Winwood and E. Wilson. Charles Moore, F.G.S., and his Work; with a List of the Fossil Types and Described Specimens in the Bath Museum, 232.—H. H. Winwood. On some Deep Well Borings in Somerset, 335.

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THE

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

Vol. XLIX.

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1. Contributions *to the* Geology *of the* Wengen *and* St. Cassian Strata *in* Southern Tyrol. By Maria M. Ogilvie, B.Sc. (Communicated by Prof. Chas. Lapworth, LL.D., F.R.S., F.G.S. Read June 22nd, 1892.)

Contents.

Note.—Various modifications have been embodied in the present paper which are the result of further work in Southern Tyrol undertaken by the Authoress from July to September 1892. The most important additions are those referring to the Dürrenstein district. The lists of fossils have also been largely extended from collections recently made in the field.

I. Introduction.

My interest in the Alpine Trias was first aroused by several geological excursions in Northern Tyrol during the summer of 1891. In response to a wish of mine to undertake some original research, it was kindly suggested by Freiherr F. von Richthofen, of the Berlin University, that I might make a detailed study of the

Wengen and St. Cassian Beds in the valleys of Enneberg and Ampezzo in Southern Tyrol, and with these valleys in particular the present paper deals.

I shall ever regard it as a peculiar honour that Freiherr von Richthofen, whose early work, 'Geognostische Beschreibung der Umgegend von Predazzo, St. Cassian, und der Seisser Alpe,'[1] still holds the highest place in the literature of the Southern Tyrol 'Dolomites,' guided me in my first attempt in Alpine geology, that he himself taught me the chief points at issue concerning the district between Schlern and Ampezzo, and gave me, in a short space of time, a far clearer insight into the work which lay before me than falls to the lot of most young geologists.

In the course of my work during the two seasons of 1891–92, I have been led to extend somewhat my primary object, and to include some of the more interesting tectonic aspects of the whole group of Upper Triassic strata in the 'Dolomite Alps.'

My most grateful thanks are due to Herr Prof. von Zittel for the constant kindness he has shown me, and for his advice and encouragement during the two years of my studies in Munich. I am indebted to Herr Dr. Schäfer for frequent help and suggestion in carrying out the work of this paper, and also to Herr Dr. Rothpletz and to Freiherr Dr. von Wöhrmann for their kind response whenever I have had occasion to refer to them.

The Dolomite region of Southern Tyrol has long been one of the most famous in geology. Not only is it pre-eminent for its beautiful scenery, but in this district, as in Northern Tyrol (the Hallstadt district, the Bavarian Alps, and the Vorarlberg), are found the lithological and palæontological links which fill up the great hiatus between the Palæozoic and the Mesozoic formations in Britain.

In Britain, as every geologist knows, the zoological break between the Palæozoic and the Mesozoic is absolutely complete. No species is known to pass from the Carboniferous into the Jurassic across the great hiatus marked by our sparsely fossiliferous Permian and Triassic beds. Even in Central Germany, the rich limestone of the Muschelkalk only affords a few transitional genera of any consequence, and these by no means fill up the gap.

But, in place of the barren Triassic sandstones of our own land, masses of the richest limestone rise in the Tyrol, and our non-fossiliferous Keuper marls are represented locally in that province by extremely prolific fossil-bearing shales and limestones. No better example of such fossiliferous beds in the Alpine Trias can be found than the group which forms the main subject of this paper. Yet, while the fossils contained in these beds are of remarkable interest, and are well-known to all geologists, the stratigraphy of that district of Southern Tyrol in which they pre-eminently occur has always been a matter of dispute since the days of Leopold von Buch. I may here indicate shortly, for the English reader, the present state of opinion regarding the systematic position of these strata.

[1] This work was published at Gotha in 1860; a preliminary notice appeared in 1858, Jahrb. d. k. k. geol. Reichsanstalt, p. 466.

The Muschelkalk is succeeded in Southern Tyrol sometimes by an immense thickness of dolomitic rock, poor in fossils, sometimes by a non-dolomitic series of strata. The lowest of the non-dolomitic series are the Buchenstein Beds, a series of shales and limestones comparatively poor in fossils, but indicative of shallow-water conditions; next, a group known as the Wengen strata, consisting of sandstones and shales, formed apparently more or less by the washings of volcanic (sub-basic) material, and known usually as 'sedimentary tuffs.' These are cut through by augitic porphyry-dykes, or are interrupted at various horizons by flows of augite-porphyry, with volcanic tuffs. The sedimentary beds are fossil-bearing, and while the species are few, the individuals are numerous.

Next follow the most celebrated beds of the whole Triassic series, the marls and limestone-rocks of St. Cassian, which afford that curious mixture of older forms of life, as yet almost unique in the geological world.

Above the St. Cassian Beds, according to one opinion, follow at once the fossil-bearing Raibl Beds; in Southern Tyrol these are especially characterized by the brilliant colouring of the reddish and violet marls, which are interstratified with dolomitic flags in the upper horizons. According to another opinion, there is between the fossiliferous St. Cassian and the fossiliferous Raibl Beds a distinct horizon, formed by the same Schlern Dolomite as that which extends in some localities in Southern Tyrol from the Raibl Beds above to the Muschelkalk below.

The Dachstein Dolomite succeeds the Raibl Beds in all cases, and above the whole Triassic series follow the acknowledged Liassic strata.

The difficulty in Southern Tyrol arises in the anomalies presented by those beds which are above the Muschelkalk and below the Raibl strata. The dolomitic rock thickens out locally into mountain-masses or is suddenly replaced by shales. The very fossiliferous beds of one locality are represented, a few miles off, by strata wholly barren of organic remains.

As yet, comparison with the ascertained succession in Northern Tyrol lends little help. In Northern Tyrol, the Raibl Beds, as a series of marls and oolitic limestones often richly fossiliferous, and interbedded with unfossiliferous dolomite, limestone, and gypsum, rest upon the thick development of limestone known as Wetterstein Kalk. This limestone is generally regarded as the representative of the dolomitic rock below the Raibl Beds in Southern Tyrol. Below the Wetterstein Kalk and above the Muschelkalk are the Partnach strata, a series of dark thin-bedded shales which von Gümbel, von Hauer, and others have compared with the Wengen strata of Southern Tyrol, owing to the identity of some characteristic fossils, e. g. *Halobia Lommeli*, Wissm.

Thick beds of hard limestone are interstratified at various horizons in the Partnach shales and marls, and such limestones bear typical St. Cassian fossils, e. g. *Koninckina Leonhardti*, Wissm., and have hence been called 'St. Cassian limestones.' Several of the species appear again at the higher horizon of the Raibl Beds, together with a certain number belonging to a distinct 'Raibl' fauna.

The Wetterstein Kalk in some places, however, lies directly upon the Muschelkalk, no Partnach strata being developed; and in its eastern and western extension the Wetterstein Kalk thins out. In Eastern Tyrol its place is taken by the Hallstadt Limestone,[1] while in the west the Raibl Beds lie conformably on the Partnach Beds.

The various opinions which have been held regarding the probable representative in Northern Tyrol of the St. Cassian strata of Southern Tyrol will be stated below in the review of the special literature. Suffice it to say that the name of 'St. Cassian strata' has now no value as indicating a sure horizon in the series of Alpine Upper Trias; at most it has retained clear association with the fauna found in the immediate neighbourhood of St. Cassian.

II. Previous Discovery and Speculation regarding the Upper Triassic Strata in the Tyrol (with special reference to the St. Cassian Beds in Southern Tyrol).

At a time when the historical geology of the British Isles, France, and Germany had been firmly based on the careful and comparative studies of geologists in those countries, the elements of Alpine geology were scarcely understood. Those immense masses of limestone and dolomite which characterize the northern and southern zones of the Alps seemed without parallel elsewhere in Europe.

As the limestone-rocks have outwardly much similarity, and the few fossils which they contain were for a long time unknown, the older writers believed them to belong to one and the same formation, and grouped them conveniently together under the title of 'Alpenkalk.' There are, however, here and there amidst the wonderful rock-scenery of the Tyrolese Alps, high-lying stretches of green meadow and 'Alm.'[2] Gradually geologists carried their researches into these remote 'Alpen,' and found the marls and shales to be, in many cases, fossiliferous. Fossils were collected and examined, and it became evident that the fauna occurring in the Alpine mountains of the Tyrol had a character quite different from that of any fossil fauna up to that time known in other parts of Europe.

It was on such high mountain-meadows that the *Avicula contorta*-zone was traced in Northern Tyrol soon after Leopold von Buch's[3] first discovery of the characteristic fossils at Hirschberg.

[1] The Hallstädter Kalk belongs to the development of Trias in the 'Jurassic Province' recognized by Mojsisovics, whereas Wetterstein Kalk occurs in the 'Mediterranean Province' (this embraces the Western and Southern Alps). Mojsisovics also distinguishes a Lower Keuper division of the Alpine Trias, the 'Noric zone,' including the strata from the Upper Muschelkalk to the Raibl Beds, and an upper division, the 'Karnic zone.'

[2] *Alm* or *Alp* is the German word for pasture-land in the mountains, where cattle remain the whole summer through in the open air. In Southern Tyrol hay is often grown and gathered into small huts, *Alpenhütten*, and for the convenience of herd-boys empty huts are left, the so-called *Kochhütten*. These huts help much in reading the maps, as they are always marked.

[3] 'Schichten mit *Avicula* . . . .,' Abh. d. k. Akad. Berlin, 1828, p. 84.

One definite horizon in Triassic strata was thus ascertained in the Northern Alps, namely, the Kössen Beds of Upper Keuper age.

The next important group of fossiliferous strata to be observed was a series of marls exposed on passes and mountain-meadows in the midst of the dolomite-rocks of Southern Tyrol.

As early as 1834 Graf Münster [1] described the favourable exposure of these strata in the neighbourhood of St. Cassian in Enneberg; and not long afterwards he and Wissmann [2] published their well-known work, in which they described 400 species from the St. Cassian strata, and figured them in a masterly manner.

Klipstein [3] in the following years much increased the number of known species. The remarkable fact was that no single species agreed with species described from countries north of the Alps.

In 1844 Emmrich [4] examined the strata of Enneberg and came to the conclusion that the St. Cassian strata were at any rate above the Alpine Muschelkalk, the age of which had shortly before been determined. In the course of a warm discussion, which arose after the publication of Klipstein's [5] work, Bronn [6] wrote a short editorial note which deserves to be mentioned. In it he promulgated the opinion, still current among many geologists, that the fauna of St. Cassian had lived in the neighbourhood of rocks and cliffs in a shallow sea, where coral-banks were numerous, and gasteropods, sponges, brachiopods, etc. associated under conditions favourable alike to all. In extra-Alpine formations of nearly all ages the local occurrence of special faunas, and more particularly of the fauna of a coral sea, had frequently been proved. And Klipstein was so far misled by receiving from the collectors some Liassic ammonites among the St. Cassian fossils, and by a general resemblance in the characteristics of the St. Cassian fauna to that of the Upper Jurassic Coral Rag at Nattheim or Kelheim, as to attribute a Jurassic age to the St. Cassian strata. Bronn, on the contrary, thought from palæontological evidence that the St. Cassian strata were equivalent to the Muschelkalk.[7]

Between 1850 and 1860 a marked advance was made in the knowledge of the Triassic strata in Northern Tyrol through the energy of Austrian and German geologists. A letter from Escher

[1] 'Ueber das Kalkmergellager von St. Cassian in Tyrol und die darin vorkommenden Ceratiten,' Neues Jahrb. 1834, p. 1.

[2] 'Beiträge zur Petrefaktenkunde,' Bayreuth, 1841–43.

[3] 'Beiträge zur geologischen Kenntniss der östlichen Alpen,' Giessen, 1843.

[4] 'Ueber die Schichtenfolge der Flötzgebirge des Gaderthales, der Seisser Alpe, und insbesondere bei St. Cassian,' Neues Jahrb. 1844, pp. 791–803; 'Gervillienschichten bei Lienz,' Zeitschr. d. Deutsch. geol. Gesellsch. vol. vi. (1854) p. 668.

[5] 'Schichtenfolge in Süd-Tirol,' Amtl. Ber. über die Naturforscherversammlung zu Mainz, 1843; Neues Jahrb. 1845, pp. 799–801.

[6] Neues Jahrb. 1845, pp. 504–508.

[7] [In 1847 Sir R. Murchison made an excursion to St. Cassian, with von Buch and de Verneuil (see Q. J. G. S. vol. v. (1849) pp. 165–167; where reference is made to the work of Emmrich and others). Mr. W. J. Hamilton, in his Anniversary Address for 1855, discussed 'The Position of the Fossiliferous Beds of San Casciano,' Q. J. G. S. vol. xi. pp. lxiii–lxix.—Ed.]

von der Linth[1] in 1854 tells how he and others convinced themselves that the Raibl strata ('Schiefer u. Sandstein') of the Vorarlberg and of Northern Tyrol were of Keuper and not of Liassic age: that similar strata with *Cardita crenata*, Goldf., occurred near Hall, in Lavatsch Thal, and in several other localities, in close association with strata containing *Halobia Lommeli*, Wissm.; that these represented without doubt true St. Cassian strata, and must be regarded as a marine equivalent of a part of the Keuper.

In a paper written by Merian[2] from Basel, a series of greenish-grey sandstones with plants, now recognized as Raibl strata, was included with dark-grey or black fossiliferous limestones, and beds with *Halobia Lommeli*, Wissm., as 'Lower St. Cassian Formation' below the horizon now called 'Hauptdolomit.'

Following a preliminary contribution made by von Hauer[3] in 1855, Foetterle[4] gave in 1856 subdivisions of the Raibl strata from observations which he and the first-named author had made in the country from Raibl to Dogna. The succession he regarded as:—

Raibl Strata.
- Uppermost horizon.
- Marly shales and limestones: characteristic fossils—*Astarte* (*Corbula*) *Rosthorni*, Boué, sp., *Ostræa montis-caprilis*, Klipst., etc.
- Marls with *Myophoria Kefersteini*, Goldf., sp.
- Bituminous shales with plant- and fish-remains, forming the lowest horizon.

While he remarked that the fossils, even up to the *Corbula Rosthorni*-beds, much resembled the St. Cassian fossils, he gave to the whole group the name of 'Raibl strata,' and defined them as the series of beds above the Hallstädter Kalk (= Wetterstein Kalk of Gümbel) and below the Dachstein Kalk (= Hauptdolomit of Gümbel).

In the following year, Hauer[5] gave a complete description, with plates, of the mollusca of the Raibl strata as exposed at Raibl, at Agordo in Lombardy, at Schlern, and at other places.

The fossils of the lowest horizon of Raibl strata in Foetterle's subdivision were handled by Bronn.[6] In reviewing Bronn's work and combining the results of previous research, Hauer came

[1] Zeitschr. d. Deutsch. geol. Gesellsch. vol. vi. (1854) p. 519. In 1853 his important work appeared (*cf.* pp. 49-52), 'Geolog. Bemerkungen über d. nördl. Vorarlberg u. einige angrenzenden Gegenden,' Neue Denkschr. d. allg. Schweizer. Gesellsch. für die Naturwissenschaften. [See Abstract in Quart. Journ. Geol. Soc. vol. xi. (1855) Misc. p. 16.—Ed.]

[2] 'Ueber die St. Cassian-Formation im Vorarlberg und im nördlichen Tirol,' Zeitschr. d. Deutsch. geol. Gesellsch. vol. vi. (1854) p. 642. [See also Quart. Journ. Geol. Soc. vol. xi. (1855) p. 451.—Ed.]

[3] Jahrb. d. k. k. geol. Reichsanstalt, 1855, pp. 744 & 745.

[4] *Ibid.* 1856, pp. 372 & 373.

[5] 'Ein Beitrag zur Kenntniss der Fauna der Raibler Schichten,' Sitzungsber. d. kais. Akad. d. Wissensch. Wien, vol. xxiv. (1857) pp. 537-566.

[6] 'Beiträge zur triasischen Fauna u. Flora d. bitum. Schiefer v. Raibl,' Neues Jahrb. 1858; 'Nachtrag über die Trias-Fauna von Raibl,' *ibid.* 1859.

to the conclusion that these Raibl strata were identical with the *Cardita*-beds of Northern Tyrol.

Von Gümbel[1] had in 1857 stated that the *Cardita*-beds overlying the Wetterstein Kalk were the true equivalent of the St. Cassian strata.

In 1859 von Richthofen,[2] who had been working in the St. Cassian district and in the Vorarlberg, expressed his opinion that the *Cardita crenata*-beds in the last-named area ought to be included with the Raibl strata: but that in Northern Tyrol, and in the Northern Alps generally, the *Cardita*-beds ranged lower than the Raibl strata in Southern Tyrol, and that therefore their fauna more closely resembled the St. Cassian fauna.

In the literature of this period the Raibl, *Cardita*-, and St. Cassian strata were understood to belong generally to the same horizon, and the various names began to be rather loosely applied to fossiliferous beds in the Upper Triassic Series of Northern and Southern Tyrol.

Before leaving this subject, it ought to be mentioned that the subdivisions made by Hauer and Foetterle for the Raibl strata near Raibl were corroborated some 10 years later, and considerable clearness attained, by means of the detailed examination of these beds made by Suess[3]: this author also suggested an interesting comparison with the strata in Southern Tyrol.

A further paper on the subject was contributed by Stur,[4] who published with it the first map of the Raibl and Kaltwasser district. The opinion of Stur that the lowest subdivision of Raibl strata made by Foetterle corresponded with the Wengen Beds containing *Halobia Lommeli* in Southern Tyrol has not since been accepted, the palæontological evidence adduced by him being afterwards corrected by Mojsisovics. Comparison is now made between this horizon, the so-called 'Fischschiefer,' in the Raibl Beds and 'Aonschiefer,' a horizon of St. Cassian strata (see a footnote in Mojsisovics' work 'Dolomit-Riffe,' p. 61).

By means of the work of Sandberger[5] and Gümbel[6] on extra-Alpine Keuper in Bavaria, comparison was made between the Raibl strata in the Alps and the 'Gypskeuper' of Franconia.

Pichler,[7] in several papers published before 1862, placed the strata with *Cardita crenata*, Goldf., between what he called 'upper and middle Alpenkalk,' corresponding respectively to Hauptdolomit

[1] 'Die Aequivalente der St. Cassianer Schichten im Keuper Frankens, Jahrb. d. k. k. geol. Reichsanstalt, 1859, p. 22.

[2] 'Die Kalkalpen von Vorarlberg u. Nord-Tirol,' *ibid.* p. 101.

[3] 'Studien über die Gliederung der Trias- und Jura-Bildungen in den östlichen Alpen,' von Eduard Suess und Edmund von Mojsisovics, *ibid.* 1867, p. 553.

[4] 'Beiträge zur Kenntniss der geol. Verhältnisse der Umgegend von Raibl und Kaltwasser,' *ibid.* 1868, p. 71.

[5] 'Die Stellung der Raibler Schichten in dem Fränkischen und Schwäbischen Keuper,' Neues Jahrb. 1866, p. 34.

[6] 'Bavaria,' vol. iv. I. p. 53 (Geology by Gümbel).

[7] 'Zur Geognosie der Tyroler Alpen,' Neues Jahrb. 1857, p. 691.

and Wetterstein Kalk. But in later papers (1862, 1866, etc.[1]) he changed his opinion, mainly on stratigraphical grounds, and gave two horizons with *Cardita crenata*, Goldf., the succession being as follows:—

Upper horizon of *Cardita crenata*, Goldf.
= *Cardita*-strata of Gümbel.
= Raibl strata of Hauer.
Strata with *Chemnitzia Rosthorni*, Hoern.
= Wetterstein Kalk.
Lower horizon of *Cardita crenata*, Goldf.
= St. Cassian strata of Richthofen.
= Partnach strata of Gümbel, or strata with *Halobia Lommeli* of Gümbel and other authors.

Mojsisovics[2] accepted, in the main, Pichler's horizons and gave (in 1869) the following succession (in descending order):—

Seefelder Dolomit (= Hauptdolomit).
Wetterstein Kalk.
Cardita (= St. Cassian)-beds.
Dolomitic limestone (Haselgebirge and Reichenhaller Kalk).
Partnach dolomite.
Partnach strata with *Halobia Lommeli*, Wissm., and St. Cassian fossils.

In 1871 Mojsisovics[3] recognized even three *Cardita crenata*-horizons, although they were lithologically and palæontologically the same. The third of these horizons he introduced above the Wetterstein Kalk as being the equivalent of Raibl strata. A year later[4] he struck out the *Cardita*-zone *below* the Wetterstein Kalk, saying that the *Cardita*-beds *above* the Wetterstein Kalk were the equivalent of St. Cassian strata. But, in 1874,[5] Mojsisovics returned to his opinion that the *Cardita*-beds above the Wetterstein Kalk were Raibl strata, containing a fauna which would probably on closer study be found to differ from the St. Cassian fauna.

As may be seen from the above references, the question of the relative ages of these fossiliferous strata has given rise to great confusion in the literature. This is largely owing to the difficulty of attaining a sound knowledge of the stratigraphy of the Triassic rocks. Like other formations in the Alps, they have been much folded and faulted, and names were given to the fossiliferous beds before any comparison of the succession in different regions could be reasonably made. In every case the succession must be determined for itself, as no formation in Northern and Southern Tyrol or in Bavaria presents so many-sided a development as the Trias.

A careful study of the *Cardita*- and Raibl strata of the Northern

[1] 'Zur Geognosie Tirols,' Jahrb. d. k. k. geol. Reichsanstalt, 1862, p. 531; '*Cardita*-Schichten und Hauptdolomit,' *ibid.* 1866, p. 73.

[2] 'Ueber die Gliederung der oberen Triasbildungen der Alpen,' Verhandl. d. k. k. geol. Reichsanstalt, 1869, p. 65.

[3] 'Ueber die Stellung der Nord-tiroler *Cardita*-Schichten,' *ibid.* 1871, p. 213.

[4] 'Parallelen in der oberen Trias der Alpen,' *ibid.* 1872, p. 7.

[5] 'Faunengebiete und Faciesgebilde der Triasperiode in den Ostalpen,' Jahrb. d. k. k. geol. Reichsanstalt, 1874, p. 81.

areas was made a few years ago by von Wöhrmann.[1] He came to the following conclusions:—

(1) That in all the places where former writers believed Lower *Cardita*-strata (*i.e.* the *Cardita*-beds *below* the Wetterstein Kalk) to be present, these strata were none other than the Upper *Cardita*- or Raibl strata (*i.e.* the *Cardita*-beds *above* the Wetterstein Kalk) which had been brought by faulting into the apparently lower position.

(2) That these so-called *Cardita*-strata contain in their lower zones chiefly St. Cassian fossils; on the other hand, in the upper zones, nearly all the typical Raibl fossils are present.

The same author publishes this year, in co-operation with Koken, a special work[2] on the fossils contained in the 'Rothe Raibler Schichten' of Schlern.

Dr. T. Skuphos,[3] during the summer of 1891, examined the Partnach strata in the Northern Alps; his results prove that these beds lie under the Wetterstein Kalk and above the Muschelkalk, and that the plant-bearing sandstones (previously in several places included with the Partnach strata) belong to the Raibl horizon. He further concludes that the Partnach strata form an upper zone of Alpine Muschelkalk, while the Wetterstein Kalk probably represents the highest zone of the extra-Alpine Muschelkalk.

Before entering on the special stratigraphical work of this paper, a short summary may be given of the marked general features in the geology of the Southern Tyrol Dolomites and the explanation they have found in previous research. These are:—

(1) The dolomitic character of immense thicknesses of rock.

(2) The apparently rapid variations in the thickness of strata, noted chiefly in the dolomitic rocks.

(3) The occurrence of volcanic rocks, as flows and dykes, and the admixture of volcanic tuff with ordinary stratified detrital deposits.

(4) The local development of the rich and highly typical fauna of St. Cassian.

Leopold von Buch's[4] valuable researches first directed the attention of geologists to the neighbourhood of the 'Dolomites,' and various theories were propounded to explain the origin of the imposing masses of dolomite-rock. These I need not here recount. An exhaustive list of the literature which appeared during the first half of the century is given by von Richthofen.[5]

The stratigraphy of the district first found full and systematic treatment in the work of Richthofen above referred to. A coloured

[1] 'Die Fauna der sogenannten *Cardita*- u. Raibler Schichten in den Nordtiroler und bayerischen Alpen,' Jahrb. d. k. k. geol. Reichsanstalt. 1889, p. 181.

[2] 'Die Fauna der Raibler Schichten vom Schlernplateau,' Zeitschr. d. Deutsch. geol. Gesellsch. vol. xliv. (1892) p. 167.

[3] 'Die stratigraphische Stellung der Partnach- und der sogen. Unteren *Cardita*-Schichten in den Nordtiroler und bayerischen Alpen,' Jahresheften d. kgl. bay. Oberbergamt, iv. 1891.

[4] 'Geognostische Beobachtungen auf Reisen durch Deutschland und Italien,' vol. i. pp. 263–320. Berlin, 1802.

[5] 'Geognostische Beschreibung der Umgegend von Predazzo, St. Cassian, etc.' Gotha, 1860.

geological map and several sections give additional value to his original work. A clear idea will be gained of the succession of Triassic strata adopted by that author from the important section over the Seisser Alpe and the Schlern mountain.[1]

After his examination of the Triassic strata over a large tract in the west and south-west of this district, Richthofen sought to explain the peculiar local features by the application of Darwin's theory of the origin of, and conditions attending, coral-reefs. Whereas in the older literature it had been suggested that the St. Cassian fossils, occurring in marly strata and limestone-beds, had the special character of coral-banks and represented the fauna of a shallow sea, Richthofen suggested that the dolomite mountains themselves were in truth altered coral-reefs, formed during subsidence of the land, while the fauna of the St. Cassian and of the Raibl strata had been developed in the restricted lagoons, bays, and channels of a coral sea.

This explanation[2] of the origin of the dolomite *massifs* in Southern Tyrol as a varying and disconnected reef-facies during continued deposition of sedimentary beds has been accepted and supported, after careful original investigations in the district, by the well-known geologists Stur[3] and Mojsisovics.

The publication of the latter's book, 'Die Dolomit-Riffe von Süd-Tyrol u. Venetien' in 1879 embraces the work of several geologists associated with him in a survey of the district. A large extent of country was mapped (scale 1 : 75000), and Mojsisovics entered fully into the question of facies. In this work the nomenclature of the strata differs somewhat from that of Richthofen, *e. g.* the 'Sedimentary Tuffs' and 'Cipit Limestones' of Richthofen in the Seisser Alpe section are included by Mojsisovics as Wengen strata, and the name of 'St. Cassian strata' is limited to the small upper series of beds containing the well-known and unusually rich fauna collected chiefly on the Stuores meadow, near St. Cassian, in the Enneberg Valley.

In developing and extending the application of the coral-reef theory of Richthofen, Mojsisovics emphasized the 'heteropic'[4]

[1] 'Geogn. Beschr. d. Umg. v. Predazzo,' pp. 40–43.

[2] In several cases Austrian geologists have found Richthofen's coral-reef theory applicable to the occurrence of thick masses of limestone elsewhere, and in other formations than the Trias. I may mention the recent work of Dr. Franz Wähner in the Rofan Group, near the Achen See, in Northern Tyrol. Dr. Wähner attributes the white Liassic limestones of Sonnwendjoch to the agency of corals, while a facies-development of foraminiferal limestone occurs quite near, on Pfons Joch. Zeitschr. d. Deutsch. Alpenver. vol. xxii. 1891.

[3] 'Eine Excursion in der Umgegend von St. Cassian,' Jahrb. d. k. k. geol. Reichsanstalt, 1868, p. 529.

[4] [On p. 6 of his 'Dolomit-Riffe,' Mojsisovics explains, as follows, 'heteropisch' (a compound apparently derived from ἕτερος and ὄψ, ὀπός):—'Ebenso wie sich zu gleicher Zeit und neben einander im selben Raume verschiedenartige Facies bilden, erscheinen in verschiedenen Räumen (Provinzen) und zu verschiedenen Zeiten gleichartige Facies. Die ersten nennen wir *heteropische*, die letzteren *isopische* Bildungen.' See also his paper 'Ueber heteropische Verhältnisse im Triasgebiete der lombardischen Alpen,' Jahrb. d. k. k. geol. Reichsanstalt, 1880, p. 695.—Ed.]

nature of the Upper Triassic rocks. He differed from Richthofen in assuming that the coral-reefs began to form in certain localities directly after the deposition of the Muschelkalk strata.

A case in point is offered by the dolomite-rock of the Schlern mountains. Referring to Richthofen's section (*op. jam cit.* pp. 40–43) this rock is regarded as a reef built on a subsiding portion of Muschelkalk rock after the period of the deposition of the Buchenstein and Wengen Beds exposed on the Seisser Alpe. The highest beds exposed on the Seisser Alpe contain a St. Cassian fauna, and these are the beds regarded by Richthofen as the time-equivalent of the dolomite-reef in part; he further believed that the reefs continued to grow after the St. Cassian period, and that Raibl Beds and a Raibl fauna spread themselves then irregularly above the reefs and above the St. Cassian Beds in the channels beyond. The name of 'Schlern Dolomite' was given by Richthofen to the dolomitic rock developed within these ages.

Richthofen's idea that after Muschelkalk time a gradual uprising of the rock, followed by subsidence, took place in the Schlern district and farther south, was not accepted by Mojsisovics, who held that the reefs grew upon the Muschelkalk during the deposition of the whole series of Buchenstein, Wengen, and St. Cassian sedimentary beds. Mojsisovics, therefore, gave up the name of 'Schlern Dolomite,' and introduced names for the dolomitic horizons in correspondence with the names of the non-dolomitic beds. The alteration thus introduced by him may be represented as follows:—

Richthofen's Succession.		Mojsisovics' Succession.	
Conformable Succession.		Sedimentary Beds.	Dolomitic Facies.
Raibl Beds.	Raibl Beds.	Raibl Beds.	
Schlern Dolomite.	Schlern Dolomite.	St. Cassian Beds.	St. Cassian Dolomite.
St. Cassian Beds.	(Unconformity.)	Wengen Beds.	Wengen Dolomite.
Wengen Beds.			
Buchenstein Beds.		Buchenstein Beds.	Buchenstein Dolomite.
Muschelkalk (Mendola Dolomite).		Muschelkalk.	

Many cases are quoted by Mojsisovics as affording proof of the 'heteropism' of the strata, either by the thinning-out of the zones of sedimentary beds in the dolomitic facies, or by the conformable succession of the Raibl Beds, sometimes on the dolomitic, sometimes on the non-dolomitic facies of the St. Cassian horizon.

Ever since its first publication the coral-reef theory has had its opponents. In the year 1872 Gümbel[1] published a paper on the Mendola and Schlern mountains, in which he gave several sections, and made a comparison between the succession of Triassic strata in Northern and Southern Tyrol. He proved that the Mendola and Schlern Dolomites could be distinguished as palæontological horizons. In the Mendola Dolomite the fossil of most frequent occurrence is *Gyroporella pauciforata*, Gümbel, characteristic of the Muschelkalk in the Northern Alps, whereas in the Schlern Dolomite other species of *Gyroporella* occur, especially *G. annulata*, Schafh., common in the Wetterstein Kalk in Northern Tyrol. Gümbel defined the Schlern Dolomite in a twofold sense:

1. As the dolomite-rock equivalent in age to the whole series of sedimentary strata, from the lowest St. Cassian Beds exposed on the Seisser Alpe (Richthofen's 'Sedimentary Tuffs' included here) to the 'Red Raibl Beds' of the Schlern plateau.

2. As the dolomite-rock denoting a distinct palæontological horizon lying above the St. Cassian strata and below the Raibl strata.

Gümbel opposed Richthofen's coral-reef theory, chiefly on the ground that there was little proof of coral agency, corals being seldom found in the Schlern Dolomite, whereas algæ such as *Gyroporellæ* are often obtained and with their fine structure well-preserved. He also showed that the variation in thickness of the Schlern Dolomite was analogous to the variation in other rocks, such as the Wetterstein Kalk in the Bavarian Tyrol. These objections of Gümbel were replied to by Richthofen in a paper 'Ueber Mendola-Dolomit u. Schlern-Dolomit.'[2]

Loretz,[3] who published the first detailed study of the Ampezzo district in two papers (1874–75), did not accept the reef-theory. At the same time he recognized two equivalent facies of strata, a dolomitic and a non-dolomitic, representing the period between the Muschelkalk and the Raibl strata. In this he anticipated the view of the complete 'heteropic' development of the Buchenstein, Wengen, and St. Cassian zones held by Mojsisovics.

Lepsius,[4] in his work on the Nonsberg *massif*, south-west of the Schlern mountains, concluded that the Schlern Dolomite in that district was a stratified marine deposit, covering an immense area, and that the same deposit varied in thickness in the Schlern and Fassa districts, mainly owing to the outpouring, during its period of deposition, of masses of volcanic matter.

[1] 'Das Mendel- u. Schlern-Gebirge,' Sitzungsb. d. math.-phys. Classe d. k. bayerisch. Akad. d. Wissensch. vol. iii. (1873) p. 14.

[2] Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxvi. (1874) p. 225.

[3] 'Das Tirol-Venetianische Grenzgebiet der Gegend von Ampezzo.' *ibid.* p. 377; 'Einige Petrefacten der alpinen Trias aus den Südalpen,' *ibid.* vol. xxvii. (1875) p. 784.

[4] 'Das Westliche Süd-Tirol,' Berlin, 1878; see particularly pp. 77–83.

III. Topography of the District.

In the valleys of Ampezzo and Enneberg, south of the Pusterthal, the Wengen and St. Cassian Beds are well exposed, and abundant opportunity is afforded of studying their stratigraphical position with regard to the overlying strata.

I mapped in detail three areas in the northern part of the 'Dolomite Alps.'[1]

(A) The classical district of St. Cassian in Enneberg and Sett Sass;
(B) The Falzarego Valley, west of Cortina d'Ampezzo;
(C) The Prags Valley and the Dürrenstein mountain near Toblach.

The field-work was done upon the Survey Maps of Austria-Hungary, scale 1 : 25000; the maps published with the present paper are reduced to the scale of 1 : 50000, or 1·267 inch to the mile.[2]

With the view of securing at once a series of typical sections I made several traverses of other districts, such as the Seisser Alpe, north of Schlern; the Sella Joch and the Gröden Joch; the Lower Enneberg; Tre Croci and Misurina. Only a part of my observations in these districts is given here.

The Enneberg Valley opens into the main east-and-west valley of the Pusterthal at Bruneck, while the Ampezzo Valley opens into the Pusterthal at Toblach.

The Gader stream flows north through Enneberg, cutting in its upper part through the Abtey slopes between Stern and St. Leonhardt (Abtey). At Stern the two branches of the Gader stream meet; these are the Pescadoi or Grosser stream from the west (on which Colfuschg and Corvara lie) and the Sore stream (on which St. Cassian lies) from the north. The Sore is joined higher up by the Eisenofen (or Valparola) and by the Stuores and Piccol streams.

The Gardenazza *massif* rises on the western side of the Enneberg Valley, and the Sella *massif* extends farther south, forming the watershed between this northern region and the Fassa district. Between these two dolomite-*massifs* the Gröden Pass leads from Enneberg to the Grödenthal. The latter is the narrow valley north of Lang Kofl, Platt Kofl, and Schlern, which joins the Eisack some distance north of Botzen.

On the eastern side of the Enneberg Valley the great *massif* of Kreuz Kofl, La Varella, Centurinus and Lagazuoi extends south to the Tra i Sassi Pass. The district of Sett Sass and Prelongei lies between the two sources of the Gader (Sore and Grosser streams), is bounded by the Buchenstein Valley in the south and south-east, and is surrounded on every other side by dolomite-*massifs*.

The Tra i Sassi Pass leads from Enneberg eastward to Cortina, between Sett Sass and Lagazuoi, and holds north of Nuvolau. The Ospizio in Falzarego is high on the eastern side of the Pass, and the

[1] These three areas are included within the Austrian Map. Scale 1 : 75000; Sheet Cortina, Zone 19, Col. vi.

[2] The sections are drawn to the natural scale, vertical and horizontal; but in some cases the dip of the beds, and therefore the thickness, has been slightly exaggerated.

road to Cortina continues to descend for the greater part of its length along the northern bank of the Costeana stream. Tofana Prima and Secunda form high dolomite-*massifs* north of the valley, while Nuvolau and Cinque Torri extend along the southern side.

Cortina lies in a deep basin where two tributary streams, the Costeana from Falzarego and the Bigontina from Tre Croci in the east, open into the Boita Valley. Ascending the Boita Valley the Ampezzo road leads north between Tofana and Pomagagnon, then turns eastward at Peutelstein and passes between Croda Rossa and Cristallo to Schluderbach. Here the road again turns northward and follows the course of the Rienz stream past Landro to Toblach. West of the road is the Dürrenstein *massif*, extending north and south between the Rienz Valley and the high mountain-pass of the Plätz Alp. Northward it is bounded by high-lying meadows; an outer band of dolomite, the Sarl Kofl and Sarl Brand, forms then the steep descent north of the Dürrenstein to the Pusterthal between Toblach and Niederdorf.

IV. The General Stratigraphical Succession.

The Triassic strata exposed within the district examined are, in descending order:—

8. The Dachstein Dolomite.
7. The Raibl Beds.
6. The Schlern Dolomite.
5. The St. Cassian Beds.
4. The Wengen Beds.
3. The Buchenstein Beds.
2. The Muschelkalk.
1. The Werfen Beds.

1. *The Werfen Beds.*[1]—A glance at the geological maps accompanying this paper (facing pp. 18, 28, and 32) shows that the Werfen Beds seldom have an outcrop in the districts examined. They are mainly exposed in the neighbourhood of the crystalline schists south of the Pusterthal, near Prags, and again in the Lower Enneberg Valley. In the Cortina district they are nowhere exposed. In the Upper Enneberg, an exposure of Werfen Beds occurs from the Gröden Pass eastward towards the village of St. Cassian, but their chief extent is farther south, along the valley of Buchenstein.

These strata are a series of dark-grey limestones and marls, argillaceous shales, reddish micaceous or sandy clays, attaining a thickness of 300 to 500 feet. Their characteristic fossils are *Posidonomya Clarai*, Emmrich, and *Naticella costata*, Münster.

2. *The Muschelkalk.*—In all the above-mentioned cases of outcrop of the Werfen or Lower Triassic Beds, they are conformably succeeded by beds of limestone and dolomite, containing characteristic Muschelkalk fossils.

[1] The name was given to this lowest horizon of Alpine Trias from the village of Werfen in Salzkammergut.

This series has been subdivided in Southern Tyrol into:—

Upper Muschelkalk (=Richthofen's 'Mendola Dolomite').
Characteristic fossils:—
Trachyceras trinodosum, Mojs.
Ptychites gibbus, Benecke, etc.

Lower Muschelkalk (=Richthofen's 'Virgloria Kalk').
Characteristic fossils:—
Trachyceras binodosum, Hauer.
Ptychites Studeri, Hauer.
Terebratula vulgaris, Schloth.

At both horizons occurs the representative fossil alga, *Gyroporella pauciforata*, Gümbel. Where exposed in the Buchenstein and Enneberg Valleys, the Lower Muschelkalk Beds are dark, bituminous, evenly-bedded limestones and shales varying from 40 to 60 feet in thickness. Near Prags, these beds are at least 300 feet thick; in the lower portion they are greyish or reddish limestones and bituminous shales, succeeded by a great thickness of greyish-white dolomitic limestone and dolomite containing *Gyroporella pauciforata* often in great number.

The Upper Muschelkalk is throughout a pure dolomite, drusy and crystalline, brittle, and forming débris of small angular fragments. Although well-bedded in thick massive layers, the planes of bedding are often less striking to the eye than those of the vertical joints and clefts, and are, moreover, in some measure obscured by the general effects of weathering. Like the Lower Muschelkalk, this dolomite also varies much in thickness; thus in Enneberg it is very little developed, not reaching more than 120–150 feet, while in the Prags district it reaches a maximum thickness of 1200 feet.

3. *The Buchenstein Beds*.—The village of Buchenstein or Pieve (from which these beds derive their name) lies in the Buchenstein Valley, south of Prelongei and Sett Sass.

The strata succeed the Muschelkalk conformably, and their fauna shows so great a similarity to that of the underlying formation that several authors[1] have included them as a higher zone of Alpine Muschelkalk. Besides such typical Upper Muschelkalk fossils as *Terebratula angusta*, Schloth., *T. vulgaris*, Schloth., *Pecten discites*, Schloth., sp., *Trachyceras binodosum*, Hauer, others specially characteristic of this horizon occur, e. g. *Tr. Reitzi*, Böckh, *Tr. Böckhi*, Roth., *Halobia Taramellii*, Mojs., etc.

Hard limestone-beds with siliceous concretions, and the 'Pietra Verde' rock so characteristic of Southern Tyrol, together with interbedded fossiliferous shales, predominate in the exposures found near Buchenstein and farther west. On the other hand, the 'Pietra Verde' and siliceous limestones, although present in the neighbour-

[1] See especially Loretz, *op. cit.* Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxvi. (1874) p. 406, etc.

hood of Prags, are less developed and of less marked character, while thick beds of dark-blue limestones containing plant-remains, and more rarely the typical ammonites and brachiopods, are interstratified with dark bituminous shales, and form the greater thickness of the Buchenstein series.

4. *The Wengen Beds.*—The Wengen Beds, and indeed all the higher members of the Triassic succession, have a much wider distribution in the districts which I have mapped than the foregoing strata.

The conformable succession of Wengen Beds above Buchenstein Beds is proved in all the outcrops of Lower and Middle Trias already indicated. Enneberg is the classical district of Wengen and St. Cassian Beds. It was in the village of Wengen, lying in one of the transverse valleys of Lower Enneberg, that the characteristic fossils were first collected. The name of Wengen strata was then given by Wissmann ('Petrefaktenkunde,' p. 21). Emmrich had called these strata on the Seisser Alpe '*Halobia*-strata.' Farther south, in the vicinity of Spessa, on Armentara Berg, and throughout the whole Gader stream-cutting from Abtey (or St. Leonhardt) as far as the confluence of the Sore and Eisenofen streams, the outcrop of the Wengen Beds and of the St. Cassian Beds succeeding them on the higher ground has given rise to the slopes and meadows of Upper Enneberg. More favourable exposures of the Wengen Beds are found on the southern slopes of Prelongei, between the villages of Corvara and Buchenstein, and from these the sections to be presently described were mainly taken.

As the Cortina map shows (Map B, facing p. 28), true Wengen Beds are but little exposed in the Ampezzo Valley.

In the Prags district, the Wengen Beds have a wide outcrop on the Sarl Alp and Schafriedl, and on the Kameriod Wiesen.

5. *The St. Cassian Beds.*—These richly fossiliferous strata are spread over the Prelongei Alpe and occur on the higher parts of the surrounding slopes. In the other districts mapped, near Cortina and the western slopes of the Dürrenstein, the St. Cassian Beds extend, in my opinion, over a wider area than has hitherto been admitted.

I now enter into the details of the original maps and sections with regard to the Wengen and St. Cassian Beds; the strata lying above them will be described later on in this paper.

V. Stratigraphy of the Wengen and St. Cassian Beds.

The succession of these strata in the districts of Corvara, Prelongei, and Sett Sass is described in detail in the annexed Table, with reference to the three typical sections (figs. 1, 2, 3, on pp. 17, 19, 21) through the area of Map A.

Tabular Description of the St. Cassian and Wengen Beds (in descending order).

(Map A.)

Section I., p. 17.

Corvara and Ruones Wiese.

(Lower parallel section=cutting of Kirchen Bach.)

Middle St. Cassian.

15. Fossiliferous marls (characteristic Stuores fossils); thin shaly limestones with *Posidonomya*, n. sp.: ashy grits, unfossiliferous thin-bedded shales, limestones, and sandstones, with frequent unrecognizable plant-remains.

14. Thick-bedded grey-blue limestone, with augite-porphyry and tuff. The limestone is altered at both its contact-surfaces with the volcanic rocks.

Low. St. Cas.

13. Marls and hard thick-bedded limestone. This limestone has a rough, yellow-weathered surface, sometimes has no fossils, sometimes is full of cidarid spines and stem-fragments of *Encrinus cassianus*, Laube.

Fault

Middle St. Cassian.

12. Fossiliferous marls and thin-bedded limestones. These are more favourably exposed farther south, in the Ruones Muren (see Additional Remarks on p. 17); here some thickness of beds is concealed under grassy meadows before the complex of beds No. 11 is reached.

11. Marls and limestones, the marls ferruginous, the limestones oolitic and containing a few characteristic Stuores or St. Cassian fossils, small gasteropods and brachiopods.

10. Dark bluish limestone, with a few doubtful ammonite specimens, along with one good specimen of *Trachyceras Aon*, Münst. sp., and several of *Posidonomya wengensis*, Wissm.

Augite-porphyry and tuff.

Lower St. Cassian.

9. Thin-bedded marls (unfossiliferous); volcanic bed, 1 foot thick (tuff), beds of aragonite, one oolitic limestone-bed with St. Cassian fossils.

8. Hard, thick-bedded, yellow-weathering Cipit Limestone with rough surface; in this are found occasional specimens of *Cidaris dorsata* (Braun) and other cidarid species.

Upper Wengen.

7. Blue, fissile marls (*Posidonomya wengensis*); thick beds of limestone, with veins of calcite, poor specimens of *Ammonites*, sp., and of *Posidonomya*, sp.; also stems of ferns.

Thin-bedded shales and limestone, often interbedded with aragonite-layers.

6. Beds of volcanic tuff and ashy calcareous grit (unfossiliferous).

Shales full of *Posidonomya wengensis* and the small variety of the same (?) species (originally known in the literature as *Avicula globulus*, Wissm.).

Lower Wengen.

5. Thin-bedded black tuffs, shales, marls, and limestones, occasionally with fragments of stems and leaves of plants. These beds vary constantly in strike and dip owing to bending and slight faults.

4. Fine breccias of tuff and calcareous material. Shaly limestones with *Halobia Lommeli*, Wissm., and *Posidonomya wengensis*, Wissm.

3. Hard thick limestone.

2. Augite-porphyry, of great thickness, and beds of volcanic tuffs.

1. Black *Halobia*-shale, with the well-known 'Wengen flora' from the Corvara locality.

Section II., p. 19.

Prelongei and Stuores Wiese.

Middle St. Cassian.

12. Fossiliferous marls (concealed in great measure by fallen blocks from the Dachstein Dolomite and Raibl Beds of the western part of Sett Sass) containing several fossils, especially ammonites; together with large blocks of limestone containing encrinite and cidarid fragments, and scattered over the whole meadows. These are probably the remnant of higher beds of fossiliferous St. Cassian strata now eroded from the ridge and slopes of Prelongei.

11. Fossiliferous marls, and thicker beds of fossiliferous oolitic limestone with yellowish-weathered surface; interbedded ferruginous marls and shales and layers of aragonite. This horizon is mainly that in which the great number of Stuores fossils occur (50–60 feet).

10. Less fossiliferous thin-bedded shales, marls, oolitic and shaly limestones. Beds of tuff and ashy sediment. Thin, blue, marly limestones, with calcite veins; light grey shales with *Posidonomya*, n. sp.; ashy rocks with fragments of fossils, especially thick shells of bivalves. Among the fossils actually found in position in these beds are:—*Nucula lineata*, Gdf.; *Terebratula cassiana*, Bittn.; *Mytilus Münsteri*, Klipst.; *Koninckina Leonhardti*, Wissm. sp.; several species of *Cidaris* and corals. The fossils occur in the marls and shales belonging to the higher portion of the series. The whole complex is exposed in a series of 'Muren' on the southern side of Prelongei, as well as in frequent slips on the northern side.

9. Blocks of augite-porphyry strewn singly; sometimes a bed of dark-blue limestone occurs in position, and augite-porphyry along with it.

Low. St. Cass.

8. Unfossiliferous shales and marls; thick series of hard-bedded sandy-looking limestone. This is sometimes very fossiliferous (true St. Cassian fossils), and sometimes it is developed like the characteristic Cipit Limestone of the Seisser Alpe.

Up. Weng.

7. Thin-bedded unfossiliferous limestones and shales containing a few poor specimens of cidarid spines.

6. *Posidonomya wengensis*-shales, interbedded with grits, often ashy.

L. Weng.

5. Thick series of black tuffs.

4. Beds containing *Halobia Lommeli*.

3. Augite-porphyry and breccias.

2. Augite-porphyry and tuffs.

1. Buchenstein Beds.

Section III., p. 21.

Sett Sass and Monte Sief.

(Lower parallel section=Castello Wiese.)

Schlern Dolomite.

Middle St. Cassian.

14. Fossiliferous marls and thin beds of limestone, containing the fauna included in the fossil-list under Sett Sass (Forcella). Interbedded limestones contain almost solely corals and encrinites.

13. Lens-shaped mass of drusy, unfossiliferous dolomite, known as 'Richthofen Riff,' thinning out in the series of fossiliferous marls as thick beds of limestone (Cipit Limestone), with cidarid spines and, rarely, brachiopods.

12. Thin-bedded marls, covered largely by blocks of the higher dolomite and limestone. These beds are continuous with the strike of the beds on the Prelongei ridge, and agree with them in lithological and palæontological character (*cf.* Prelongei section, and fig. 2, p. 19). Yellowish shaly limestone and fossil-bearing marls.

11. Coarse grits with fragments of fossils and of volcanic rock (mixed together as a rock possibly better named a volcanic and calcareous breccia).

Typical oolitic limestone with St. Cassian fossils. Hard porphyry and ashy grits. Beds of aragonite; reddish grits with fossils and yellow-weathered limestones. Ashy grits and ferruginous marls.

Thin-bedded shaly limestone with *Posidonomya*, n. sp., which may be followed eastward under the blocks.

10. Beds of porphyry and tuff. Hard limestone with cidarid spines. Volcanic tuffs.

L.C.

9. Yellowish fossiliferous limestones and marls. Blocks of Cipit Limestone with corals.

U.W.

8. Grits, shales, and ashy beds. Some poor specimens of *Posidonomya wengensis* found.

Lower Wengen.

7. Calcareous grits and shales, with *Halobia Lommeli*, Wissm., *Posidonomya wengensis*, Wissm., *Trachyceras Gredleri*, Mojs.

6. Argillaceous tuff, with plant-remains.

5. Grey limestone-bed.

4. Volcanic grits and agglomerates.

3. Augite-porphyry and agglomerates, with lenticular masses of irregularly-bedded felsitic rock.

2. Limestone (one thick bed), interbedded with rough slaggy conglomerate and true porphyritic rock.

1. Unfossiliferous greyish-blue crystalline limestone, followed as two thick bands of rock among interbedded shales and ashy, thin-bedded limestone. = Buchenstein Beds.

Note.—In the parallel section of Castello Wiese, the beds of series No. 11 (in part) and of Nos. 10 and 9 are wanting. The section then continues as follows:—

L. Cas.

9a. Calcareous thick-bedded grits. Impure ashy limestone with coarse texture and yellow-weathered surface.

Upper Wengen.

8a. Thin-bedded oolitic limestones and marls rarely containing fossils, *Cidaris dorsata*, encrinite-remains, and poor impressions of *Posidonomya wengensis* occur, together with frequent impressions of plants. (These series, Nos. 9a and 8a, are wanting in the upper section of Sett Sass and Monte Sief.)

8. Ferruginous earthy beds, interstratified with ashy grits. (*Cf.* No. 8 in upper section).

L. W.

7. *Halobia*-shales. (*Cf.* No. 7 in upper section.)

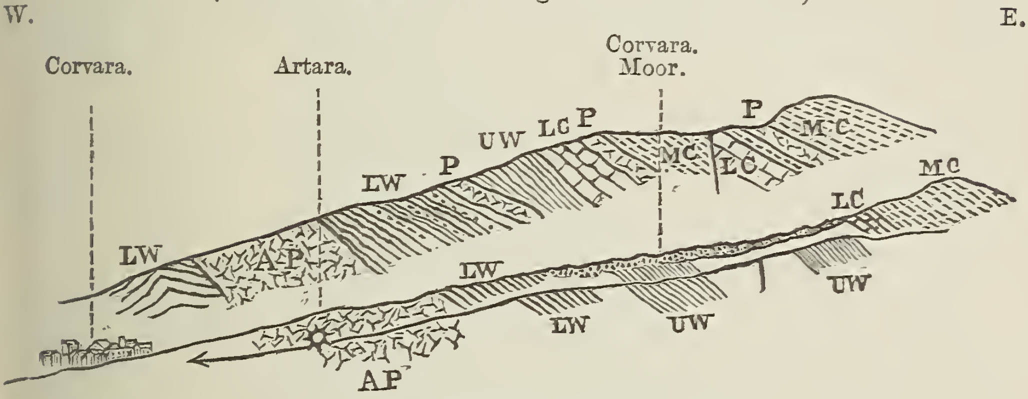
Tuffs and volcanic rocks.

[These lower beds strike through the Castello Wiese as a continuous series with Nos. 6–1 exposed on Monte Sief.]

Section 1. *Corvara and Ruones Wiese.* (See Table and Map A.)

Fig. 1.—*Section through the Ruones Wiese.*

(The lower section is along the Kirchen Bach.)



[Scale : $\frac{1}{37500}$ = 1·9 inch to the mile.]

For explanatory index, see p. 19.

Additional remarks.—In the Ruones Muren, between Kirchen Bach and Incisa Bach, very fossiliferous strata are exposed; they correspond to bed No. 12 (Middle St. Cassian) in the first column of the Table, and contain the same fossils as are found on Stuores Wiese. These strata are (in descending order):—

Series corresponding to No. 12 in the Table.
- Marls, often ferruginous, and thin layers of aragonite.
- Grey limestones and shales with irregular surface, sometimes ripple-marked.
- Oolitic limestone-beds, several inches thick, containing at intervals highly fossiliferous layers from 1 to 3 inches thick.
- Unfossiliferous marls, limestones, aragonite, etc.
- Fossiliferous, yellowish, oolitic limestone, sometimes crowded with corals and sponges.
- Fossiliferous marls and thin-bedded shaly limestones.
- Thick bed of limestone in which alternating layers, fossiliferous and non-fossiliferous, may be distinguished.

Marls, etc., of the more ashy series denoted in the Table as Nos. 10 and 11, etc., containing fewer fossils.

In the succession of beds described for Section 1, Nos. 13 to 15 are identical with the beds of Nos. 8 to 12, and these relations continue for some distance north and south. A slight fault causes the fossiliferous series to occur at the two levels.

From the fossils which I carefully collected at the various horizons I classify the succession of beds in this section in two groups:—

St. Cassian Series	= Nos. 15–8.	See Table.
Wengen Series	= Nos. 7–1.	

The Wengen Series is continued with a general north-and-south strike over the Incisa Pass, and has a wide distribution on the heights of Campolungo. In the woods towards Rudort Valley the exposures are unfavourable, and I found few fossils even in the higher slipped portions of rock. The beds dip slightly outward from the hill, and are at times much contorted. The best exposure of

Wengen Beds is seen along the Rudort stream where it bends towards Corvara, cutting through a conformable succession of rocks from augite-porphyry and *Halobia*-shales to St. Cassian Beds below the Crap de Sella rock. The occurrence of some slight throws does not seriously interfere with the succession. The 'contact' appearances in the beds of No. 6 are here very clearly shown.

Section 2. Prelongei and Stuores Wiese. (See Table and Map A.)

Additional remarks.—The beds form a shallow syncline, dipping more steeply on the southern side, 20° to 25°, and less on the northern, 5° to 10°; general strike east and west.

This section, described in the Table, offers peculiar difficulties, owing to the slips of larger or smaller portions of rock. On the southern side the beds of Nos. 11–7 are exposed in steep 'Muren,' and the débris from these are heaped up at all the lower levels, and on the banks of the Selvaza sources coming from Prelongei. Following the strike of the beds, frequent opportunities are afforded in the streams and on the slopes above Contrin of convincing one's self that there is a conformable series from Contrin to Prelongei, agreeing in the main with the series in Section 1. This section has the more value, as the underlying Muschelkalk and Werfen Beds, exposed along the Buchenstein Valley, follow conformably in downward succession.

On the Stuores side of Prelongei, the beds are so altered in their position by the small throws, associated with the slips, that in the meadows drained by the sources of the Piccol stream the exposures have a north-easterly strike. Lower down the strike is more regular.

While the most richly fossiliferous beds are limited to the comparatively thin series No. 11, from 50 to 60 feet, these are borne downwards as a cap, from the high ridge of Prelongei towards the lower-lying meadows of Stuores and Piccol, on the soft yielding mass of the underlying ashy and less fossiliferous beds. To this fact, as well as to the very slight dip of the strata, and the many minor throws they have undergone, we owe the ever-renewed abundance of the St. Cassian fossils strewn on the banks of the streams and on the hillocks of slipped material.

At the same time many fossils are found, belonging to true St. Cassian species, in beds Nos. 10, 9, 8 in the tabular description (facing p. 16), and according to their evidence the strata may be grouped as follows:—

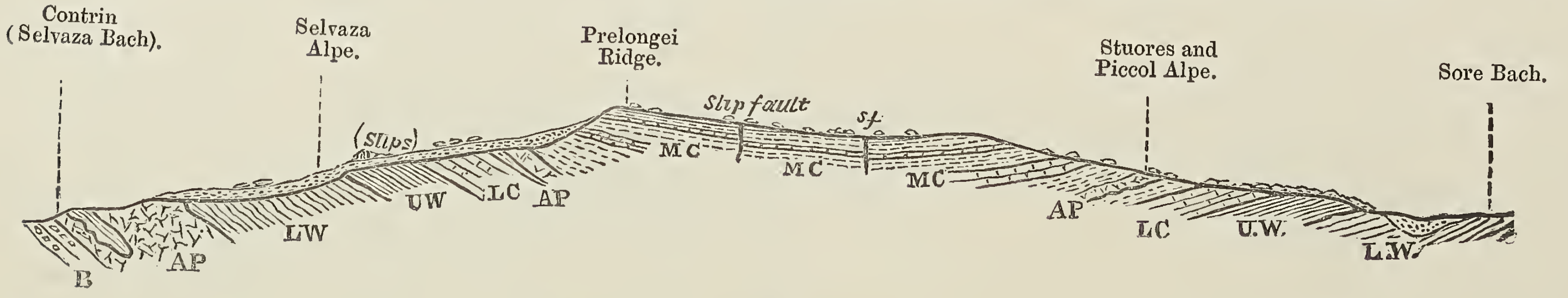
$$\left.\begin{array}{ll}\text{St. Cassian Beds} & = \text{Nos. 12–8.}\\ \text{Wengen Beds} & = \text{Nos. \ 7–2.}\end{array}\right\}\text{ See Table.}$$

Section 3. Sett Sass and Monte Sief. (See Table and Map A.)

Additional remarks.—The important fact here proved is that the fossiliferous series of St. Cassian Beds underlie conformably the dolomitic rock of Sett Sass. This is seen, not only on the Forcella between Sett Sass and the Richthofen Riff, but also in two or three places where Sett Sass bends round towards the west.

Note.—The area left white immediately south of Sett Sass is the Richthofen Riff.

Fig. 2.—*Section from Contrin over the Prelongei Ridge to the Sore Bach.* (See Table.) N.



[Scale: $\frac{1}{50000}$ = 1·267 inch to the mile.]

MC = Middle St. Cassian (' Stuores' horizon).
LC = Lower St. Cassian (Cipit Limestone).
UW = Upper Wengen Beds (*Posidonomya wengensis*-shales).
LW = Lower Wengen Beds (*Halobia Lommeli*-shales).
AP = Augite-porphyry.
B = Buchenstein Beds.

The fossiliferous beds of Prelongei continue in a general easterly direction with the strike, although often lost sight of under the long lines of blocks tumbled from Sett Sass Berg, and pass under the lens-shaped dolomitic rock of the Richthofen Riff. They form the slight hollow eroded between the Riff and the mass of blocks on the Castello Wiese, and are occasionally traced on the banks of streams flowing eastward to the Valparola stream. The series of beds, Nos. 10 to 8 in the Prelongei section, are however cut off on the Castello Wiese by an east-and-west line of fault, demonstrable in two ways:—

(1) The light-grey shales with *Posidonomya*, n. sp. (the species differs slightly from *Posidonomya wengensis*), which form a constant horizon in the St. Cassian strata of this district of Prelongei (see Section 1, No. 16, and Section 2, No. 10), pass over the ridge and are traced beneath the blocks on the Castello Wiese. This is true for other beds, such as the ashy series, the ferruginous marls, and the beds of hard Cipit Limestone. One after another, these beds are cut off, and beds of a different palæontological and lithological character appear in their place.

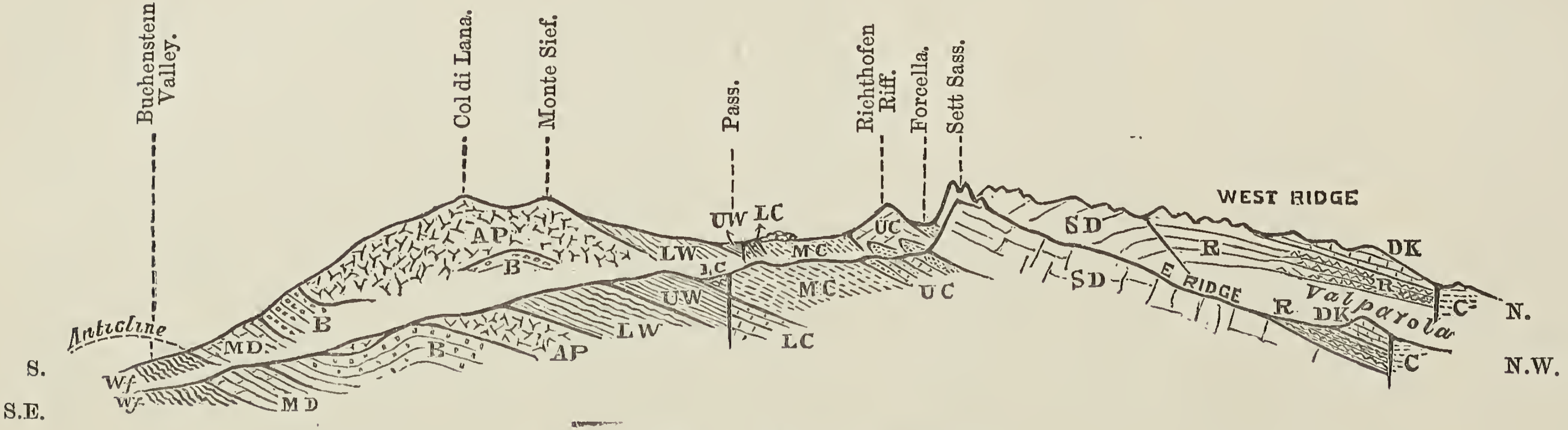
(2) The beds thus cut off have in the neighbourhood of the line of fault a strike N. 50° W., and the beds faulted against them strike N. 25°–30° E., the two systems meeting almost at right angles to one another.

The succession of beds in the section, although interrupted by this fault-line, fall into the main groups as before:—

	Sett Sass and Monte Sief.	Castello.	
St. Cassian Beds . .	Nos. 14–9. * * *	Nos. 14–11 (in part). * * * No. 9 *a*.	See Section 3 in Table facing p. 16.
Wengen Beds	* * * Nos. 8–2.	No. 8 *a*. No. 8–2.	
Buchenstein Beds . .	No. 1.	No. 1.	

The Wengen and St. Cassian strata of all three sections may be further subdivided into well-marked zones, based both on palæontological and stratigraphical evidence. A marked feature in the Prelongei district is the occurrence of thickly-bedded and sometimes massive limestones at the base of the St. Cassian Series. They have all the appearance of, and agree palæontologically with, the Cipit Limestones first recognized by Richthofen on the Seisser Alpe. In several traverses which I made over St. Cassian and Wengen strata exposed in various localities between the Seisser Alpe and the district of Prelongei, I observed such Cipit Limestones always at the horizon where the St. Cassian fauna begins to appear, and where the commonly occurring Wengen fossils begin to lessen in number. I have therefore accepted this horizon as the best stratigraphical limit between the Wengen and St. Cassian Beds.

Fig. 3.—*Section from the Buchenstein Valley through Sett Sass.*



[Scale : $\frac{1}{50000}$ = 1·267 inch to the mile.]

DK = Dachstein Dolomite.	LC = Cipit Limestone—Lower St. Cassian.	B = Buchenstein Beds.
R = Raibl Beds.	UW = Upper Wengen Beds.	MD = Mendola Dolomite (Muschelkalk).
SD = Schlern Dolomite.	LW = Lower Wengen Beds.	Wf = Werfen Beds.
UC = Forcella Zone. } Middle	AP = Augite-porphyry (with Agglomerates).	
MC = Stuores Zone. } St. Cassian.		

This horizon is further accentuated by a sheet of augite-porphyry in the fossiliferous marls and limestones immediately above the Cipit Limestone, and the subsequent intermixture of ashy rock with the ordinary marine sediments. The fossils in the ashy rocks are few and fragmentary, but passing upward they increase in number and variety, until in the beds on the Prelongei ridge the St. Cassian fauna as such reaches its highest point.

As appears from Section 3, a higher series of fossiliferous marls and shaly limestones succeeds, in which thick beds of limestone and a dolomitic rock thin out. The limestone-rock has been called 'Cipit Kalk,' and indeed it looks exactly like the Cipit Limestone of the lower horizon. Nevertheless, it is no constant bed at this horizon; the beds above and below have the same characters and the same fauna, whereas the Cipit Limestone group at the lower horizon has both a stratigraphical and palæontological value. Above this, the highest fossiliferous series, the rock is entirely dolomitic.

For palæontological reasons which are explained below, I have grouped the whole series of strata between the Lower St. Cassian zone and the Schlern-Dolomite rock of Sett Sass as the 'Middle St. Cassian' or 'Stuores' zone; farther east, a higher palæontological horizon succeeds above the 'Stuores' zone and below the Schlern Dolomite. In collecting the fossils in the St. Cassian district I was very careful to keep separate these of the Forcella di Sett Sass from those of Prelongei and Stuores meadows, the 'Forcella' zone having been more than once referred to Raibl age.

	Local Development and Exposure.
Middle St. Cassian Beds.	The 'heteropic' strata of the Richthofen Riff and Castello conformably underlying the Schlern Dolomite. Fauna: see List of Fossils found on Forcella di Sett Sass. The series of fossiliferous beds on the Prelongei ridge. The less fossiliferous ashy beds forming the main mass of the strata on Stuores, Piccol, Ruones and Corte slopes. Fauna: see List of Fossils, pp. 48 *et seqq.*, under 'Stuores' (Prelongei, Stuores, Piccol, Ruones and Corte slopes included).
Lower St. Cassian Beds.	Hard thickly-bedded limestone, sometimes forming massive rock—occurring as a firm band throughout the lower level of the slopes mentioned above. Fauna: pre-eminently that of a reef-limestone, including: *Cidaris dorsata*, *C. Rœmeri*; *Encrinus cassianus*, *Pentacrinus propinquus*; *Thamnastræa Zitteli*.

The best exposures of Wengen Beds occur on Monte Sief and near Corvara; and, comparing these, a lower series, in which sedimentary tuffs, ashy grits, and *Halobia*[1] *Lommeli*-shales predominate,

[1] [In a recent publication—'Die Perm- Trias- und Jura-Formation auf Timor und Rotti' (Palæontographica, vol. xxxix. Aug. 1892), Dr. A. Rothpletz has shown (pp. 91–96) that the differences hitherto recognized between *Daonella* and *Halobia* are not of generic value; the older name of *Halobia* is therefore used throughout the present paper.]

may be distinguished from an upper series, where the rocks remain comparatively free from the black volcanic material and are filled with remains of *Posidonomya wengensis*.

		Ruones.	Prelongei.	Sett Sass and Monte Sief.
Wengen Beds.	Upper Wengen Beds (not more than 100 feet thick).	Nos. 7 & 6	Nos. 7 & 6	Nos. 8^a & 8 (in Castello section)
	Lower Wengen Beds (not less than 200 feet thick).	Nos. 5–3	Nos. 5 & 4	Nos. 7–5 (Monte Sief)
	Augite-porphyry, tuffs, and *Halobia*-shales.	Nos. 2 & 1	Nos. 3 & 2	Nos. 4–2 (*ibid.*)
			Buchenstein Beds.	Buchenstein Beds.

It is more especially in the Lower Wengen Series of black tuffs and thin-bedded shales that the bending and faulting occur. The augite-porphyry is very thick, and, together with the tuffs and black *Halobia*-shales of Corvara, adds a considerable thickness to the Wengen Series.

Only after a detailed examination of the Wengen and St. Cassian Beds, such as has been above attempted, is it possible to attain a clear idea of the tectonic relations of the neighbourhood of St. Cassian. I could only map the main faults; while the numerous small disturbances in the beds of a single series could not be shown in the reduced map which accompanies this paper. But the fact that it is impossible to walk for half an hour in these meadows without meeting some apparently insignificant change in the strike and dip is, if in the beginning bewildering, in the end the surest testimony that the whole succession has been subjected at one time or another to great strain and pressure; the small faults within the series of softer beds have thus an important significance with regard to much greater faults in the near vicinity.

The outlying parts of the geological map of Prelongei and Sett Sass, those towards the Sella *massif*, Centurinus Spitz, and Lagazuoi, were not examined in the same detail as the central area, but only with the view of confirming the broad features of the succession and of determining the tectonic relations of the district.

Sections 4 *and* 5. *Enneberg* (*Abtey*). (See pp. 26, 28.)

The next two sections which will be considered are taken from the Abtey portion of Enneberg; they are to the north of the area included within Map A. The first is drawn in an east-and-west direction from the Kreuz Kofl (9500 feet) through the exposures beside the Heiligkreuz Kirche (a pilgrimage chapel at a height of 6600 feet), meets the Gader stream (4200 feet), and ascends on the opposite side to the Gardenazza *massif* at a level of about 6200 feet. In the line of section the Gardenazza Berg does not reach a greater height than 7600 feet.[1]

Section 4 (see p. 26).

A. Gardenazza Slope.

Schlern Dolomite.

Middle St. Cassian.	A certain portion of marly beds almost entirely covered by the dolomite-blocks from above. Shaly thin-bedded limestones, with interstratified thick beds of fossiliferous limestone (the fossils are typical 'Stuores' St. Cassian). Beds of dark blue limestone with calcite-veins, less fossiliferous (about the 1740 met. contour-line). Ashy shales, and beds of tuff. (Sometimes fossils occur in the shales; plant-remains are very frequent.)
Lower St. Cassian.	Oolitic limestone-beds, especially full of corals and encrinites (*Encrinus cassianus*, Laube), various sponges and cidarid spines.
Wengen.	Grey shaly limestones and dark shales at the 1600 met. contour. Numerous well-preserved specimens of *Posidonomya wengensis* and of the previously mentioned small variety of *Posidonomya* (sp.?); *Trachyceras furcatum*, Münst., 1 specimen. Several ammonites were found, but not in good preservation. Rough marls and limestones, with plant-remains and unrecognizable fossils on the weathered surface. Some of these were cidarid spines. A series of ashy grits and sandy rocks, brown earthy tuffs, and impure limestones; not well exposed, except in the course of the Gader stream below St. Leonhardt (Abtey).

The St. Cassian Beds in this section strike through the Abtey 'Muren' towards Pescol, where the characteristic fossils are found both lying free and in the hard limestone-rock.

B. Heiligkreuz Slope.

Dachstein Dolomite of Kreuz Kofl.

Raibl Beds.

* * * * * * * * *

Upper St. Cassian.	'Heiligkreuz Schichten'[2] (according to the original application of the name by Wissmann) = grey, thinly-bedded shaly limestones with (*Natica*) *Ptychostoma sanctæ-crucis*, Wissm. sp.; *P. pleurotomoides*, Wissm. sp.; *Nucula inflata*, Wissm.; *Avicula depressa*, Wissm.;

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[1] I give these heights in the usual English measure, but the sections are more conveniently described with direct reference to the Austrian Survey Map, by using the 100-metre contours.

[2] The name of 'Heiligkreuz Schichten' was first used by Wissmann ('Beiträge zur Geognosie u. Petrefactenkunde des S.-O. Tirols,' Heft iv. pp. 19, 21, Bayreuth, 1841) to denote 'einige graue Kalksteinschichten, welche auf dem rechten Gehänge des Abteithals und zwar etwa in der Mitte zwischen der weithin sichtbaren Heiligkreuzkirche und St. Leonhardt (Abtei) ganz isolirt zu Tage gehen.' Wissmann then gives the list of fossils.

Upper St. Cassian.	*Av. Gea*, d'Orb.; (*Unionites*) *Anoplophora Münsteri*, Wissm.; *Omphalophyllia boletiformis*, Münst. sp. The horizon containing these fossils extends some distance above and below the Heiligkreuz Kirche (thickness about 70 feet).
Middle St. Cassian.	Series of marls and concretionary shales, with occasional thicker beds of limestone much disturbed by slips. Fossils:—*Nucula strigilata*, Goldf.; *N. lineata*, Goldf.; *Mytilus Münsteri*, Klipst.; *Halobia Richthofeni*, Mojs. sp.; *Koninckina Leonhardti*, Wissm. sp.; *Pentacrinus propinquus*, Münst.; *P. lævigatus*, Münst.; *Cidaris* (various); *Omphalophyllia cyclolitiformis*, Laube; *Lobites pisum*, Wissm. [These beds were apparently included by Wissmann with the 'Heiligkreuz Schichten.']
Lower St. Cassian.	Thick beds of limestone below the 1900-metre contour (at this horizon the weathered stones and blocks scattered about had the Cipit Limestone character). *Encrinus cassianus* frequent.
Wengen Beds.	Limestones, thinly-bedded and full of *Posidonomya wengensis*, Wissm. (below the 1800-metre contour). Ferruginous clays and shales. Plant-bearing sandstones and shales. Ashy rock, chiefly earthy unfossiliferous tuffs and grits. Although the Wengen Beds on both sides of the valley have a large outcrop, they are seldom favourably exposed, and I did not succeed in finding good fossils.

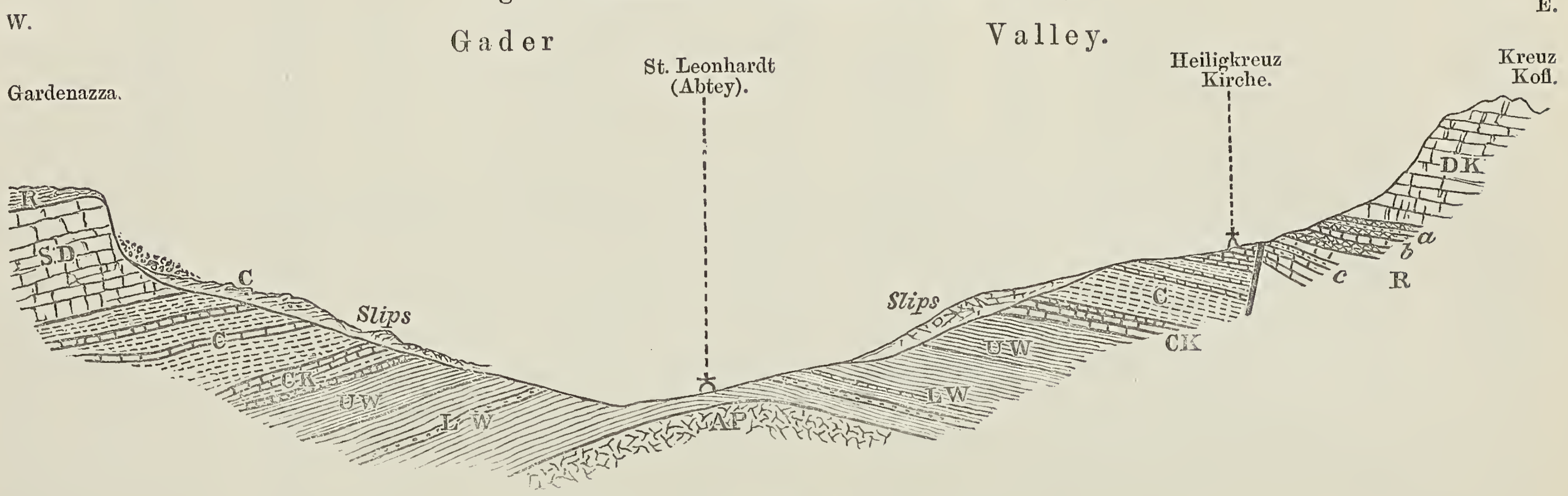
Having convinced one's self of the conformable succession of the Schlern Dolomite upon the St. Cassian strata at this part of the Gardenazza *massif*, it is the more striking to find this dolomitic horizon entirely absent in the section of the eastern side of the valley. This fact, no less than the special character of the fossils in the so-called 'Heiligkreuz Schichten,' has made the Abtey valley almost as interesting to geologists as the neighbourhood of St. Cassian.

The stratigraphical question will be discussed later, but the palæontological difficulty is to fix the age of the 'Heiligkreuz strata.' The beds immediately above them are indisputably of Raibl age; they are also very fossiliferous, and they have gradually become known in the literature as 'Heiligkreuz strata.' This confusion was largely due to a generally-held opinion that both series of strata were of Raibl age, and the main line of effort in the literature has been to determine with what horizons of the Raibl Beds they should be correlated.

Richthofen's sequence of strata from below the Heiligkreuz Kirche up to the Dachstein Kalk may be thus shortly quoted (in descending order):—

- Limestone of Kreuz Kofl.
- Red sandstone with lignite, interstratified with fossiliferous limestone (*Ostræa montis-caprilis*, Klipst.; *Fimbria* (*Corbis*) *Mellingi*, Hauer, sp., etc.).
- Reddish limestone.
- 'Heiligkreuz Schichten' with *Anoplophora Münsteri*, Wissm., *Avicula Gea*, d'Orb., etc.
- Dolomite-bank with baryta.
- Fine-grained sandstone.

Fig. 4.—*Section from Gardenazza to Kreuz Kofl.*



[Scale : $\frac{1}{50000}$ = 1·267 inch to the mile.]

DK = Dachstein Dolomite.

R = Raibl Beds. { *a.* Dolomitic marls, breccias, and flags. *b.* Marls and dolomite. *c.* Fossiliferous beds.

SD = Schlern Dolomite.

C = Middle St. Cassian (' Stuores' zone).

CK = Cipit Limestone beds (Lower St. Cassian).

UW = Upper Wengen shales and limestones.

LW = Lower Wengen ashy shales.

AP = Augite-porphyry.

Note.—The limestones shown at the Heiligkreuz Kirche are ' Heiligkreuz Strata' (Upper St. Cassian).

Richthofen described the stratigraphical position of the 'Heiligkreuz strata' as being above the St. Cassian Beds, and remarked that it was possible, owing to similarity of the fossils, to look upon the 'Heiligkreuz strata' merely as a higher stage of St. Cassian. However, influenced by other reasons, and from the fact that at that time the same fauna had not elsewhere been found either in the Raibl or St. Cassian Beds of the district, he concluded that they belonged in reality to a much higher horizon than the St. Cassian Beds.

Stur[1] found the same fossils as those collected by Wissmann, also *Myophoria chenopus*, Laube, and *Cardinia problematica*,[2] Klipst. A comparison of the fossils found at the horizon of the 'Heiligkreuz strata' and in the higher horizon of beds containing *Ostrea montis-caprilis*, Klipst., led Stur to group the whole series together as the probable equivalent in age of the 'Torer' horizon of Raibl strata (*i. e.* Upper Raibl). He noted, however, certain resemblances between the special mode of development of the 'Heiligkreuz strata' and the strata on the Forcella di Sett Sass—both he regarded as Raibl Beds. Mojsisovics, on the other hand, assigned the Heiligkreuz Series ('Dolomit Riffe,' pp. 263, 264) to *Lower* Raibl, resting conformably on St. Cassian strata containing *Halobia cassiana*, Mojs. sp., *H. Richthofeni*, Mojs. sp., etc.

After comparison of the fossils from the 'Heiligkreuz Schichten' of Wissmann (sections on pp. 24 & 25) I regard these beds as a true St. Cassian horizon, succeeded unconformably at Heiligkreuz by a true Raibl horizon (viz. the *Ostræa*-limestone, etc.). For there is no characteristic fossil in the 'Heiligkreuz strata' which has not been found in the St. Cassian strata, either on Stuores or below Sett Sass. *Anoplophora Münsteri*, Wissm., and *Avicula Gea*, d'Orb., occur in the strata below Sett Sass. The *Ptychostomata* occur on Stuores; *Myophoria chenopus*, Laube (identified by Wöhrmann with *Myophoria Whateleyæ*, Buch, sp., a characteristic Raibl form) is found both below Sett Sass and on Stuores Wiese, as also *Cardita crenata*, Goldf.

The peculiarity of the fauna rests alone in the fact that at Heiligkreuz the species are few and the individuals very numerous. In the main the fauna is of St. Cassian type, although some species are common to the later 'Raibl' period. The horizon of the 'Heiligkreuz Schichten' is higher than the St. Cassian strata of Prelongei and Forcella di Sett Sass, and may be called "Upper St. Cassian."

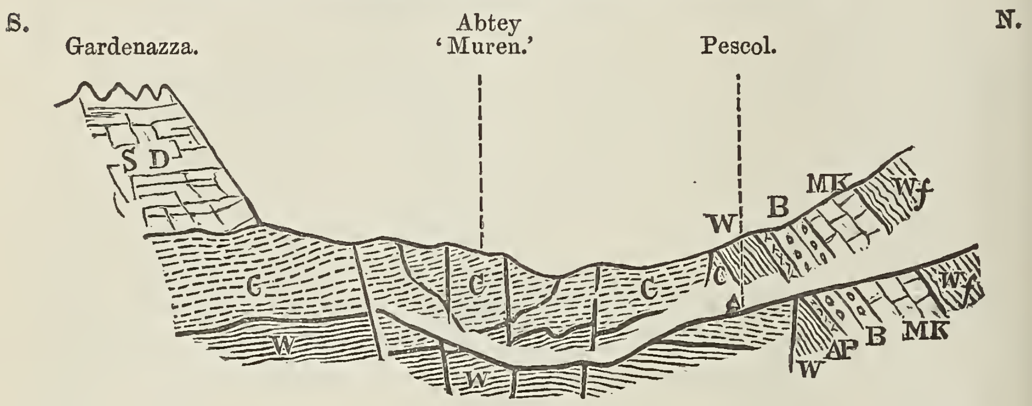
I must briefly mention Section 5 (p. 28) to the north of Gardenazza. On going over the pass between the Gader and Campil valleys, St. Cassian fossils are found among the rocks below Gardenazza. Just as on the eastern side, the marls and limestones on

[1] Stur, 'Eine Excursion in die Umgegend von St. Cassian,' Jahrb. d. k. k. geol. Reichsanstalt, 1868, pp. 555, 556, and 'Beiträge zur Kenntniss d. geol. Verhältnisse d. Umgegend von Raibl u. Kaltwasser,' *ibid.* pp. 111–117.

[2] *Cardinia* (*Unio*) *problematica*, Klipst. sp., is quoted by Klipstein as occurring in beds at a much lower horizon on the slopes; see his 'Beiträge zur geol. Kenntniss d. östlichen Alpen,' p. 265, Giessen, 1843.

the western side have given way in a number of places, although no such extensive landslip has occurred as on Abtey Muren. These beds are continued westward and underlie conformably the Schlern Dolomite of Zwischenkofl. (See p. 65 for further notes on this Section.)

Fig. 5.—*Section from Gardenazza northward.*



[Scale : $\frac{1}{37500}$ = 1·9 inch to the mile.]

SD = Schlern Dolomite.
C = St. Cassian Beds.
W = Wengen Beds.
AP = Augite-porphyry.

B = Buchenstein Beds.
MK = Mendola Dolomite.
Wf = Werfen Beds.

Cortina d'Ampezzo (*Map* B).

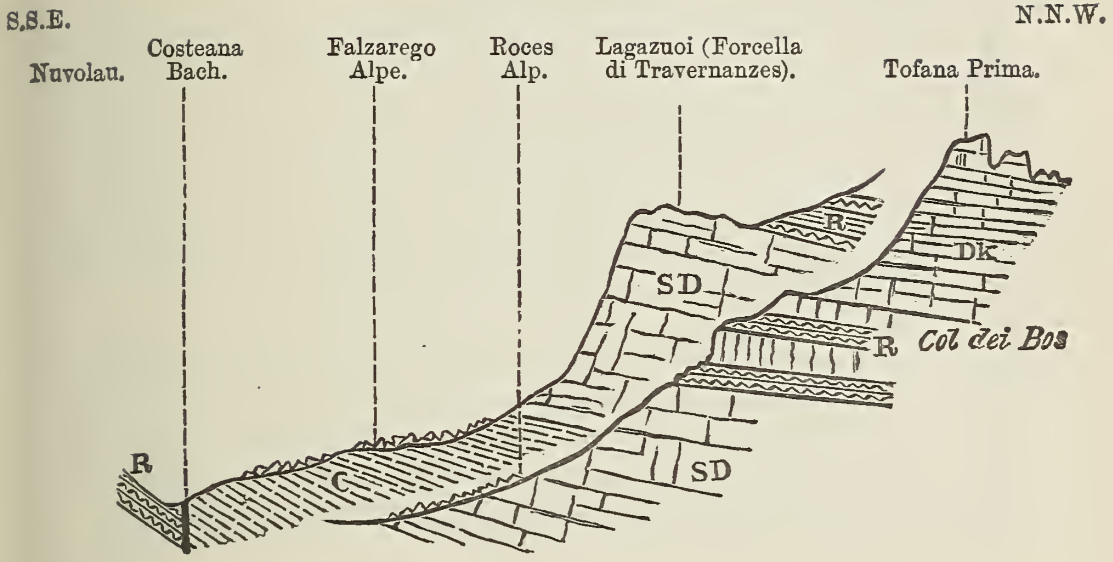
The district of Ampezzo has occupied a less important place in the older literature than Schlern and the Seisser Alpe or St. Cassian. Loretz, who first made known the fauna of the Falzarego Valley, Misurina, and Seeland Valley, laid the foundation of our knowledge of the Ampezzo dolomites; and the work of Hoernes in co-operation with Mojsisovics materially advanced the geology of the district.

The meadows and slopes west of Cortina d'Ampezzo proved of unusual interest for the study of St. Cassian strata, and I spent several days in collecting the fossils at various horizons. The localities where the fossils weather out of the beds in any considerable number are:—

(1) On the hill above Romerlo.
(2) Below the Majorera ridge, in the stream-sources and the exposed slips of thick series of beds, facing Crepa.
(3) Among the wooded slopes of Roscatto e Fratta, from the highest beds below the rocks of Tofana to the Costeana stream in the valley.
(4) South of the Costeana stream, in a series of strips along its southern bank, eastward from Pec di Palu.
(5) West of Ospizio in Falzarego, in marls and limestones conformably underlying the dolomite-rock of Lagazuoi.

GEOLOGICAL MAP OF FALZAREGO VALLEY & CORTINA

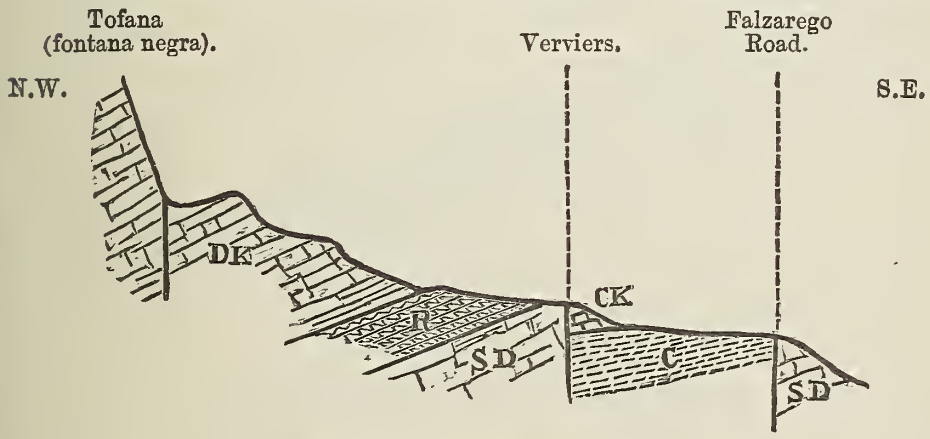
Fig. 6.—*Section through the Roces Alpe.*



[Scale: $\frac{1}{25000}$ = 2·534 inches to the mile.]

DK = Dachstein Dolomite.
R = Raibl Beds.
SD = Schlern Dolomite.
C = St. Cassian Beds.

Fig. 7.—*Section from Tofana (fontana negra) to the Falzarego Road.*



[Scale: $\frac{1}{50000}$ = 1·267 inch to the mile.]

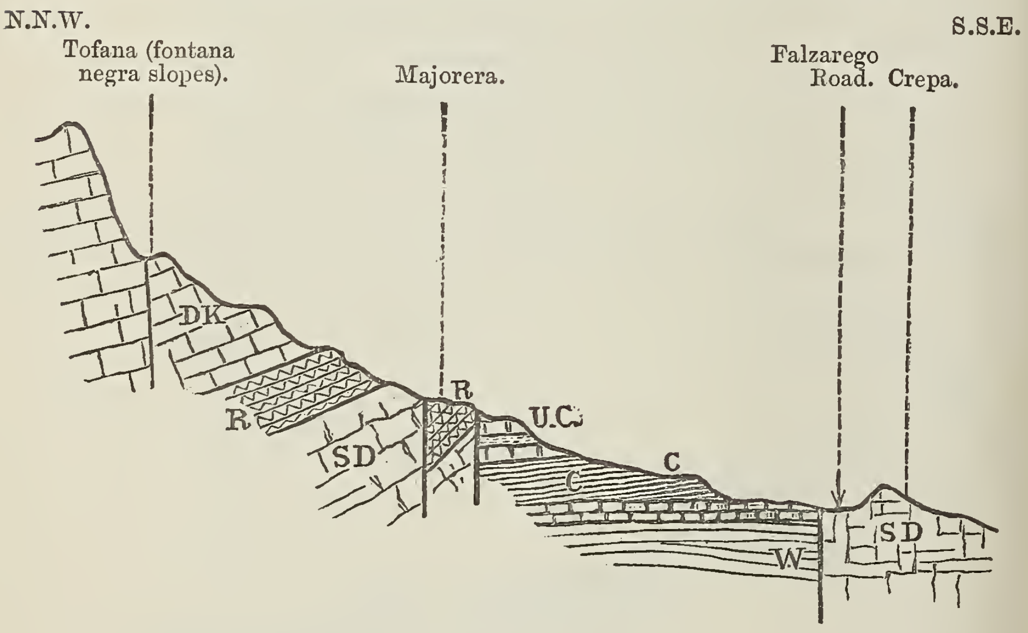
DK = Dachstein Dolomite.
R = Raibl Beds.
SD = Schlern Dolomite.
Upper St. Cassian. { CK = Cipit Limestone Beds.
C = Ferruginous Marls.

Fig. 6 (p. 29) has chiefly a tectonic interest, and will be referred to under Part VIII. of this paper (p. 67).

The strata on the Falzarego Alpe, which conformably underlie the Schlern Dolomite of Lagazuoi, and extend down to the Costeana stream, contain the typical St. Cassian fossils; and the series may be traced farther west, conformably underlying the Schlern Dolomite on both sides of the descent from the Tra i Sassi Pass towards Valparola. The same beds, containing an identical fauna, are exposed beside the Raibl Beds and the Dachstein Dolomite north of Sett Sass, and appear with their greatest outcrop freely exposed on the Stuores Wiese, Prelongei, and the Forcella di Sett Sass.

Fig. 7 may be compared with fig. 8; in the latter a conformable succession of the fossiliferous strata is shown from the Majorera slope, at about the 1800-metre contour, to the meadows at the base of Crepa, between the 1400 and 1500-metre contours. The beds strike north and south, and dip not more than 10° west.

Fig. 8.—*Section from Tofana (fontana negra) to Crepa.*



[Scale: $\frac{1}{50000}$=1·267 inch to the mile.]

For explanation, see index to fig. 9, p. 32.

Upper St. Cassian Beds (see 'Cortina' in the List of Fossils, pp. 48 *et seqq.*).	Below the 1800-metre contour a hard, light grey limestone-rock, sometimes slightly dolomitic, containing spines of *Cidaris dorsata*, and looking like the Cipit Limestone of lower horizons. In parts of the rock, bedding is more marked, and fossils weather out. Cidarid spines, small corals and gasteropods were found. Shaly limestone-beds, breccias of tuff and limestone, highly fossiliferous. This rock is often coloured dark red by interstitial ferruginous earth.

Middle St. Cassian (see 'Romerlo' in the List of Fossils).	(About the 1600-metre contour) reddish-brown ferruginous marls, and black earthy beds, containing characteristic St. Cassian fossils and, in especial abundance, various species of *Cidaris*. Marls and thin-bedded limestones, aragonite and gypsum-bands, with sometimes large geodes; very good specimens of corals and sponges were found.
Lower St. Cassian.	Hard yellowish limestone, breaking up in large blocks; on the weathered surface of some of these, lithodendroid corals and encrinites are frequently seen.
Wengen Beds (part).	Ashy beds, exposed in the streams below Lacedel.
	Débris at lower levels.

The character of the fossils which occur in the five lowermost divisions of the above section; the great predominance in number of the small bivalves, gasteropods, cidarid spines, corals, and sponges; as well as the lithological character of the hard limestone, the marly beds and loose ferruginous earth in which the fauna occurs, enable one to refer these horizons with certainty to the St. Cassian Series.

The Middle St. Cassian strata are present on the hill and the 'Wiese' west of Romerlo, on the slopes west of the Verviers chalets, again south of the Costeana stream, and west of Ospizio in Falzarego. The Upper St. Cassian strata have their chief exposure south-east from Verviers and in the stream-sources below the Majorera ridge, conformably above the wide outcrop of Middle St. Cassian on the 'Wiese.' The fossils found in the last-named strata are at once recognizable as essentially a 'Stuores' fauna, but in the Upper St. Cassian, although many species of corals, gasteropods, etc., are characteristic of the 'Stuores' horizon, a certain number of species are common to both St. Cassian and Raibl faunas (e.g. *Grünwaldia* (*Cassianella*) *decussata*, *Myophoriopis lineata*, *Avicula Gea*, *Ptychostoma pleurotomoides*, *Cidaris dorsata*), while several species, such as the very commonly occurring *Avicula*, n. sp., and *Placunopsis*, n. sp., have not yet been found in any other locality.

The palæontological relations of these two horizons of St. Cassian strata are more fully discussed in Part VII. of this paper (p. 45).

As has already been said, the 'Heiligkreuz strata' of the previous section contain a limited fauna which seems to diverge from that of the Middle St. Cassian strata of Stuores. The fossils of the 'Heiligkreuz strata' do not definitely prove a higher horizon; they might be simply a local facies. It is therefore very important to find that two of the characteristic species found in the 'Heiligkreuz strata,' *Ptychostoma pleurotomoides* and *Naticopsis neritacea*, are common in these Upper St. Cassian strata of the Cortina district. This fact suggests that the 'Heiligkreuz strata' are the equivalent in part of the Upper St. Cassian horizon.

I have dwelt at some length on the St. Cassian strata of Cortina, chiefly because they have for the most part been included with the Wengen strata by Mojsisovics, with the Schlern-plateau strata (Raibl fauna) by Loretz, and also because the fauna up to this time was comparatively little known.

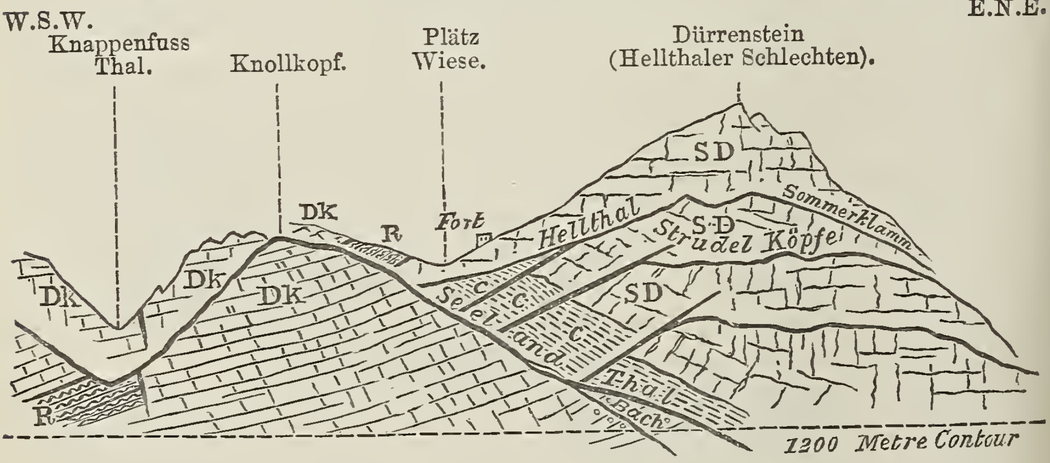
As the Cortina map shows (Map B, facing p. 28), St. Cassian Beds are faulted against all the higher strata—Dachstein Dolomite, Raibl Beds, and Schlern Dolomite, and the identification of the fauna is all-important for the tectonic relations of the valley.

Section 9. *St. Cassian and Wengen Beds in the Dürrenstein Massif* (*Map* C).

Although the fossils collected in the Seeland Valley, north of Schluderbach, have been familiar to palæontologists since Loretz's first examination of them in 1874,[1] the exact age of the strata in which they occur remains still doubtful. Loretz referred the beds, like those on Cortina and Falzarego meadows, to the horizon of the Raibl strata known generally as Schlern-plateau strata, while in Mojsisovics' 'Dolomit-Riffe' they are regarded as Wengen Beds, with the exception of a very small portion at the head of the Seeland Valley, which are recognized as St. Cassian Beds.

The strata of the Seeland Valley are composed of fossiliferous marls and shales, unfossiliferous beds of hard light-grey limestone with celestine or calcite-veins, and thinly-bedded unfossiliferous shaly limestones. In the higher horizons some thick limestones occur,

Fig. 9.—*Section through Knollkopf and the Dürrenstein.*



[Scale: $\frac{1}{50000}$ = 1·267 inch to the mile.]

[The Schlern Dolomite of the Dürrenstein should have been shown dipping to the W.S.W., and passing conformably under the Raibl Beds.]

DK = Dachstein Dolomite.
R = Raibl Beds (marls, limestone, rauchwacke).
SD = Schlern Dolomite.
UC = Upper St. Cassian Limestones.
C = St. Cassian Strata (marls of the Stuores zone in fig. 8; fossiliferous marls and limestones, unfossiliferous marls and shales in fig. 9).
W = Wengen shales and limestones.

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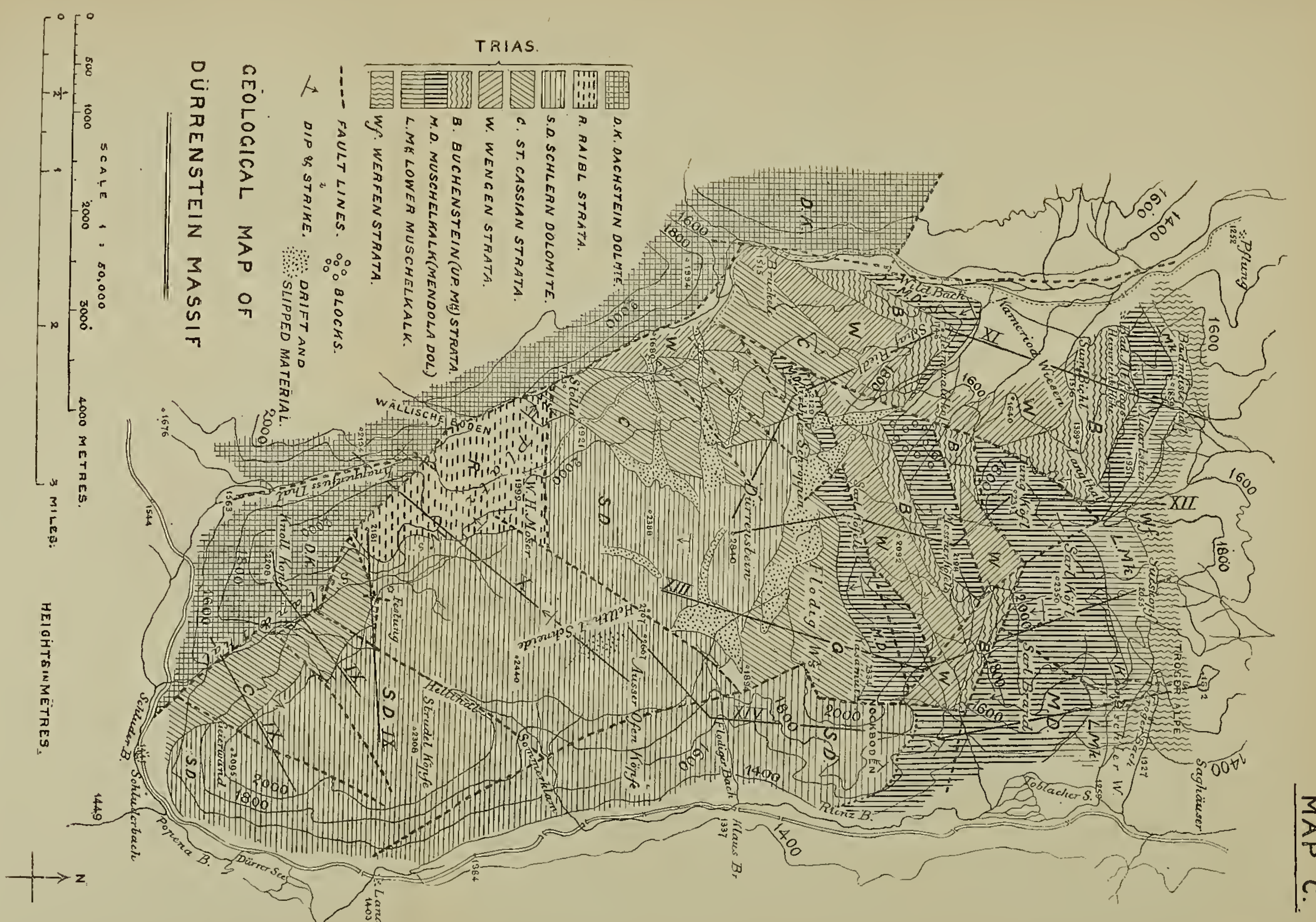
[1] 'Einige Petrefacten d. alpinen Trias a. d. Südalpen.' Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxvii. (1875) p. 784; see also *ibid.* vol. xxvi. (1874) p. 377.


MAP C.
GEOLOGICAL MAP OF DÜRRENSTEIN MASSIF
TRIAS.
D.K. DACHSTEIN DOLMTE.
R. RAIBL STRATA.
S.D. SCHLERN DOLOMITE.
C. ST. CASSIAN STRATA.
W. WENGEN STRATA.
B. BUCHENSTEIN (UP. Mk) STRATA.
M.D. MUSCHELKALK (MENDOLA DOL.)
L.Mk LOWER MUSCHELKALK.
Wf. WERFEN STRATA.
FAULT LINES.
BLOCKS.
DIP & STRIKE.
DRIFT AND SLIPPED MATERIAL.
SCALE 1 : 50,000
0 500 1000 2000 3000 4000 METRES.
0 ½ 1 2 3 MILES.
HEIGHTS IN METRES.
N
Dürrenstein
Flodig
Wällische Boden
Toblacher S.
Rienz B.
Saghäuser
Pflung
Klaus Br.
Landro
Dürrer See
Schluderbach
Popena B.
Sarl Kofl
Strudel Kopfe
XI
XII
XIII
XIV
IX

full of corals and sponges, and larger blocks from these, weathering to a bright yellow colour, are strewn across the valley. The fossils in the marly beds weather out loose, and are found, as at Stuores, in a perfectly preserved state. If the ground here be carefully studied and the fossils collected in the individual beds, the extent and distribution of the various horizons may be clearly marked, and it is found that the confusion complained of in the Seeland Valley is largely owing to two small cross-faults which have brought the fossiliferous strata in immediate contact with less fossiliferous beds. I have attempted to represent these relations in Section 9 by drawing parallel sections in perspective through different heights of the Seeland Valley, from the Ampezzo road (at a height of about 4600 feet) to the prominent rock on which the new fort is built (height about 6600 feet).

The interest of the Seeland Valley centres in the fauna, and, referring to the List of Fossils (pp. 48 *et seqq.*), it becomes at once clear that, as in the case of Cortina, the greater number of species agree with the true Stuores fauna, but a certain number are new. To accept the Seeland Valley strata as a facies of Raibl Beds would be difficult on stratigraphical grounds, for they unquestionably dip under the Schlern Dolomite of the Dürrenstein. As St. Cassian fossils occur in greater or lesser number throughout the whole series of strata exposed in the valley, I have mapped these as St. Cassian, distinguishing the higher horizons, containing many new species, as Upper St. Cassian Beds. In recent palæontological work this view is already gaining ground. For example, Bittner[1] says, with reference to the brachiopods which he describes from Falzarego, Misurina, and the Seeland Valley:—"The strata of these three localities belong apparently to the same horizon, which, if not identical with that of St. Cassian, stands, as regards fauna and stratigraphical position, at any rate very near [to it]."

Kittl[2] says:—"Judging from the position of the St. Cassian strata on the Seeland Alpe, these seem to answer to the upper part of the *Aon*-zone of the Stuores-Wiese St. Cassian Beds, with which they agree in lithological characters."

In the second part of the same paper, Kittl, influenced by the occurrence of the same species in all three localities (Stuores Wiese, Heiligkreuz, and the Seeland Valley), says in a short note that probably, after all, the Heiligkreuz strata may not be far removed from the *Trachyceras Aon*-zone. The specimens in question were of *Ptychostoma pleurotomoides*: this species, and also the characteristic *Naticopsis neritacea*, I found on the Cortina meadows. Without doubt, the further examination of the fauna in all four localities will supply corroborative evidence of their close relationship.

[1] 'Brachiopoden der Alpinen Trias,' Verhandl. d. k. k. geol. Reichsanstalt, vol. xiv. (1890) p. 112.

[2] 'Die Gastropoden der Schichten von St. Cassian der südalpinen Trias,' Annal. d. k. k. Naturhist. Hofmuseums, vol. vi. pp. 166–262, Vienna, 1891.

Fig. 10.—*Section from Badmeister Kofl to the Dürrenstein.*

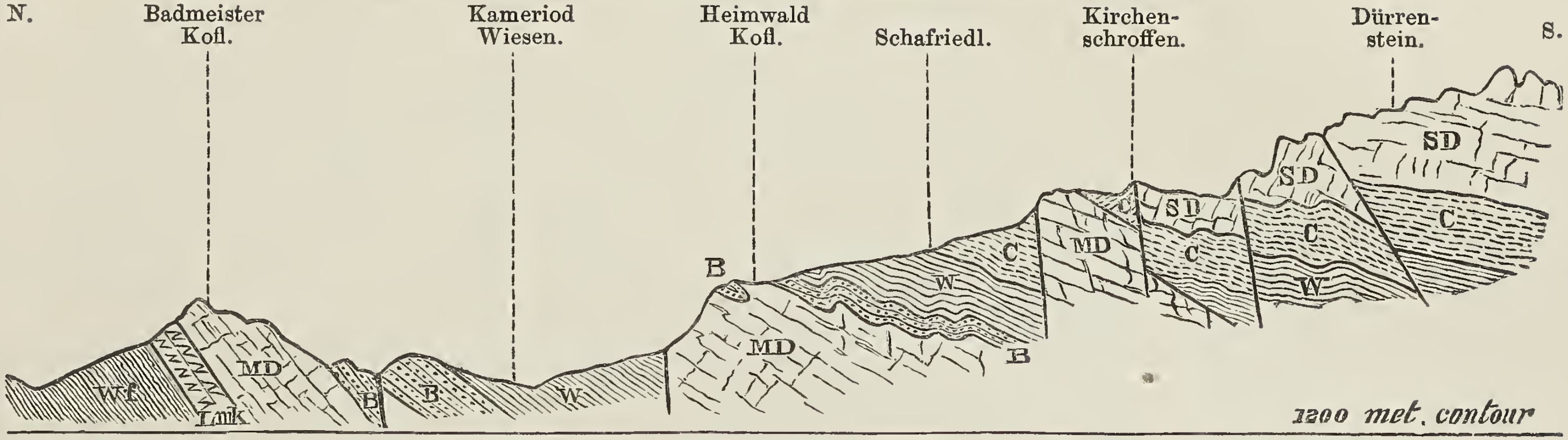
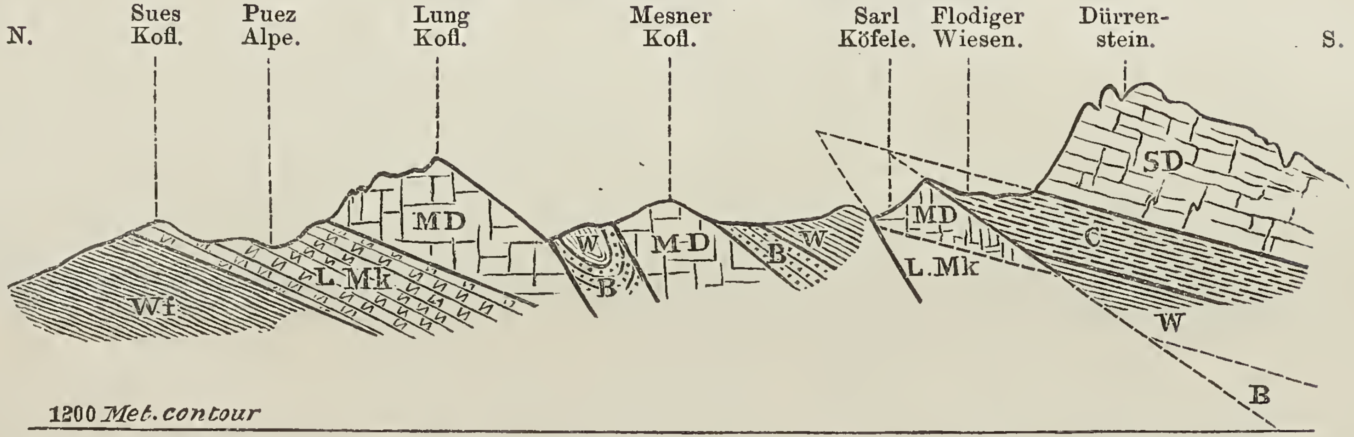


Fig. 11.—*Section from Sues Kofl to the Dürrenstein.*



SD = Schlern Dolomite.	B = Buchenstein Beds and Upper Muschelkalk.	LMk = Lower Muschelkalk.
C = St. Cassian strata.	MD = Mendola Dolomite.	Wf = Werfen Beds.
W = Wengen Beds.		

Fig. 12.—*Section from the Dürrenstein to Sarl Kofl.*

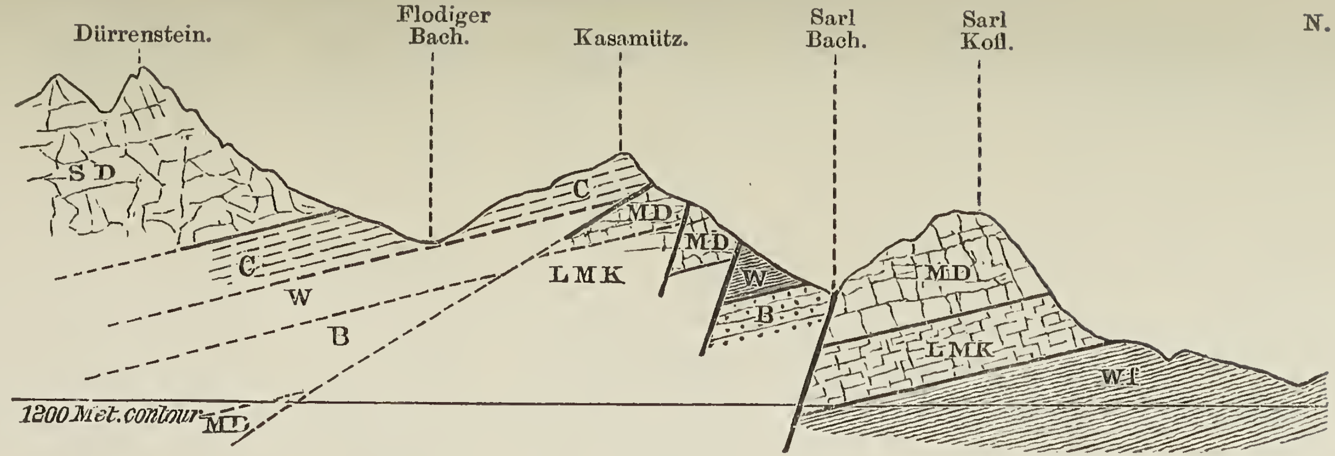
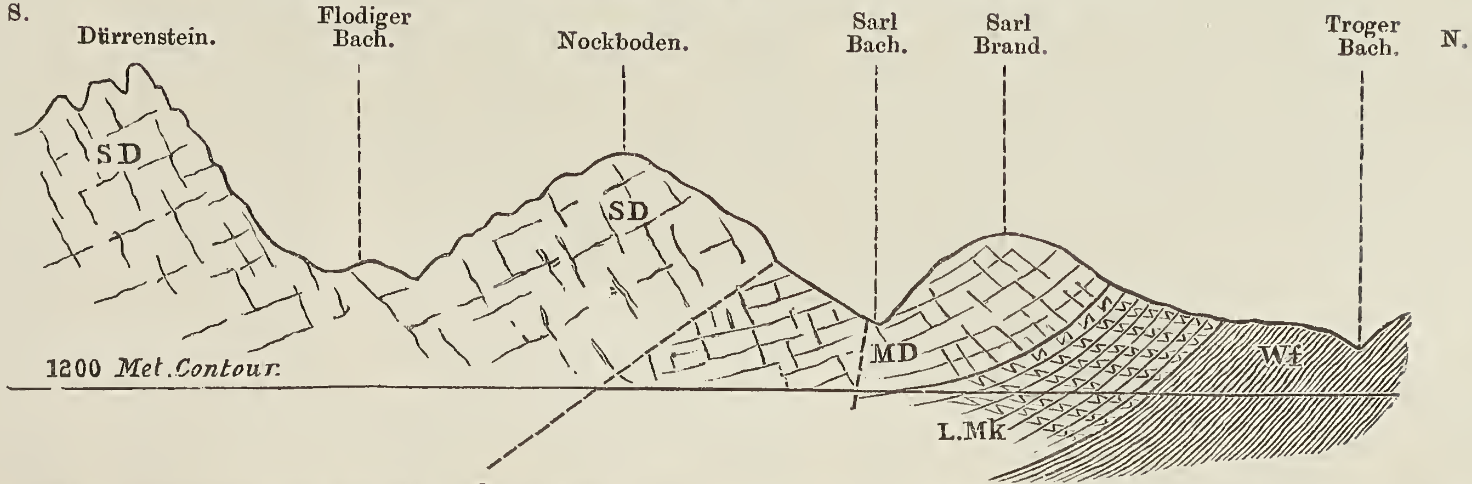


Fig. 13.—*Section from the Dürrenstein to the Troger Bach.*



[Scale of the above four sections : $\frac{1}{50000} = 1{\cdot}267$ inch to the mile. *Note.*—For explanatory index, see below fig. 11.]

On the Misurina Alpe, the fossiliferous strata are identical with those of the Seeland Valley, and they dip eastward beneath a low range of hills towards Rimbianco. In the stream at the bend of the Rimbianco Valley towards Monte Pian I found some particularly fine corals and sponges, small cidarid spines, and bivalves in dark earthy marls. Above these St. Cassian strata one finds dolomite in position on the low hills forming the Misurina and Rimbianco watershed; it occurs on the eastern slopes as blocks, sometimes massed together like huge ruins of a continuous wall.

The further occurrence of fossiliferous horizons below the Schlern Dolomite of the Dürrenstein *massif* is on the steep slopes between Stolla and Brückele and on Flodiger Wiese. Just above Stolla, at the 2000-metre contour, a thick bed of Cipit Limestone forms a prominent rock on the wooded slopes. It belongs to the highest horizon of the St. Cassian Beds. Lithologically, the beds have the same character as in the Seeland Valley, but except at one or two favourable points, such as the Stolla and the Brückele Alpen, the fossils do not weather out in the same abundance. This arises partly from the steepness of the incline on which they are exposed, and from the constantly increasing screes of débris from the overlying rocks; largely also because a scrubby vegetation of larch and dwarf-pine prevents the free exposure of the fossiliferous marls. Within the last two years new landslips have occurred just south of Stolla, and the St. Cassian Beds are now laid open below the Dürrenstein over a considerable area—so that in course of time fossils of that age may be readily collected there.

This case I emphasize, because it is analogous to several others, where the St. Cassian Beds underlie the Schlern Dolomite in their normal thickness, but are apparently poor in fossils, and where no favourable outcrop on a broad 'Alp' or 'Wiese' is afforded to them in the immediate vicinity.

The Wengen Beds are not exposed on the Misurina hills or in the Seeland Valley; but towards Prags the Wengen Series follows conformably below the St. Cassian. The distribution of the beds is shown in Map C, facing p. 32, and in figs. 10, 11, & 12 (pp. 34 & 35).

They are not of an ashy character, as in the exposures farther west, but are interbedded shales and limestones, containing few fossils except in certain brown, banded shales full of *Posidonomya wengensis* and more rarely containing specimens of characteristic ammonites and *Halobia Lommeli*.[1] The thin and unevenly-bedded limestone, often with a micaceous glance on the bedded surface, the thick blue limestone with strongly marked calcite-veins, and the comparative poverty of fossils, are the chief features of the Wengen Beds in this locality. On the other hand, the Buchenstein Series below them is more fossiliferous than in the western districts; as already mentioned, it also includes but little ashy rock.

[1] See Loretz, Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxvi. (1874) p. 378.

Seisser Alpe.

The particular interest attached to the exposure of Wengen and St. Cassian Beds on the Seisser Alpe lies in their stratigraphical relations with the Schlern Dolomite of Schlern. These have been discussed at length in the works of Richthofen, Gümbel, Mojsisovics, and others.[1]

On entering the Seisser Alpe from the Pufels ravine, the augite-porphyry and tuffs of Lower Wengen age are succeeded by a series of ashy rocks, strike N. 70° E., dip slightly southward, as follows:—

Middle St. Cassian Beds (in part).	Cipit Limestone series, almost entirely eroded from the Alpe. Fossiliferous marls, interbedded with unfossiliferous earthy tuffs, and ashy shales and grits.
Lower St. Cassian.	Fossiliferous limestone=first Cipit Limestone-bed of Richthofen.
Wengen Beds.	Grey shales with *Halobia Lommeli*, fine breccia of tuff and limestone-fragments. Black earthy tuffs and shales. Plant-bearing sandstones, grey limestone, with rough weathered surface on which badly-preserved fossils are observed. Tuffs and augite-porphyry=the 'Regenerirte Tuffe' series of Richthofen; *Pachycardia rugosa* occurs in the tuffs.

The Cipit blocks scattered on the higher parts of the Seisser Alpe are yellowish-brown limestone full of lithodendroid corals and *Encrinus cassianus*. These are found in position near the source of the Cipit Bach, hence the name originally given by Richthofen.

The strata on the Seisser Alpe form a syncline, and the same beds bend upward and are found on the Günserbuchl and the Mahlknecht slopes below Rosszähne. The rocks west of Mahlknecht are interbedded breccias and tuffs dipping slightly north. Wedged in the breccias are irregular masses of the Cipit Limestone, and upon the whole system the Schlern Dolomite of Rosszähne rests with a slight unconformity.[2]

The term 'regenerirte Tuffe' was applied by Richthofen (*op. cit.* p. 91) to the development of tuffs and conglomerates in the Upper Fromm Bach on the Seisser Alpe, previously observed by Emmrich, and containing *Pachycardia rugosa* in great abundance. Richthofen took these beds for a local development of Raibl strata resting upon the sedimentary tuffs of the Seisser Alpe, but Stur[3] observed the continuation of the 'regenerirte Tuffe' over a wider

[1] Richthofen, 'Geogn. Beschr. d. Umg. v. Predazzo,' p. 40, 'Seisser Alpe-section'; Gümbel, 'Das Mendel u. Schlern Gebirge,' Sitzungsb. d. k. k. Akad. d. Wissensch. Wien, 1873 (Pufler Schlucht-section); Mojsisovics, 'Dolomit-Riffe,' p. 154; Fraas, 'Scenerie der Alpen,' Leipzig, 1892, pp. 137, 166, etc.

[2] I owe this observation at Mahlknecht and Rosszähne in the first instance to the kindness of Dr. Rothpletz; in 1892, on a later visit to Schlern, I myself saw the relations of the Cipit Limestone and the tuffs at Mahlknecht.

[3] Jahrb. d. k. k. geol. Reichsanstalt, 1868, p. 541.

area of the Seisser Alpe and underlying the marls containing St. Cassian fossils.

Mojsisovics quotes '*Pachycardia*-tuffs' in Wengen strata from other districts, referring them to a horizon immediately above the plant-bearing sandstones ('Dolomit-Riffe,' pp. 55 and 56).

Emmrich, in 1840, found certain fossils in the higher marls, and on a later visit he obtained a great number and recognized them as a thoroughly representative 'Stuores Wiese' (*i. e.* St. Cassian) fauna. The fossils however occur, comparatively speaking, seldom; some of the characteristic species in Emmrich's collection are: *Cidaris baculifera, C. Rœmeri, C. Buchii, C. trigona, C. dorsata, C. decorata, C. flexuosa*; *Encrinus varians, E. cassianus*, etc.; many *Terebratulæ, Koninckina Leonhardti*; *Cardita crenata, Nucula lineata*, and many gasteropods. Emmrich says, referring to the Stuores fauna:—"The agreement was complete; even their general appearance and their mode of occurrence were the same."

In other words, as a general conclusion from the above sections, the St. Cassian strata of the Seisser Alpe correspond only with a part of the St. Cassian strata of Stuores; the richly fossiliferous zones on the ridge of Prelongei and below Sett Sass are not present on the Seisser Alpe.

Another feature which is at least worthy of mention here is the occurrence of the fossiliferous marls and Cipit Limestones on the Seisser Alpe, interbedded with ashy rocks; this is exactly how those fossiliferous horizons are found which I was enabled to distinguish in the Prelongei and Stuores district as Lower St. Cassian, and the ashy, less fossiliferous portion of Middle or 'Stuores' St. Cassian.

Richthofen called the strata of the Seisser Alpe "sedimentary tuffs with interbedded St. Cassian Limestones and Cipit Limestones." This is analogous to the Northern Tyrol contemporaneous series—namely, the "Partnach marls and shales with interstratified beds of St. Cassian Limestone." [1]

Mojsisovics maps all the strata on the Seisser Alpe as Wengen Beds. While it is impossible to draw any but an arbitrary limit between the complex of Wengen and St. Cassian Beds in Southern Tyrol, I believe a clearer conception of the Upper Triassic succession will be gained by grouping these fossiliferous marls and limestones as a St. Cassian Series in which (at least throughout the wide district from Schlern to the Dürrenstein) St. Cassian fossils form the bulk of the fauna, while retaining the name of Wengen Beds for the thick ashy series underlying them, with a remarkably limited fauna and interrupted by dykes and flows of augite-porphyry. The occurrence of *Posidonomya wengensis* (which is quoted even from the Raibl Beds in the Esino district) in the St. Cassian Series, or, conversely, the occurrence of *Cidaris dorsata* and a few other forms of higher range in beds of Wengen age, need not preclude a convenient subdivision of the whole complex into the two main

[1] See Gümbel (*op. cit.* 1873): the 'St. Cassian strata' include a great part of the 'sedimentary tuffs' of Richthofen.

sub-groups recognized throughout the sections that I have just described.

VI. The Stratigraphy of the Beds above the St. Cassian Series.

6. *The Schlern Dolomite.*[1]—The Schlern Dolomite is a drusy, crystalline, greyish-white rock, less splintery than the Mendola Dolomite, and breaking up into débris of fairly large stones and blocks.

Within the districts of Ampezzo and Enneberg which I have examined, the conformable succession of the Schlern Dolomite upon the St. Cassian Beds has been observed at Zwischenkofl and Gardenazza, Sella, Sett Sass, Lagazuoi, Tra i Sassi, Dürrenstein, and the *massif* east of Misurina. The thickness is normally from 1000 to 1400 feet: but it varies, *e. g.* at the Dürrenstein it is 2000 feet.

In all these mountains, the Schlern Dolomite rests upon the St. Cassian Beds and is succeeded by Raibl strata. In districts south of those which I have personally examined, such as Schlern (south side), Rosengarten, etc., the Schlern Dolomite rests upon the Mendola Dolomite and has there a thickness of 3000 feet.

Other localities occur where the Schlern Dolomite is apparently wanting, or where it has a very slight thickness. One or two cases of the disappearance of the Schlern Dolomite come within the scope of this paper, and I shall refer to them in considering the tectonic details (Part VIII.).

Fossils are very rarely found in the Schlern Dolomite; but the occurrence of *Gyroporella annulata*, Schafh., is important, as it is a species frequently obtained in the Wetterstein Kalk of Northern Tyrol. Corals occur occasionally, but are not well preserved. Among other casts of gasteropods, a large species of *Chemnitzia* has been found.

7. *The Raibl Strata.*—The Raibl strata form a characteristic series, largely dolomitic, above the Schlern Dolomite, and below the Dachstein Dolomite. As their development is especially subject to local variation, a rapid review of a few sections noted within the districts examined is desirable. On the western slope of Sett Sass the Raibl strata are exposed below the Dachstein Dolomite in the following succession (in descending order):—

I. Sett Sass (western slope).

Dachstein Dolomite.

Raibl Beds.	Pale greenish or white dolomitic flags.
	Variegated dolomitic marls, red, bluish purple, and greenish. Fossils rare; only one found:—*Myophoria*, sp.
	Fine conglomerate; fragments of brightly-coloured marls and of dolomite cemented by a whitish dolomitic sand. This rock is very striking, and occurs frequently at the same horizon.
	Variegated dolomitic marls as above, containing iron ore. Interstratified beds of dolomitic flags and dolomitic limestone.
	Brown sandstones containing *Myophoria Kefersteini*, Klipst.

[1] See Introduction (p. 3), where the different names hitherto applied by geologists to this dolomitic rock are enumerated and explained.

The whole series is not more than 200 feet thick and rests upon the Schlern Dolomite. The same series is again favourably exposed in the neighbourhood of Valparola Alphütten, north of Sett Sass. There I found more fossils, among them a small *Megalodon* (species not easily identified), *Corbis Mellingi*, and several specimens of *Myophoria Kefersteini*.[1]

Some beds, apparently at the base of the Raibl strata, were exposed in the course of the Eisenofen Bach some little distance above the huts—hard, yellow-weathering limestone, with spines of various species of *Cidaris* and fragments of *Pentacrinus tirolensis*, Laube; also a light-coloured dolomite and dolomitic limestone full of a lithodendroid coral.

II. Heiligkreuz. (*Compare* fig. 4, p. 26.)

The Raibl strata exposed below the Dachstein Dolomite of Kreuz Kofl consist essentially of three series. The uppermost horizons are thicker here than at Sett Sass. The succession is, in descending order:—

Variegated marls, interstratified with dolomitic shales and limestones.

Thick banks of limestone and dolomitic limestone, interstratified with dolomitic marls. Occasional beds of a reddish breccia and of a hard siliceous limestone, with a few cidarid spines and encrinite-remains.

Sandstones and breccias with plant-remains and lignite, *Ostræa*-limestone and Lumachellen-limestone, very fossiliferous: *Fimbria* (*Corbis*) *Mellingi*, Hauer, sp.; *Ostræa montis-caprilis*, Klipst., etc.

(See Part VIII. of this paper, p. 64.)

III. Falzarego,[2] Cortina. (*Compare* figs. 6, 7, 8, pp. 29, 30.)

The Raibl strata throughout this part of Ampezzo have much the same development as at Heiligkreuz. The higher beds form a series of terraces on Col dei Bos by the alternation of the variegated dolomitic marls with hard beds of dolomite corresponding to the two lower beds in the Heiligkreuz section (thickness about 360 feet). The fossiliferous lower horizon, with a thickness of 50–70 feet, rests conformably on Schlern Dolomite, here apparently not more than 300 feet thick. Below the escarpment of Schlern Dolomite, in the neighbourhood of the Roces Alphütten, is a wooded hill entirely made up of dolomite-blocks.

On the opposite side of the Costeana stream, the Raibl strata are again exposed. The beds of the lower fossiliferous horizon are seen striking towards Ospizio and dipping at a high angle. In these strata I collected a number of typical Raibl species, viz.:—*Trigonodus rablensis*, Gredl., sp.; *Ostræa montis-caprilis*, Klipst.; *Fimbria* (*Corbis*) *Mellingi*, Hauer; *Megalodon*, cf. *complanatus*, Wöhrm.; *Megalodon*, sp. indet.; *Placunopsis*, sp. indet.; *Cidaris Braunii*, Desor.

[1] See Loretz, Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxvi. (1874) p. 378.

[2] *Ibid.* p. 448, etc.; and Mojsisovics, 'Dolomit-Riffe,' p. 260.

Conformably succeeding these beds on the Nuvolau slope are thickly-bedded dolomite, then marls with interstratified dolomitic flags, and the same breccia as that which occurs on Sett Sass.

On the Pomedes and Majorera slopes the Raibl Beds are unusually well exposed. In the higher horizon of thinly-bedded smooth dolomite and marls some beds are filled with casts of *Megalodon*, sp. (Loretz had previously found these); in the middle horizon gypsum occurs, interbedded with dolomite-layers; and the thicker banks of dolomite are remarkable for the very intimate combination they show of marls, dolomitic sand, and breccia.[1] The fine interlayering of these different materials forms a dolomite-rock differing essentially from the drusy, crystalline Schlern Dolomite.

The fossiliferous beds are reddish breccias with small fragments of silica, brownish sandstones with stems of plants, hard white sandstone, dark limestones with *Myophoria Kefersteini* and *Megalodon* sp., and greyish limestone with cidarid spines. These beds rest on a dolomite-rock 50–60 feet thick, and at other parts of the slope they succeed a bed of Cipit Limestone and St. Cassian marls. The difficulties presented by the succession here are much increased by an extensive slip, between Majorera and Romerlo, of the Raibl Beds and of the dolomite-layer beneath upon the St. Cassian marls, as also by the growth of trees and underwood upon the lower slopes.

IV. Plätz Wiese, Dürrenstein. (*Compare* fig. 14, p. 42.)

This broad meadow-land at the height of 6000 feet has for its soil the Raibl marls. A section drawn west and east from the Wällsche Boden and Knoll Kopf to the Dürrenstein gives, in conformable succession:—

	Dachstein Dolomite.
Raibl strata, 160–200 feet thick.	Rauchwacke, brownish-grey, very porous, sometimes still retaining enclosures of gypsum. Bituminous limestone and shales with layers of gypsum. Dolomitic limestone and breccia. Variegated dolomitic marls, intercalated with thin beds of dolomite and dolomitic flags. Gypsum layers occur frequently. Thicker beds of dolomite, of shaly uneven surface.
Dolomitic strata, probably of Raibl age.	Thickly-bedded dolomite, showing on close examination fine layers of red or greenish marl, between layers of dolomitic sandy breccia. Dolomite with smooth compact structure; a bed of lithodendroid coral-limestone occurs in this dolomite just below the fort.
	Drusy, crystalline Schlern Dolomite.

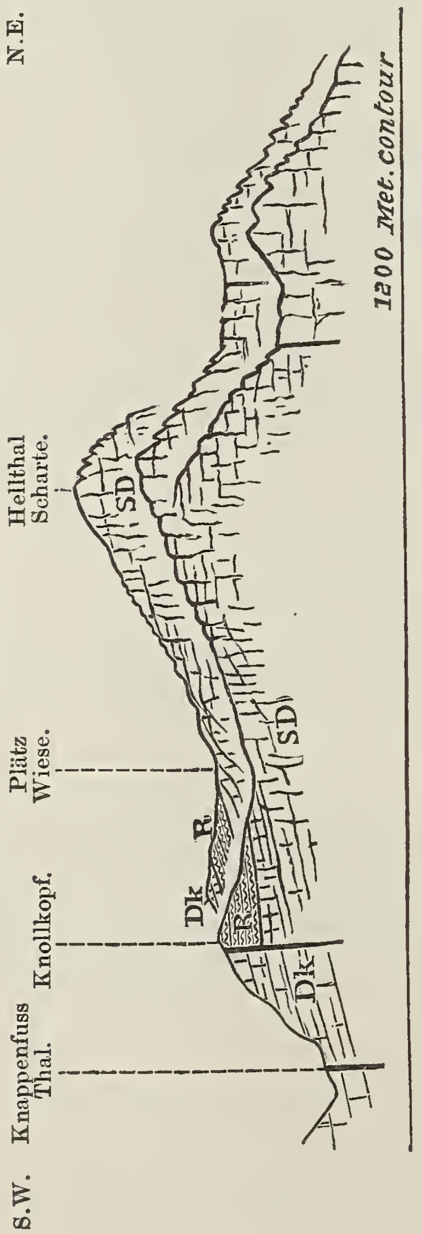
[1] Gümbel, 'Das Mendel- u. Schlern-Gebirge,' Sitzungsb. d. k. k. Akad. d. Wissensch. Wien, 1873, p. 14. Gümbel observed occasionally also in Schlern Dolomite 'dünne, oft nur haut-ähnliche Zwischenlagen von Mergel.'

There are no fossiliferous sandstones and limestones as in the Cortina and Heiligkreuz district, but the entire series is highly dolomitic, and the transition to the Schlern Dolomite very gradual. This explains in part the greater thickness of the dolomitic rock of the Dürrenstein.

V. Schlern Plateau: Raibl Beds.

These have been long familiar in the literature of Southern Tyrol, and have been again recently made the subject of special research.[1] I quote briefly the result of these palæontological studies for comparison with my sections elsewhere. The fossiliferous beds exposed in the Schlern Klamm pass on the plateau into a facies of coral-bearing dolomite, and farther on into red and bluish-purple ferruginous marls. These rest upon a stratified dolomite, in which a bed of augite-porphyry and tuff is locally present, and are succeeded by stratified dolomite, in which corals and cidarid spines, and, at higher horizons, small species of *Megalodon* often occur.

Fig. 14.—*Section across the Plätz Wiese.*



[Scale: $\frac{1}{50000}$ = 1·267 inch to the mile.]

DK = Dachstein Dolomite. R = Raibl strata. SD = Schlern Dolomite.

A full comparison of the fauna has been made by Wöhrmann, and the conclusion drawn that the fossiliferous Schlern-plateau strata correspond with the *Myophoria Kefersteini*-horizon at Raibl and the upper part of the *Cardita*-strata in Northern Tyrol.

A number of species are entirely peculiar to the one locality of the Schlern plateau; others occur in St. Cassian or Raibl Beds, or are common to both. But, as more St. Cassian species are present in the Schlern-plateau Beds than in the

[1] Wöhrmann u. Koken, 'Die Fauna der Raibler Schichten vom Schlern plateau,' Zeitschr. d. Deutsch. geol. Gesellsch. vol. xliv. (1892) p. 167.

fossiliferous Raibl horizon which I have mentioned in the above sections, one must conclude that the Schlern-plateau Beds are still older. The Raibl Beds of Southern Tyrol fall into the following sub-groups:—

Raibl Beds.	Variegated marls and *Megalodon*-bearing dolomitic flags.	
	Ostræa-limestone	passing into a dolomitic facies.
	Myophoria-limestone	
	Schlern-plateau strata, and dolomitic encrinite- or coral-limestone	

8. *The Dachstein Dolomite.*—The Dachstein Dolomite is the highest subdivision of the Triassic system in Southern Tyrol. It is a continuous development of dolomite and dolomitic limestone several thousand feet thick; and since it lies conformably above the Raibl Beds and below the Liassic strata it is the representative, in the Southern Tyrol Dolomites, of the 'Hauptdolomit' Kössen Beds, and the Dachstein Limestone of Northern Tyrol.

The rock is a crystalline dolomite, generally greyish-white in colour, but sometimes reddish. It is always well stratified, and may be either of compact or drusy structure. Fossils occur commonly enough, although in small variety. The typical fossil *Megalodon triqueter*, Wulf., is common also in the Dachstein Kalk of Northern Tyrol. Specimens of a very large *Megalodon* occur sometimes in great number in the Dachstein Dolomite of Tofana.

VII. Palæontological Conclusions.

The first nine columns of the List of Fossils (pp. 48 *et seqq.*), containing 345 species, include the various localities in Enneberg and Ampezzo where I worked. The tenth column, referring to Partnach Beds, etc., is introduced only to show the particular species in this list which are already known to occur elsewhere in other strata. The fauna of the Partnach Beds in Northern Tyrol is comparatively meagre, about half the known species being identical with St. Cassian and Wengen species in Southern Tyrol. On the other hand, only about 6 per cent. of the fossils given in the Wengen and St. Cassian horizons in the list have been found in Partnach strata. Comparing then the tenth column with the others, we find that 16·5 per cent. of the St. Cassian species occur also in Raibl Beds (including all the districts referred to). The faunal relations of the two series of Upper Triassic strata are readily seen from the following percentages:—Of St. Cassian sponges 13 per cent. are present in Raibl strata, of corals 5·9 per cent., of echinoderms 33·3 per cent., of brachiopods 3 per cent., of lamellibranchs 40·3 per cent., of gasteropods 8·2 per cent., of nautiloid and ammonite forms 19·2 per cent.

The writer collected also a number of fossils in the Raibl strata exposed within the district of Enneberg and Ampezzo. These are:—

Ostræa montis-caprilis, Klipst.
Gervillia Bouéi, Hauer.
Hoernesia Johannis-Austriæ, Klipst.
Myophoria fissidentata, Wöhrm.
—— *Kefersteini*, Klipst.
Trigonodus rablensis, Gredler, sp.
Fimbria (Corbis) Mellingi, Hauer, sp.
Megalodon, sp. indet.
Megalodon, cf. *complanatus*, Wöhrm.
Placunopsis, sp. indet.
Halobia rugosa, Gümbel.
Thecospira Gümbeli, Pichler, sp.
Cidaris Braunii, Desor.
Pentacrinus tirolensis, Laube.

On the western slopes of the Dürrenstein, a bed of lithodendroid coral-limestone occurs, and may be followed for some distance between the thinly-bedded dolomitic flags belonging to the Raibl series.

In considering the list of Wengen and St. Cassian fossils, the extreme faunal poverty of the ashy Wengen strata calls for remark. Species of *Halobia* and *Posidonomya* frequently occur, but in addition to these I found only a few ammonites, the majority, unfortunately, too badly preserved for identification.

There are, among the 345 species of St. Cassian fossils found, 23 sponges, 51 corals, 30 echinoderms, 32 brachiopods, 62 lamellibranchs, 121 gasteropods, 26 nautiloid and ammonite forms, together with a number of polyzoa. The great preponderance of gasteropods, of which only about 10 per cent. continue into the Raibl period, is very striking, and they indeed give a quite peculiar stamp to the St. Cassian fauna. The brachiopods are mostly peculiar to Middle and Upper St. Cassian strata; the number present in Lower St. Cassian or in Raibl Beds being extremely limited.

The following table shows the percentages of St. Cassian species which occur at all the horizons in the list on pp. 48 *et seqq.*

Percentage Table.

	N. Tyrol.	Enneberg and Ampezzo.				N. & S. Alps.	
	Partnach Strata.	Wengen Strata.	St. Cassian.			Raibl.	
			Lower.	Middle.	Upper.	Lower.	Upper.
Corals	0	0	8	74·5	66·6	6	0
Echinoderms	26·6	6·6	26·6	86·6	63·6	30	16·6
Brachiopods	21·8	0	3·1	78·1	34·3	3	0
Lamellibranchs	6·4	5	6·4	64·5	54·8	38·7	17·7
Gasteropods	0	0	0	77·6	45·4	7·4	0·8
Naut. and Amm. sp.	7·7	?	11·5	80·7	15·3	19·2	0

A few typical Wengen fossils still continue in the Lower St. Cassian zone, which I identify with the first bed of Cipit Limestone on the Seisser Alpe. In this zone the first significant beginning of the St. Cassian fauna occurs; the fauna reaches its maximum development in Middle St. Cassian time; still continues strongly marked in Upper St. Cassian time; dwindles gradually, or sporadically reappears in a limited variety, during the Lower Raibl period, and is almost entirely absent from the highest or 'Torer' zone of Raibl strata.

Lower St. Cassian Zone.—Instead of the continuous stratified Cipit Limestone present at this horizon in the St. Cassian and Prelongei district, there is, at several places farther west, a characteristic blocky structure. Large blocks and masses of coralline Cipit Limestone are embedded in ashy strata; for instance, near the higher sources of the Cipit stream, at Mahlknecht, below Plattkofl on the Christiner Ochsenwald, on Sella Pass, at Val la Sties, at Cima Pasni, south of the Pordoi Pass, and again in the lower part of the Cortina meadows. Cidarid spines belonging to one or two species, and lithodendroid corals, are the only fossils which I found in these blocks or lenticular beds of Cipit Limestone.

Middle St. Cassian Zone.—In all cases, the marls and limestones immediately succeeding the 'Cipit' horizon contain St. Cassian fossils of the 'Stuores Wiese' type. The Middle St. Cassian Beds are not more than 150–200 feet thick in the Mahlknecht and Plattkofl district, and the 'blocky structure' recurs at several horizons. The dolomite-rock of Schlern Mountain and Rosszähne succeeds immediately above this comparatively slight thickness of St. Cassian Beds on the north-eastern side. Farther east, the St. Cassian Beds become thicker, until on the eastern side of the Sella *massif* the higher and very fossiliferous beds of Middle St. Cassian age reach their first complete development on the Prelongei ridge, and above the Richthofen Riff, continuing farther in the Enneberg Valley (Abtey slopes), on the Valparola Pass, and in the Falzarego Valley (west of Verviers, and at Romerlo, etc.).

I was inclined at one time to regard the fossiliferous beds exposed on Forcella, between the Richthofen Riff and Sett Sass, as of Upper St. Cassian age, but the material which I have now collected here and at Stuores does not justify a palæontological separation of the two horizons. The fauna on Forcella, excepting one new species of *Omphalophyllia*, has been entirely identified with the St. Cassian fauna described by Münster and Laube. At the same time, the absence of some of the fossils more characteristic of lower horizons on Stuores (e. g. *Koninckina Leonhardti*, Wissm.), and the presence in greater number of fossils characteristic of higher horizons (e. g. *Avicula Gea*, d'Orb., *Macrodon strigilatum*, Mnst., sp., *Anoplophora Münsteri*, Wissm.), mark the Forcella beds as a clearly higher horizon of the Middle St. Cassian fauna.

The difficulty of attaining a positive result arises from the fact that the fossils from Prelongei, Stuores, Sett Sass, Abtey, and Heiligkreuz could not be kept apart in the literature, for the fossil-collectors of the district mixed them all together. To take an example from the appended list of fossils: among 18 corals occurring on Forcella di Sett Sass 6 are identifiable only with Middle St. Cassian (Stuores) corals, 5 only with Upper St. Cassian corals, 1 with both Middle and Upper St. Cassian, and 6 were found only on the Forcella. But as 5 out of these last-named 6 specimens are species described in the 'St. Cassian fauna' of Münster and Laube, they may or may not occur at Stuores, Prelongei, or Abtey. Two thirds of the gasteropods and brachiopods actually found on Forcella di Sett Sass are forms which I also found on Stuores; this and other results are in favour of including the Sett Sass-Forcella Beds with the Stuores or Middle St. Cassian zone.

Upper St. Cassian Zone.—In the Falzarego and Seeland Valleys (also in the district of Misurina and Rimbianco), strata which belong to the Middle St. Cassian or Stuores zone are succeeded by beds which I have distinguished as Upper St. Cassian on account of the occurrence of many new species. The percentages of species common to both Middle and Upper St. Cassian strata in the appended list are—sponges 21·7 per cent., corals 27·4 per cent., echinoderms 53·3 per cent., brachiopods 15·6 per cent., lamellibranchs 16·1 per cent., gasteropods 17·3 per cent., nautiloid and ammonite forms 11·5 per cent. At least 2 new species of corals are present from Cortina, and 7 new species from the Seeland Valley (one agrees with a new species of *Thecosmilia* from the Seeland Alpe previously described by Loretz). Of 10 brachiopods 6 species are common to both Middle and Upper St. Cassian horizons, while 4 species are confined to the Upper St. Cassian strata; among 20 species of lamellibranchs from Cortina, 10 are Middle St. Cassian forms and 10 are new species (1 of these is a Raibl form, and 3 have affinity with Raibl species). On the Seeland Alpe only 4 lamellibranchs were found; 3 are identified with St. Cassian forms and 1 is a new species. Of the gasteropods from the Cortina locality 10 are Middle St. Cassian forms, and 8 are either new species or of doubtful identity, while among 39 gasteropods from the Seeland Alpe 25 are Middle St. Cassian forms and 14 are indeterminate or new species.

The 'Heiligkreuz strata' (as explained on pp. 24–27) contain few fossils, but as they are all of frequent occurrence in the Upper St. Cassian of the Cortina district, it would seem best to refer the 'Heiligkreuz strata' to that zone.

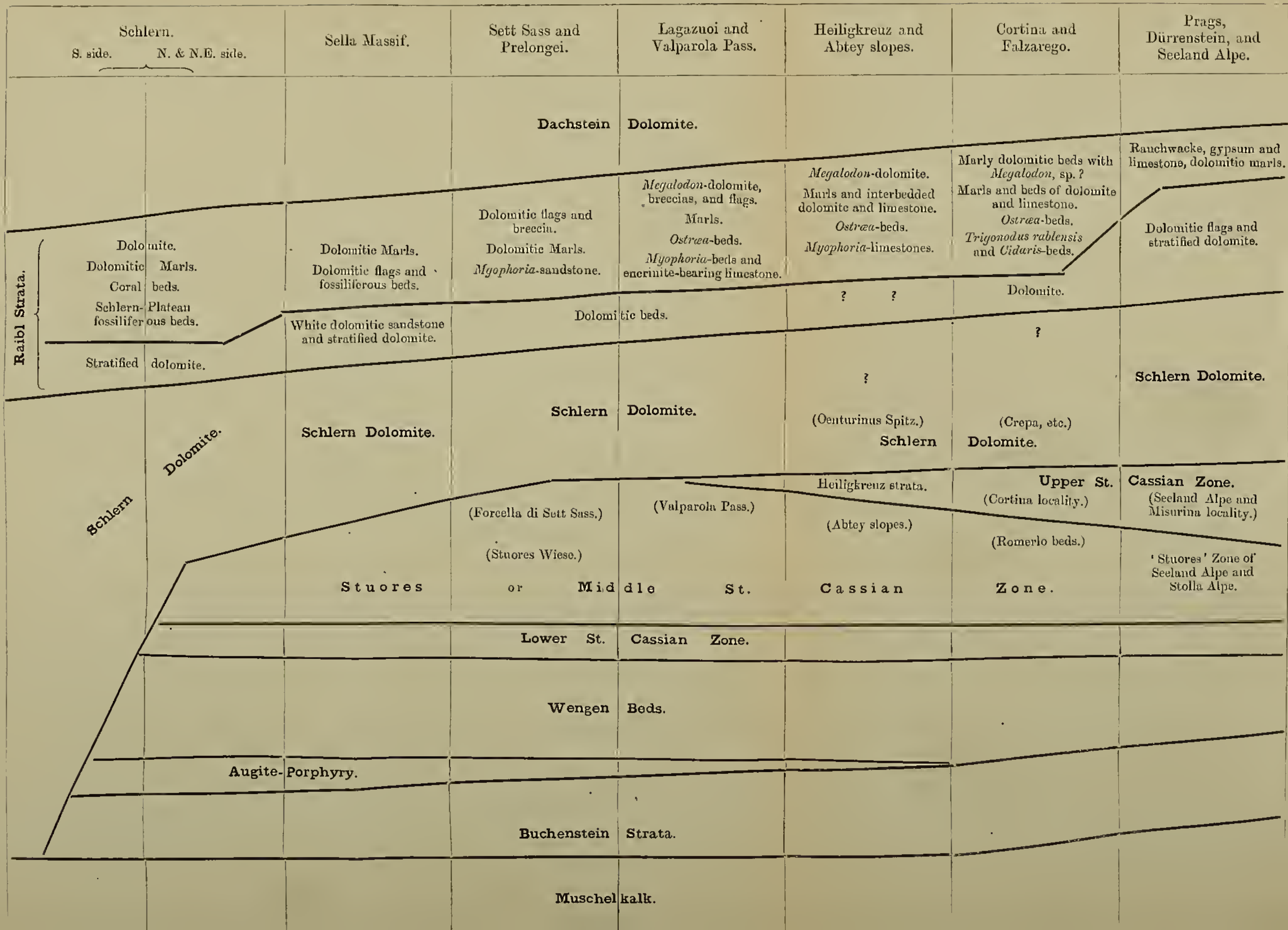
Again, in comparing the Cortina and Seeland strata with one another, it is found that several commonly-occurring species are peculiar to them; but each locality bears the impress of a local faunal facies, further supported by the nature of the rock at both localities. The thick-shelled and other new species of lamellibranchs at Cortina are not found on the Seeland Alpe, whereas the great number of sponges and polyzoa at the last-named locality are poorly represented at the other. The gasteropods, brachiopods, and corals show, however, a closer relationship between the fauna of the two localities.

Summarizing the above palæontological facts, we conclude—

(1) That the St. Cassian strata are present throughout a wide extent of country, from the Seisser Alpe in the west to Misurina and the Seeland Alpe in the east.

(2) That in the west only the lower and less fossiliferous horizons

Diagram of Upper Triassic Strata in Enneberg and Ampezzo.



of St. Cassian strata are present; the typical Stuores or Middle St. Cassian zone is first completely developed in Enneberg, while above it there succeeds, at Cortina, Misurina, and the Seeland Alpe, a fossiliferous Upper St. Cassian zone.

In the wide district north of Falzarego and Ampezzo Valleys, where St. Cassian strata are not exposed, their non-occurrence is due to tectonic relations.

The fossiliferous horizons of Raibl strata exposed in Enneberg and Ampezzo represent the *Myophoria*-beds and the slightly higher *Ostræa montis-caprilis* horizon of the typical species of Raibl strata near Raibl. The unfossiliferous variegated marls, the thin-bedded dolomitic flags, the beds of gypsum and dolomite, and the rauchwackes which succeed the fossiliferous Raibl Beds in Enneberg and Ampezzo, represent at least in part the 'Torer' or highest horizon of the 'Raibl' succession.

On several of the dolomite-*massifs* (Gardenazza, Sella, etc.) the rock immediately underlying the *Myophoria*-horizon is dolomitic, but is not the characteristic drusy Schlern Dolomite. This variable thickness of dolomitic shaly flagstone or sandy rock is of Lower Raibl age. At Schlern the unique development of fossiliferous 'Schlern Plateau' Beds has been proved by the recent work of Wöhrmann and Koken (see footnote, p. 42) to be of Lower Raibl age. I found no exactly corresponding fauna in the districts of Enneberg and Ampezzo.

Thus, in the Raibl period also, the occurrence of rock-facies is recognizable in the district from Schlern to the Dürrenstein, while the dolomitic or flaggy development of Lower Raibl beds extends higher in the Dürrenstein district than in Enneberg or Falzarego. In the Raibl strata on Plätz Wiese (Dürrenstein district) no *Myophoria* or *Ostræa montis-caprilis* beds are present, but the highest marls-and-rauchwacke horizon succeeds a continuously dolomitic development.

Inequalities of thickness are remarked in the rocks of all horizons from the Muschelkalk to the Dachstein Dolomite; these inequalities are correlated with the frequent occurrence of ashy beds and of augitic volcanic rock during the Buchenstein, Wengen, and St. Cassian periods, and with the highly magnesian and ferruginous contents of the sea-water during the Schlern-Dolomite and Raibl periods.

The accompanying diagram illustrates the general stratigraphical relations in the districts examined.

The fossils found in the various localities are enumerated in the appended list. I must express my thanks to Herr von Suttner, of Munich, for having kindly identified the ammonites; and to Herr Söhle, who was good enough to identify the fossils found on Stuores during the second season of my field-work.

List of Fossils found by the Writer[1] in various Localities of Southern Tyrol (Enneberg and Ampezzo).

Note.—The numbers in the tenth column of the following table denote the occurrence of similar species in corresponding strata of other districts:—

1. St. Cassian (Partnach) strata of Northern Tyrol.
2. Lower Raibl or *Cardita*-strata of Northern Tyrol.
3. Upper Raibl or 'Torer' strata of Northern Tyrol.
4. Fischschiefer (Lower Raibl), Carinthia.
5. *Myophoria*-beds (Lower Raibl), Carinthia.
6. Torer Beds (Upper Raibl), Carinthia.
7. Raibl strata, Friaul.
8. Raibl strata, Lombardy.
9. Lower Schlern-plateau Beds, Southern Tyrol.

			St. Cassian.							
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	Occurrence elsewhere.
Spongida.[2]										
Eudea polymorpha, Klpst. sp.	...	...	*							
—— *Manon*, Mnst. sp.	...	...	*	...	...	*	...	...	*	
Colospongia dubia, Mnst. sp.	...	...	...	...	...	...	...	...	*	2.
Verrucospongia armata, Klpst. sp.	...	*	...	...	...	...	...	...	*	Spong. indet. 9
Cryptocœlia Zitteli, Steinm.	...	...	...	...	...	...	...	...	*	2, 7.
Peronella Loretzi, Zittel	...	...	*	...	...	...	...	...	*	2, 7.
——, sp.?	...	...	*							
Corynella gracilis, Mnst. sp.	...	...	*							
—— *astroites*, Mnst. sp.	...	...	*	...	...	...	...	...	*	
——, sp.?	...	...	*							
Stellispongia variabilis, Mnst. sp.	...	...	*	...	...	...	...	...	*	
—— *stellaris*, Klpst. sp.	...	...	*							
—— *rotularis*, Mnst. sp.	...	...	*	...	...	...	...	...	*	
—— *Manon*, Mnst. sp.	...	...	*							
——, n. sp.	...	...	...	...	...	...	...	...	*	
Spongia, n. gen.	...	...	...	...	...	...	...	...	*	
Sestrostomella robusta, Zitt.	...	...	...	...	...	...	...	...	*	
? *Amorphofungia granulosa*, Lbe.	...	*	*	...	...	*				

[1] Several fossils have been kindly given me by Freiherr Dr. von Wöhrmann from Seisser Alpe, Stuores, and Forcella di Sett Sass.

[2] Besides the sponges in the above list, many species are as yet unidentified; some (among which are 10 specimens of *Pharetrones*) are in the hands of Dr. Rauff, of Bonn, others are in the Munich collection. Species were found at Cortina, and more especially at Romerlo, which are the same as some of the figures given by Laube, but identification, according to more recent work on sponges, has not yet been accomplished.

LIST OF FOSSILS (*continued*).

			St. Cassian.							
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	Occurrence elsewhere.
SPONGIDA (*continued*).										
Leiospongia rugosa, Mnst. sp.	...	...	...	...	...	...	...	...	*	
—— *radiciformis*, Mnst. sp.	...	...	*	...	...	...	...	...	*	
—— *verrucosa*, Lbe.	...	...	...	...	...	...	...	...	*	
—— *reticularis*, Mnst. sp.	...	...	...	...	...	*	...	...	*	
CŒLENTERATA.										
Calamophyllia cassiana, Lbe.	...	*	*	...	*	*	...	...	*	
Cladophyllia subdichotoma, Lbe.	...	*	*	...	...	*				
—— *sublævis*, Mnst. sp.	...	...	*	...	*	*	...	*		
—— *gracilis*, Mnst. sp.	...	...	...	...	...	*	...	...	*	
——, n. sp.	...	...	...	...	*					
Rhabdophyllia recondita, Lbe.	...	...	*	...	...	*				
Thecosmilia neglecta, Lbe.	...	...	...	...	*	*				
—— *Hoernesi*, Lbe.	..	...	*	...	...	...	...	...	*	
—— *rugosa*, Lbe.	...	...	*	...	*	...	...	...	*	
—— *granulata*, Klpst.	...	...	*	...	...	*				
—— *irregularis*, Lbe.	...	...	*	...	*					
—— *confluens*, Mnst. sp.	...	...	...	...	...	*	...	...	*	
—— *Zieteni*, Klpst. sp.	...	...	...	...	...	*				
——, n. sp. 1 & 2	...	...	*	...	...	...	...	...	*	
——, n. sp. 3 & 4	...	...	...	...	...	...	...	...	*	
——, n. sp. 5	...	...	...	...	...	...	...	*	*	
Montlivaltia tirolensis, Wöhrm.	...	...	...	...	...	*	...	...	...	2.
—— *cæspitosa*, Mnst.	...	...	...	...	...	*				
—— *capitata*, Mnst.	...	...	*	...	*	*				
—— *crenata*, Mnst.	...	...	...	...	...	*	...	...	*	
—— *radiciformis*, Mnst.	...	...	*							
—— *obliqua*, Mnst.	...	...	*							
—— *rugosa*, Mnst.	...	...	*							
—— *perlongata*, Mnst.	...	...	*							
—— *recurvata*, Lbe.	...	...	...	...	...	...	...	...	*	
—— *granulata*, Mnst.	...	...	...	...	*	...	...	...	*	
—— *acaulis*, Mnst.	...	...	...	...	*	...	...	...	*	
——, n. sp. 1 & 2	...	...	...	...	...	...	...	...	*	
——, n. sp. 3	...	...	*	...	...	...	...	...	*	
Axosmilia alpina, Loretz	...	...	...	...	...	...	...	...	*	
Omphalophyllia gracilis, Mnst. sp.	...	...	...	...	*	...	...	...	*	
—— *cyclolitiformis*, Lbe.	...	...	*	...	*	...	*	...	*	
—— *pygmæa*, Mnst. sp.	...	...	...	...	...	...	...	...	*	
—— *boletiformis*, Mnst. sp.	...	...	...	...	...	*	*	...	*	2.

List of Fossils (*continued*).

			St. Cassian.							Occurrence elsewhere.
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	
Cœlenterata (*continued*).										
Omphalophyllia, n. sp.	...	...	...	...	...	*				
Elysastræa Fischeri, Lbe.	...	...	...	...	...	*				
Phyllocœnia decipiens, Lbe.	...	...	...	...	...	*				
——, n. sp.	...	...	...	...	...	...	...	...	*	
Astrocœnia Oppeli, Lbe.	...	...	*	...	...	...	...	...	*	
Isastræa Gümbeli, Lbe.	...	*	*	...	...	...	...	*	*	
—— *Haueri*, Lbe.	...	...	*	...	...	...	...	*	*	
Latimæandra Bronni, Klpst. sp.	...	...	...	...	*	...	...	*	*	
—— *plana*, Lbe.	...	...	...	...	...	...	...	...	*	
——, cf. *labyrinthica*, Klpst.	...	...	...	...	...	...	...	*		
Thamnastræa Zitteli, Wöhrm.	...	*	*	...	*	...	...	*	*	2.
Dimorphastræa, n. sp. 1 & 2	...	...	...	...	...	...	...	...	*	
Stylina, n. sp.	...	...	...	...	...	...	...	*		
Echinodermata.										
Encrinus cassianus, Lbe.	...	*	*	*	*	*	...	*	...	1, 2, 3, 6, 7, 8, 9.
—— *varians*, Mnst.	...	*	*	*	*	*	...	*		
—— *granulosus*, Mnst.	...	...	*	...	*	*	...	*	*	1, 2.
Pentacrinus propinquus, Mnst.	...	*	*	*	*	*	...	*	*	1, 2, 3.
—— *tirolensis*, Lbe.	...	...	*	...	*	...	...	...	*	3, 6.
—— *subcrenatus*, Mnst.	...	...	*	...	*					
—— *lævigatus*, Mnst.	...	*	*	...	*	*	*			
Cidaris dorsata, Braun	*	*	*	*	*	*	...	*	*	1, 2, 3, 7, 9 (?).
—— ——, n. var.	...	...	...	...	...	...	...	...	*	
—— *Hausmanni*, Wissm.	...	*	*	...	*	*	...	*	*	1.
—— *Braunii*, Desor	...	*	*	*	*	*	...	*	*	1, 2, 3, 6.
—— *semicostata*, Mnst.	...	...	*	...	*	*	...	*		
—— *alata*, Agas.	...	...	*	*	...	*	...	...	...	1 (?), 9.
—— *Roemeri*, Wissm.	*	*	*	*	...	*	...	...	...	9.
—— *linearis*, Mnst.	...	...	*	*	...	*	*	...	*	
—— *Liagora*, Mnst.	...	...	*	...	...	*	...	*		
—— *triserrata*, Lbe.	...	...	*	...	...	...	...	...	...	7.
—— *flexuosa*, Mnst.	...	...	*	...	*	...	*	*	...	1.
—— *decorata*, Mnst.	...	...	*	...	*	*	...	*		
—— *trigona*, Mnst.	...	...	...	...	...	*				
—— *subsimilis*, Mnst.	...	...	...	...	...	*				
—— *fasciculata*, Klpst.	...	...	...	*						
—— *Klipsteinii*, Desor	...	...	...	...	...	...	...	...	*	
—— *spinosa*, Agas.	...	...	...	...	...	...	...	...	*	

LIST OF FOSSILS (*continued*).

			St. Cassian.							
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	Occurrence elsewhere.
ECHINODERMATA (*continued*).										
Cidaris parastadifera, Schafh.	...	...	...	...	...	...	...	*	...	2, 3.
—— *subnobilis*, Mnst.	...	...	*							
—— *Buchii*, Mnst.	...	...	*							
—— *biformis*, Mnst.	...	...	*	...	...	...	...	...	...	1.
—— *scrobiculata*, Braun	...	...	*							
Rhabdocidaris subcoronata, Mnst. sp.	...	...	*	...	...	...	...	*		
POLYZOA.[1]										
Ceriopora, sp. divers.	...	...	...	...	...	...	...	...	...	2 (*C. cnemidium*).
BRACHIOPODA.										
Waldheimia Münsteri, d'Orb. sp.	...	...	...	...	...	*				
—— *Eudora*, Lbe. sp.	...	...	*							
—— *subangusta*, Mnst. sp.	...	...	*	...	...	*				
—— *carinthiaca*, Rothpl.	...	...	*	...	...	...	...	...	...	5, 7.
Rhynchonella tricostata, Mnst. sp.	...	...	*	...	...	*	...	...	*	
—— *semicostata*, Mnst. sp.	...	...	*							
—— *subacuta*, Mnst. sp.	...	...	*	...	...	...	...	...	*	1.
—— *linguligera*, Bittn.	...	...	*	...	...	...	...	...	...	1.
—— *quadriplecta*, Mnst. sp.	...	...	*	...	...	...	...	...	*	
—— *subacuta*, var. *coralliophila*, Bittn.	...	...	...	...	...	...	...	...	*	
Amphioclina Suessi, Lbe.	...	...	...	...	...	*				
—— *amœna*, Bittn.	...	...	...	...	...	...	...	...	*	
—— *scitula*, Bittn.	...	...	...	...	...	...	...	*		
Koninckina Leonhardti, Wissm., sp.	...	...	*	*	...	...	...	...	...	1.
——, n. sp.	...	...	...	*						
Koninckella triadica, Bittn.	...	...	*	...	...	...	...	...	...	1.
Spirigera Wissmanni, Mnst. sp.	...	...	*	...	*	*	...	...	*	1.
—— *indistincta*, Beyr. sp.	...	...	*	...	*	*	...	*	*	1.
—— *subcurvata*, Mnst. sp.	...	...	...	...	...	...	...	...	*	
—— *quadriplecta*, Mnst. sp.	...	...	*	...	...	*				
—— —— (var. *euplecta*, Bittn.)	...	...	...	...	*					
—— *Schloenbachii*, Lbe. sp.	...	...	*							
—— *flexuosa*, Mnst. sp.	...	...	*	...	...	*				
—— *contraplecta*, Mnst. sp.	...	...	*							

[1] Several species of polyzoa were found in all the above localities, but they have not yet been identified.

LIST OF FOSSILS (*continued*).

			St. Cassian.							Occurrence elsewhere.
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	
BRACHIOPODA (*continued*).										
Retzia Klipsteinii (nov. nom. Klipst. sp.), Bittn.	...	...	*							
—— *distorta*, Bittn.	...	...	...	...	...	...	...	...	*	
——, n. sp.	...	...	...	...	*					
Cyrtina Zitteli, Klipst. sp.	...	...	...	...	...	*				
Spiriferina Frechii, Bittn.	...	...	...	...	...	...	...	...	*	
——, sp. indet.	...	...	...	...	...	*				
Crania Calymene, Klipst.	...	...	*							
Discina (*Orbicula*) *discoidea*, Mnst. sp.	...	*								
LAMELLIBRANCHIATA.										
Lima subpunctata, d'Orb.	...	...	...	...	...	...	...	*	...	8.
——, n. sp.	...	...	...	...	...	...	...	*		
Placunopsis, sp. indet.	...	...	...	...	...	...	...	*		
——, sp. n. aff. *fissistriata*, Winkler	...	...	...	...	...	...	...	*		
Hinnites obliquus, Lbe.	...	...	*							
Pecten Nerei, Mnst.	...	...	*							
—— *subalternans*, d'Orb.	...	...	*	...	...	...	...	...	...	2, 3, 6, 7.
—— *tubulifer*, Mnst.	...	...	...	...	...	*				
—— *subdemissus*, Mnst.	...	...	*	...	...	*				
——, cf. *Schlosseri*, Wöhrm.	...	...	...	...	...	...	...	*	...	3, 6.
——, n. sp.	...	...	...	...	...	...	...	*		
Gryphæa arcta, Braun	...	...	...	...	...	*				
—— *avicularis*, Mnst.	...	...	*							
Avicula arcuata, Mnst.	...	...	*	...	...	*	...	...	...	7.
—— *depressa*, Wissm.	...	...	*	...	...	...	*			
—— *Gea*, d'Orb.	...	...	*	...	...	*	*	...	...	2, 6, 7, 8.
——, n. sp. aff. *Gea*, d'Orb.	...	...	...	...	...	...	...	*		
Cassianella decussata, Mnst. sp.	...	...	*	...	*	*	...	...	...	2, 8, 9.
—— *grypheata*, Mnst. sp.	...	...	*	...	...	*	...	*	...	8.
—— *tenuistriata*, Mnst.	...	...	*							
—— *euglypha*, Lbe.	...	...	*	...	...	*				
Halobia Richthofeni, Mojs.	...	...	*	*	...	...	...	...	...	1.
—— *Lommeli*, Wissm.	*	*	...	...	...	...	...	...	...	1, 2, 4 (?).
—— *rugosa*, Gümbel	...	...	...	...	...	...	*	...	...	1, 2, 8.
Posidonomya wengensis, Wissm.	*	*	*	*	*	...	...	*	...	2, 8.
——, n. sp. 1	*	*	*	*						
——, n. sp. 2	...	...	*							
Gervillia angulata, Mnst.	...	...	*	...	*	...	*	*	*	
—— *angusta*, Goldf.	...	...	*	*	...	*	*	*	...	3, 6.
Nucula lineata, Goldf.	...	*	*	*	...	...	*			

List of Fossils (*continued*).

			St. Cassian.							
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	Occurrence elsewhere.
Lamellibranchiata (*continued*).										
Nucula subcuneata, Goldf.	...	...	*	*						
—— *strigilata*, Goldf.	...	...	*	*	...	*	...	...	...	6, 8.
—— *inflata*, Wissm.	...	...	...	...	...	...	*			
—— *subtrigona*, Mnst.	...	...	...	...	...	...	*			
—— *cordata*, Mnst.	...	...	*							
—— *subobliqua*, d'Orb.	...	...	...	...	...	*	...	...	...	7(?).
—— *expansa*, Wissm.	...	...	...	...	...	*				
Cucullæa impressa, Mnst.	...	...	*	...	...	...	...	*	...	7 (?).
Macrodon strigilatus, Mnst. sp.	...	...	...	...	...	*	...	...	...	2, 3, 6, 7, 8, 9.
Leda elliptica, Goldf.	...	...	*							
—— *præacuta*, Klipst.	...	...	*	...	...	...	...	...	...	7 (?).
—— *tirolensis*, Wöhrm.	...	...	...	...	...	...	*	...	...	2, 3, 7, 8.
Myophoria Whateleyæ, Buch, sp. (=*Myophoria chenopus*, Lbe.)	...	...	*	...	...	*	*	...	...	2, 3, 5, 6, 7, 8, 9.
—— *harpa*, Mnst. sp.	...	...	...	...	...	*				
Grünwaldia (*Myophoria*) *decussata*, Mnst. sp.	...	...	*	...	...	...	...	*	*	2, 3, 7.
Myophoriopis lineata, Mnst. sp.	...	...	*	..	...	...	*	*	...	2, 7.
Anoplophora Münsteri, Wissm.	...	...	...	...	...	*	*	...	...	5, 7, 8.
—— *recta*, Gümb. sp.	...	...	...	...	...	*	...	...	...	3.
Cardita crenata, Goldf.	...	...	*	...	...	*				
—— ——, var. *Gümbeli*, Pichl.	...	...	...	...	...	...	...	...	*	2, 3, 7.
——, n. sp.	...	...	...	...	...	...	...	...	*	
Pachyrisma rimosum, Mnst. sp.	...	...	...	...	...	...	...	*	...	7, 8.
—— *rostratum*, Mnst. sp.	...	...	*							
——, n. sp.	...	...	...	...	...	...	...	*		
Trigonodus rablensis, Gredler	...	...	...	...	...	...	...	?	...	7, 8, 9.
Modiola, cf. *obtusa*, Eichw.	...	...	...	...	...	...	...	*	...	9.
—— *gracilis*, Klpst.	...	...	...	...	...	...	*	...	...	7, 8, 9.
Mytilus Münsteri, Klpst.	...	...	*	*	...	*	*	...	...	1.
——, n. sp.	...	...	...	...	...	...	...	*		
Lucina anceps, Lbe.	...	...	...	...	...	...	*	...	...	8, 9.
Fimbria (*Corbis*) *astartiformis*, Mnst. sp.	...	...	*	...	...	...	...	...	...	2, 8, 9.
Pinna, n. sp.	...	...	...	...	...	...	...	*		
Gasteropoda.										
Dentalium decoratum, Mnst.	...	...	...	...	...	...	...	*		
—— *undulatum*, Mnst.	...	...	*	...	...	...	...	...	...	3.
Patella granulata, Mnst.	...	...	*							
Emarginula Münsteri, Pictet	...	...	*	...	...	...	...	...	*	
Zygites delphinula, Klpst. sp.	...	...	*							

List of Fossils (*continued*).

			St. Cassian.							
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	Occurrence elsewhere.
Gasteropoda (*continued*).										
Raphistomella radians, Wissm. sp.	...	...	*	...	*					
Kokenella costata, Mnst. sp.	...	...	*							
Temnotropis fallax, Kittl	...	...	*							
—— *bicarinata*, Lbe.	...	...	...	...	...	...	...	*		
Pleurotomaria, n. sp. aff. *nodosa*, Mnst.	...	...	...	...	...	...	...	...	*	
Worthenia (*Pleurotomaria*) *coronata*, Mnst. sp.	...	...	*	...	...	*				
—— (——) *cirriformis*, Lbe. sp.	...	...	*							
—— (——) *subcostata*, Mnst. sp.	...	...	*							
—— (——) *canalifera*, Mnst. sp.	...	...	*	...	...	*	...	...	...	9.
—— (——) *subgranulata*, Lbe. sp.	...	...	*							
—— (——) *Münsteri*, Klpst. sp.	...	...	*							
—— (——) *spuria*, Mnst. sp.	...	...	*							
—— (——) *coralliophila*, Kittl	...	...	...	...	...	...	...	...	*	
—— (——) *turriculata*, Kittl	...	...	...	...	*	...	...	...	*	
—— (——) *Joh.-Austriæ*, Klpst.	...	...	*	...	*					
—— (——) *rarissima*, Kittl	...	...	...	...	*					
—— (——) *cassiana*, Kittl	...	...	*							
Chilotoma Blumi, Mnst. sp.	...	...	*	*	...	*				
Laubella, n. sp.	...	...	...	...	*					
Euomphalus (=*Schizostoma*, Kittl) *dentatus*, Mnst.	...	...	*							
—— *spiralis*, Mnst. [em.) (=*Margarita lævigata*, Mnst. sp., Kittl	...	...	*	...	...	*	...	*	*	
—— *lineatus*, Klpst. sp.	...	...	...	...	...	*				
Cœlocentrus Pichleri, Lbe. sp.	...	...	*	...	*	*				
Schizogonium scalare, Mnst. sp.	...	...	*	...	*	*				
—— *serratum*, Mnst. sp.	...	...	*	...	...	*				
—— *Laubei*, Klpst. n. sp.	...	...	...	...	*					
Turbo vixcarinatus, Mnst.	...	...	...	...	*	...	...	...	*	
—— *subcarinatus*, Mnst.	...	...	*	...	...	...	...	...	*	
——, n. sp.	...	...	...	...	...	...	...	...	*	
Umbonium helicoides, Mnst. sp.	...	...	*							
Pachypoma Damon, Lbe.	...	...	...	...	...	*				
—— *calcar*, Mnst. sp.	...	...	*	...	*					
Trochus subglaber, Mnst.	...	...	*	...	...	...	...	...	*	
—— *nudus*, Mnst.	...	...	*							
—— *sub-bisertus*, d'Orb.	...	...	*							
—— *subconcavus*, Mnst.	...	...	*							
—— *lissochilus*, Kittl	...	...	*							
—— *bistriatus*, Mnst.	...	...	*							
—— *glandulus*, Lbe.	...	...	...	...	*					

List of Fossils (*continued*).

			St. Cassian.							
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	Occurrence elsewhere.
Gasteropoda (*continued*).										
Ziziphinus (*Trochus*) *semipunctatus*, Braun sp.	...	...	*	...	...	*	...	...	*	
Colonia cincta, Mnst. sp.	...	...	...	...	*	...	...	*		
Eunemopsis dolomitica, Kittl	...	...	*							
—— *Epaphus*, Lbe. sp.	...	...	*	...	...	*				
Delphinula lævigata, Mnst.	...	...	...	...	...	...	...	...	*	
Clanculus (*Monodonta*) *cassianus*, Wissm. sp.	...	...	*	...	*	*	...	...	*	
—— (——) *nodosus*, Mnst. sp.	...	...	*	...	...	*				
Neritopsis ornata, Mnst. sp.	...	...	...	...	...	*				
—— *armata*, Mnst. sp.	...	...	*	...	...	...	...	...	*	9.
—— *armata*, var. *plicata*, Kittl	...	...	...	...	...	...	...	...	*	
—— *decussata*, Mnst. sp.	...	...	*	...	*	...	...	...	...	9, & in 2, *N. pauciornat.*
——, n. sp.	...	...	...	...	...	...	...	*		
Scalaria triadica, Kittl	...	...	...	...	...	...	...	...	*	
—— *ornata*, Mnst. sp.	...	...	...	...	...	...	...	...	*	
—— *Damesi*, Kittl	...	...	...	...	...	...	...	...	*	
—— *venusta*, Mnst. sp.	...	...	...	...	...	*				
—— *binodosa*, Mnst. sp.	...	...	*							
—— *biserta*, Mnst. sp.	...	...	*							
—— *elegans*, Mnst. sp.	...	...	*							
—— *supranodosa*, Klpst. sp.	...	...	*							
Palæonarica constricta, Kittl	...	...	*							
—— *concentrica*, Mnst. sp.	...	...	*	*	*	...	...	...	*	9.
(Cf. *pseudofossarum*, Koken.)										
Oncochilus globulosus, Klpst. sp.	...	...	*	...	...	*				
Naticella concentrica, Mnst.	...	...	...	...	...	*				
—— aff. *sublineata*, Mnst. sp.	...	...	*	...	...	...	...	...	*	
Naticopsis neritacea, Mnst. sp.	...	...	...	...	...	...	*	*	*	
—— *impressa*, Mnst. sp.	...	...	*	...	...	*	...	*	*	
—— *ornata*, Mnst. sp.	...	...	*	...	...	...	...	*	*	
—— *expansa*, Lbe. sp.	...	...	*	...	...	...	...	*		
—— *elongata*, d'Orb. sp.	...	...	*	...	...	...	...	...	*	
——, cf. *cassiana*, Wissm. sp.	...	...	...	...	...	...	...	*		
——, sp. indet.	...	...	...	...	...	...	...	*		
Natica Mandelslohi, Klpst.	...	...	*	...	*					
—— *neritina*, Mnst.	...	...	*							
—— *sublineata*, Mnst.	...	...	...	...	...	*				
Amauropsis paludinaris, Mnst. sp.	...	...	*	...	...	...	...	...	*	
——, sp. indet.	...	...	...	...	...	...	...	*		
Ptychostoma pleurotomoides, Wissm. sp.	...	...	*	...	*	*	*	*		
—— *Wähneri*, Kittl	...	...	*							
——, sp. indet.	...	...	...	...	...	...	...	*		

List of Fossils (*continued*).

			St. Cassian.							
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	Occurrence elsewhere.
Gasteropoda (*continued*).										
Lacuna Karreri, Kittl	...	...	*							
Delphinulopsis binodosa, Mnst. sp.	...	...	*	...	...	...	...	*	*	
—— *Laubei*, Kittl	...	...	*							
——, sp. indet.	...	...	...	...	...	...	...	...	*	
Turritella subtilestriata, Klipst.	...	...	...	...	...	*	...	...	*	
—— (*Undularia*, Koken) *carinata*, Mnst.	...	...	*	...	...	...	...	...	*	9.
——, n. sp.	...	...	...	...	...	...	...	...	*	
Loxonema subornatum, Mnst.	...	...	...	...	...	*	...	...	*	
—— *tenue*, Mnst. sp.	...	...	*	...	...	...	...	...	*	
—— *obliquecostatum*, Bronn	...	...	...	...	...	...	...	...	*	8, 9.
—— *arctecostatum*, Mnst. sp.	...	...	*	...	...	...	...	...	...	9.
(For the preceding two, cf. *Zygopleura*, Koken)										
—— *acutecostatum*, Mnst. sp.	...	...	*							
—— *Haueri*, Klpst. sp.	...	...	*							
—— *hybridum*, Mnst. sp.	...	...	*							
——, n. sp. (cf. *Hypsipleura* ?)	...	...	...	...	...	...	...	*		
——, n. sp.	...	...	...	...	...	...	...	...	*	
Chemnitzia gracilis, Mnst. sp.	...	...	*	...	...	*				
—— *longissima*, Mnst. sp.	...	...	*							
—— *supraplecta*, Mnst.	...	..	*							
—— *subcolumnaris*, Mnst.	...	...	*	...	...	*				
—— *subscalaris*, Lbe.	...	...	*	...	...	...	...	...	*	
—— *turritellaris*, Mnst. sp.	...	...	*	...	...	...	...	...	*	
—— *reflexa*, Mnst.	...	...	...	...	...	*				
—— *Dunkeri*, Klpst.	...	...	...	...	...	*				
Cerithium fenestratum, Lbe.	...	...	*	...	...	*				
—— *Koninckianum*, Lbe.	...	...	*							
—— *nodoso-plicatum*, Mnst.	...	...	...	...	*					
—— *bisertum*, Mnst.	...	...	*							
——, sp. indet.	...	...	...	...	...	...	...	*		
Holopella Lommeli, Mnst. sp.	...	...	*							
Niso conica, Klpst. sp.	...	...	*							
Neritaria, cf. *plicatilis* ?, Klpst.	...	...	...	...	...	...	...	*		
Katosira, cf. *fragilis* ?, Koken	...	...	...	...	...	...	...	...	*	9.
——, cf. *Zygopleura spinosa*, Koken	...	...	...	...	...	...	...	...	*	9.
Hypsipleura, n. sp. 1 & 2	...	...	...	...	...	...	...	...	*	
Cephalopoda.										
Aulacoceras inducens, Mojs.	...	...	*	...	...	...	*	*	...	9.
Orthoceras elegans, Mnst.	...	...	*	...	...	...	...	*		

List of Fossils (*continued*).

			St. Cassian.							
			Middle or 'Stuores' Zone.				Upper Zone.			
	Wengen Beds.	Lower St. Cassian.	Stuores.	Abtey slopes.	Romerlo.	Sett Sass (Forcella).	Heiligkreuz Strata.	Cortina.	Seeland Alpe.	Occurrence elsewhere.
Cephalopoda (*continued*).										
Orthoceras, aff. *subellipticum*, Mojs	...	...	*							
Nautilus granulosostriatus, Klipst.	...	...	*							
——, cf. *linearis*, Mnst.	...	...	...	...	...	...	...	*		
Arcestes bicarinatus, Mnst.	...	...	*	...	...	*				
——, aff. *Gaytani*, Klipst.	...	...	*							
——, sp. indet.	...	...	...	...	...	*				
Joannites cymbiformis, Wissm.	*	...	*	*	...	...	...	...	...	2, 9.
Lobites pisum, Wissm. (acc. to Mojs. = *nautilinus*, Lbe.)	...	...	*	*						
Celtites, aff. *Buchi*, Lbe.	...	...	*	...	...	...	...	...	...	1.
—— *epolensis*	...	*								
Klipsteinia Boetus, Wissm.	...	...	*							
—— *irregularis*, Mnst.	...	*								
Trachyceras Aon (forma—typical *Aon*), Wissm.	...	*	*	*	...	...	...	...	...	1, 4.
—— —— (forma *Münsteri*), Wissm.	...	...	*							
—— —— (forma *Brotheus*), Wissm.	...	...	*							
—— *furcatum*, Mnst.	*	...	...	...	...	...	...	...	...	4.
—— *Basileus*, Wissm. (=*Busiris*, Lbe.)	...	...	*	...	...	...	...	...	...	4.
—— *Zeuschneri*, Klipst.	...	...	*							
—— *sulciferum*, Mnst. (=*Saulus*, Lbe.)	...	...	*							
—— *Gredleri*, Mojs.	*									
——, cf. *Archelous*, but an evolute form; see also Parona, 'Fauna Raibliana di Lombardia.'	...	...	...	...	...	...	...	*	...	8 (?).
Badiotites Eryx, Mnst.	...	...	*							
Megaphyllites Jarbas, Mnst.	...	...	*							
Lecanites glaucus, Mnst.	...	...	*							

Note.—Besides the well-known plant-fauna occurring in the Wengen Beds near Corvara, badly-preserved remains of plants were found both in the St. Cassian and Raibl Beds, but the identification of these is impossible.

The fossils occurring in the Wengen Beds at Prags have been so fully quoted by Hoernes and by Loretz that it is unnecessary for the present writer to mention the specimens found by her.

VIII. The Tectonic Relations.

(*See General Tectonic Map, facing* p. 70.)

Before entering into a detailed consideration of the geological maps, it is perhaps advisable to refer to the general tectonic relations of the northern district of the Dolomites; the three separate districts which I have specially studied will thus be more clearly brought before the reader. My own knowledge of this wider region is based on a study of the literature, as well as on personal observations in several places.

A glance at a geological map of the Dolomites shows that the pre-Triassic rocks are exposed in the Pusterthal, and are succeeded in the south by younger strata. In the neighbourhood of Prags, west of Toblach, we meet Werfen and Muschelkalk beds; these continue westward in the Hoch Alpe towards St. Vigil and Wengen, and cross the Enneberg Valley north of Pedratsches. Here they bifurcate, the northerly branch passing off in the Villnös direction, the southerly over the valley of Campil to that of Gröden. From the Gröden Valley it turns southward, and, leaving Schlern on the east, is exposed in the Tiers Valley and farther south. The same strata strike along the base of the Rosengarten *massif* and the Fassa Valley, eastward over the Pordoi Pass into the Buchenstein Valley; from Buchenstein they strike south-west towards Caprile, where they are in great measure lost sight of, owing to an east-and-west fault-line, but may be partly traced as far as St. Vito in the Boita Valley. Within these limits the older Triassic strata are nowhere exposed, with the exception of a small band from the Upper Gröden Valley, over the Gröden Pass to Colfuschg and St. Cassian. The younger Triassic strata attain, on the other hand, an extended outcrop, so that in a merely general sense we may regard this as a synclinal area, in which at one part (Gröden Pass—Langs-da-für—St. Cassian) the older beds form a broken anticline. This folding of the beds, although indicated on a broad scale, has been modified and sometimes entirely destroyed by a number of faults.

Not many miles distant from the outer zone of older Triassic strata there rises abruptly a great complex of Dachstein Dolomite, succeeded in many places by Jurassic and Cretaceous rocks. This Dachstein-Dolomite complex embraces Hohe Gaisl, Seekofl, Heiligkreuz Kofl, La Varella, Tofana, Monte Cristallo, and one may add Gardenazza in the west. Numerous faults have let down this whole region of Dachstein rock, and it is perhaps better to speak of it as a subsided area than as a syncline. In many of the sections given by Mojsisovics (‘Dolomit-Riffe,’ pp. 209, 213, 288, 289, etc.) the lines of disturbance and faulting are shown.

The relations in the outer zone of older Trias vary. At many places (*e. g.* the Dürrenstein, Wengen district, Puflatsch) the older Triassic strata are let down by step-faults, whereas in the neighbourhood of Pedratsches they are folded.

Of more importance are the faults which have brought down the younger Triassic against this zone of older Triassic rocks.

These faults have an east-and-west course, and extend along the whole region north of the sunken area. If, now, the strata on the southern or downthrow side be brought down to the level of the Mendola Dolomite on the other side of the fault, we have from the Lower Muschelkalk a continuous outcrop of dolomite up to the Raibl strata.

Loretz has previously explained this as in part the result of such east-and-west faults. Mojsisovics, on the other hand, has explained it as an unbroken dolomitic rock, part of which is a 'heteropic' development of dolomite corresponding in age to the marls, tuffs, etc. of the St. Cassian, Wengen, and Buchenstein periods.

In several cases I found that the younger strata were brought down by faults against different horizons of older strata; naturally, in the particular case of two dolomitic horizons being faulted against one another, the line of fault, or even its presence, is extremely difficult to prove, not only from the lithological similarity of the two rocks, but also from their poverty in fossils.

One of the main fault-lines recognized by Mojsisovics (in co-operation with the survey of Hoernes) is the Villnös fault, which, he says, may be traced through the Villnös Valley, over Campil, then across the Enneberg Valley, through Fanis, south-east to Peutelstein and towards Tre Croci. I could not convince myself that this was one and the same fault-line; for instance, Mojsisovics says (*op. cit.* p. 293):—"West of the Wengen Valley, the northern wing of the fault-line is the downthrow; east of the Wengen Valley, on the contrary, it is the southern wing which is the downthrow."

So far as my own observations go, the Villnös fault, from the Upper Villnös Valley up to near Campil, belongs to the set of step-faults already mentioned, which have thrown down the older Triassic strata to the north. That part of the Villnös fault which is found west of the Enneberg Valley is one of a set of parallel faults with a repeated downthrow to the south occurring within the sunken district of Dachstein Dolomite.

The system of older Triassic rocks faulted up both east and west of the Gröden Pass meets farther west the outer zone of Werfen Beds, Muschelkalk, etc. West of the Tschisler Alpe and Wolkenstein, therefore, we find no outcrop of Dachstein Dolomite and younger Triassic rocks, the Gardenazza *massif* and Puez forming the western limit of the sunken area. Hence it is, also, that the relations of the strata are so much simpler towards Puflatsch and Schlern.

Two of the districts mapped lie in the southern portion of the wide area just discussed. That of Prelongei (Map A) is precisely on the boundary-limit where, in the Buchenstein Valley, the southern wing of the broad syncline of older Trias bends up; that of Cortina (Map B) lies just south of the area of subsidence, below the Dachstein *massif* of Tofana. But the map of the Dürrenstein (Map C) lies partly in the outer zone of older Trias, and shows interesting transitional features from this zone to the Dachstein Dolomite.

(i.) *The District of Prelongei and Sett Sass.*
(See Map A, facing p. 18.)

At the north-eastern corner of the Prelongei map lies Centurinus Spitz, a peak of Dachstein Dolomite. Southward, towards Sore Bach, this Dachstein Dolomite is in contact with the Schlern Dolomite, and below the Schlern Dolomite are the St. Cassian Beds. Very little farther south the St. Cassian Beds form the slopes below Lagazuoi, and above them follows the complete succession, *i. e.* Schlern Dolomite, Raibl Beds, and Dachstein rocks.

The Raibl Beds and part of the Schlern Dolomite have disappeared at Centurinus Spitz, owing to an east-and-west fault. The Lagazuoi *massif* is south of the fault-line, while the Centurinus Spitz, north of it, is on the downthrow side, Dachstein Dolomite having been faulted down against Schlern Dolomite. This fault-line bends round towards the north, and may be followed along the eastern side of the Enneberg Valley. The rocks east of it are everywhere let down against older strata. I shall have occasion to refer again to this fault in connexion with the Heiligkreuz section.

The Falzarego fault-line, observed by Mojsisovics in the Falzarego or Cortina Valley, is further continued over the Tra i Sassi Pass and Valparola in a south-east and north-west direction, and cuts off the Lagazuoi *massif* from Sett Sass. The relations at this western end of the fault remain the same as those already proved in the Falzarego Valley, *i. e.* the rocks south of the fault-line are in all cases thrown down.

In the Falzarego Valley Raibl strata and Schlern Dolomite are faulted against St. Cassian strata; at Valparola, within the district of my map, Raibl strata and Dachstein Dolomite are faulted against St. Cassian strata and Schlern Dolomite. The throw is greater in the west than in the east, where Schlern Dolomite is present above the St. Cassian Beds south of the fault-line. According to the explanation of Mojsisovics, the Raibl strata rest at Valparola conformably upon St. Cassian strata, as a natural consequence of the thinning-out of the Schlern Dolomite of Sett Sass. As may be seen in Map A and in fig. 3 (p. 21), there is clear evidence of the already mentioned fault north of Sett Sass, bringing at first Raibl Beds and then Dachstein Dolomite down to the horizon of the St. Cassian strata.

Moreover, I have proved that south of Sett Sass the higher Middle St. Cassian horizons are separated by an east-and-west fault from the Wengen Beds of Monte Sief, while towards the west the Schlern Dolomite, Raibl Beds, and Dachstein Dolomite are cut off from the St. Cassian strata of Prelongei and Stuores by a north-and-south fault-line of considerable throw.

The Sett Sass Berg has a horseshoe shape, steep cliffs rise all round the outer convex side, but the rocks descend more gently towards the inner side. In this way the woods and Alpe of Valparola lie in a rocky hollow. The strata have a general east-and-west strike, and a northerly dip.

The southern wall of Sett Sass is Schlern Dolomite, succeeded towards Tra i Sassi (on the eastern limb of the horseshoe) by Raibl and Dachstein strata. On the southern wall itself these rocks have been eroded, but are seen lying conformably upon the Schlern Dolomite in the Valparola hollow; here the dip of the beds is steeper than the angle of incline of the mountain (see fig. 3, p. 21). On the western limb of the horseshoe the Raibl and Dachstein rocks have a wider outcrop than on the eastern limb, and are brought against the Schlern Dolomite and the Raibl strata at Valparola by means of a south-west and north-east fault-line.

The fault is seen again at the south-western corner of Sett Sass, between Raibl strata and Schlern Dolomite. It is, however, merely of minor importance, branching from the north-and-south fault which extends between the whole of the western limb and the Stuores Wiese. Both transverse faults are then cut off by the main longitudinal east-and-west Valparola fault, this triangular break having thrown the western limb farther down than the rest of Sett Sass. Towards Prelongei, long lines of Raibl and Dachstein blocks and débris occur in the course of the fault below Sett Sass and above Stuores wood.

The system of Monte Sief and Col di Lana belongs to the previously-mentioned anticlinal outcrop of older Triassic strata. In the valley between Andraz and Pieve the Werfen Beds strike east-and-west; above them Muschelkalk, Buchenstein Beds, and augite-porphyry follow in symmetrical succession, both southward towards Marmolata and northward towards Sett Sass. This valley was not included in my detailed study, although in the map I have for convenience indicated the general relation of the older Trias to the strata exposed on Prelongei.

On the northern side of the valley the Buchenstein limestones and the augite-porphyry and sedimentary tuffs have an unusually thick development on the Col di Lana hill. The strata dip northward, and are bent up towards the south as an anticlinal arch, which may be very clearly observed in the north-east and north-west of Monte Sief—in the north-east, where the stream running to Castello takes its source; in the north-west, where the slopes of Monte Sief descend steeply to Montagna della Corte. Here the bed-surface is often almost parallel with the slope of the hill, and in many places, where the Wengen Beds have been eroded, augite-porphyry reappears suddenly, sometimes with a fairly large outcrop.

The strike of the older Triassic rocks continues west over Cherz and Varda to Arabba. They dip northward, and are here also conformably succeeded by Wengen Beds. A complication is caused by an east-and-west fault above Varda, throwing down the southern wing, and cutting off the exposure of Werfen Beds on the northern wing. I found, however, Werfen Beds (which I identified by the fossils occurring in them) on the right hand of the ascent to Campolungo Pass. These strike north-east and south-west, dip 30°–40° S.E., and are succeeded by Muschelkalk and Buchenstein Beds. This small outcrop of older Trias is then faulted from the Buchenstein Beds and volcanic agglomerates exposed higher on the Pass. The whole system on the Pass belongs to the northern wing of the Varda fault; augite-porphyry forms the southern wing, and is present below the exposure of Werfen Beds in the stream which flows towards Arabba. The Buchenstein anticline is therefore broken north of Arabba by an east-and-west fault of reversed hade. I did not follow the eastward continuation of this Varda fault, but at Cherz I observed that the succession from the Werfen to the Wengen Beds was conformable. The latter are exposed on a wide hilly upland between Cherz and the Incisa Bach; again, descending along the Incisa Bach towards Corvara, they are found in complete succession, resting upon the augite-porphyry near Corvara (see fig. 1, p. 17). This whole system meets (along the transverse fault west of Campolungo) the system of Wengen and St. Cassian strata which underlie Sella. Close under the rocky wall of the Sella *massif* several small faults occur; Dachstein Dolomite and Raibl strata are faulted down against St. Cassian strata; sometimes, again, the Schlérn Dolomite remains in considerable thickness above the St. Cassian Beds.

North of Monte Cherz the Prelongei succession is exposed (see fig. 2, p. 19); in this the St. Cassian strata are predominant. A fault of small throw runs from the north-west at the Incisa Bach towards the south-east. Although this fault can be easily traced towards Corvara, it is difficult to follow it through the meadows of the Selvaza Bach, partly owing to the presence of slipped débris, and partly because its course here is only through different horizons of Wengen Beds. It apparently meets the (east-and-west) Monte Sief fault near Cherz, and the Prelongei succession north of it is slightly let down.

That succession, which occupies the central portion of Map A, is cut off eastward towards Sett Sass by the north-and-south fault against the Dachstein Dolomite; southward by the Monte Sief-Cherz fault and the Cherz-Incisa Bach fault against the Wengen Beds; north-westward and northward by the fault from the Gröden Pass. Another fault runs parallel with the Gröden Pass-and-Prelongei fault, and north of it; between them, on Langs-da-für, the older strata, from the Werfen to the Wengen Beds, are exposed. This is the southern wing of the Gröden Pass anticlinal fold; the northern wing is cut out here, but is exposed farther west and faulted against the Gardenazza *massif* at Sass Songe, north of Colfuschg.

The main strike of the Langs-da-für system is south-west and north-east, and the strata dip south-east. On the northern slope (towards the confluence of the Grosser Bach and the Sore Bach) the Langs-da-für system is faulted against Wengen Beds, which form part of the system of Wengen and St. Cassian Beds exposed on both sides of the Gader Bach (see fig. 4, p. 26).

Near St. Cassian the Werfen Beds and the Muschelkalk are again cut off against younger strata by a minor east-and-west fault. Augite-porphyry and bedded tuffs are the rocks chiefly exposed in the lower part of the Freiner Bach, along with a great many blocks of Buchenstein limestone; but the strata are largely hidden by all kinds of débris. They strike in an east-and-west direction across the valley at St. Cassian. Immediately north of St. Cassian is a thick mass of augite-porphyry, and above it follow the Wengen shales containing *Halobia Lommeli*. The higher Wengen horizons and the St. Cassian strata form the Ru and Peravuda slopes on the north. At St. Cassian, therefore, a small outcrop of augite-porphyry and *Halobia*-shales is cut off on all sides, except Langs-da-für, against younger strata, the outcrop being essentially a continuation of the Langs-da-für anticline, only slightly disjointed.

To return now to the central Prelongei succession, we may consider it as a shallow synclinal exposure of Wengen and St. Cassian strata. Southward (Selvaza or Buchenstein Alpe) the series of beds dip at a small angle, 15° to 20° north, whereas on Stuores Wiese, wherever a sure reading of the beds in their true position is obtainable, they are found to dip at a still smaller angle (5° to 10°) south. The most fossiliferous St. Cassian horizons are found on the ridge of Prelongei, and, as I have already said, are repeated in Ruones Muren (see fig. 1, p. 17). For, towards Corvara, the strata on Prelongei are twice let down by small step-faults. A large district in the north-west, known as 'Siadu,' is also faulted down from the Prelongei succession, so that the St. Cassian strata, which are in position between Sorega and the Piccol Bach, have a quite different strike-system from the strata between the latter stream and the Stuores Bach. Numerous blocks and an unusual thickness of dolomitic débris cover the St. Cassian Beds of Siadu, and indicate the presence at a former period of a continuous bank of Schlern Dolomite in that locality.

The palæontological difficulties introduced by the landslips on the Stuores Wiesen have already been touched upon (p. 18). The constant sliding down of younger strata upon older strata, and of a whole piece of meadow into a secondary and quite irrelevant position, may be observed at every part of the northern slopes of Prelongei. The soft marls, shales, and ashy Wengen Beds become saturated with water, and give way under the St. Cassian marls, with their numerous interstratified beds of hard Cipit Limestone. Slips then occur in the St. Cassian strata on a more or less grand scale, and one finds remnants of thick St. Cassian limestone at varying heights, looking at first sight like tongues of limestone thinning out in the fossiliferous marls, and only with difficulty recognized as the broken and slipped fragments of originally continuous beds.

Naturally the slips occur more readily on Prelongei than in cases where Schlern Dolomite rock still remains as a protection upon the St. Cassian strata. The mossy hollows and high meadows of Prelongei form an extensive eroded surface exposed to the action of heavy rains, melting snow, and swollen streams, and the down-wash of centuries is spread as a loose soil upon the outcrop of older beds.

(ii.) *The Upper Enneberg.*

Although no map of the Abtey portion of Enneberg is presented in this paper, I made very careful observations of the tectonic relations, and they are best considered in conjunction with the Prelongei district. The Wengen and St. Cassian strata are in place on both sides of the Enneberg Valley; they dip on the Gardenazza side westward, and on the Heiligkreuz side eastward. The succession in the northern part of the Gardenazza *massif* is complete from the Wengen Beds to the Dachstein Dolomite; but southward, between Varda and Colfuschg, the succession is broken by the Gröden Pass faults, and the Schlern Dolomite is found abutting against various horizons, *e.g.* at Sass Songe, against augite-porphyry and Wengen tuffs. In the central portion of the *massif* Jurassic and Cretaceous strata are faulted down, the relations within Gardenazza showing a general similarity to those in the large 'Dachstein' area farther east.

The relations of the strata exposed below Heiligkreuz Kofl and La Varella are more complicated.

As I have already said, in describing fig. 4 (pp. 25–27, 40), the Raibl Beds appear to succeed St. Cassian strata. The exposures of acknowledged Raibl Beds containing *Ostræa montis-caprilis*, *Corbis Mellingi*, etc., lie north of the Heiligkreuz Kirche. They strike N. 15° W., dip slightly east, and are succeeded on the steep slopes below Kreuz Kofl conformably by a series of marls, breccias, beds of dolomitic limestone, and dolomite interstratified with thinly-bedded dolomite-flags. The 'Heiligkreuz Schichten' behind the Kirche, which contain St. Cassian fossils, strike north-and-south, and, if followed northward along their strike, would continue in part directly into the fossiliferous Raibl Beds, while above them are strata belonging to a higher horizon of the Raibl Series than the *Ostræa*-limestones. A slight cross-fault cuts, therefore, the succession of Raibl Beds just north of the Kirche from the 'Heiligkreuz strata.'

Going southward, the Raibl Beds, now with a different strike (N. 15° E., dip 45° E.), crop out all along the road and strike against different horizons of the same system of St. Cassian strata as that to which the exposures at the Kirche belong. A north-and-south fault is thus proved between the Raibl and St. Cassian Beds here. In the system north of the cross-fault, owing to large slips and to the thick surface-covering of fallen blocks, it is impossible to follow this north-and-south fault, but better evidence of its presence is found farther south. Again, on the Medis Wiese, the whole system is cut by a cross-fault; and, as before, the St. Cassian strata are faulted up on the southern side.

On a mountain Alp, above the woods of Peravuda, there are steep exposures of the grey limestone-shales ('Heiligkreuz Schichten') and, below them, St. Cassian limestones full of fossils (*Halobia Richthofeni*, *Mytilus Münsteri*, corals, etc.). Still farther south a ridge may be seen running out towards Ru. I did not myself examine it, but Dr. Rothpletz has kindly communicated to me the result of observations he had previously made here. The marls and limestones on the ridge are St. Cassian strata, above which Schlern Dolomite follows conformably. The dolomite has, however, only a thickness of 80–100 feet, and is then faulted against the Dachstein Dolomite of La Varella. Very little farther north Dr. Rothpletz had seen the succession of Raibl Beds in full sequence. The outcrop of the Raibl Beds is therefore cut off on this ridge by a north-and-south fault. As I have already mentioned, the Schlern Dolomite is also faulted against the Dachstein Dolomite on the southern wall of Centurinus Spitz (see Map A, facing p. 18).

Considering now the relations on the northern side of Kreuz Kofl, we find the high Alpe of Armentara, on which Wengen tuffs are in place; only a small outcrop of St. Cassian strata occurs close to the mass of débris from the Kofl. Dachstein Dolomite then rises at once as a precipitous crag, faulted from the strata on the Alpe.

These facts—namely, that different horizons of Raibl strata meet St. Cassian strata, and that Dachstein Dolomite is brought down to the level of Schlern Dolomite and of St. Cassian rocks—prove that an important fault-line, whose general direction is north and south, occurs along the western limit of Kreuz Kofl and La Varella. This conclusion need not surprise us when we consider that these mountains are included within the sunken area of Dachstein Dolomite. The Gardenazza *massif*, together with the whole system of strata in the Enneberg Valley, is less deeply sunk than Kreuz Kofl, and, further, the downthrow of the Gardenazza *massif* is locally minimized by the anticlinal folding of the strata in the Enneberg Valley.

I must say a few words in explanation of Section 5 (p. 28). At that section the St. Cassian strata strike east-and-west, and dip gently below the northern wall of Gardenazza, whereas in Section 4 (p. 26, across the Enneberg Valley) the same beds strike north-and-south. The strata therefore bend round, as is also the case north of Kreuz Kofl, towards the Armentara Alpe. At the lowest point of the pass between Enneberg and Campil, Wengen strata are exposed; these may be followed westward and are seen to crop out on the Campil Alpe a little south of the saw-mills. This outcrop is farther north than the position of the same strata on the pass, and although, owing to the rich vegetation, there are few points at which a dip-and-strike reading can be obtained with certainty, it may be concluded from their direction of outcrop that the Wengen Beds dip steeply northward. The succeeding strata form outstanding features, and are more easily studied. Augite-porphyry, Buchenstein, and Muschelkalk strata appear northward from the pass in the usual succession, but their strike is east-and-west, and they dip steeply towards the north. Again, below the two saw-mills, on the Campil Alpe, the beds occur in the same way, and the Werfen Beds are also exposed. This inverted succession of older Trias must be separated from the St. Cassian Beds below Gardenazza by a fault-line. Farther north the same beds form a normal succession, as anticline and syncline, the latter extending north to the pre-Triassic schists.

I have also drawn a parallel section in the Gader Valley below the pass. As the fault which separates the inverted system from that of Gardenazza does not strike exactly perpendicular (*i. e.* east and west) to the plane of the section, but W.S.W. and N.N.E., the St. Cassian and Wengen Beds of the Gardenazza system exposed in the Abtey Muren extend farther north than in the Pass section.

Recapitulating briefly the tectonic relations in the Upper Enneberg :—

(1) We have in Abtey, west of Kreuz Kofl, a region of less sinking, where Wengen and St. Cassian Beds possess an extended outcrop. The same result is attained in Prelongei, and the St. Cassian strata are still more favourably exposed by the folding of the whole series into the form of a flat syncline. Towards the Buchenstein Valley the Prelongei syncline passes into an anticline, and, erosion having removed the higher beds, the older Triassic strata are there fully exposed.

The system of older Trias which comes over the Gröden Pass separates the Wengen and St. Cassian strata in Abtey from those of Prelongei; and the strike of the two systems is different: in Abtey the strike is north and south, on Prelongei it is east and west.

(2) St. Cassian strata lie conformably below Schlern Dolomite on the southern side of Sett Sass, at various parts of Sella, Gardenazza, and Zwischenkofl, at one part of La Varella, at Centurinus Spitz, Lagazuoi, and Tra i Sassi. In all other places the Schlern Dolomite has either been removed by erosion (Prelongei and Abtey), or it has been faulted down.

(3) At Heiligkreuz Kirche, on the western side of Sett Sass, and at Valparola, the Raibl strata do not lie conformably upon St. Cassian beds, but *beside* them, separated by faults.

(iii.) *The District of Cortina and Falzarego.*

The Cortina map (B, facing p. 28) forms the easterly continuation of the Sett Sass district and embraces the high-lying valley of Falzarego between the Tofana and Nuvolau *massifs*, and the western portion of the Cortina hollow. Over an extent of ground measuring 12 miles as the crow flies, from Falzarego northward to Schwalben Kofl, one meets no other rocks than Dachstein Dolomite, Jurassic, and Cretaceous strata.

The road from St. Cassian to Ospizio in Falzarego leads over Valparola and Tra i Sassi. As was shown in discussing the Prelongei map (see pp. 20. 60), the fault separating the Valparola and Lagazuoi system from Sett Sass passes eastward towards Falzarego, while the north-and-south Heiligkreuz fault bends round north of the Sore Bach, and is continued eastward over Monte Cavallo.

These relations may be thus shortly represented :—

NORTH.	NORTH.
Centurinus Spitz	Sunk.
* * Fault * *	*
Lagazuoi and Valparola	Raised.
* * Fault * *	*
Sett Sass..	Sunk.
(Gradual passage to the anticlinal fold of older Trias.)	
SOUTH.	SOUTH.

The Lagazuoi system consists of Dachstein Dolomite forming Fanis Spitz, then a band of Raibl strata, resting conformably upon the Schlern Dolomite rock of Lagazuoi, and lastly, below the Schlern Dolomite, the St. Cassian strata exposed west of Ospizio; south of these we meet again Raibl strata on Nuvolau. Whereas the St. Cassian strata below Lagazuoi dip only slightly northward, the Raibl Beds on Nuvolau dip very steeply in the same direction, and the Schlern Dolomite below them is exposed on the high ridge of Nuvolau. Farther south (on the slopes of Nuvolau towards Andraz and Buchenstein), St. Cassian, Wengen, and older Triassic strata follow in regular succession below the Schlern Dolomite.

These strata on Nuvolau form the continuation in part of the anticlinal fold of Wengen and older Triassic strata on Monte Sief and in the Buchenstein Valley, while the continuation of the east-and-west fault from Sett Sass throws down the Nuvolau system against the St. Cassian strata, west of Ospizio in Falzarego.

Before I follow the Falzarego fault farther east, I would like to refer to certain observations of Hoernes which seem to indicate the eastward continuation of the fault between Centurinus Spitz and Lagazuoi (see Mojsisovics' 'Dolomit-Riffe,' p. 291). According to Hoernes, the southern peak of Tofana Secunda is formed by Dachstein Dolomite and Lias, the northern peak by Jurassic rocks alone; a fault separates the two peaks, and the strata to the north of it have sunk. It seems probable that the fault-line which I observed at Centurinus Spitz coincides with this one observed on Tofana Secunda, in which case relations analogous to those farther west at Valparola and Sett Sass exist here:—

North.	North.
Monte Casale (northern peak of Tofana Secunda)...	Sunk.
* * Fault * *	*
Tofana Secunda (southern peak)	Raised.
* * Fault * *	*
Nuvolau	Sunk.
(With passage to the anticlinal fold of older strata.)	
South.	South.

Looking up from the Falzarego road at the dolomite-cliff of Lagazuoi, nothing can be seen either of the Raibl strata or of the Dachstein Dolomite. They lie at a height of more than 1000 feet above the road, and their outcrop is some little distance north of it.

East of Ospizio in Falzarego, the Raibl strata are seen on Col dei Bos at a relatively low level, and above them the Dachstein Dolomite forms the imposing wall of Tofana Prima. Associated with this unexpected geological feature, a change in the mere terrain makes itself felt (see fig. 6, p. 29).

Lagazuoi descends southward with steep walls close to the Falzarego road, and eastward it descends towards a good stretch of meadow, the Roces Alp. Some little distance back from the road, Tofana rises above the meadow, and between Lagazuoi and Tofana a narrow ravine leads up from the Roces Alp to the Travernanzes Pass. In this ravine there is a north-and-south fault-line cutting Lagazuoi completely off from the Roces Alp and from Tofana Prima.

The Tofana system east of the fault has been thrown down; hence it is that Raibl strata are in contact with the Schlern Dolomite of Lagazuoi, and blocks of Schlern Dolomite cover the greater part of the Roces Alp near Lagazuoi. The continuation of this fault-line is followed across the Costeana Bach, where it passes between fossiliferous Raibl beds (mentioned in the stratigraphical part of the present paper) on the western or upthrow side of the fault, and unfossiliferous variegated marls on the eastern or downthrow side.

The general strike of the Tofana Prima *massif* at the Roces Alp is east-and-west, and the dip north; but on the eastern slopes of Tofana Secunda the strata strike north-and-south, and dip west. (This bending round of the strata is similar to that which was observed in the Enneberg Valley, north of Gardenazza and Kreuz Kofl, and again at Centurinus Spitz; the strata always dip towards the central area of Dachstein Dolomite.)

This bending round has been accompanied in the neighbourhood of Cortina by several radial faults. I cannot enter into the minute details of these. Figs. 7 and 8 (pp. 29, 30), together with a glance at Map B, show that the radial faults are again broken by faults parallel with the main direction of the mountain *massif*. The higher strata are faulted down, and are always brought to different horizons, until, at Col Druscie, Dachstein Dolomite and Raibl strata extend down to the Boita Valley.

The Schlern Dolomite is seen only at two places within the system of radial faults. One of these is near the Verviers or Federale chalets; the other is on the Majorera slope, just north-east of the Lago di Majorera. A downthrow of Raibl Beds occurs immediately below the Schlern Dolomite on Majorera, and these are again faulted in a north-and-south direction against St. Cassian strata.

At the Roces Alp a triangular arrangement of faults has raised the St. Cassian Beds; in the south they come in contact with Raibl strata (the 'Falzarego fault'), in the west with different horizons of the Col dei Bos system, and in the east they reach quite close up to the sharp angle where the Dachstein Dolomite is faulted so far forward, and forms the prominent Verviers (or Federale) ridge. Near Cortina the outcrop of the St. Cassian Beds forms a wide undulating meadow, in many parts entirely covered by a superficial mass of slipped débris and broken masses from the steep Tofana slopes. Extensive slips have occurred in the neighbourhood of the Romerlo chalets, where the red Raibl marls and the lower fossiliferous beds have slipped eastward.

The Schlern Dolomite crag of Crepa rises abruptly from the midst of these Cortina meadows. South of Crepa, a small stream has cut its way through a rocky gorge in the dolomite; and immediately south of that, St. Cassian and Wengen strata are seen in place. Exposures of these strata are, however, better seen in the Costeana stream and near Pec di Palu. Crepa is faulted on all sides, and is a part of the overlying rock let down in the midst of the St. Cassian and Wengen strata.

The observations detailed above, so far as they go, show that:—

(1) The Cortina district has, in its western part, the closest tectonic connexion with the Valparola district.

(2) The strata of Tofana Secunda bend round near Cortina by means of radial faults;

(3) There follows in this neighbourhood, south of the sunken area of Tofana, a raised system of strata in which St. Cassian Beds now form the surface-outcrop.

(4) Within the raised system, Crepa occurs as a faulted-down block of younger beds.

(5) St. Cassian strata conformably underlie Schlern Dolomite in the neighbourhood of Ospizio in Falzarego; in the other parts of the map the St. Cassian Beds are faulted, and come into contact with the Schlern Dolomite, the Raibl Beds, and the Dachstein Dolomite.

(iv.) *The District of the Dürrenstein and the Sarl Alp.*

(See Map C, facing p. 32.)

As already mentioned, the district of the Dürrenstein is intermediate between the outer zone of older Trias forming the low hills south of the Pusterthal, and the sunken 'Dachstein' district represented here by the great dolomite-*massifs* of Croda Rossa, Cristallo, etc.

The Werfen Beds and the Muschelkalk are exposed north-east of Alt-Prags. The Muschelkalk is repeated three times, at Lung Kofl, at Mesner Kofl, and at Sarl Köfele; the strike is always east-and-west, and the dip southerly. Faults parallel with the strike of the beds separate the three systems from one another; these faults must be regarded as one system of step-faults, throwing down the strata to the north and repeating them to the south. I referred, in the general remarks on the tectonic relations (p. 58), to such step-faulting as being of frequent occurrence in the outer zone of older Triassic rocks.

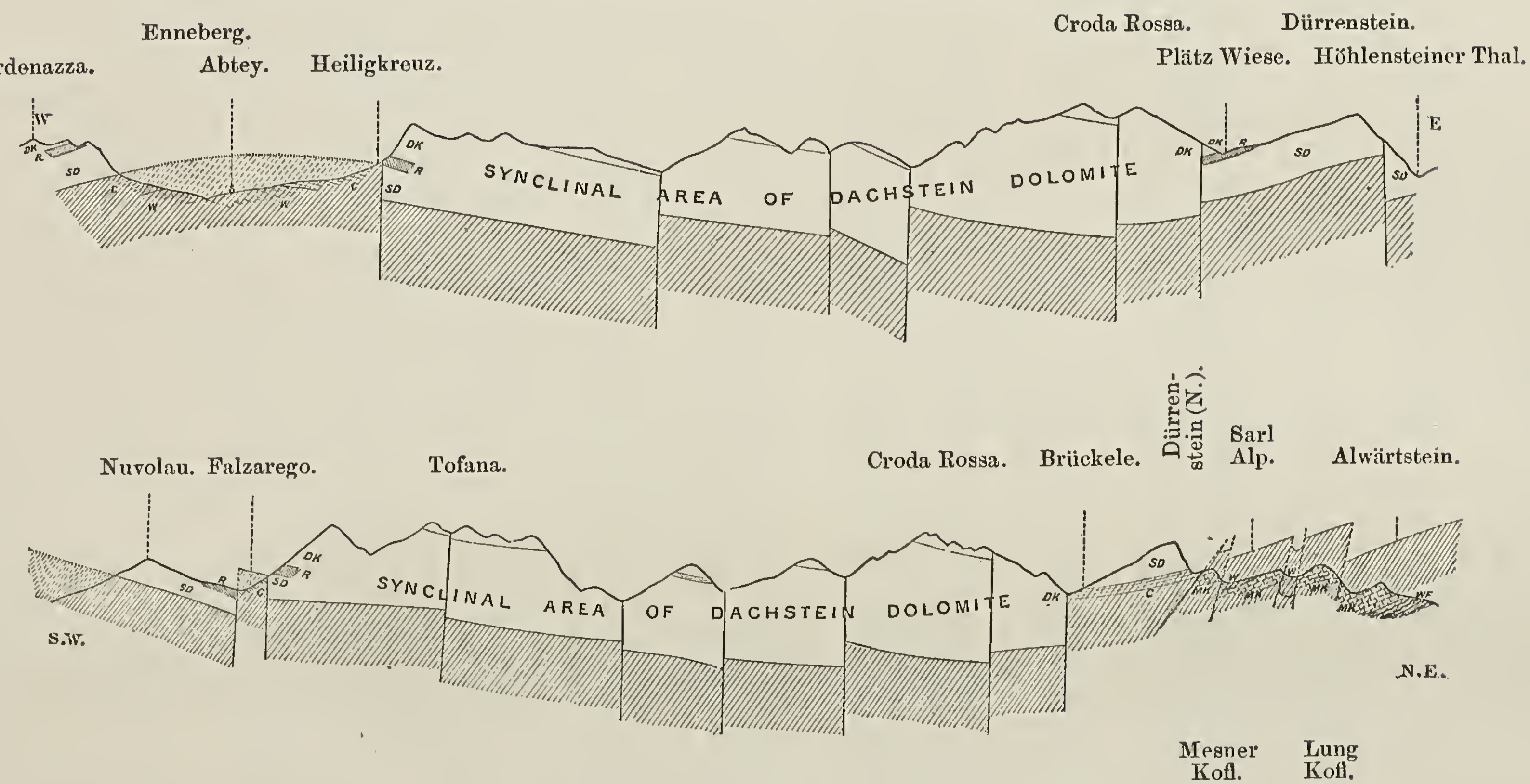
The Werfen Beds are exposed north of Badmeister Kofl and Alwärtstein, and pass over Puez Alp, Sueskopf, and Troger Alp, eastward to the Toblach Valley. At Badmeister Kofl and Alwärtstein, Lower Muschelkalk, Mendola Dolomite, Upper Muschelkalk, Buchenstein strata, and Wengen Beds succeed the Werfen Beds regularly, the lower strata dipping at a very high angle southward, the higher strata not so steeply (strike W.N.W. and E.S.E.).

The Wengen Beds form the Kameriod Wiesen and extend southward towards Heimwald Kofl. Heimwald Kofl is a steep cliff of Mendola Dolomite rock, succeeded on Schafriedl by highly-contorted beds of Buchenstein, Wengen, and St. Cassian age. The general strike of this system is north-eastward, the dip south-easterly. A fault therefore separates the systems of Heimwald Kofl and Schafriedl from the Kameriod Wiesen.

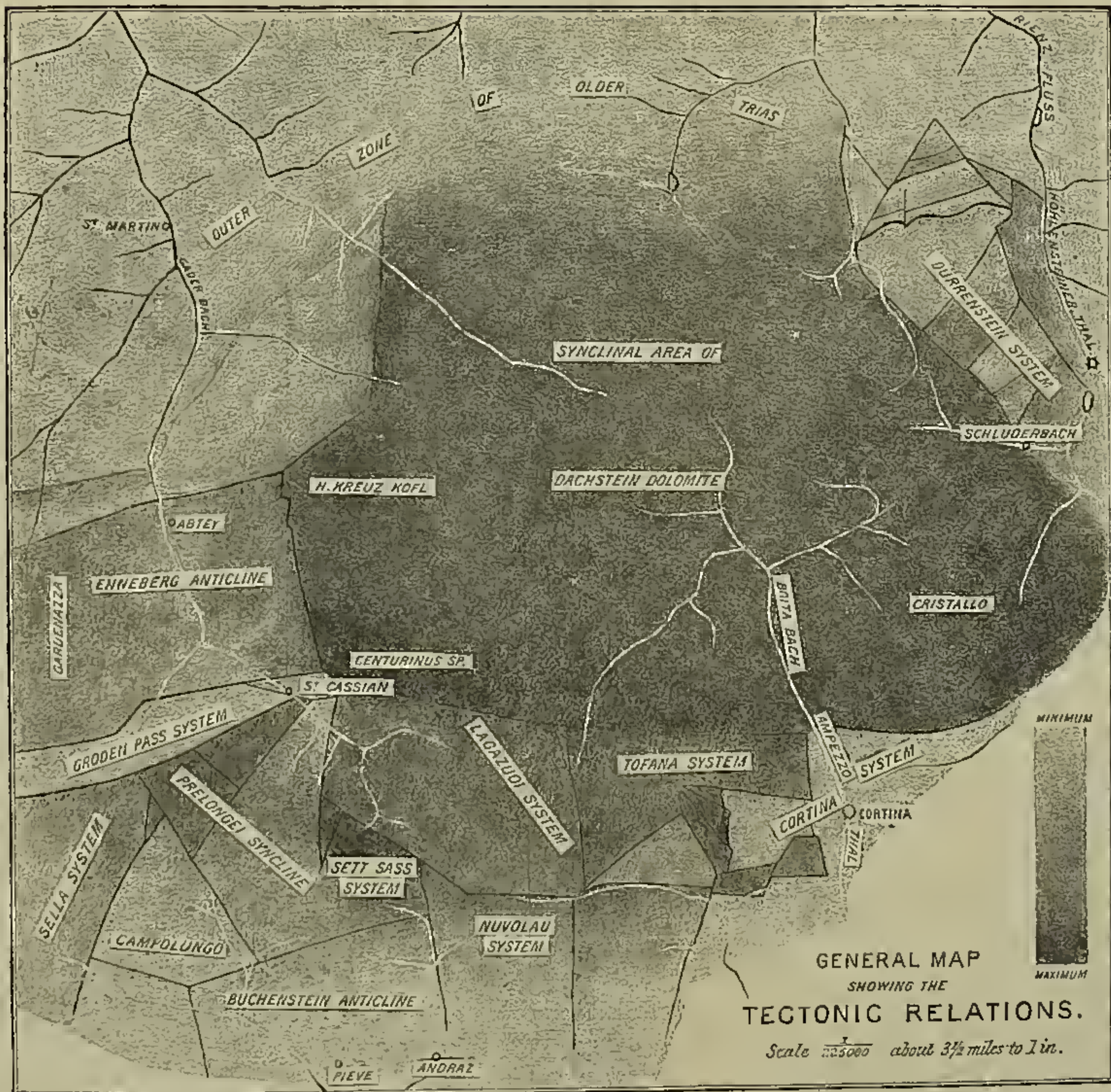
The Mendola Dolomite of Lung Kofl meets in the Lung Valley the Buchenstein and Wengen strata of the outer system. Again, in the ravine between Lung Kofl and Mesner Kofl, Buchenstein and Wengen strata occur. Here they have a very high dip and are much

General Sections through the 'Dachstein' Area.

(Enneberg, Falzarego, and the Dürrenstein from personal observations.)



[Scale: $\frac{1}{225000}$ = ·281 inch to the mile.]



Note.—The above Map shows the main faults and the depressed areas, the greater amount of depression being indicated by deeper shading. For details, see Maps A, B, and C (facing pp. 18, 28, 32). The term 'system' is here, and in the text of the accompanying paper, used to denote an area surrounded by faults. Such faulted areas are termed *Schollen* by German geologists, and the English equivalent of that expression would appear to be 'fault-block;' see J. S. Diller, 'Notes on the Geology of Northern California,' Bull. U. S. Geol. Survey, vol. v. (1887) no. 33, p. 15 (379).

crushed and folded between fault-lines both north and south. The Lung Valley outcrop is less disturbed, the Mendola Dolomite of Lung Kofl being merely the continuation of the Alwärtstein system thrust forward.

On the southern side of Mesner Kofl the Buchenstein and Wengen Beds on the Sarl Alp are again faulted down below Sarl Köfele. The strata of all three systems, Lung Kofl, Mesner Kofl, and Sarl Köfele, have a north-easterly strike and dip to the south-east. The same transverse fault which is observed in the Lungthal may be followed southward between the Kameriod Wiesen on the downthrow side and the Sarl Alp and Mesner Kofl succession on the upthrow.

From Lung Kofl the outcrop of Mendola Dolomite and Lower Muschelkalk is continued eastward over Sarl Kofl and Sarl Brand to the Toblach Valley. On both sides of the Ampezzo road, from Lake Toblach to Schluderbach, dolomite is present, nowhere interrupted by marly strata. The dolomite-rock of Sarl Kofl and Sarl Brand strikes north-east and dips south-east; this changes, however, south of the Sarl Bach, for the Mendola Dolomite which forms the lower part of Nockboden strikes north-west and dips south-west.

Lastly, wedged in between Sarl Kofl, Sarl Brand, Nockboden, Kasamütz, and Mesner Kofl, we find Buchenstein and Wengen strata on the Sarl Alp, and they have much the same tectonic relations to the Mendola Dolomite around them as the outcrop between Lung Kofl and Mesner Kofl. Here, however, the strata are thrown down by a triangular break.

Summarizing these observations, we find therefore the system of older beds from Prags to the Toblach Valley broken up into three main sub-systems by two transverse faults:—

a.	*b.*	*c.*
Alwärtstein.	Lung Kofl.	Sarl Kofl.
Kameriod Wiesen.	Mesner Kofl.	Sarl Brand.
	Sarl Köfele—Sarl Alp.	Nockboden.

Sarl Brand is somewhat sunk from Sarl Kofl towards the Toblach Valley; the fault may be followed farther north in the Werfen Beds exposed in the Troger Bach.

Looking southward from the Sarl Alp beyond the low dolomite escarpment which extends (although in some places more or less eroded) from Sarl Köfele to Nockboden, the view is entirely shut in by the Dürrenstein *massif*. This *massif* is of Schlern Dolomite rock and lies conformably upon the St. Cassian strata exposed on the Flodiger Wiese. The St. Cassian strata of the Flodiger Wiese rest apparently conformably upon the dolomite-rock of Sarl Köfele and of Kasamütz. Regarding the dolomite here as Mendola Dolomite, the following section is obtained (in descending order):—

$\left\{\begin{array}{l}\text{Schlern Dolomite of the Dürrenstein.}\\ \text{St. Cassian strata of the Flodiger Wiese.}\\ \text{Mendola Dolomite of Sarl Köfele and Kasamütz.}\end{array}\right.$

At Nockboden, where St. Cassian strata are no longer present, the section, according to the same reading, would give:—

$$\left\{\begin{array}{l}\text{Schlern Dolomite.}\\ \text{Mendola Dolomite.}\end{array}\right.$$

This is, so far as mere succession of beds goes, a case exactly analogous to the succession in the Tiers Valley, the Rosengarten, and other *massifs* of the western region. It has been proved in that district that the strata which in many other places intervene between the Mendola Dolomite and the Schlern Dolomite thin out gradually in a continuous development of dolomite. And this very natural explanation has also been applied to the district north of the Dürrenstein. The evidence which previous authors have found in the latter district is largely based on the appearances at Mesner Kofl and at Sarl Köfele; these are regarded as dolomitic masses belonging to Wengen or St. Cassian time and thinning out in the marls or shales of the Sarl Alp and of the Kameriod Wiesen, a conformable succession being thus presented from the Dürrenstein to Lung Kofl (in descending order):—

Dürrenstein	Dolomite (by some regarded as St. Cassian Dolomite).
Flodiger Wiese	St. Cassian strata (non-dolomitic).
Sarl Köfele	St. Cassian or Wengen Dolomite.
Sarl Alp, Mesner Kofl	Wengen strata (non-dolomitic), with contemporaneous Reef-dolomite.
Intervening Valley	Wengen and Buchenstein strata (non-dolomitic).
Lung Kofl	Mendola Dolomite.

According to the same view, the non-dolomitic strata are represented above the Toblach Valley by a dolomitic facies continuously developed during all the periods that elapsed between the laying down of the Mendola Dolomite and of the Raibl strata.

The dolomite-rock of Mesner Kofl is, according to the succession quoted, a *Wengen* Dolomite, and not *Mendola* Dolomite. As yet no fossils have been found in it, but in the districts east and west *Gyroporella pauciforata*, a Muschelkalk form, occurs frequently in a dolomitic rock which has also been assigned to the Wengen period.

With respect to the dolomite of Mesner Kofl I can only bring forward stratigraphical evidence. As I have already said, and as may be seen in my map, the Buchenstein and Wengen Beds which are exposed in the valley between Lung Kofl and Mesner Kofl are strongly crushed and sheared. The Wengen Beds come in contact with the dolomite-rock of Lung Kofl on the ridge, while lower down on the western slope the Buchenstein Beds are in contact with that of Mesner Kofl. Farther east, on the eastern slope of the Sarl Alp, the Buchenstein and Wengen Beds are cut off against the dolomite of Mesner Kofl, and have a different strike from it and from the outcrop of the same beds on the western slopes.

South of Mesner Kofl large blocks of the characteristic Buchenstein limestones with siliceous secretions are found on the grassy slope, and on the Sarl Alp Wengen Beds are in place. Nowhere is it possible to see the thinning-out of the Mesner Kofl dolomite-rock in the series of Buchenstein and Wengen strata, and we are confronted therefore by two stratigraphical possibilities:—

(1) The dolomite of Mesner Kofl may be a reef-dolomite thinning out in Buchenstein and Wengen strata, although, owing to later faulting, the relations of dolomitic and non-dolomitic beds have been obscured.

(2) The dolomite of Mesner Kofl may be Mendola Dolomite brought into its present position as the axis of a small anticlinal fold embracing the whole system between Sarl Köfele in the south and Lung Kofl in the north. This anticlinal fold is the result of crush, and is broken in several places by fault-planes.

The same conclusions are applicable with slight differences to the case of the Heimwald Kofl dolomite-rock and its relations with the Kameriod Wiesen system of non-dolomitic rocks.

The dolomite of Sarl Köfele (below the St. Cassian strata) and of Kasamütz (also underlying Cipit Limestones probably of St. Cassian age) forms a no less debatable point. Thinning-out of the dolomite in bedded limestones and shales is said to occur between these two prominent rocks. But the limestones and shales which are exposed do not occur in the same direct east-and-west line with the dolomite, and their exposure might be explained as the result of erosion. Leaving this for the present, we find that below Kasamütz the whole of the Sarl Alp system of strata is cut off against the dolomite. This system is also cut off north and south above the rocky ravine of Sarl Bach, so that nowhere is thinning-out of the Sarl Alp non-dolomitic strata directly observable.

The St. Cassian strata above Kasamütz are still very thick, nor are they observed to thin out gradually in the dolomite of Nockboden. In short, the disappearance of the Buchenstein and Wengen strata on the Alpe below and of the St. Cassian strata on Kasamütz is not gradual, but sharp, and takes place exactly in the same north-and-south line. This is a north-and-south fault-plane separating the central or Sarl Alp system (general strike E.–W.) from the eastern or Toblach Valley system (general strike N.N.W.–S.S.E.). It may be said that in this case, as at Mesner Kofl, the actual thinning-out of the strata has been faulted out of sight, and this is very possible. It is at the same time striking that there should be a perfectly normal thickness and perfectly characteristic development of non-dolomitic St. Cassian strata on Kasamütz, so close to the dolomitic facies of Nockboden.

Following the dolomitic rock exposed on Sarl Köfele westward, it is seen to strike across to Kirchenschroffen. Here it meets the Schafriedl system of non-dolomitic beds, with which it has no possible relation of thinning-out. A further complication is introduced by the Dürrenstein system, and the beds at Kirchenschroffen are thrown into a series of large folds, which prove the presence at one time of important strain between the two large systems—that of the older Trias of Prags and the Sarl Alp, and that of the younger Trias of the Dürrenstein *massif*. The Sarl Köfele Dolomite disappears finally in Kirchenschroffen, and the Wengen and St. Cassian strata of the Schafriedl system come in contact, very little north of Brückele, with the Wengen and St. Cassian strata of the Dürrenstein system.

If now both Kirchenschroffen and Heimwald Kofl are Wengen Dolomite, we have (according to the view which accepts for this district a gradual transition of non-dolomitic into dolomitic strata) again the following conformable succession between the Dürrenstein and the Kameriod Wiesen:—

Locality.	*Nature of Rock.*	*Probable age.*
Dürrenstein.	Dolomitic.	St. Cassian.
	Non-dolomitic.	
Kirchenschroffen.	Dolomitic.	Wengen.
Schafriedl.	Non-dolomitic.	
Heimwald Kofl.	Dolomitic.	
Kameriod Wiesen.	Non-dolomitic.	
Buchenstein and older Trias.		

But below Kirchenschroffen the non-dolomitic strata are St. Cassian with beds of Cipit Limestone, and they are the same beds as those which apparently follow conformably above the dolomite of Sarl Köfele and below the dolomite of the Dürrenstein; hence, even if we accept the view of facies-developments, we must rather consider the Kirchenschroffen and Sarl Köfele Dolomite as a dolomite-bed in the St. Cassian marls, such as we have at the Richthofen Riff, in marls of the same age below Sett Sass.

From the already-mentioned tectonic features and the marked disturbance and folding of the strata on Schafriedl, I find it much harder to explain the dolomite-rock of Kirchenschroffen and Sarl Köfele as 'St. Cassian Dolomite' than the Richthofen Riff; the latter is a bed of dolomite which is seen to thin out gradually and regularly in St. Cassian marls and limestones. Again, the non-dolomitic strata above the Heimwald Kofl are present in normal thickness; on the Sarl Alp the succession of non-dolomitic rock ends with Wengen Beds, but the surface here has been deeply eroded.

So many difficulties having suggested themselves to me in accepting the facies-development as a complete explanation of the facts which I observed, another view may be stated as a possible explanation.

When examining the dolomite-rock at Nockboden I found that *Gyroporella pauciforata*, the typical fossil of the Mendola Dolomite

(Muschelkalk), occurred at a considerable height above the Toblach Valley in the Sarl Bach ravine; it also occurs in the dolomite on both sides of the valley nearly as far south as the bridge below the Flodiger Wiese. On the other hand, the ascent to that Wiese cuts through a dolomite which is unquestionably Schlern Dolomite, often possessing the oolitic structure characteristic also of the Wetterstein Kalk in Northern Tyrol. I concluded that Schlern Dolomite rests on Mendola Dolomite at Nockboden, although an exact limiting-line can naturally not be drawn.

Assuming that the Sarl Köfele and Kasamütz dolomite-rock is Mendola Dolomite, the St. Cassian Beds of the Flodiger Wiese rest on the last-named horizon. They dip below the Schlern Dolomite of the Dürrenstein, and on the western slopes of that mountain, towards Stolla, rest conformably upon Wengen strata. We have, between the Flodiger Wiese and the Dürrenstein, a fault-plane hading gently to the south, on which a system of Upper Trias has been thrust down upon a system of Lower Trias. A thrust of that kind explains the apparent unconformity of the St. Cassian Beds and the Schlern Dolomite upon the Mendola Dolomite.

The north-and-south vertical fault, which separates the system of strata exposed on the Sarl Alp and Kasamütz from that of the Toblach Valley, is of later date, and cuts through the thrust-plane. This fault lets down the Schlern Dolomite and Mendola Dolomite which form the Nockboden system. On the western side the thrust-plane system is cut off at Kirchenschroffen by the continuation of the north-and-south fault between Lung Kofl and the Kameriod Wiesen. It may be that there is a farther extension east and west of this thrust-plane, and in the subsequent changes brought about by vertical faulting we may have an explanation of the various anomalies in the neighbouring regions.

In the four sections 10–13 (pp. 34, 35) I have shown the result of my observations at the Dürrenstein, and can only regret that time did not allow of my continuing the study of the geology farther west. With the same inclination and throw of the thrust, Dachstein Dolomite and Raibl strata of the upper system would rest on Schlern Dolomite of the lower; but I need not enter into considerations which do not immediately concern the district mapped. I have already indicated, in my preliminary remarks (p. 60) on the district between the northern outer zone and the Falzarego Valley, the general tectonic features, as I should interpret them after detailed study of some portions.

The tectonic relations of the Dürrenstein *massif* are simple. It is separated from the 'Dachstein' region by a main north-and-south line of fault, continued also across the Ampezzo Valley at Schluderbach.

The road between Alt Prags and Schluderbach bends eastward at Brückele, and winds round the base of the Dachstein *massif* of Rauhe Gaisl on the right. Wengen and St. Cassian strata are in place on the left, with an east-and-west strike and a slight southerly dip. The St. Cassian strata are the same as those which dip below the Dürrenstein along its northern face, and here also the Schlern Dolomite follows conformably above them. Several south-west and north-east faults of small throw let down the Schlern Dolomite and the underlying strata at this northern corner. The St. Cassian and Wengen strata which form the base of the valley are faulted against the Dachstein Dolomite on the west.

Farther up the valley, towards the Plätz Wiese, the road passes through Schlern Dolomite, but towards the summit the Raibl strata form steep slopes below the road, cut by stream-gullies and slipped in various directions.

On the Plätz Wiese Raibl strata are exposed in conformable succession upon the dolomite descending from the highest ridge of the Dürrenstein. The beds strike north-west and south-east, and dip south-west. On the steep wooded slope between Stolla and the road, the dolomite and the St. Cassian strata of the first system strike against the slipped Raibl Beds which form part of a second system. This fault passes then through the dolomite itself in a general north-east and south-west direction, and although it cannot be followed in the dolomite, the strike of the two systems differs as mentioned.

The Raibl Beds above Stolla do not properly belong to the strike-system of the Plätz Wiese and the Wällsche Boden farther south, but are plainly the remains of a big slip at some former period from the rocks of the Dürrenstein above the Wiese.

Dachstein Dolomite follows conformably above the Raibl strata on the Wällsche Boden (see pp. 41, 42, and fig. 14), and the whole Plätz Wiese system is, like the first system, faulted against the Dachstein Dolomite to the west.

The road continues southward on beds of dolomitic flags, which underlie the red Raibl marls on the meadow, and only very gradually descends towards the new fort. Here a rocky ridge running west from the Hellthaler Schlechten spans the Plätz Wiese and slopes steeply south towards the Seeland Valley. The dolomite-flags and Raibl marls bend up on the northern slope towards Knollenkopf. On the ascent to Knollenkopf from the Plätz Wiese they are succeeded conformably by rauchwackes and Dachstein Dolomite, but on the Seeland Valley face of the ridge the beds of the Lower Raibl horizon meet the north-and-south fault from the Wällsche Boden and are cut off against Dachstein Dolomite. Again, as at Stolla, the 'Plätz Wiese system' is let down by a fault running east-and-west and continuing into the Schlern Dolomite of the Dürrenstein. On the southern side of this fault, an upthrow of St. Cassian strata forms the base of the Seeland Valley and is succeeded eastward by Schlern Dolomite on Strudelkopf. This southerly system of the Dürrenstein strikes N.N.W., and dips with varying angle to N.E.; it is separated by the continuation of the north-and-south fault from the Dachstein Dolomite of Knollenkopf on the west (see fig. 9, p. 32). The 'Strudelkopf system' is broken by several small cross-faults which bring down the

St. Cassian strata and overlying dolomite repeatedly to the south, so that, although a comparatively small thickness of St. Cassian strata is exposed on the Alpe, their outcrop continues very nearly as far as Schluderbach. Then, however, the north-and-south fault has on the western or downthrow side Dachstein Dolomite, and on the eastern or upthrow side the Schlern Dolomite of Strudelkopf and of Monte Pian farther south.

The most important tectonic relation is that brought out by the north-west and south-east fault which separates the Dürrenstein *massif* from the 'Dachstein Dolomite region' of Rauhe Gaisl, Schlecht Gaisl, and Hohe Gaisl (Croda Rossa). These form part of the sunken area west of the Dürrenstein. The Knollenkopf is a mass of Dachstein rock, let down between two branches of this main fault, the westerly branch passing through the Knappenfuss Valley.

Downthrow of the strata has taken place also on the eastern side of the Dürrenstein. The Sarl Brand, as already mentioned, is sunk from the Sarl Kofl, and the Muschelkalk faulted down; the Nockboden is sunk from Kasamütz and the Sarl Alp; and towards Landro the eastern part of the Dürrenstein is sunk from the main ridge. By this north-and-south fault through the Dürrenstein, an apparently much greater thickness of Schlern Dolomite is seen above the Toblach Valley than on the northern or western sides. No part of this thickness is due to Mendola Dolomite, as, for instance, is the case south of Schlern; in the Dürrenstein *massif*, the only place where Mendola Dolomite underlies Schlern Dolomite is at Nockboden.

We have, therefore, sunken *massifs* both west and east of the Dürrenstein; that mountain itself remains at a higher level between the two, and may be called a 'Horst' in the sense originally applied by Suess.[1] At the same time the 'Dürrenstein Horst' borders on the 'Dachstein' region, and this nearness to the important fault finds expression, especially on the western side, in a number of smaller faults.

In the Plätz Wiese system, the strata are sunk much lower in the south-western portion near the 'Dachstein' region than in the eastern or Dürrenstein-ridge portion, and in the Strudelkopf system we find repeated sinking of the strata southward, towards the Dachstein Dolomite *massif* of Monte Cristallo.

Discussion.

Mr. J. W. Gregory remarked on the many questions of interest which this paper affected. The Authoress's work had destroyed faith in the most famous fossil atoll, doubts as to which had been previously suggested by palæontological and stratigraphical considerations. Careful zonal collecting in these beds was greatly needed, as in the three principal collections (Vienna, Munich, and London) the fossils are simply localized as St. Cassian. The fauna, with its

[1] 'Antlitz der Erde.' 1st ed. 1885, vol. i. p. 167.

abnormal forms such as *Tiarechinus*, suggested an unfavourable environment, and the speaker hoped that Miss Ogilvie's work would demonstrate whether these were due to deep-sea or lagoon conditions.

Mr. VAUGHAN JENNINGS said that any geologist who knew the country of the Schlern, the Lung Kofl, and the Sella Joch would welcome new evidence on the stratigraphy of the district. If the area of discussion were widened, as it had been by previous speakers, to include the Western Alps, it should also include the Southern. In the Ligurian region, which he had recently been able to examine, there was a sudden thinning-out of dolomite-reefs similar to that of the Tyrol—for instance, Monte del Gazo near Genoa. Here, careful examination and mapping precluded the idea of simple faulting; at any rate, later than the Eocene. If it were a system of faults which here caused the thinning-out of the dolomite, it was a very ancient series of earth-movements, not a recent one.

Mr. TOPLEY remarked that whilst one important result obtained by Miss Ogilvie was to fix the position of the Schlern Dolomite between the St. Cassian and Raibl strata, her observations at the same time showed that masses of dolomite occurred at other horizons; for instance, the Cipit Limestone lies in the Lower St. Cassian Beds, whilst the Richthofen Riff is a lenticular mass of dolomite in the Middle St. Cassian.

The Rev. J. F. BLAKE also spoke.

2. *The* Base *of the* Keuper Formation *in* Devon. By the Rev. A. Irving, B.A., D.Sc. (Lond.), F.G.S. (Read November 23rd, 1892.)

In my two previous communications to the Society on the Devon Red Rocks[1] I have recognized the insufficiency of the evidence then available for drawing a clear and well-defined boundary-line between the Keuper and the Bunter in the country lying west of Sidmouth; and now that the Permian age of the lower breccia-series has been definitely recognized by the Director-General of the Geological Survey in his Presidential Address of last February,[2] this may be said to be the only remaining dubious point of importance in our new classification of the Red Rocks of Devonshire, and their correlation with the Permian and Trias of the Midlands and the Severn country. The difficulty I found in drawing the basement-line of the Keuper in my 1888 paper seems to have been felt by Mr. Strahan in the Cheshire area,[3] for, after discussing the evidence on both sides, he seems inclined to think that there are about as good reasons for drawing the basement-line of the Keuper at the bottom of the 'Waterstones' (as I did in Devon four years ago) as for drawing it at the base of the 'Lower Keuper Sandstones' of Prof. Hull. Briefly, these seem to resolve themselves into two:—(1) overlap in places of the Waterstone series; (2) lithological similarity of the Keuper basement-beds to the mottled, current-bedded soft sandstones of the Upper Bunter—a similarity which, as I showed in my paper of last year, is even stronger than he has made it out to be in Cheshire, for the beds in the coast-section north-east of Otterton Point. The present communication will perhaps serve to show that in the Devon area, where no signs of overlapping have been recorded at this stage of the Trias, there is a great preponderance of evidence in favour of the lower of these two horizons being accepted as marking the true downward limit of the Keuper formation.

In my last paper (published in Feb. 1892), at the suggestion of Prof. Hull I definitely accepted the breccia, which is clearly marked on the left bank of the Sid at Sidmouth, for the base of the Keuper—as that formation is exhibited in its entirety in the coast-section from Sidmouth eastwards to Seaton: but I had not then satisfactory data for determining a similar basement-line through the country lying to the west of Sidmouth and between the valleys

[1] Quart. Journ. Geol. Soc. vol. xliv. (1888) pp. 149–163; and vol. xlviii. (1892) pp. 68–77.

[2] I can scarcely see how I have 'followed Murchison,' who merely gave an opinion on the value of the correlation of the Devon breccias with the Rothliegendes of Germany by Buckland and Conybeare. My correlation, like theirs (of which I was ignorant at the time), was based on direct knowledge acquired in the field, as my papers plainly show.

[3] 'On the Lower Keuper Sandstone of Cheshire,' Geol. Mag. for 1881, pp. 396 *et seq.*

of the Sid and the Otter. On page 70 (Quart. Journ. Geol. Soc. vol. xlviii.) I stated that, while recasting that paper, I had received from the Rev. Dr. Dixon, of Aylesbeare, a specimen of a breccia from the eastern side of the Otter (at Harpford) so nearly resembling that which I had accepted for the base of the Keuper on the eastern bank of the Sid, that I was inclined to attach great importance to it, as tending to settle this moot-point for the country on the eastern side of the Otter Valley. That specimen was shown at the meeting of the Society on Nov. 25th, 1891, when the paper was read.

At my request Dr. Dixon prosecuted the search for a similar breccia for some miles along the left bank of the Otter, in order to see whether a sufficient number of exposures could be found to connect the Harpford breccia with that occurring at Otterton Point (mentioned by Mr. Ussher, and more fully described and commented on by myself), allowance being made for the effect of the faults visible in the cliffs about Ladram Bay.[1] In a few weeks I received a letter from Dr. Dixon informing me that, while he had failed to find anything of the sort on the western side of the Otter (where everything seen in river-escarpments and road-sections seems to be unmistakably Upper Bunter Sandstone), he believed that he had detected the breccia at several points along the line indicated on the eastern side of the river. For several reasons we were unable to make arrangements for going over the ground together until the end of August, when very satisfactory results were obtained with the aid of the six-inch Ordnance map.

Being unable to get across the Otter-mouth from Budleigh Salterton, and the time at our disposal not permitting of our making a détour by the bridge a mile inland, we were prevented from undertaking a re-examination of the breccia on the eastern side of the estuary; but this was the less necessary on account of the close examination I had made of the breccia there in 1887.[2] Crossing the river at Otterton to the eastern (left) bank, and following the road, which runs due north (in places along the river-escarpment) to Newton Poppleford, we found the breccia we were searching for exposed on both sides of the road about half a mile north of Otterton. There is an ascent of the road from this point, with cuttings much overgrown by vegetation: but in one place a huge block in the bank (apparently slightly displaced) was found to consist of this unmistakable breccia. This was about halfway up the hill. In the fine cutting with clean-cut rock-walls near the top of the hill a little way south of Press Lane (see the six-inch Ordnance map) the breccia is exposed in continuous horizontal section for a number of yards on both sides of the road, with just that slight difference of level on opposite sides which agrees with what appears to be the general normal easterly dip of the strata. In the Upper Bunter beneath it the same ramifying

[1] Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 381.
[2] See my 1888 paper, *ibid.* vol. xliv. p. 153.

calcareous concretionary masses were observed as I described in my 1888 paper (p. 153), occurring below the breccia at Otterton Point.

At the farmhouse known as Burnt House (marked Manyard on the older maps) we descended to the alluvium of the river. On reaching the point where the river strikes against the red cliff on its left bank, the calcareous concretionary masses were again seen in the reddish sandstone, which has a decidedly Upper Bunter facies. Here the breccia was again found at about 50 feet above Ordnance datum surmounting these beds, and partly concealed by the vegetation which covers the hill-slope above. The rocks appeared to have been let down by a small landslip, as we were unable to trace the continuance of the breccia-zone in the inaccessible, clean sandstone-escarpment which overhangs the river immediately to the south. Less than a quarter of a mile farther north the same sequence of Bunter Sandstone surmounted by the breccia was seen; and from the bench-mark on the roadside above this spot we estimated the breccia to be at about 70 feet (O.D.). Here, at a somewhat higher level than at the spot last mentioned, it was evidently in place.

In Halse's Lane, which strikes up the hill to the east, just before reaching Passaford, there is one of the most complete exposures of the breccia seen perhaps anywhere in Devonshire. It projects, with a varying thickness, for several yards along the sides of the higher part of the lane, the soft Bunter rock below it having been much worn down by weathering since the lane-cutting was made. A second lane-cutting strikes southward from this, exposing the breccia at a lower level, and with an abnormal dip, nearly south, of 5° or 6°. This exposure probably owes its position to some local faulting, though the faults are obscured by the overgrowth of vegetation on the hill-face.

Passing Houghton, we again found the breccia at the corner of the road near Northmoston Farm. After that no more exposures are met with along the road until Newton Poppleford is reached. In a cutting of the road, which strikes north at the eastern end of this village to Harpford, the same hard breccia, about 2 feet thick, is seen near the bottom of the cutting, at about 90 feet (O.D.). The vertical rock-walls of the cutting offer great facilities for examining the relation of the breccia to the overlying Keuper Beds, and for observing its irregularity in thickness and its repetition upwards in one or two places. In this cutting also there are good exposures of the overlying Lower Keuper Sandstones, which are seen to consist here (for 8 or 10 feet) of soft, variegated, strongly current-bedded, brecciated sandstone. In no section in Devon have I seen the brecciated character of the sandstones at this horizon so strongly marked; and, after the observations made here, I am inclined to regard the brecciated and pebbly sandstones lower down the river, near its mouth, which are mentioned in my 1888 paper (*loc. supra cit.*), as in reality belonging to the Keuper basement-beds, though there referred to the Upper Bunter.

North of Harpford there are some exposures of the Keuper rocks, and the Upper Bunter is seen in good lane-sections between Tipton railway-station and Aylesbeare, as it is farther south round about East Budleigh; but between Harpford and Ottery St. Mary the basement-breccia is not easily traced, owing to the want of good exposures.

Now, when we recollect that the Otter River falls from about 80 feet (O.D.) at Newton Poppleford to its mouth, and when we allow for the difference of level between Ordnance datum and the breccia at Otterton Point, allowing also for the effect of the faulting visible in the coast-section about Ladram Bay, the aggregate of which, according to Mr. Ussher's estimate, would be about 60 feet[1] (this may be less than the real amount), and the probability of some repetition of the breccia at slightly different horizons, I think there can no longer be any doubt, in the light of the facts described in this paper, that we have succeeded in tracing the *true base of the Keuper along the left bank of the Otter, which for many miles seems to mark the western limit of that formation in Devonshire.*

If this conclusion be admitted, several interesting results would seem to follow.

(1) The palæontological difficulty, which the occurrence of remains of *Hyperodapedon* in the sandstones east of the Otter-mouth still presented (after the difficulty, which had appeared to some writers to follow from the occurrence of Labyrinthodont remains, had been explained away in my paper of last year), is now removed, since the sandstones in which the remains in question were found are stratigraphically above the Keuper basement-breccias; and, so far as our present knowledge goes, the stratigraphy and the palæontology of the Devon Trias are thus brought into complete accord. The parallelism between the Trias (properly so-called) of Devonshire and that of the Midland-Severn-Cheshire area seems to be fully established, as tabulated by Prof. Hull in his paper of last year, and shown in the section which accompanies that paper.[2]

(2) The statement contained in the paragraph of my paper of last year—"For the reasons here given . . . . . in company with Prof. Hull" (p. 71)—needs some modification. Prof. Hull in fact only had an opportunity of examining the rocks lying *west* of the Otter; and I am glad to take this occasion of correcting the oversight contained in the statement here referred to. It is hardly necessary to observe that the reference of these false-bedded Lower Keuper sandstones to the Bunter is superseded by the results given in this paper.

(3) Our geological maps of the Devon area require considerable revision, to the extent of cutting off from the western margin of the Keuper a fairly good slice, as it is shown on Sir A. C. Ramsay's map of England and Wales, while the Upper Bunter will have to be introduced in the valley of the Sid, owing to repetition by faulting. It is, however, satisfactory to note that only a small correction for

[1] The algebraic sum of Mr. Ussher's measurements is $50-5+14=59$ feet. See Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 381.

[2] *Ibid.* vol. xlviii. pp. 66–67.

the boundary-line of the Keuper is required on Greenough's map, which is published by the Geological Society.

The question of the mapping of the Devon Permian lies outside the scope of the present paper; but it is to be hoped that, as soon as we can agree upon the true boundary between the Bunter and the Permian, we may have a new edition of the Geological Survey map in which a definite classification in accordance with more modern nomenclature shall be recognized, to supersede the vague division, adopted half a century ago by De la Beche, into 'New Red Marl' and 'New Red Sandstones.'

(4) As is usual with such soft and easily-disintegrated beds, the general absence of good exposures at the base of the Upper Bunter makes it very difficult to estimate its thickness. But in the coast-section *west* of the Otter we find these beds in stratigraphical alignment with the beds beneath the breccia on the *eastern* side, and agreeing with them in lithological character. These are seen lying upon the eroded surface of a more homogeneous sandstone, the hollows in which are occupied by a loose breccia. This line of erosion would seem to furnish a very good divisional horizon, between which and the Keuper breccia not more than 100 feet of Upper Bunter would come in. It does not appear easy to sharply subdivide the Devon Bunter, nor is it a matter of more than secondary importance.

(5) As a point in the physiography of the county, it is of some interest to note the general parallelism of the three lines of river-drainage marked by the Sid, the Otter, and the Clist; the two former being obviously determined by the strike of the soft Upper Bunter sandstones, the latter by the equally soft Permian sandstones.

Discussion.

The President stated that it was very remarkable that Murchison had many years ago compared the lower red rocks of the district with the Rothliegende, but afterwards he seems to have allowed them to be relegated to the Trias. He (the speaker) did not understand why the change was made, but it seemed probable that Murchison's successor now believed that they were of Permian age, and much credit was due to the Author and Prof. Hull for urging this point a year ago. One would like to know what the peculiar lithology of the breccia was.

Prof. Hull concurred in the view that the breccia referred to was the real base of the Keuper Series, the beds being repeated by the Sidmouth fault. He also wished to take this opportunity of stating that, since reading his paper on the Devonshire 'red rocks' about a year ago, he had come to the conclusion that the Budleigh Conglomerate was the real base of the Trias, as held by Dr. Irving, and that the great series of red marls, sandstones, and breccias below the conglomerate were of Permian age.

The Author thanked the Fellows for the courteous attention with which his paper had been received.

3. *The* GOLD-QUARTZ DEPOSITS *of* PAHANG (MALAY PENINSULA). By H. M. BECHER, Esq., F.G.S., Assoc.R.S.M., Assoc. Mem. Inst. C.E. (Read November 9th, 1892.)

[Abridged.]

THE Gold-quartz formation of Pahang traverses an extensive series of sedimentary rocks, of which the low hill-country lying on the eastern side of the granitic mountain-axis chiefly consists. These rocks, probably of Palæozoic age, are for the most part thinly-bedded slates, with some sandstones, and fewer dark-coloured, impure limestone-beds. Locally they are more or less metamorphosed and contorted; quartzites, and micaceous and other schists, often intervening between the slate-series proper and the greater igneous rock-masses.

Generally the strata are regularly and evenly bedded, with a prevailing strike approximately north-and-south; they dip at steep angles, mostly eastwards, from which it would appear that they have been subjected to an upheaval, due to intrusion of the central granite. Other upheavals are traceable to syenitic intrusions, which form lesser hill-ranges between the backbone-chain and the eastern coast; while numerous dykes of trappean rock have caused minor local disturbances. There are not, to my knowledge, any indications of eruptive volcanic action in Pahang, or in any other part of the Malay Peninsula.

Besides the extensive slate-formation, the only sedimentary rock noticeable is a peculiar crystalline limestone, which apparently overlies the first-named unconformably, and is found in isolated hill-patches, characterized by abrupt vertical cliffs and numerous caves.

All the alluvial formations appear to be of quite recent origin, and to have been undisturbed since the commencement of their deposition.

Although the Gold-quartz formation in Pahang is most frequently associated with certain characteristic dark-grey and black slate-rocks, it is not confined to these, but is also found in other sedimentary strata, extending indeed to the metamorphic rocks, and in some places even penetrating the adjacent intrusive syenite. It has not, however, been traced in any connexion with the main granitic formation, which is generally considered to be the matrix of another system of metalliferous deposits—namely, the cassiterite-veins which have produced the vast expanse of the alluvial tin-fields of the 'Straits.' Very little is yet known of the nature of the Malayan Gold-quartz deposits, and further researches will be needed before definite conclusions can be safely drawn.

For the purpose of present description the quartz-deposits in the solid rock may be divided into two classes, though it is difficult to draw the line very definitely between them, and some deposits can hardly be classed under either. These two classes I describe as :—

1st. Lodes.
2nd. Irregular Formations.

All the deposits have so much in common that they consist essentially of quartz-veins, with which the gold is associated, though it may not be actually confined to the vein-forming mineral. The differences between the various deposits are rather those of form and extent than of mineralogical composition, and are due to the varying size, shape, continuity, etc., of the quartz-veins.

The first class may be taken to include all the more regular quartz-veins of sufficient size and individuality to be worthy of the name of 'lodes.' The second class comprises such others as are either so irregular as to have lost all resemblance to lodes, or so small and numerous as to constitute an aggregate mass with the stratified deposits which they impregnate.

1. Lodes.

A highly important feature of even the first class of so-called lodes is their great irregularity as regards the conditions which generally characterize 'true fissure-lodes,' for, although some of these are well defined in short sections, they seldom maintain such regularity for more than a few score feet in length; and generally they are faulted, split up, cut out, or thinned away in the course of a few fathoms. It is noticeable that the greater the width of a quartz-body the less continuous is it usually found to be, and, as a general rule, the less auriferous; while the small veins are often the most regular and continuous, and are sometimes very rich for a considerable length of their course. Most of the larger lodes in the Penjom and Jelai districts, which have been found to be exceptionally regular, have proved valueless for gold, and have therefore not been examined to any great extent.

A peculiarity of this auriferous formation is that, while hardly any of the quartz is actually barren of gold (as proved by hundreds of assays made in the writer's laboratories at Singapore and Penjom), its richer impregnations are confined to local patches, occurring in the small and indefinite-shaped, rather than in the larger and more symmetrical, quartz-bodies.

Rich streaks sometimes follow one or other wall of the lode, and often more gold is found in the adjacent slaty lode-stuff than in the solid quartz; again, where 'horses,' or masses of rock, occur in the lode, these are found to carry gold as well as the lode itself. Some of the best-yielding lodes at present known are of a 'mullocky' (decomposed) nature, and of these the Western Lode of Raub and the Mount Siam Lode of Ketchau, which are in many respects very similar, are examples. Embedded in yellowish shales, both these lodes have proved very irregular in shape, course, and continuity, seldom having a definite wall even on one side for many feet, while the quartz-body varies from a few inches to many feet in thickness in the course of a few fathoms. They are generally split up into several branches, among which it is difficult to distinguish and to follow the main vein.

Within a few feet of the largest swellings the quartz is apt to thin out, and continue only as a mere thread; sometimes it changes to a streak of clay, or pinches out altogether, and on cross-cutting the lode it is sometimes found to have continued in a parallel course, which may or may not be connected with the first, and be equally rich, or be quite devoid of gold. These lodes have everywhere been found to be very irregular in dip, and at Ketchau all trace of regular downward continuity was apparently lost in the upper workings; though in levels 50 feet deeper several lodes were found of quite different nature, and having no connexion with those above.

The nearest approach to the conditions of true lodes appears to be at the Kermoi and Silencing Mines, which are situated on a small right tributary of the River Jelai; and it is worthy of notice that these lodes occur in talcose schists instead of shales.

From the irregular distribution of gold in these Pahang lodes they must be characterized as distinctly 'patchy.' We have no information of the changes experienced in the richness of the Raub Western Lode, which has been worked to a greater extent than any other in the country.

At Kermoi the average quality of the lodes first explored was found to be very inferior, but patches showing gold were sometimes, and have lately been more frequently, met with.

At Ketchau the first discoveries of large quartz-bodies were of very poor quality. This was on Mount Siam Lode, where the average quartz assays only a few dwts. to the ton, but in which small shoots were found yielding quartz of extraordinary richness, in the vicinity of which the bulk of the vein is also of high quality. These patches were of very limited extent, and cut out in all directions, but most abruptly and completely in depth. The rich shoots were more or less separated from the main quartz-lode and 'cased' with dyke-like rock, though no actual intrusion of trap was seen in contact with the lode at this level. This igneous rock (a highly felspathic porphyry) is, however, found in considerable development at a somewhat greater depth, and with it are associated the lodes already alluded to.

The most common and widely distributed occurrence of quartz in these rocks is in the form of very narrow veins, sometimes maintaining their individuality in numerous and parallel recurrences as miniature lodes at distances varying from a few inches to several feet apart, at others forming a reef-like mass by proximity and confluence of a number of such parallel veins, and again impregnating zones of rock in infinite number and varying directions, intersecting and indefinitely disintegrating one another to form what may be called 'stockworks.' It is probably from these minute veins in one form or another, rather than from the larger quartz-lodes, that most of that alluvial gold is derived which is now found in the gravel of so many river-beds and valleys in the Malay Peninsula.

The peculiar formation of the famous Raub Hole may be considered as intermediate between the two classes of deposits, for though each vein may be regarded as a separate lode, yet within a certain zone the whole series of the black slate-rock which contains the veins is distinctly 'mineralized,' being highly charged with iron pyrites, and thus a more or less definite rock-zone is constituted, which may be considered as one great ore-deposit.

2. Irregular Formations.

I pass now to a description of the second form of deposits. Many quartz-lodes, and even some of those which appear most regular in portions of their course, are intimately associated with dykes or intrusions of igneous rock which traverse the sedimentary strata of Pahang, and constitute an important element in the geological formations of that country; it seems even probable that the whole auriferous occurrence is induced by, or is in some way consequent on, this igneous agency, though its connexion is distinctly evident in some places only and has not yet been traced in others. These dykes consist of several varieties of highly felspathic rock, which (though they have not hitherto been critically examined) may be called trachyte-porphyries.

Where prominently associated with auriferous quartz, these dykes are generally found to be in a state of decomposition, rendering their substance (which has become chiefly kaolin) soft and disintegrating, from the surface down to the limited depths as yet reached in the mines. Their junction with the sedimentary rocks is sometimes sharply defined, and often marked by a strong intervening contact-vein of quartz. At others the juncture is irregular, branches of the dyke penetrating the strata or confusedly mixing with the latter, which are consequently contorted and metamorphosed. Auriferous quartz-veins traverse these dykes besides following their junction with the sedimentary rock, sometimes in large lodes and sometimes in numerous minor strings and parallel veins, the general strike of which seems to coincide with that of the dyke, though often they follow several contrary and intersecting courses.

These dykes may then be regarded as another form of deposit of the stockwork type, in many respects resembling those in the slates with which they are sometimes in juxtaposition or intimately associated.

Much of the gold in the alluvial deposits of Pahang must have been derived from these dyke-quartz formations, the tendency of which is to decompose rapidly, in respect of their felspathic matrix. Owing, however, to the harder skeleton of quartz-veins which they contain, their courses are frequently marked as low hill-ranges, from which the soft slates have been more rapidly denuded into depressions on either side. A remarkable result of the process of weathering on these outcrops is found in the peculiar detrital deposit into which they become superficially converted and which is often extraordinarily productive of gold, the precious metal having concentrated in pockets as the outcrop becomes reduced in level and volume. These 'drift deposits,' as they may be styled, have been the object of some of the most extensive ancient workings in Pahang, as probably elsewhere in the Malay Peninsula, both on the dyke-veins and on parts of the slate stockwork-formation.

A characteristic and notable example of the irregular stockwork-form of deposit, combining both impregnated zones of slate and a strong associated dyke-quartz, is found in the very extensive deposit on which the Penjom Mines are situated. Here a continuous belt of auriferous quartz-bearing rocks is traceable for about 7 miles from north to south; the breadth of this belt is several hundred feet, and in places several hundred yards, but its extent and nature are as yet only slightly known from actual mining operations. Throughout its length the porphyry dyke, which in places is many hundred feet thick, is highly important; enormous surface-workings show that it has been worked on a very large scale by the Chinese, in ground-sluices with banks over 100 feet high.

The dyke is intermixed with the neighbouring sedimentary rocks, and quartz occurs throughout the confused mass. In the best known and richer portions, the rock carrying most gold-quartz and otherwise most highly 'mineralized' is the same peculiar black slate as that which distinguishes the Raub Hole. There, in direct contact with the dyke-rock, this slate is either very soft and highly graphitic as well as pyritous, and auriferous throughout, or of a harder grey type much converted into a breccia and sprinkled with large crystals of arsenical pyrites. In the dyke and graphitic reef-mass the quartz-veins are generally small and run more or less parallel, conformably with the general strike; but in the grey slate they follow an opposite direction like cross-courses, sometimes of considerable magnitude, and the two series join, fault, and intersect one another with great irregularity.

4. Note *on the* Nufenenstock (Lepontine Alps). By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S. (Read December 7th, 1892.)

A change for the worse in the weather, as mentioned in my paper on 'Crystalline Schists and their relation to Mesozoic rocks in the Lepontine Alps,'[1] prevented Mr. J. Eccles and myself from completely examining the Nufenen Pass. In the summer of 1891 we were enabled to make an excursion thither from Ulrichen in the Rhone Valley. Though our visit was necessarily a brief one, for even to the top of the pass it is nearly three hours' steady walking and an ascent of over 3600 feet from Ulrichen, yet, as the present paper does something to finish off an obviously 'ragged edge' in my former communication, I venture to bring the results before the Society.

The upper part of the Nufenen Pass (8006 feet) is a nearly level 'corridor,' north of the Nufenenstock (9400 feet), the highest point being at the western end, though the eastern one, above the ascent from the Val Bedretto, is not many feet lower. We were obliged on the former occasion to give up work soon after entering the 'corridor' from the latter end.[2] On our second visit we found that the rain had begun at a very inconvenient moment, for another hour of fine weather would have sufficed for clearing up our principal difficulties.

On the northern side of this 'corridor,' as stated in the above-mentioned paper, is a gneiss, south of which is a little rauchwacke. This can be traced some distance westward down the slopes.[3] It contains rather numerous fragments of the silvery disthene-schist.[4] Jurassic rock follows, sometimes containing 'knots,' 'prisms,' and fossils; some is *in situ*, but how much is doubtful. I mentioned that on the former occasion we had seen a few erratics of the black-garnet schist; on this we soon found the rock abundantly. It covered an area, north of the track, to a distance, roughly estimated, of 300 yards and to a height of 50 or 60 feet above it—in outline a very rude semi-oval. The rock closely resembled that in the crags at the head of the Ritom Boden (Val Piora), the black garnet-bearing schists being often interstratified with brownish quartzose

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 219.

[2] When rocks are not easily distinguished, such as the dark schists with garnets and the Jurassic rocks with 'knots' and 'prisms,' on which we were then engaged, it is worse than useless to work in heavy rain.

[3] The path during the last part of the ascent on this side passes almost wholly over steep slopes of grass and débris.

[4] I use the names employed in my former paper. It is there stated that the black-garnet schist and the dark-mica schist are only varieties of the same rock. In the latter other silicates than garnet and mica may be present, also calcite; sometimes it has quartzose layers. The disthene-schist consists mainly of two micas, as shown by Dr. Grubenmann. Though the name seems given sometimes on the principle of Bottom's dream I retained it, as it had been used by Dr. von Fritsch, and 'Two-mica-schist' looks odd in English.

layers. The mass clearly was broken up, but as the stratified structure lay generally at low angles we were at first uncertain whether some of it might not be in place. But we were ultimately satisfied that it was a great *bergfall* from the Nufenenstock, and, on looking down from the flanks of that peak, saw that we were right. So soon as we had practically joined on to our former work, we began to climb the Nufenenstock, the summit of which is about 1400 feet higher than the 'corridor.' We went up the northern face, making as straight a course for the summit as circumstances permitted, and descended by the southern face, bearing westwards after a time, so as to cross the watershed between the Val Corno and the Gries Glacier. From this we struck down to the track from the Gries Pass and followed it till we reached the spot where we had branched off from it in the morning: by this means running two sections across the general strike of the strata (roughly E.N.E.) at a distance for the most part of a good half-mile.

We mounted first by a steep slope of screes, where we identified dark-mica, black-garnet, and disthene-schists, with rauchwacke and 'spotted' Jurassic rock,[1] indicating that all these occur higher up on the peak. We then climbed crags with intervening snow-slopes: the former consisted for a time of the first and second schists, with a thin bed of disthene-schist in the lower parts of the mass, followed by a little rauchwacke,[2] but we presently reached outcrops of the 'spotted' Jurassic, with the usual hard, brown, sandy bands in places; above another slope came some more crags of the 'spotted' rock,[3] but the final ascent is over dark-mica and black-garnet schists.

The same dark schists continue down the southern face of the peak: black garnets often being plentiful, and the quartzose layers occurring as usual. We worked, as stated, rather to the west; till, on approaching the watershed between the Val Corno and the Gries Glacier, we crossed a band of disthene-schist, only a few feet thick, and shortly afterwards reached a mass of rauchwacke which had been conspicuous from the summit. It lies north of the lowest point of the watershed. We then descended a shallow ravine, which runs nearly with the strike of this rock, till we approached the right bank of the ice-stream of the Gries Glacier, when we got back on to the black-garnet schists and presently struck into the path from the Gries Pass. The last-named rock continued for a considerable distance; then came disthene-schists (about a dozen yards across at the outcrop and nearly vertical), which were followed by a couple of

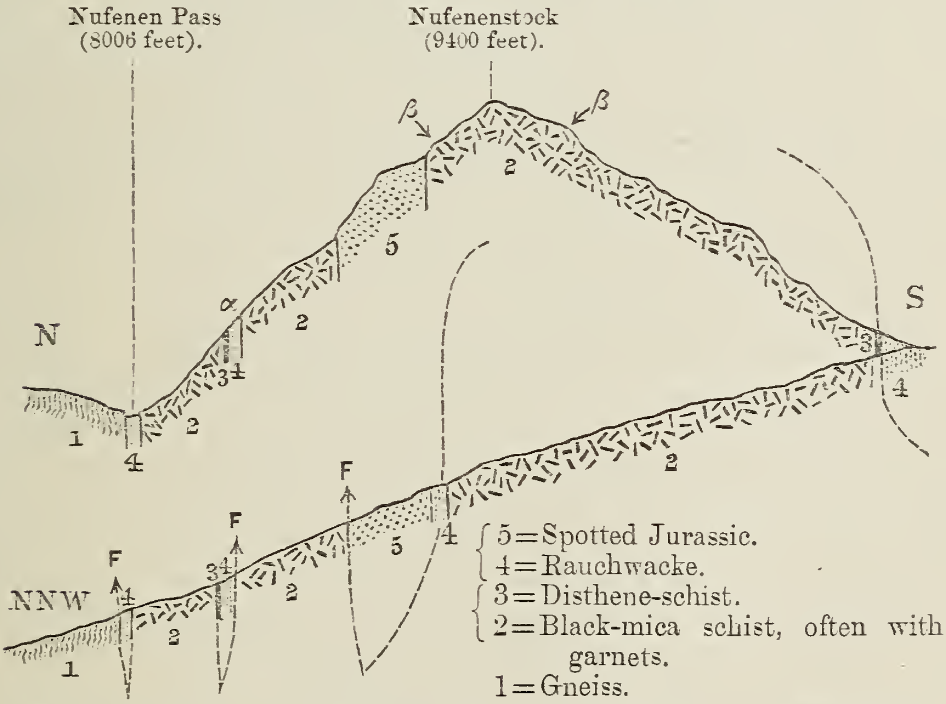
[1] Namely, as shown in the former paper, that containing belemnites with *knoten* and *prismen*, which have been (as there proved) wrongly identified with garnets and staurolites.

[2] Both imperfectly exposed among screes, so that I am not quite certain that even these are in place.

[3] Here was a bit of bad climbing where the rope was necessary, and I was thankful for the aid of a first-class guide (Michel Payot, the constant helper and companion of Mr. Eccles's photographic and geological, as well as of his serious mountain expeditions). There is no other difficulty in the ascent; on the descent any one can go. I think a crag-climber would not maintain the identity of the 'spotted' Jurassic rock and the black-garnet schist. The former is scaly, treacherous stuff, with no good ledges, the latter firm and trustworthy.

yards of calcareous rock much 'troubled' and quartz-veined on the southern side, and this was succeeded by a fair thickness of Jurassic rock with 'knots,' 'prisms,' plenty of belemnites, and traces of other fossils. Then, after a short interval, we found the black-garnet rock,[1] in places much crushed. Interruptions of turf and débris now became frequent, but in a ravine, rather above us on the right, Mr. Eccles (while I was working in another direction) found outcrops both of disthene-schist and of rauchwacke. After this we passed some more outcrops of schist and a little rauchwacke, but the exposures now became few till we joined our morning's track at the foot of the steeper slopes.

Diagrammatic Sections on the Nufenenstock.



α = Bad exposures. β = Indications of fan-structure. F = Faults.

[Length of sections = rather less than one mile.]

Note.—The folds and faults in the above diagrammatic sections are to a great extent hypothetical, but the general correspondence of the several parts of the two sections can be made out with tolerable certainty on the ground, without actually traversing the intervening space. The line followed in the first part of the ascent did not take Mr. Eccles and myself over good outcrops, and we are not quite satisfied about those marked α, though we believe them to be right. At the top of the pass, just behind the line of section, some Jurassic rock occurs.

The above sections, though only a diagrammatical record of our observations, may make the preceding description more intelligible. I believe them to be generally correct, but cannot vouch for the relative

[1] The garnets are sometimes so well cleaved that one can remove them in slices. Here and there, owing to the crushing, the schist is difficult to distinguish from the Jurassic rock. But these puzzles are only local, and are got rid of by making a 'cast' or two in the neighbourhood.

thicknesses of the rock-masses or assert that nothing has been overlooked. To make an accurate map or a measured section would take several days' hard work with the large-scale topographical map and could only be done by camping out at the head of the Eginenthal.[1]

The disturbances just in this part of the Alps have been very great. Where indications of bedding can be obtained the rocks are often seen to dip at very high angles.[2] I think the most probable interpretation of the section to be that the dark schists, constituting the crest and southern flank of the Nufenenstock, form a sharp anticlinal fold, being doubled back to back. The Val Corno, and the plateau or shallow trough, occupied by the long *névé* of the Gries Glacier, run along a synclinal, indicated by the rauchwacke and by some 'spotted' Jurassic rock, which, according to my notes of 1883, occurs on the northern ascent to the Gries Pass. At and near the top of this, as shown by my specimens, black-garnet schist occurs, and rocks belonging to the same group continue for some distance down the southern side. On the northern side of the Nufenenstock is another infold of Jurassic rock, forming probably a syncline, which is broken by upthrust faults, and so 'wedges in' small strips of rauchwacke, etc. The dotted lines on the sections are intended to give a hypothetical interpretation of our observations.[3]

The Nufenenstock district is interesting as exhibiting the 'spotted' Jurassic rocks closer to the black-garnet schists than was shown by any sections noticed in my former paper, and so facilitating comparison and contrast. The comparative abundance of the disthene-schist in the rauchwacke and the absence of the black-garnet schist from it (for I have not yet detected any fragments of this rock therein) are curious. The explanation may be found either in some peculiarity in the relation of the two rocks to the old land-surface, or, more probably, in the fact that the black-garnet schist is a solid and durable rock, the disthene-schist the reverse.

I venture to differ from Dr. von Fritsch's map (which is on a larger scale and in more detail than that of the Swiss Survey) on the following points:—(1) As said in my former paper, I consider the strip traversed by the path from All' Acqua to the Nufenen Pass, which he colours 'black-garnet schist,' to be Jurassic, but I substitute the former rock for some of his 'Lias.' (2) I should prefer to colour the southern side of the Nufenenstock as 'black-garnet schist' rather than 'calc-mica schist'; this, however, is a small difference. (3) We did not find, north of the pass leading to the Val Corno, the broad strip of 'marble' which he depicts parallel to the rauchwacke; possibly, however, only a variety of the latter rock, and not an associate of the crystalline schists, is intended. (4) Although this

[1] From Ulrichen it is about three hours' good walking to the top of the Gries Pass, and I think the summit of the Nufenenstock could hardly be reached, even by the easier climb from this route, in less than four.

[2] The actual peak of the Nufenenstock seems to show a kind of fan-structure.

[3] The evidence is slight, but the suggestions may be useful as a basis for the work of others. It should be said that the absence of the rauchwacke is not important. This rock varies much in thickness and often is missing.

matter belongs to a different part of the map, I may mention that we failed to discover, after a careful search, the black-garnet schist on the eastern side of the Furka Pass, all being Jurassic rock at that locality.

It must be remembered that Dr. von Fritsch's map was made before the microscope was generally employed in petrology. Without that instrument, and the training which it gives, the black-garnet schist and the 'spotted' Jurassic may be easily confused. In the field, even now, difficulties occasionally arise, and the geologist is compelled to work round about a particular outcrop in search of rocks in better preservation, before he can make up his mind.[1] So that, while expressing these differences of opinion on some points of detail, I cannot conclude without expressing my sense of the high value of Dr. von Fritsch's map. Those who know the region well can best appreciate the untiring patience and labour which that author has devoted to a very difficult task.

[1] For instance, I am now not quite satisfied about the nature of the actual summit of the peak, the specimen brought therefrom proving to be a little abnormal.

5. *On* some Schistose 'Greenstones' *and* allied Hornblendic Schists *from the* Pennine Alps, *as illustrative of the* Effects *of* Pressure-metamorphism. By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S. (Read December 7th, 1892.)

That a rock originally augitic may become hornblendic is well known, but the cause of the change is less certain. Some authors seem disposed to attribute it, almost as a matter of course, to the direct effects of pressure; that it is so in some cases can hardly be doubted, but that this explanation universally applies must not be hastily assumed. It may, for instance, be demonstrated, as in the classic case of the Scourie Dyke, that a dolerite has been converted into a hornblende-schist, but the question of the efficient cause may still remain open. At the Lizard, as the present author has endeavoured to show, augite is replaced by hornblende, as in certain of the gabbros, under circumstances which make it highly improbable that pressure has been operative to any appreciable extent.[1] Hence, although schistose 'greenstones' have already attracted considerable attention,[2] it may be worth while to describe certain cases in which pressure must have been an important agent of change, in the hope of ascertaining some mineral or structural characteristics which may help us in recognizing metamorphism due mainly to mechanical causes.[3]

The first group of specimens to be noticed in the present paper was obtained in the summer of 1891, when Mr. J. Eccles and myself spent some time at Saas Fee, in the Visptbal. The structure of the great mountain-mass drained by the two branches of the Visp is rather complicated. The rocks are almost wholly crystalline: gneisses appear to occupy the lowest position, and to be succeeded, perhaps discordantly, by a mass of schists, calcareous, micaceous, and quartzose — rocks clearly of sedimentary origin, but highly metamorphosed. In some districts green schists, apparently interstratified, form part of the latter group; in others—as in this—the same rock occupies a considerable area, is by no means uniform in character, and its relations to the other rocks are more uncertain. The Swiss geological surveyors evidently found it a difficulty. On the western side of the chain of the Mischabelhörner (*i. e.* in the environs of Zermatt) three tints are employed, indicating respectively,

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 489.

[2] See, for instance, Teall, 'Brit. Petrogr.,' pp. 161, 198, 242, etc., and Hyland, Geol. Mag. for 1890, p. 205. These authors, and others to whom they refer, have already argued for certain of the conclusions adopted above, but seeing that in some cases the phenomena are not placed in relation as cause and effect, and that in others pressure seems to be too readily assumed as the agent of change, I have discussed the question at some length.

[3] Dr. Callaway, Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 480 *et seq.*, claims biotite as a result of 'shearing' in a diorite, but I am unable to accept some important details in the history of its development as given by him.

according to the legend,[1] *Grüner Schiefer, Hornblende-Schiefer*, and *Serpentine*; on the eastern all the green rocks are coloured as serpentine. In the former case this term is correctly employed, so far as my knowledge goes, but in the latter it has scarcely any petrological value. Some patches of serpentine undoubtedly occur in the tract thus coloured, but there is also a little gabbro[2] (including the well-known smaragdite-euphotide of the Saasthal), and the predominant rock is a schist, generally hard, which consists mainly of hornblende, chlorite (or altered biotite), with more or less epidote, garnet, felspar, quartz, etc.—in short, it is the *Hornblende-Schiefer* or the *Grüner Schiefer* of the Zermatt district, generally corresponding more nearly with the former.[3] The relations of this rock to the other crystalline schists of the district are not easily determined. Evidently it is in close connexion with the calcareous and other associated schists (*Graue Schiefer, kalkhaltig*, of the map), but dykes occur in the latter near to the boundary of the two masses, which seem like offshoots from the former, and so suggest an intrusive origin.[4]

That the region as a whole has been affected by great pressure—perhaps on more than one occasion—cannot be doubted. The calc-schist group is folded up with the gneisses; all alike exhibit distinctive signs of a cleavage-foliation, produced by movements posterior to the stratification-foliation,[5] whatever may have been the cause of the latter. Immense masses of rock have been removed by denudation. Here and there, sometimes in isolated spots among the peaks and glaciers, we come upon fragmentary infolds of the calc-schist group. These, within no great distance of Saas Fee, differ in elevation above sea-level by about 7000 feet; from the immediate neighbourhood of the hamlet they can be seen cropping out on the mountain-slopes through full half that range. They are cut by the serpentine and by a granite, as a rule coarsely porphyritic, as well as by the 'greenstone'-dykes, which have been more or less modified by pressure.

Of these schistose 'greenstones' the first to be described was found on the eastern flank of the peak of the Mittaghorn (10,328 feet) at a height probably of about 9600 feet above the sea. It forms a lenticular mass about half a yard wide and from 2 to 3 yards long,[6] completely included in the calc-schist, the micaceous bands in which, indicative, I presume, of an original stratification, sweep round it

[1] Sheet XXIII. of the 'Geologische Karte der Schweiz.'

[2] Distinguished by another colour on Sheet XXII.

[3] So far as I know these rocks, the names designate somewhat different types, the former being rather the coarser and more obviously hornblendic, the latter the more 'slaty' looking, but I believe them to be really closely related. On Sheet XXII. only one colour is used.

[4] On the Mittaghorn the evidence of intrusion into the gneiss seems very strong.

[5] The terms are used in the senses proposed by the writer, Quart. Journ. Geol. Soc. vol. xlii. (1886) *Proc.* p. 64.

[6] Débris masked the lower end; about 2 yards was exposed, and in little more than a yard the calc-schist formed a continuous mass.

like the lids round the ball of the eye. Both rocks have been affected by pressure, which has acted roughly at right angles to the banding of the calc-schist. It has crushed the 'greenstone' generally into a 'papery' mass, but one or two bits, which have suffered less severely, present a general resemblance to the 'green schist' of the peak.[1] The specimen taken is, macroscopically, a rather fissile, faintly speckled, dull-green and warm-grey coloured rock, containing a considerable amount of a mineral resembling chlorite. Microscopic examination shows that this mineral has one well-marked cleavage, and occurs in fairly thick flakes with irregularly projecting edges and without any definite crystalline form. The colour in ordinary light is a very pale sea-green. The dichroism is not strong: with vibrations in the direction of the cleavage the mineral is either colourless or a very faint straw tint; with vibrations perpendicular to the cleavage, a pale olive-green. With crossed nicols the tints are of a low order, the brightest being a greyish-white, and extinction is parallel with the cleavage. The mineral is occasionally associated with small flakes of biotite, into which it sometimes seems to pass, so that part at least of it may be a hydrous form of that mineral rather than a true chlorite. Epidote is fairly abundant, occurring in various shapes, from grains to moderately-regular prisms with a well-developed basal cleavage. With transmitted light it is practically colourless; with crossed nicols the tints are often brilliant. An actinolitic hornblende is present, but is small and not very abundant. Here and there are grains of calcite and some granules of iron oxide, with occasionally a dusty-looking mineral, sometimes aggregated, probably sphene; possibly also a few microliths of zircon. One rather abundant constituent still remains. It commonly occurs in roundish or somewhat prismatic grains, up to about ·05 inch in the longer diameter, water-clear and very free from cavities, except a few extremely minute, but frequently enclosing microliths of the chlorite, epidote, and actinolite. It does not present any distinct cleavage or any sure outline of a crystal-face, but if we may trust certain faint indications of the former the extinction is oblique. The colours are like those of quartz, but sometimes even richer. It presents many resemblances to that mineral, and some to kyanite, but on the whole I incline to regard most of it (for some of the smaller grains may be quartz) as a felspar. Both its inclusions and its relations to the larger constituents indicate that this was one of the last formed minerals. The constituents exhibit some orientation, and the rock would be accepted without hesitation as a crystalline schist; yet

[1] On the Swiss Survey Map (Sheet XXIII.) this and about half the ridge connecting it with the Egginerhorn (11,080 feet) is coloured as gneiss. That rock undoubtedly occurs on the flank of the Mittaghorn; but the summit consists of 'green schist,' and this rock, with calc-schist, so far as I could see, dominates on the upper part. I ascended the two peaks on different days and did not traverse the long ridge between them, but have no reason to doubt that all the upper part of this mountain-mass consists of the 'green schist,' though at any moment one might come upon serpentine (of which, however, there is not likely to be much) or upon a small infold of calc-schist.

that it was formerly a basalt or dolerite can hardly be doubted, of which condition practically not a trace remains.[1]

The next specimen is from the north side of the eastern flank of the Mittaghorn.[2] Here a group of dykes (about a dozen in all, one or two branching) cut the calc-schist, above which, at no great distance, is gneiss. Commonly these dykes are about six inches thick; the largest has a thickness of about half a yard. Similar dykes can be traced some little distance up the mountain-side, both in the calc-schist and in the gneiss. They have been sometimes folded with the calc-schist: their relation to the foliation of the gneiss is not so clear.[3] The specimen examined is a dull greyish-green rock, slightly fissile, with a faint silvery sheen on the irregular divisional surfaces. Under the microscope the constituents are seen to be the same as in the last-described rock, but there is rather less epidote, more biotite, the 'chlorite' is slightly deeper in colour, and actinolite is more frequent.[4] The constituents are rather smaller, and the structure of the rock is a little more suggestive of crushing.

The third specimen is from a dyke obviously much affected by pressure, from 1 to 2 yards wide, cutting calc-schist, on a shoulder of the Fee-Gletscher Alp, near the right bank of the left arm of the Fee Glacier.[5] The specimen examined is a rather fissile greyish-green rock, with a slightly silvery sheen on the cleavage-surfaces.

[1] This identification is confirmed by an analysis kindly made for me by Mr. A. A. Longsden in the chemical laboratory at University College, London. After treatment with dilute HCl for about 24 hours, 8·99 per cent. of the rock proved to be soluble, and was thus composed:—FeO = 1·63, CaO = 3·87, MgO = 0·57, CO_2 = 2·92. The residue gave SiO_2 = 43·70, Al_2O_3 = 23·44, Fe_2O_3 = 3·14, FeO = 3·64, CaO = 9·18, MgO = 2·97 (probably slightly too high), Na_2O = 4·86, H_2O = 2·40 (combined):—Total = 93·33. Combining the two results for a bulk analysis, the composition is:—

SiO_2	=	43·70
Al_2O_3	=	23·44
Fe_2O_3	=	3·14
FeO	=	5·27
CaO	=	13·05
MgO	=	3·54
Na_2O	=	4·86
H_2O	=	2·40
CO_2	=	2·92
		102·32

The rather high percentage of lime may be accounted for by some infiltration of calcium carbonate from the neighbouring calc-schist, but the analysis on the whole fairly represents a somewhat decomposed basalt.

[2] Somewhat lower down than the last locality, where the track is running nearly on a level.

[3] Perhaps I should mention that in the Alps the date of the cleavage-foliation is not so readily determined as might be supposed. Their rocks were greatly affected by the earth-movements to which the present chain is due, *i. e.* of Tertiary age, but there is evidence that a cleavage-foliation existed, at any rate in some parts, in pre-Triassic or even pre-Carboniferous times.

[4] There are some microliths of rutile or possibly pseudobrookite.

[5] Across a shallow depression is a larger mass of 'green schist' with which the dyke is probably connected. About 20 yards from it is a mass of serpentine, which throws off a dyke cutting the calc-schist.

It is generally fine-grained, but a few flakes of a chlorite-like mineral and specks of iron oxide and pyrite are visible on close inspection. In a slice of this rock we find the same constituents as above, but there is less chlorite and only a little epidote, while microliths and small crystals of actinolite are abundant, and there are grains of a brownish, somewhat dichroic mineral, possibly an augite in process of change to hornblende.[1] An impure sphene is probably associated with some of the grains of iron oxide, and not only the latter mineral, but also the constituents generally, suggest crushing.

The result then of crushing some thin dykes, which were probably once dolerites or basalts, has been to produce foliated schists in which all traces of the original structure have disappeared, and biotite or chlorite and an actinolitic hornblende have replaced the original pyroxenic constituent.

Next we may briefly notice two or three specimens from the larger masses of 'green schist.' In the coarser varieties of these (restricting ourselves to the Zermatt-Saas district), in addition to a foliated structure, slight indications of mineral banding—not, however, in broad stripes, but in thin, rather irregular lines—may be sometimes observed. The first specimen, a moderately foliated greyish-green rock, with tiny whitish specks, evidently rich in a fibrous hornblende, represents the summit of the Mittaghorn; it consists mainly of actinolite, epidote, chlorite, and the above-named water-clear mineral,[2] the first being rather abundant.

The next specimen is a rather coarser variety of the 'green schist,' slightly more fissile, but otherwise very similar in appearance to the last, and was taken from the Hinter Allalin Joch.[3] Under the microscope this exhibits a very definite foliated structure, is rich in actinolitic hornblende, with a fair amount of epidote, but not much chlorite. The water-clear mineral has a more definitely porphyritic habit than in any previous case, and one or two grains exhibit a polysynthetic twinning, like a plagioclase felspar—the extinction-angles on either side of the twin-line being 14° or less. A large 'eye-shaped' grain of brownish-green hornblende, cut transversely, is present in one slide. This has every appearance of being an original constituent. The rest of the rock seems to have completely recrystallized subsequent to the crushing, for the undulating lines of actinolitic and other microliths can be traced right through the grains of water-clear mineral.

The third specimen comes from the southern flank of the ridge running east of the Hinter Allalinhorn, near the Hochlaub Glacier. It is a somewhat banded or streaky, not very fissile rock, in which a

[1] Sometimes part of a grain is greenish blue in colour. There are a few microliths of rutile.

[2] For brevity I will omit the minor constituents (such as iron oxides, rutile or pseudobrookite, zircon, etc., some of which are usually present), since they have no bearing on the main subject of this paper.

[3] A pass east of the Hinter Allalinhorn, about 10,800 feet above sea-level, discovered, I believe, by Mr. Eccles.

dark green acicular hornblende and a grey felspar-like mineral alternately predominate, and contains some reddish garnet in grains about the size of a mustard-seed. Under the microscope the first mineral is rather strongly coloured, dichroic, and shows the characteristic cleavages: most of the second proves to be epidote. There is probably a little interstitial quartz. The garnets appear to be original constituents, or at any rate anterior to the pressure.

The last specimen is representative of one of the more banded varieties of the *Hornblende-Schiefer* from the upper part of the Riffelberg (collected a few hundred feet above the Hotel).[1] The chief constituents are actinolite, a rather strong green hornblende in somewhat irregular ill-formed prisms, evidently replacing glaucophane,[2] which still remains in places, and epidote, with some reddish garnets and white mica. The rock is but slightly fissile and is somewhat foliated.

To sum up: it is certain that one of the groups described above is of igneous origin; it is highly probable that the other is the same, and that pressure has been a most important if not the main agent of change. The original structure is lost; the constituents to a great extent (if not altogether) have entered into new combinations; a considerable quantity of biotite (or chlorite) and of hornblende has been formed, and the last-named mineral is more or less acicular in habit.

For the next set of specimens I am indebted to my friend Mr. Eccles, but my general knowledge of the district from which they come enables me to affirm that the rocks in which they are intrusive belong to the great calc-mica-schist group already mentioned.[3]

The first specimen, from the Tschampigel Keller, near Binn,[4] is a somewhat foliated dark-green hornblendic rock, faintly speckled with grey and white. Under the microscope a rather dull-green hornblende is seen to be the most abundant mineral. It usually occurs in prisms about 6 or 7 times as long as broad, ranging from about ·07 inch to mere belonites, from ·03 inch to ·04 inch being a common length; the larger grains exhibit the characteristic cleavage, but their faces generally are not well developed. Biotite is fairly

[1] I have in my collection specimens (unsliced) of the *Grüner Schiefer* from the neighbourhood of Zermatt, the flank of the Hörnli, and the Furggen-grat, and do not see how to separate them either from the last-named or from others described above.

[2] Boulders of a slightly foliated rock rich in glaucophane are rather common in the Saasthal, and evidently come from the mountains enclosing the Allalin and Hochlaub glaciers.

[3] They are generally dark-mica schists, sometimes calcareous, occasionally interbedded with white crystalline limestone or dolomite. For description, see Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 199–204.

[4] From a rather irregular dioritic dyke which breaks through the black-garnet schists, irrespective of their bedding. It varies from 5 to 20 feet in thickness, is rather massive, and shows externally little, if any, evidence of schistosity. Striking (roughly) E.N.E.-W.N.W., it does not appear to extend far, but is probably connected with a larger mass of similar rock which, however, is interbedded like a sill between the garnet-schists.—J. Eccles.

abundant; it has a tendency to aggregation, for in parts of the slide it is almost absent; it has formed after the hornblende, to which it forms a kind of 'setting.' There are grains of iron oxide, part at least hæmatite and limonite, and of an almost opaque, brownish, granular substance which also occurs in streaks (the residue of more or less crushed felspar?). These minerals appear to be set in a water-clear ground, which, on using crossed nicols, breaks up into a rather irregular granular mass, the individuals having a rather polygonal outline. These, though their tints are somewhat less brilliant, may be identical with the secondary felspar already mentioned. The constituents of the rock exhibit a fairly marked orientation.

The second specimen, from Kehlmatten near Binn,[1] is a dull-green, fairly strong and solid schist, containing some flakes of biotite, and marked in parts by fine white lines, which correspond with a slight fissility. Under the microscope the hornblende is seen to be more acicular, rather smaller in size, but of a deeper blue-green colour and more definitely orientated than in the last case; epidote as before. The flakes of biotite are larger, more scattered, and include both these minerals: they do not stand in any definite relation to the foliation—in this rock very well marked—for many flakes lie more or less transversely to it. The water-clear mineral occurs both in patches and in streaks, and is more variable in size: some of the grains undoubtedly show polysynthetic twinning, others a 'clustered' structure: quartz may be present, but most of them are more probably a felspar (secondary): here mechanical disturbance is suggested even more definitely than in the last case, and one of the streaks exhibits small flexures.

The third specimen, from a mass of rock which is exposed in the bed of the river, opposite Giessen, near Binn,[2] is rather similar to the last one, but is without the white streaks and has more biotite, which dominates in fairly well-marked bands. The same minerals are present as in the two previously-described specimens, with a more definitely banded arrangement. Here also some of the clear mineral shows plagioclastic shaping.[3] While most of the constituents have a roughly parallel ordering, some of the biotite, especially in the case of the larger flakes, seems to be quite independent.

[1] Probably this rock and that at Giessen are portions of one and the same nearly vertical dyke, striking N.E. and S.W., the continuation of which in the latter direction is seen under the Hotel at Binn and at several points between that village and Giessen. At Kehlmatten, in two exposures the vein varies from 15 to 70 feet in thickness, is very schistose, and its cleavage is identical in direction with that of the corresponding *Calc-Schiefer*; the schists and limestones in contact with the dyke are rather altered, and some of the latter have been caught up in the hornblende-rock.—J. Eccles.

[2] Here the rock is 120 feet thick, much crushed and contorted, in short a hornblende-schist, conforming (like the last) in its cleavage with the surrounding schists. Evidently the rock, after penetrating the older *Calc-Schiefer*, has been subjected with them to one and the same pressure.—J. Eccles.

[3] This rock is exceptionally rich in rutile and pseudobrookite.

A fourth specimen, from the Gorge of Gondo,[1] when examined macroscopically and microscopically, only exhibits varietal differences from those above described.

Examples of like kind from other parts of the Alps might be added, but these may suffice. They suggest the following conclusions:—

(1) That basic intrusive rocks, presumably once dolerites or basalts, can be converted into foliated, possibly even slightly banded schists, in which no recognizable trace of the original structure remains.

(2) That in an early (possibly the first) stage of the process the primary constituents of the rock-mass are crushed or sheared, and thus their fragments frequently assume a somewhat 'streaky' order: that is to say, the rock passes more or less into the *mylonitic* condition.

(3) That next (probably owing to the action of water under great pressure) certain of the constituents are decomposed or dissolved.

(4) That in consequence of this, when the pressure is sufficiently diminished, a new group of minerals is formed (though in some cases original fragments may serve as nuclei).

(5) That, of these, hornblende is the earliest formed,[2] closely followed, if not accompanied, by epidote: next comes biotite (the growth of which often suggests that by this time the pressure was ceasing to be definite in direction[3]), and lastly the water-clear felspar and quartz.

In all these cases the hornblende occurs either in very elongated prisms or in actual needles (in other words, is more or less actinolitic). The inference that this form of the mineral and pressure frequently stand in the relation of effect and cause is supported by not a few instances in my collection. Thus the glaucophane in the *amphibolite* of the Ile de Groix[4] commonly occurs in rather long-bladed prisms, and the general aspect of the rock recalls some of the above described, less fissile 'hornblende-schists' from the Alps. The whole region has obviously been subjected to great pressure, and I think it highly probable that the *amphibolite à glaucophane*

[1] Seen at the roadside a little above the Alte Kaserne. It has apparently been injected between the beds of the calc-mica-schists and subsequently subjected to great pressure together with the surrounding rocks. It is nowhere more than 7 feet in thickness, and in the cliff-face west of the chalets of Alpigen it is seen to break across the bedding of the surrounding schists and finally to die out.—J. Eccles.

[2] The rutile, zircon, and some of the iron oxides are probably original constituents—the sphene may in some cases be secondary. Calcite of course, when present, would form at a late stage.

[3] For the present the question, whether the 'chlorite' is an alteration-product of biotite or independently produced, may be left open. In some cases I think it the former. Doubtless, much would depend upon the amount of alkali originally present in the rock or introduced by water.

[4] Quart. Journ. Geol. Soc. vol. xliii. (1887) pp. 302–304. See also the figure of the Anglesey glaucophane-schist, Teall, 'Brit. Petrogr.' pl. xlvii (1). In my specimen of glaucophane-schist from Japan the mineral is in very long prisms.

is intrusive in the *schistes à chloritoïde*. A similar resemblance to some of these Alpine rocks may be observed in an *amphibolite* from near Le Poldu (Britanny).[1] The hornblende-schists from the Hebridean series of Ross-shire, where much affected by pressure, become actinolitic.[2] So also are the 'green schists' from the south coast of the Lizard (where the rock is indubitably much affected by pressure), from near the great boundary-fault at Porthalla, and in one case at Polkerris.[3] But the ordinary dark hornblende-schists, as already described, exhibit quite a different structure, which more nearly resembles that of the foliated part of the dyke in Caerleon Cove[4] and the portion of the Scourie Dyke figured in plate xxi. (1) in Mr. Teall's 'British Petrography.' In these (and many of them show a well-marked mineral banding) the hornblende is more granular and normal in form. So, referring to the plates in that book, I should say that the structure figured in plates xx. (2) and xxi. (1) was due, not to pressure, but to a fluxional movement during the last stage of consolidation. That figured in pl. xx. (1) possibly may have been produced by pressure, but of this I am doubtful.

Thus it appears to me that an augitic rock may be converted into a hornblendic rock—

(1) By simple 'uralitization' (without foliation).

(2) By the same, with the formation of some actinolitic hornblende, generally rather minute, often fringing larger crystals (without foliation).

(3) By fluxional movement (causing foliation) followed by uralitization.

(4) By dynamo-metamorphism,[5] followed by reconstitution, the result being foliation.

[1] Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 312.

[2] Since the above paper was written I have obtained additional evidence from Scotland. In the Pass of Killiecrankie dioritic dykes, more or less schistose, are frequent, some of which present interesting resemblances to certain of these Alpine 'hornblende-schists.' The rocks can be examined *in situ* close to the Garry and occur as boulders in its channel. They are more or less foliated, evidently sometimes contain biotite, and not unfrequently red garnet. Occasionally the former presence of a porphyritic felspar is indicated by white spots, in other parts of the same mass garnets are abundant (I have long suspected that most eclogites are diorites in which garnet has taken the place of felspar). I have examined microscopically one of the less foliated examples (from a dyke above the bridge in the village) and the most foliated one (from a boulder); both, especially the latter, strikingly correspond with some of the rocks described in this paper, the hornblende occurring in dark green prisms with enclosures (evidently of later date than the principal crushing), the biotite being newer than the hornblende and sometimes suggesting pseudomorphic replacement, and the garnets being anterior to the crushing.

[3] Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 480–482. [4] *Ibid.* p. 493.

[5] This seems to produce the most complete reconstitution: not only the augite being replaced by actinolite, but also epidote and felspar (the latter probably of different species from the original felspar) appearing. I suspect that some of the finer granules of iron oxide sometimes are 'absorbed.' It is noteworthy that there is the greatest amount of biotite and the least of actinolite (indicative of a more complete exchange of constituents between the augitic and felspathic materials) in the thin dykes, which would be in all probability more crushed than the thicker masses.

The first and second of these changes (so far as my experience goes) occur in regions which offer no evidence of dynamo-metamorphism on an important scale. Of course, in any district occupied by ancient rocks, local disturbances may have produced their effects, so that a structure due to pressure might occur, here and there, in such a neighbourhood as Coverack Cove or the coast south of Carrick-Luz (Cornwall): but in these (to take them as an example) I believe that the altered gabbros would fall under one of the first three heads, and only by some rare chance under the fourth. We must also be prepared for the last process being superimposed on the third, as already mentioned in the case of some of the Lizard (hornblendic) schists, and as may very likely have happened in parts of the Scourie Dyke.

Accordingly I believe it to be generally possible, in cases of the genesis of a hornblende-schist from an augitic rock of igneous origin, to distinguish those which are the more direct product of dynamometamorphism, both from those in which the original structure is more or less retained (or ordinary epidiorites) and from those where the foliated structure is due to some kind of fluxional movement during consolidation.

I may remark in conclusion that the formation of biotite or chlorite in a felspar-pyroxene rock probably requires a greater amount of crushing than the conversion of augite into actinolite. To produce the first two minerals there must be an exchange of constituents between the felspars and pyroxenes;[1] biotite comes at once from the partial melting of hornblendite by an acid magma.[2] In the cases above described, where the biotite forms a kind of 'setting' for the actinolite, this occurs in that part of the rock where the powder of the felspars and pyroxenes would be most completely mixed. The thin dykes described above strongly favour this conclusion, for in these either pulverization would be most complete, or the two constituents (if the rock was glassy or compact) would be already mingled in a state of fine division, and it is in these that we find very much chlorite or biotite and only a little actinolite.

[1] This, as I believe has been observed, accounts for the frequent association of epidote and saussurite.

[2] Hill and Bonney, Quart. Journ. Geol. Soc. vol. xlviii. (1892) pp. 127–137.

6. *On a* Secondary Development *of* Biotite *and of* Hornblende *in* Crystalline Schists *from the* Binnenthal. By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S. (Read December 7th, 1892.)

Pressure is one agent in mineral change. In some cases, as when a shale is converted into a phyllite, the constituents become rather larger, but more commonly the result of oppression is degradation. This is especially true of the crystalline rocks. The effects of earth-movements on granites, gneisses, marbles, mica- and other schists are familiar to all workers in such districts as the Alps or the Scottish Highlands—we might say in almost any great mountain-chain, whatever be its date. Sometimes, indeed, an original constituent has 'gone through the mill' comparatively unscathed. Its weaker associates have been crushed to powder, which has acted like a packing-material. But cases occur where new minerals of considerable size are developed here and there from the débris of the original constituents.[1] The greater part of the rock is little more than reconsolidated detritus; it still retains the marks of the *peine forte et dure* to which it has been subjected; but nevertheless it has set up a structure which might be termed porphyritic. The process is analogous to the formation of chiastolite in contact-metamorphism. The mass of the rock is little changed, but a large mineral has been developed: for the one millimetres, for the other centimetres are appropriate standards of measurement.

Still, so far as my experience goes, this secondary development on an important scale is very rare; commonly when large minerals occur in a catathlastic rock,[2] as the garnets in certain Alpine schists, or the sahlite in the fine-grained limestone of Tiree, they are survivors from the original coarsely crystalline rock. From time to time, however, I have noted instances of this secondary growth, but it generally has been on a very moderate scale. Hence it may be worth while to describe two specimens, which, curiously enough, were received together. Both came from the same neighbourhood, the Binnenthal (Canton Valais), and from the same group of rocks—the dark-mica schists, in which no small part of that valley is

[1] It will be understood that I am speaking throughout of the silicates usually present in crystalline rocks. Such minerals as quartz and calcite form so readily as not to count for much, nor do I refer to the ordinary zeolites, produced in certain igneous rocks. All these, however, seem to require room (*i. e.* occupy cavities), while those of which I speak occur in the mass of the rock.

[2] Some such word as this is needed to express detrital rock due to crushing *in situ*. 'Crushed' would do, but geologists are such excellent Greek scholars that no word has a chance of coming into fashion unless it be derived from that language. 'Mylonitic' is doubtfully correct, etymologically speaking, and suggestive of an erroneous idea, for it implies grinding as between revolving millstones. Also it has been generally applied to rock affected by a *shearing* crush, not by a direct crush, as of a press.

excavated. This group, the highest in position among the crystalline rocks of the Alps, practically extends, as I have already stated,[1] from one end of the chain to the other. Its members are usually more or less calcareous, though quartz-schists occur; mica is almost invariably present, but occasionally the rock becomes a marble, practically a crystalline mass of calcite or dolomite. Chloritic and hornblendic schists also occur, but some of these are certainly modified intrusions, though others may have been originally interstratified tuffs. These dark-mica schists are not seldom interbanded with impure quartzite or quartz-schists, just as argillaceous and arenaceous layers are associated in the Palæozoic rocks of the Isle of Man or of Morlaix,[2] or in other cases of sediment too numerous to mention, even down to the stratified drifts at Cromer. Not unfrequently, as I have noted in previous papers,[3] these dark-mica schists contain garnets, from the size of a small cherry downwards. I have found them myself at intervals from the southern slopes of the Lukmanier Pass to near Binn, a distance of over thirty miles in a straight line. In places, as in the crags at the head of the Ritom Boden (Val Piora), on the Nufenenstock, or in the ridges about the Gries Glacier, these garnet-bearing schists are of no small thickness, but there are considerable intervals in which I have not met with that mineral, and I have not yet found it on the Simplon Pass [4] or in the Vispthal.

For a description of the structure, macroscopic and microscopic, of these garnet-bearing rocks and other associated schists, I may refer to my paper, already printed in this Journal,[5] and to an elaborate investigation by Dr. Grubenmann,[6] frequently quoted therein.

The specimen now to be noticed was collected by Mr. J. Eccles, in the summer of 1890, from the outcrop in the bed of the torrent above the village of Binn.[7] Above it are schists of the 'Pian Alto' type, which become, somewhat higher up, distinctly calcareous. They are overlain by the white dolomite, mentioned in my former paper (p. 211).

This specimen (a slab about ·5 inch thick) differs little from those collected by myself in other localities. The upper and under surfaces are due to cleavage-foliation; the lustre perhaps is slightly more silvery than it is in some of my own specimens, where it more resembles that of graphite. Evidently it is due to a continuous

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 187.
[2] *Ibid.* vol. xliv. (1888) p. 11.
[3] *Ibid.* vol. xlii. (1886) *Proc.* pp. 72–75; *ibid.* vol. xlvi. (1890) pp. 202–3, 224–8.
[4] It has, however, been found by Mr. J. Eccles not far away to the east, and on the southern side of the watershed.
[5] Vol. xlvi. (1890) pp. 199–204, 208–210, 224–229.
[6] Mitt. der Thurg. naturf. Gesellsch. 1888, Heft viii.
[7] We discovered the rock in 1889, but, being quite satisfied as to its nature, we did not bring away a specimen, for some scrambling would have been required to get it, and we had done more than an eight hours' day. But as we did not find this particular rock farther east, I asked Mr. Eccles, in 1890, to be so good as to bring back a specimen.

film of a very minute white mica, forming a kind of 'varnish.' The garnets, about 0·25 inch in diameter, have been affected by pressure—but still retain a fairly regular dodecahedral form. One difference only attracts the eye, most conspicuous on the clean-cut surface, that here and there flakes of biotite (sometimes nearly the above length) occur, often parallel with, but occasionally athwart the direction of cleavage.

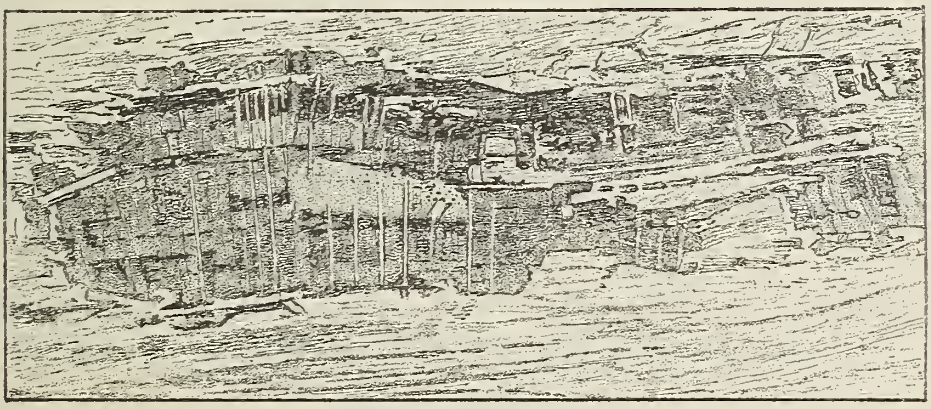
The matrix of the rock, when a thin section is examined under the microscope, indicates the effects of severe pressure, and resembles my specimen from the Val Canaria more closely than those from Val Piora. It is like a mass of matted fibres, which lie roughly in one direction. These are flakelets of a colourless mica, among which is scattered much opacite in small rods or plates, down to the most minute dust; the latter has a slightly streaky arrangement.[1] Part of one garnet is on the slide: its margin is rather irregular; the 'sides' of the grain are bounded by a narrow zone of cleaner mica, brown and white. Streaky opacite is continued through the grain, bending slightly out of the usual direction, but is almost absent for a space of nearly ·01 inch from the margin. In the garnets from the other localities lines of opacite can also be seen. Films of biotite also may be noted in the groundmass of these rocks, suggestive of a crystallization of later date than the pressure. In this slide the matter appears to be beyond doubt. Here the biotite occurs in crystalline grains, rarely in scattered films. The basal planes of the mineral sometimes almost lie in the plane of cleavage-foliation, but are often athwart it, and once at right angles to it. The grain is elongated, in the former case, in the direction of the basal plane, when it is nearly free from enclosures; in the latter case the elongation is perpendicular to the basal plane, and the streaks of opacite pass through the mineral, though the quantity seems diminished. The last-named grain, a portion of which is figured (see fig. 1, p. 107), is as nearly as possible ·175 inch long, at right angles to the basal plane. For slightly more than one third of its length, it is about ·03 inch broad. It is then invaded by a streak of matrix, which enters through a gap in one side nearly ·02 inch wide, but part of the crystal forms a continuous strip, though in it the mica for a space almost disappears, as if there had been an insufficient supply of the requisite constituents (the mineral being well developed on either side of the gap). The streaks of opacite pass through the biotite, though in the clearer portions they are diminished in quantity, the finer lines disappearing, but twice or thrice a thin strip of biotite, bounded by two cleavage-planes, interrupts them more or less completely. Generally, however, these planes can be seen to cut right through the 'dusty' streams without producing any effects.

The relations of these biotite-crystals to the matrix seem to place it beyond doubt that they have been completely reconstituted, if not wholly formed, since the epoch when the rock was modified

[1] Other silicates and probably quartz are also present, but as these are unimportant for my purpose I have passed them over.

by pressure. Ought we not to say the same of the garnet? It must be later than the opacite: this material, however, I take to be a very early constituent; it occurs in all my specimens, but with less regularity in those which show most crushing. In some cases a garnet, or part of it, has obviously been pulverized and

Fig. 1.—*Secondary development of biotite in a crushed schist.* × 30.



reconstituted[1]; in others the stratulæ of opacite lie in a different direction from those of the matrix. So I think that in the Binnenthal rock the garnet was only slightly compressed, without material fracture, and the stratulæ of opacite, already present, were slightly flattened. But if the biotite-crystal described above had been already formed when severe pressure was applied, it must have bent, zigzagged, or split open, for mica is a mineral 'sensitive' to pressure, and generally retains the marks of maltreatment. So I consider this biotite to be a constituent which appeared late in the history of the rock, though very probably the crystal may be reconstructed from the ruins of a former one. If the rock had been much sheared and its fragments mingled, then scattered films ought to have been produced, as has happened in some of the other instances. Here in all probability the crush was a direct one; still the molecules must have travelled, transverse to the structure of the rock, for some little distance, in order to build up a crystal such as that which has been described.

The next instance of constructive crystalline action seems to me still more remarkable. The specimen was obtained by Mr. J. Eccles on the Hohsandhorn, near the summit (10,515 feet). I have not ascended the peak, but have seen it from the summit of the neighbouring Ofenhorn (10,728 feet) and from a pass (about 9400 feet) over the connecting ridge. This is gneiss, but the peak of the Hohsandhorn is formed of the dark-mica schists mentioned above, which are parted by a zone of marble. The matrix of the specimen,

[1] See Quart Journ. Geol. Soc. vol. xliv. (1888) pl. xv. (Attwood on 'Geology of Mysore') for excellent representations of crushed and flattened garnet. Parts of fig. 1 (the schist), though much more quartzose, give some idea of the 'fibrous' structure referred to in this paper. Both it and fig. 2 represent the mode in which the quartz and biotite get 'mixed up' in another mineral.

macroscopically, resembles generally that of the garnet-bearing schist; it has a similar sheen, but contains, instead of garnets, numerous dark actinolites, rather roughly formed, which are commonly from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch long and about $\frac{1}{10}$ inch thick. These lie mostly in the general direction of the cleavage-foliation, but some make high angles with it. They present a certain resemblance to the still larger green actinolites in the garnet-bearing schist, so abundant on the southern slopes of the St. Gothard *massif*, but in the present case both the mineral and the rock have a 'dirtier' aspect. The matrix under the microscope (allowing for a clear streak mostly occupied by quartz, biotite, and paragonite (?), no doubt a rolled-out vein) does not differ much from that of the ordinary black-garnet schist, except that the quantity of opacite is less, and of quartz more, in proportion to the white mica. But the

Fig. 2.—*Hornblende-crystal (with some biotite) including curved stratulæ of opacite.* × 30.

streaks of opacite often exhibit sharp flexures. Films of biotite occur here and there in parts of the slide, grains and plates of iron oxide, and small narrow prisms. These last have an oblique extinction, give fairly bright colours with polarized light, and are probably kyanite; a few small grains of a plagioclase felspar can also be recognized. On closer study we perceive that in parts of the slide where the opacite and mica are less abundant, the interstitial material, on applying crossed nicols, exhibits—over spots of some size, perhaps $\frac{1}{15}$ inch wide—a uniformity of tint and of extinction, as though the opacite and mica, with some granular quartz, were embedded in one irregularly defined grain of some mineral. Further examination shows that in one of the more definite instances this intervening material exhibits an oscillatory twinning, one set of bands extinguishing at $2\frac{1}{2}°$, the other at $27\frac{1}{2}°$ with the combination-plane, which indicates one of the more basic felspars.

Two hypotheses may be advanced in explanation of this structure. One, the partial dissociation of an original felspar-grain into granular quartz and white mica, as described in some cases from near Sudbury (Canada)[1]; the other, the recombination of felspar granules in a mixture (due to crushing) of quartz, felspar, opacite, etc. The latter seems to me more probable, for the amount of white mica is much smaller than it should be on the former hypothesis, and in parts of the felspar which are most free from quartz a granular structure can be detected, sometimes by shadowy outlines, visible only in certain positions with crossed nicols, sometimes by the presence of opacite, as if in a pencil sketch of the structure the lines had been made with dots. The larger flakes of brown mica are both smaller in size and more irregular in outline than in the specimen already described, but here also, once or twice, the stratulæ of opacite are carried through them unbroken.

The hornblende is the most noteworthy mineral in this specimen. The outline of the crystals, as we might expect, is very ragged, but the usual cleavage is sometimes distinct. The colour is olive-green, the polychroism fairly strong: for vibrations parallel with a, pale greenish straw-colour; with b, strong sap-green; c, indigo green. The mineral contains, like the St. Gothard actinolite, not infrequent granules of quartz; possibly also some of felspar. The stratulæ of opacite pass through the crystals practically unaffected; *even the waves and sharp flexures are preserved.*[2] In one case (see fig. 2, p. 108) a crystal of hornblende full half an inch long[3] has formed without in any way disturbing this structure; biotite is occasionally enclosed by, and not seldom fringes, these crystals of hornblende. On a closer examination of the biotite and its mode of occurrence, we notice that the flakes often border the hornblende, and lie within a line which seems to be its natural boundary as if they cut into the mineral: groups of them occasionally occupying deep bays, as they may be called, in the grain. The most simple explanation of this peculiar association is that portions of an original crystalline grain of hornblende have been replaced by biotite,[4] just as small grains of the former mineral replace part of a large grain

[1] Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 36.

[2] It would have been easy to find instances where the flexures are much more pronounced than in fig. 2, but in some other respects this crystal is more instructive.

[3] It goes right across the slice and is broken off by the edges, which are defined by cleavage-foliation.

[4] This, however, would imply the breaking up of some felspar, because even if the hornblende originally contained alumina, more must be added, and potash obtained (if not wholly, in great part) from such a mineral as orthoclase; silica would then be liberated, and lime must be removed. In some cases the last might be used to form epidote or saussurite, in some a carbonate, which might or might not pass away in solution.

of augite. But by this change the stratulæ of opacite, whether straight or bent, are not affected, except that possibly a little of the most minute dust disappears.

That this rock was originally sedimentary, but afterwards became crystalline, seems highly probable; that it was then crushed seems certain, and that afterwards these large crystals of hornblende, the flakes of mica (in some cases at their expense), and some imperfect grains of felspar were developed seems the most natural inference. If this be so, those molecules at any rate which have built up the hornblende must have travelled about the rock for some distance, because even if we suppose that an elongated crystal existed at an earlier stage, it would be more or less crushed down if a statical pressure acted in the direction of its length, and it would be 'dragged out' and more or less distributed in a transverse direction if affected by a shearing force,[1] so that in either case a considerable displacement of some of the molecules is necessary to bring the crystal back into a position at right angles to the cleavage-foliation.

The process of crystal-building described above has evidently left the structure of the rock practically undisturbed, and resembles some forms of pseudomorphism. Hence the direct agent was probably water. As an hypothesis—but nothing more—I will venture on the following sketch of the process. After the rock had been crushed up, much of the material thus produced (in the first case) corresponded in composition very nearly with biotite. Where this correspondence was most close, crystal-building began in the presence of water. A nucleus once formed, further constituents would be derived from the water itself, which, when the pressure was greater, would have dissolved the finer dust, and would still continue to act on some of the materials. Thus the crystal would continue to grow, developing the more easily because the matrix was so nearly of the right composition. This would explain the peculiar development of the biotite described above, in parts of which the border of the crystal can hardly be said to be defined, and the process of development seems to have failed rather than to have been arrested. Quiet growth is indicated even more strongly by the large actinolitic crystals in the second case. Here we may suppose that there was a slight excess of magnesia and a defect of alkali; so hornblende began to form instead of biotite, and continued to grow as before until the conditions became more favourable to the production of the latter mineral, probably owing to the water becoming more alkaline, when it was at last even able to attack some of the hornblende already formed. Rocks very often illustrate the old proverb, 'robbing Peter to pay Paul.'

I have described these two rocks at considerable length because, so far as my experience goes, molecular movements on so large a scale are very exceptional after crushing or shearing. My collection contains over three hundred slides of Alpine rocks, and perhaps a

[1] We hear just at present so much about 'shearing' that one fancies some geologists suppose rocks to be sheep. Nature also subjects them to a treatment like that of a Bramah-press. This probably is the usual result of simple folding; while shearing results from overthrusting.

couple of hundred more from Scotland and other 'disturbed' regions, the majority of which bear marks of pressure, often considerable, sometimes extreme; but most of them testify strongly against any subsequent molecular movement of importance[1]; a few only give some hint of it, and these two specimens are the first in which the evidence seemed to be conclusive.[2]

But when did these changes occur? Do the crushing and reconstruction both date from Tertiary times: are both connected with the rise of the present Alps? Upon their rocks, no doubt, the record of that grand process of mountain-making is writ in letters bold; but may not this be even as a palimpsest, on which full often the earlier characters can still be traced, nay, may remain sometimes almost untouched by the later scribe? Mountains there were on the site of the Alps at the beginning of Mesozoic, even in Palæozoic ages. The fragments in the Triassic rauchwacke, the fragments in the Carboniferous conglomerates alike exhibit, in their cleavage-foliation, a record of earth-movements by which their parent rocks had been already modified. The former at any rate supply materials for comparison.[3] In the rauchwacke of the Val Piora, the Val Canaria, the southern opening of the St. Gothard tunnel, and on the flanks of the Nufenenstock, we find, among other rocks, fragments of a rather peculiar mica-schist (consisting, according to Dr. Grubenmann, chiefly of meroxene and margarite[4]), which also occurs *in situ* close at hand. The specimens from the two sources only differ in this respect, that those from the parent rock show more signs of crushing; they have been once oftener than the others 'through the mill.'[5] It is therefore not improbable that these more important changes are pre-Triassic, even pre-Carboniferous. But, it may be asked, would not the Tertiary earth-movements have again crushed or sheared the rock-masses and so distorted or

[1] Contact-metamorphism is not considered as a cause, though of course it is very favourable to mineral change, because there is nothing in the structure of the rock to suggest it, nor can we connect the change with the possible intrusion of some granitic rocks at no very great distance from one of these localities. Also I do not reckon certain hydrous minerals, or such as calcite, which form readily.

[2] The actinolite-schists from the southern side of the St. Gothard Pass afford the nearest parallels to the rocks now described. The actinolites are irregular in outline, implicate quartz, etc., like that in the groundmass (so also sometimes does the biotite), and are not seldom associated with small flakes of the last mineral, much as described above, as if the biotite either had formed at the expense of the hornblende, or had been compelled, in a simultaneous crystallization, to acknowledge its suzerainty. The garnets also are often cleaved, sometimes broken, occasionally crushed; but the relation of the crystal-building to the mechanical disturbances is not so clear. At the St. Gothard, however, the evidence of the garnets suggests that the amount of shearing has been slight, so the actinolites might represent older crystals, not very different in position.

[3] As it happens, the Carboniferous conglomerates, where I have examined them, have lain among gneisses and schists of a different type from those of the group described in this paper.

[4] The *Disthen-Schiefer* of von Fritsch. The rock is noticed in Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 226–228, where Dr. Grubenmann's exhaustive investigation is quoted.

[5] The enclosed fragments would be saved by the soft friable rauchwacke from suffering much. Their shapes and the position of their structure-planes, lying at all angles in a block of rauchwacke, show that they did not become foliated after being detached from the parent rock.

destroyed larger crystals of earlier date? In many cases undoubtedly they have done so; still, as already said, there is, I think, good evidence that many of the larger mineral constituents in the Alpine schists are of very ancient date and have passed through the Tertiary 'mill' with but little injury. In this, as in every mountain-region, zones of nearly uninjured rocks will be found to alternate with zones where they have been shattered almost beyond recognition.[1] It is accordingly possible that these more important changes must be carried back even to a very remote geological epoch.

To prevent misunderstanding, I wish to add that nothing in this paper is intended as an expression of doubt as to the possibility of such mineral reconstructions as have been described by Prof. Judd[2] and others. I fully believe that not only these have occurred, but also the evidence suggests that pressure has been a chief agent in producing the result. I think, however, that due caution is not always exercised in speculating on the 'flow of solid rocks under pressure.' Experiments, such as those of Spring, valuable and suggestive as they are, do not help us quite so far as is sometimes supposed, for the substances employed were homogeneous, while the crystalline rocks (with which geologists are really concerned) are heterogeneous. These substances also were opaque metals, so that the exact nature of the molecular changes could not be studied under the microscope. Hence it does not follow that if a piece of iron, for example, can be made to 'flow' under pressure, a piece of granite will do the same. The strength of a chain is that of its weakest link, so that, as it seems to me, before such a rock 'flowed' by gradual mineral reconstitution, without visible fracture, one of its constituents would have given way, and the 'flowing' would be that of a powdered mass. We have at present, so far as I know, no evidence to show that foliation, *in a heterogeneous mass already crystalline*, is produced without previous fracture.

In other words, I believe that mineral changes are due to more causes than one. Thus pressures equal in every direction are likely to produce such reconstitutions as the replacement of labradorite by scapolite, of felspar by a mosaic of quartz and white mica, of augite by granular hornblende; but pressure definite in direction, as it seems to me, will lead to crushing or shearing, and so to a foliated structure.[3] The presence of water will undoubtedly facilitate change,

[1] Often this is so conspicuous that, until the right key was found, it was interpreted (very naturally) as an interstratification of granitoid gneiss and fissile mica-schist, or a transition from schist through gneiss to granite.

[2] Min. Mag. vol. viii. (1889) p. 186; Quart. Journ. Geol. Soc vol. xlv. (1889) p. 175; Journ. Chem. Soc. vol. lvii. (1890) p. 404. The second paper contains a number of valuable references to the writings of other workers.

[3] My remarks are restricted to rocks already crystalline. It may be worth mentioning that basic crystalline rocks, after crushing, recrystallize more readily than the acid, and the latter than sediments derived from them. In the Alps one may find in the same fold a hornblendic schist, in which mineral reconstitution has obliterated the *direct* evidence of pressure, a gneissoid rock where this still remains among partially reconstituted minerals, and a detrital rock in which only micromineralogical change has occurred, of which the origin is obvious.

perhaps is essential to it; so also will a high temperature: possibly, when the resulting structure is coarse, it too is no less essential. Altered crystalline rocks, especially crystalline schists, have been produced, unless I err greatly, in more than one way. Nature, in the ages of the past, has worked 'at sundry times and in divers manners.' These perchance we may succeed in distinguishing by means of the careful study of exceptional cases, especially where something is known as to the origin of the rocks.

Discussion.

The President believed that there was every chance of the rocks being twisted in and out as stated; but there was no *a priori* improbability in the occurrence of either garnet or staurolite in Jurassic rocks, or in rocks of any age, provided the necessary materials were there and the conditions suitable.

Mr. Eccles remarked upon the occurrence of two series of hornblendic intrusive rocks in the black-mica schists and gneisses of the Binn district. One series—the older one—is generally interbedded with the surrounding crystalline rocks, and has been subjected to the same pressure-modifications as the latter. The dykes of the other series cut across the foliation-planes of the gneiss and schist, and show no appreciable cleavage. No instance of any dyke had been observed in the schists and Jurassic beds of the Nufenen district by Prof. Bonney or the speaker.

Rev. Edwin Hill, on the third paper, asked if there were any analogy in the crystals which do not disturb fossils, in some fossiliferous rocks—*e. g.* the Schistes d'Angers at Ste. Brigitte, in Britanny.

Mr. Rutley referred to a case in which the schistose banding of a rock had been seen to pass without interruption through crystals of staurolite.

Mr. Teall also spoke.

The Author said, in reply to the President, that what might be theoretically possible he would not venture to affirm, but that, as a matter of fact, no Jurassic rocks in the Alps had authigenous garnets and staurolites, and all rocks with these minerals could be proved to be far earlier than any Mesozoic strata: to Mr. Eccles, that the gneiss near the Hohsandhorn might prove to be a very important rock in relation to the geology of the district. As regards dykes in Mesozoic rocks, he had never seen any, so far as he could remember, in the Central or Western Alps. With reference to Mr. Hill's remarks, he pointed out certain differences between the case of contact-formed minerals and those described in the third paper.

7. Scandinavian Boulders *at* Cromer. By Herr Victor Madsen, of the Danish Geological Survey. (Communicated by J. W. Hulke, Esq., F.R.S., For.Sec.G.S. Read December 21st, 1892.)

During a visit to England in the autumn of 1891, I took the opportunity of making a short excursion to Cromer in order to study the interesting geological facts presented in the well-known cliffs near that village.

On my walks along these cliffs my attention was especially devoted to the boulders which occur there, for I thought it possible to find some which might with certainty be referred to definite localities in Scandinavia. The greater number of the boulders there originate indeed, as I expected, from disturbed portions of the Cretaceous strata which underlie the Drift in the vicinity of Cromer, so that it is only a few of the boulders which are likely to be of Scandinavian origin, and of these again only a small number can be definitely referred to their parent localities.

Among the boulders on the shore a little west of Cromer I succeeded in finding a 'porphyry'-boulder which I supposed had been derived from the south-eastern part of Norway, and this supposition was subsequently confirmed by Herr K. O. Björlykke, of the Norwegian Geological Survey, to whom I showed the boulder and who referred it to the neighbourhood of Christiania.

This boulder measures about $4\frac{1}{2} \times 3\frac{1}{2} \times 2$ inches. The groundmass is rather decomposed and of a grey-violet colour; in it are disseminated crystals of felspar which, on fresh fracture, show the same colour as the groundmass, while those on the surface of the boulder have become somewhat paler by decomposition. The sections of the crystals are fairly rectangular, sometimes rhombic. A large rhombic crystal on the surface of the boulder measured $\frac{3}{4}$ inch in length and $\frac{1}{4}$ inch in breadth, but most of the crystals are $\frac{1}{2}$ inch long and $\frac{1}{4}$ inch broad. Several of them are considerably smaller, *i. e.* about $\frac{1}{8}$ inch in both dimensions.

At Cromer I called on Mr. A. Savin, who gave me permission to examine several hundred boulders which he had collected in the vicinity. Among them I found two which I thought might have come from Dalarne in Sweden, and those Mr. A. Savin was kind enough to make me a present of. They were the only two in the whole collection which were sufficiently characteristic to be unhesitatingly referred to definite localities in Scandinavia.

One of these boulders is a 'porphyry' with greyish-brown groundmass, in which are seen white crystals of felspar whose greater dimensions vary from $\frac{1}{8}$ to $\frac{1}{16}$ inch and less, and greenish, partly decomposed hornblende-crystals of about the same size. It does not contain macroscopically visible quartz. Mr. A. Savin had taken it out of Boulder Clay between Cromer and Overstrand, one mile south-east of the former place. Herr Eugène Svedmark, of the Swedish Geological Survey, to whom I showed it, declared that it corresponded with the most commonly occurring porphyries of Dalarne, as, for example, with the 'porphyry' from Grönklitt in Orsa-socken (a parish in Dalarne). The boulder measures about $2\frac{1}{2} \times \frac{1}{2} \times \frac{3}{4}$ inch.

The other is a quartz-porphyry with greyish-black, felsitic groundmass, in which are disseminated several small, sharp-edged, transparent quartz-crystals (diameter ·02–·01 inch) and reddish felspar-crystals, the largest of which is $\frac{1}{8}$ inch long and $\frac{1}{16}$ inch broad, but the greater number of the felspars measure only $\frac{1}{16}$ inch in every dimension. The appearance of the rock is fresh. The boulder measures about $2\frac{3}{4} \times \frac{3}{4} \times 1$ inch; it also was taken out of Boulder-Clay one mile south-east of Cromer, between that place and Overstrand, by Mr. A. Savin. Herr Eugène Svedmark considered that it might be a felsitic-porphyry from Dalarne.

It being thus demonstrated that boulders of certainly Scandinavian origin are to be found at Cromer, the probability arises that a considerable number of the granitic and gneissic boulders which occur in that district have come from Scandinavia, even if they are not characteristic enough to be referred to definite localities in the Scandinavian area.

Discussion.

Mr. Clement Reid observed that characteristic Scandinavian rocks, such as the 'Rhomben-porphyr' from the neighbourhood of Christiania, certainly were found as erratics on the coast near Cromer. The absence of the specimens described by Herr Madsen made it impossible, however, to test the accuracy of the new identifications.

Mr. J. W. Davis remarked that the Glacial beds of the East Riding of Yorkshire and those of Norfolk were similar in character, and there was no doubt that many of the contained boulders had been derived from the region now covered by the Baltic Sea and Scandinavia. Three years ago Mr. Alfred Harker described a series of typical rocks from the East Riding in the 'Proceedings' of the Yorkshire Geological Society, and had identified a fair proportion as being of Scandinavian derivation. The highly glaciated surface, not only of Sweden and Norway, but of the numerous islands of the Baltic, was undoubtedly the source from which vast quantities of boulders were derived which had been shown by Dr. Torell to have been spread over the plains of Northern Germany, the German Ocean, and the Eastern part of England.

The Rev. P. B. Brodie said that he had collected various rocks from the Drift in Warwickshire, and, though he was not a petrologist, it had occurred to him that some might have come from Norway or Sweden.

Dr. Hicks said that when Dr. Torell visited Finchley with him some years ago, several boulders obtained from the Drift there were recognized by Dr. Torell as being identical with Scandinavian rocks;

and it seems reasonable to suppose that they may have been transported from that area.

Mr. Marr also spoke.

The Chairman (Prof. Judd), in closing the discussion, expressed regret that the Fellows had had no opportunity of examining the specimens referred to by the Author, as none of them seemed to have a very distinctive petrographical character, and their identification with the rocks of any particular locality must therefore be a matter of opinion.

8. *The* Marls *and* Clays *of the* Maltese Islands. By John H. Cooke, Esq., B.Sc., F.G.S. (Read November 23rd, 1892.)

I. Introduction.

In the year 1843 the late Admiral Spratt published a brief notice on the above subject, and a few years afterwards the late Prof. Gulia and Capt. Hutton[1] alluded to the Marls and Clays in their sketches of Maltese geology. The late Prof. Leith Adams published in 1870 a short account of them in his 'Notes of a Naturalist,' but the amount of information that he gives as to the nature of the beds and of their fossil contents is neither very extensive nor very exact. In 1874 the Islands were visited by Thos. Fuchs, of the Imperial Geological Museum of Vienna, and by him the first attempt was made to correlate the Maltese formations with those of Central Europe. In the first of the two pamphlets on the subject that he published he tells us that he was inclined to consider the Maltese Marls as being analogous to the 'Badner Tegel' of the Vienna Basin; but two years later, after having examined the marls of Bologna and compared their fossil contents with those of the Maltese beds, he changed his opinion and referred them to the Austrian Schlier. In 1889–90 Dr. John Murray, of Edinburgh, visited the Islands; and in the paper[2] which was published on his return to Scotland he gave the first detailed account that had so far appeared of the nature and constitution of the Maltese rocks. His descriptions were, however, exclusively lithological; and, excepting the list of 122 species of foraminifera which is appended to the report on the Maltese Marls, no information is given either as to the stratigraphy or palæontology of this particular formation.

Before Dr. Murray's arrival I had already devoted a considerable amount of attention to the Marls and Clays; and owing to the kind encouragement which I received from him I continued my investigations after his departure, with the result that I have been able to add largely to our knowledge of the fossil fauna and to gather together a number of important facts bearing on the geological history of the Maltese Islands. I am under great obligations to Prof. Capellini and Dr. Simonelli for the interest they have shown in my work and for the valuable assistance they have rendered me in determining the organic remains found in the strata.

[1] See Geol. Mag. for 1866, pp. 145–152, pls. viii. & ix.

[2] 'The Maltese Islands, with special reference to their Geological Structure,' Scot. Geogr. Mag. vol. vi. (1890) p. 449.

I now append a chronological list of the published notices and memoirs having reference to this subject:—

1843. Spratt, T. 'On the Geology of the Maltese Islands.' Proc. Geol. Soc. vol. iv. p. 225.

1860. Gulia, G. 'Geologist' (Notes and Queries) for 1860, p. 421.

1864. Adams, A. L. 'Outline of the Geology of the Maltese Islands.' Ann. & Mag. Nat. Hist. ser. 3, vol. xiv. p. 1.

1866. Hutton, F. W. 'Sketch of the Physical Geology of the Island of Malta.' Geol. Mag. for 1866, p. 145.

1870. Adams, A. L. 'Notes of a Naturalist in the Nile Valley and Malta.' Edinburgh.

1874. Fuchs, Th. 'Das Alter der Tertiärschichten von Malta.' Sitzungsber. d. k. k. Akad. der Wissensch. Wien, vol. lxx. p. 92.

1876. Fuchs, Th. 'Ueber den sogenannten Badner Tegel auf Malta.' Sitzungsber. d. k. k. Akad. d. Wissensch. Wien, vol. lxxiii. p. 67.

1879. Adams, A. L. 'On Remains of *Mastodon* and other Vertebrata of the Miocene Beds of the Maltese Islands.' Quart. Journ. Geol. Soc. vol. xxxv. pp. 517–530.

1890. Murray, John. 'The Maltese Islands, with special reference to their Geological Structure.' Scot. Geogr. Mag. vol. vi. p. 449.

1891. Cooke, J. H. 'Notes on the Pleistocene Beds of Gozo.' Geol. Mag. for 1891, p. 348.

1891. Gregory, J. W. 'The Maltese Fossil Echinoidea and their Evidence on the Correlation of the Maltese Rocks.' Trans. Roy. Soc. Edin. vol. xxxvi. p. 585.

II. Physical Features and General Distribution of the Strata.

The Maltese Marls and Clays occupy the third place both in the ascending and in the descending order of the Maltese formations. The table facing this page shows the order in which the beds occur, as well as the relation that they bear to the continental deposits.

The formation known as the 'Clays' consists of marls and clays varying considerably in their lithological characters as well as in their distribution. It lies conformably between the *Globigerina*-limestone and a greensand formation, but so obscure is the line of demarcation between it and the *Globigerina*-limestone, and so striking are the resemblances of the fossil fauna of each, that we seem to be justified in considering the Clay as being merely an argillaceous division of the formation upon which it rests.

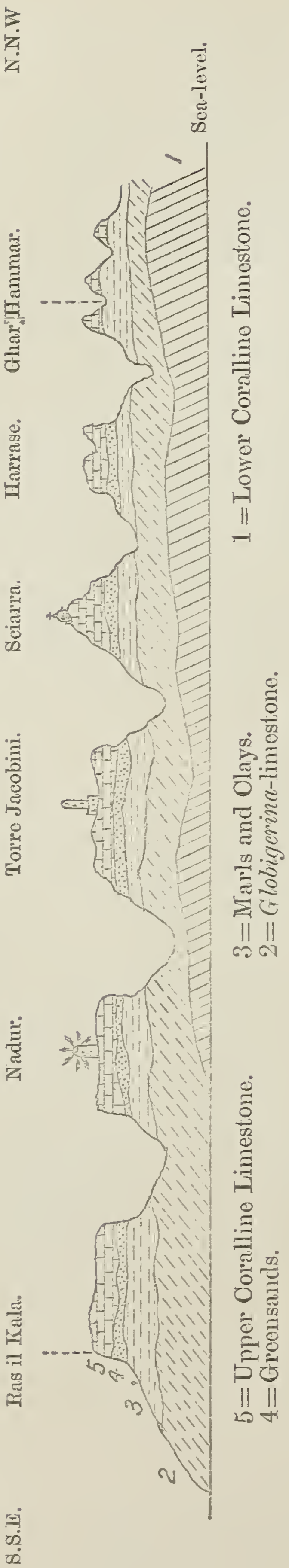
In Malta the formation is developed only in the northern and north-western districts, where it extends over about one third of the total area of the island. But in Gozo, where the forces of denudation have been more actively at work, it is so scattered among the hills and plateaux that its aggregated area would not amount to more than one fourth of that of the island in which it occurs (see fig. 1, p. 120).

In common with all the beds of the Maltese group this formation has been, then, extensively denuded. The remnants of the Clays that occur in the Dueira Valley, in Gozo, and in the caves, fissures, gorges, and valleys of both islands, show that at one time the formation probably extended much farther than it does at present.

Tabular Summary of the Maltese Rocks and their Equivalents in the Vienna Basin.

The Maltese Islands.				Vienna Basin.		
No.	Formation.	Thickness.	Subdivisions.		Series.	
5.	Upper Coralline Limestone	250 feet.	*a.* Compact white Limestone, of a breccia-like texture. *b.* Soft, porous, red Limestone.	Leithakalk.	Tortonian.	Miocene.
4.	Greensands	50 feet.	*a.* Compact yellow Sandstone. *b.* Friable black Sandstone.	Grunder Schichten.	Helvetian.	
3.	Clays	30 feet.	*a.* Yellow Clay. *b.* Blue Clay and Marl.	Schlier.	Langhian.	
2.	*Globigerina*-limestone	200 feet.	*a.* Upper *Globigerina*-limestone (variously coloured beds of freestone, inter-stratified with from three to six nodule-bands). *b.* Lower *Globigerina*-limestone.	Horner Schichten.		
1.	Lower Coralline Limestone	500 feet ?	*a.* Semi-crystalline Limestone. *b.* Non-crystalline Limestone.	Solszka Schichten.	Aquitanian.	Oligocene.

Fig. 1.—*Diagrammatic Section across Gozo.*



In the western part of Malta the Clays crop out from the sides of the plateaux and along the valleys of the Binjemmas; indeed, but for the numerous parallel faults that intersect this part of Malta and the eastern half of Gozo, the Clays would form a continuous bed extending from Gebel Ciantar in the south-east of Malta to Giurdan in the north of Gozo. These faults have broken the continuity of the bed and have caused many parts of it to descend to lower levels. At St. Paul's Bay the outcrop of the Clays is 150 feet lower than is that which occurs at the western extremity of the Great Fault of Malta; and in Melleha Valley the strata between the two faults that form the boundaries of the bay have been let down to such an extent as to completely submerge, not only the Clays, but also the beds that lie above them. These faults and the sections in the shafts at Boschetto and Gomerino, the road-sections at Gebel Imtarfa, and the outcrops at Chelmus, Madonna della Kala, Ghain Toffiha, Chambray, and Giurdan are the places that are best adapted for studying the formation.

The surface-contour of Gozo is more diversified than that of Malta (see fig. 1), and with the exception of the depressed area which lies to the south of the Gozo Great Fault (fig. 2) the strata preserve a more uniform horizontality than they do in the sister isle. In both islands the Clays are usually overlain by the Greensands; but to this order there are several well-marked exceptions. At Ghain Toffiha, in the north-west of Malta, the Clays are overlain by the Upper Coralline Limestone (bed 5), the Greensands being entirely absent, and at Boschetto, Nadur, and Gebel Ciantar the same order is to be observed (see fig. 3). In Gozo the Clays invariably occupy their normal position between beds 4 and 2, except at Chambray, Dueira, and Marsa-el-forno, where the complete denudation of the Upper Coralline Limestone and of the Greensands has left the Clays exposed as the surface-deposit. Similar surface-exposures are to be observed in Malta at Karraba (fig. 3) and Melleha. The thickness of the Clays has been variously estimated. Both Hutton[1] and Adams[2] considered that

Fig. 2.—*Section showing the effect of Gozo Great Fault.*

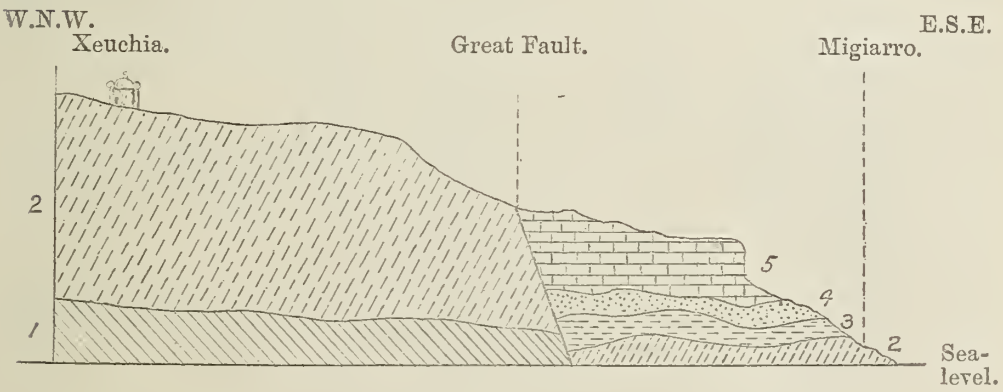
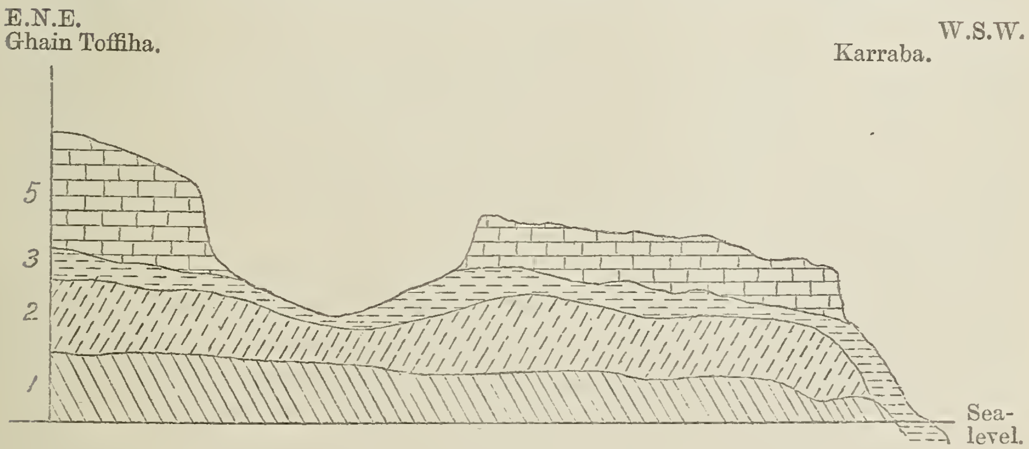


Fig. 3.—*Section from Ghain Toffiha to Karraba (Malta).*



[For explanatory Index, see fig. 1, p. 120.]

this formation attained a maximum thickness of 100 feet and more, while Dr. John Murray says that it "probably rarely exceeds 20 feet." The result of the numerous measurements that I have made of the outcrops, of the cliff-sections, and of the sections in the well-shafts in the Binjemmas, proves that the latter estimate is much nearer the truth than the former. The following table of

[1] 'Sketch of the Physical Geology of Malta,' Geol. Mag. for 1866, p. 145.
[2] Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 519.

measurements will show the extent to which the thickness varies in different parts of the Islands:—

No.	Locality.	Thickness.	Remarks.
1.	Ghain Toffiha, Malta.	about 50 feet.	These localities are in a line running due N.E. and S.W.
2.	Chambray, Gozo.	„ 30 „	
3.	Ras-el-Kammieh, Gozo.	„ 50 „	
4.	Xaghra Hill, „	„ 40 „	
5.	Dabreni, „	„ 40 „	
6.	Chelmus, „	„ 40 „	These localities lie west of the above mentioned line.
7.	Dueira, „	„ 20 „	
8.	Giurdan, „	„ 40 „	
9.	Ghar Ilma, „	„ 40 „	
10.	Gebel Ciantar, Malta.	„ 15 „	These localities are in a line running N.E. and S.W.
11.	Boschetto Valley, „	„ 25 „	
12.	Città Vecchia, „	„ 20 „	
13.	Gebel Imtarfa, „	„ 14 „	
14.	Ta Binjemma, „	„ 15 „	
15.	Wardia, „	„ 20 „	
16.	Selmone, „	from 10 to 20 feet.	
17.	Dingli, „	„ 6 to 10 „	These localities lie west of the above mentioned line.
18.	Gomerino, „	about 22 feet.	
19.	Fom-ir-rieh, „	„ 3 „	

The pressure of the overlying strata upon the plastic Clays has caused the original thickness of the formation to be much diminished in many parts of both islands, but especially so in the smaller plateaux and in the isolated hills; while in other localities the taluses that have been formed at the outcrops have, by cloaking the hillsides and cliff-sections, caused the thickness of the Clays to appear to be double and even treble of what it really is. It is to these extensive taluses that the many exaggerated estimates of the thickness of the formation are due.

Great caution is needed in determining where the lower horizon of the Clays is situated, as no little experience is necessary to be able to distinguish between the transition-bed of the Marls and Clays and the bands of argillaceous blue limestone which are distributed at various levels throughout the *Globigerina*-rock.

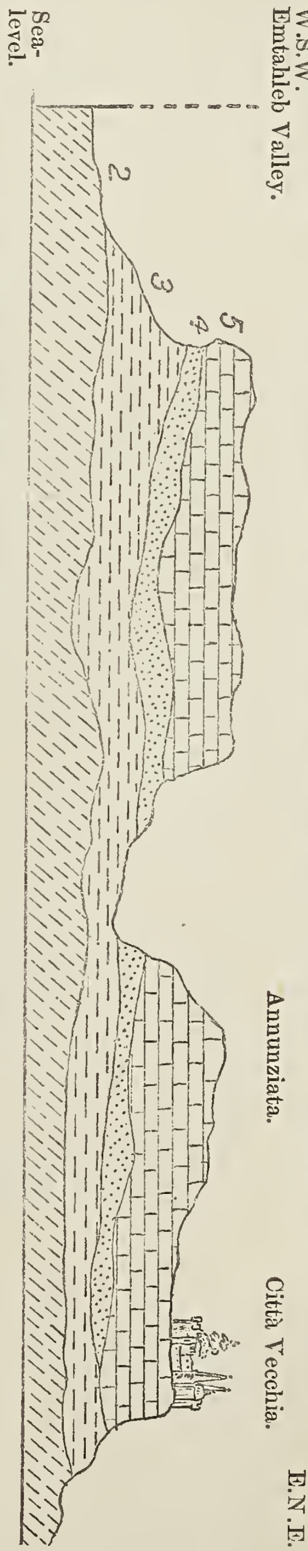
The most accurate measurements are those that were obtained in the well-shafts, and in the sections that were cut by the Engineer Corps at Gebel Imtarfa during the construction of the new road. The extreme thinning-out that the above measurements indicate is in every case due to local depressions. If a line be drawn from Gebel Ciantar to Selmone it will pass through the localities in which the Clays are most attenuated. This attenuation is apparently due to the north-east-by-east dip, which the strata have from the Great Fault to the eastern extremity of Malta. The pressure of the superincumbent strata on the Clays is therefore the greatest in that direction, with the result that the Clays have been compressed and thinned out at the outcrops on the east and north-east. In the shafts that have been cut in the Boschetto and Gomerino Valleys the Clays just exceed 20 feet in thickness, whereas at the eastern extremities of these valleys and of others situated along the same line the thickness barely exceeds 10 feet (see fig. 4). The strata lying between the northern side of the Great Fault and the fault which bounds the southern side of St. Paul's Bay dip in an easterly direction, so that the thickest part of the Clays is found on the western side at Ghain Toffiha and Karraba, and the most attenuated along the western boundary of the Nasciar Plain.

In Gozo the thickness of the formation is not so variable, owing to the comparative absence of faults and the more uniform horizontality of the strata. At Fort Chambray, and along the shores of the bay at its foot, the Clay outcrop varies from 30 to 40 feet in thickness; but the taluses that have been formed along the slopes make the formation appear to be at least 120 feet thick. At a distance of $\frac{1}{4}$ mile east of Chambray a vertical section shows the Clays to be only 10 feet thick; this thinning-out is also attributable to the marked southerly dip of the overlying strata. In the isolated hills and the smaller plateaux this dependence of the thickness of the Clay-formation upon the dip of the beds that overlie it is still more strikingly shown.

At Ghain Toffiha, in Malta, a huge mass of rock, having an area of about 100 acres, has been detached from the cliffs, and has fallen so as to dip towards the cliff of which it was formerly a part. The Clay-bed has been dislocated, and while on the shore side it shows a thickness of 20 feet, at the point of dislocation the bed has been thinned out to a few inches.

But it is not only along the outcrops that these differences in thickness occur. The formation is overlain conformably by the Greensands, the line of demarcation between the two being as a rule well defined; but in some localities the transition is shown, by the admixture of the Clay and Greensand, to be of a very

Fig. 4.—*Diagrammatic Section from the Emtahleb Valley to Città Vecchia (Malta).*



5 = Upper Coralline Limestone. 3 = Marls and Clays.
4 = Greensands. 2 = *Globigerina*-limestone.

gradual character. This line of separation is by no means uniformly horizontal, and it takes an undulatory form. Both the Clays and the Greensands, therefore, vary greatly in their thickness, and it often happens, as at Dingli, where the Greensands are 50 feet and the Clays only 6 or 10 feet thick, that the maximum development of the Greensands is accompanied by a minimum thickness of the Clays. This undulatory surface of the Clays forms a series of natural reservoirs in which the rains of winter are stored, and it is from these that the population of the Islands derive their water-supply.

III. Lithological and Mineralogical Characters of the Strata.

A microscopic examination of numerous sections that had been taken from various horizons[1] of the Clay-formation revealed the general structure of the rock, and showed it to consist of tests of foraminifera and minute fragments of minerals, the most numerous of which were oxide of iron and glauconite. Rounded grains of quartz, augite, hornblende, felspars, zircon, and tourmaline[2] were also present in comparative abundance in every part of the Clay, but more especially so in the upper portions near the junction with the Greensands.

Sulphate of lime in the form of selenite occurs also in considerable quantities. It is generally found in the Clay in isolated masses of varying size and shape, or in aggregations of small crystals that have grown round organic remains: these crystalline masses usually present a very lamellar or fibrous appearance. As a fertilizing agent their advantages are fully appreciated by the Maltese agriculturist, and it is partly to the abundance of selenite in the Marls and Clays that Malta and Gozo owe their luxuriant crops of clover and cereals.

A characteristic of the upper portions of the Clay-formation is the presence of yellow, ochreous nodules of clay, the majority of which are ovoid or subspherical in shape: they are generally much flattened above and below. When these nodules are split along their bedding-planes the perforations of *Pholades* are revealed, and often the casts of the *Pholades* themselves are found within. Similar nodules, consisting of indurated blue clay, are equally abundant in the lower divisions of the Clay. In both varieties the laminæ show distinct evidences of stratification, and they always occur lying parallel to the flattened surfaces of the nodules.

Prof. Leith Adams alludes to these nodules as being derivative[3];

[1] Besides the many slides that I prepared myself, I was enabled, through the courtesy of Dr. John Murray, to examine the numerous sections which he had caused to be prepared, and which he subsequently described.

[2] Dr. John Murray, 'The Maltese Islands, etc.,' Scot. Geogr. Mag. vol. vi. (1890) p. 449.

[3] Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 519; and 'Notes of a Naturalist in the Nile Valley and Malta,' Edinburgh, 1870, p. 131.

but, considering the nature of the clay of which they are composed and the contained foraminifera, it is more probable that many of them at any rate are indigenous to the formation in which they are found, and that they owe their origin to concretionary action due to the mutual attraction of the clay-particles one for the other. In connexion with this point it is important to note that the chemical composition and the mineralogical constitution, as well as the fossil contents of the nodules, are similar in every respect to that of the Clay in which the nodules occur.

According to the chemical analyses made by Dr. John Murray,[1] the different bands of the Clay vary greatly in their composition. These analyses I have repeated, and from them it is demonstrable that the proportion of calcium carbonate in the yellow and the dark blue clays ranges from 6 to 10 per cent., in the light blue varieties from 22 to 40 per cent., and in those parts where the Clays graduate into the underlying *Globigerina*-limestone as much as 67 per cent. of calcium carbonate has been detected. This carbonate is made up for the most part of the tests of foraminifera and the discs of coccoliths, coccospheres, and rhabdoliths.

Small quantities of phosphoric acid and traces of magnesia were also found by Dr. Murray in several specimens of Clay from Gozo. The magnesia is more distinctly perceptible in the rock of the upper horizon immediately beneath the Greensands, a fact which I am inclined to think may be due to the decomposition of glauconite (silicate of iron and magnesia), a mineral which occurs very plentifully in the Greensands.

The following table shows the extent of the quantitative variations of the several components of the rock:—

Carbonate of lime	2 to 67 per cent.
Sulphate of lime	4 to 30 ,,
Carbonate of magnesia	faint traces to distinct traces.
Phosphate of lime	traces to 2 per cent.
Alumina	25 to 58 per cent.
Oxides of iron	4 to 10 ,,
Residue insoluble in dilute hydrochloric acid	3 to 10 ,,

The uppermost Clays are very compact and impermeable: they therefore form the water-bearing stratum of the Islands.

IV. The Organic Remains.

Organic remains are well represented in the Clays, both generically and specifically, but they are not equally abundant in every part of that formation. Prof. Leith Adams,[2] alluding to this subject, expressed an opinion that the fossils in the Clays are as numerous as those in the overlying and underlying rocks; but with this conclusion I cannot agree, for, despite the large number of genera and species, the number of individuals falls far short of that contained in any other of the Maltese formations.

[1] 'The Maltese Islands, etc.,' Scot. Geogr. Mag. vol. vi. (1890) p. 449.
[2] Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 519 *et seq.*

The organic remains which occur in both the yellow and the blue clays are, as a rule, completely mineralized, their substance being replaced by peroxide of iron. It was on this account that so large a proportion of the fossils which I submitted to Prof. Capellini for identification were pronounced to be unrecognizable.

The most characteristic fossils of the formation are the 'sepiostaires' of a *Sepia*, the casts of several species of Nautilidæ, and the shells of *Pecten Koheni*, all of which are very numerous.

Several species of echinoderms occur, none of which are peculiar to the Clays, for they are also found in the nodule-beds of the underlying *Globigerina*-limestone.

The mollusca, the majority of which are in the form of casts, are represented by 47 species. The very incomplete state of our present knowledge of the *Globigerina*-limestone fossils will not admit of trustworthy comparisons being drawn between them and the Clay mollusca. I am, however, now at work on that formation, and it may be worth while to note here that the general facies of the fossils of the Clays has very much more in common with the *Globigerina*-limestone fossils than with those of the Greensands. The Pectinidæ of the Clays and the Greensands were critically examined by Dr. Simonelli, of Bologna, and of the six species found in the former bed all, with the exception of *P. Koheni*, occur in the *Globigerina*-limestone, whereas *P. dubius* and *P. Reussi* were the only species found to be common to the Clays and Greensands. *P. denudatus* is very abundant both in the *Globigerina*-limestone and in the Clays.

The more calcareous parts of the Clays are made up almost entirely of foraminifera. Dr. John Murray enumerates 122 species in his paper, but to this number I have been able to add, with the assistance of Mr. E. A. Earland, 31 more, the names of which are appended (p. 128). The blue varieties of the Clays appear to be the richest in foraminifera, and they are generally in a good state of preservation. Where, however, the Clays are overlain by the Greensands, large patches composed almost entirely of foraminifera extend to depths varying from 6 to 18 inches into the Clay, thus presenting the appearance of pockets. The most numerous species found in these 'pockets' are small *Globigerinæ* associated with *Truncatulina lobatula*. Of the foraminifera found in the *Globigerina*-limestone 94 per cent. also occur in the Clays; but of those found in the Greensands only 37 per cent. are common to the Clays.

Fish-remains are not very abundant, and those that do occur are so badly preserved as to be scarcely recognizable. Teeth and vertebræ of sharks are fairly common; teeth of *Chrysophrys* are rare; and teeth and spines of *Ætobatis*, *Myliobatis*, and *Diodon* are occasionally met with. Large-sized fragments of bones of whales, dugongs, and other mammals are very abundant, but are badly preserved.

List of the 'Clay' Fossils.

Mammalia.

Vertebræ and bones of whales, dolphins, dugongs, and manatees, sp. indet.; and jaws and teeth of *Phoca rugosidens*, Owen.

Pisces.

Carcharodon megalodon. }
Oxyrhina, sp. } Teeth and vertebræ very common.
Lamna, sp. }
Ætobatis, sp. } Teeth and spines common.
Myliobatis, sp. }
Diodon Scillæ. One tooth from Chambray, Gozo.
Chrysophrys. Teeth only, rare.
Vertebræ, sp. indet. Very common.

Cephalopoda.

Aturia Aturi, Bast. This is one of the commonest fossils of the Clays, and of the Upper *Globigerina*-limestone.
Sepia, sp. See Fuchs, 'Ueber den sogennanten Badner Tegel auf Malta.'

Pteropoda.

Vaginella depressa, Daudin. (Very common in the Clays.)
Hyalæa. (Casts only.)

Solenoconchæ.

Dentalium, sp. indet. (Casts.)

Gasteropoda.

Dolichotoma cataphracta, Brocchi.
—— *ramosa*, Basterot.
——, 2 sp. indet.
Murex vaginatus, Jan.
——, sp. indet.
Mitra, sp. indet.
Nassa granularis, Borson.
—— *exsculpata*, Bischof.
——, sp. indet.
Cassis, sp. indet.
Xenophora cumulans, Brongt., sp.
—— *testigera*, Bronn.
Natica, sp. indet.
Scalaria melitensis, Fuchs.—This pretty little shell was first figured and described by Fuchs. It is rare and averages only 20 mm. ($\frac{4}{5}$ inch) in length, and from 6 to 8 mm. ($\frac{1}{3}$ inch) in breadth.
Scalaria, nov. sp.
Trochus, sp. indet.
Dolium, sp. indet.
Volutilithes, sp.
Conus melitensis, de Gregorio.
Solarium, sp.
Cypræa, sp.
Rostellaria, sp.
(The 8 last-named are casts.)
Chenopus pes-pelicani, Philippi.

Lamellibranchiata.

Ostrea Bobylayei.
—— *tenuiplicata*.
Anomia costata.
Pecten Koheni, Fuchs. (Figured and described by Fuchs.)
—— *dubius*, Wood.
—— *Reussi*, Hörn.
—— *denudatus*, Reuss.
——, sp. indet.
Spondylus crassicosta, Lam.
Nucula, 2 sp. indet. (Casts.)
Lucina sinuosa, Don.
Tellina, sp. indet.
Cardita, sp. indet.
Corbula gibba, Olivé.
Clavagella, sp.? comp. *C. oblita*, Michelotti.
Leda pellucida, Phil.
—— *fragilis*, Chenu.
Neæra, comp. *cuspidata*, Olivé.
Astarte, nov. sp.
Nucula, sp. indet. (Casts.)
Isocardia, sp. indet. (Casts.)
Pholas, sp.
Marginella Deshayesi, Michelotti.

Brachiopoda.

Treebratula sinuosa, Bast. One specimen from Gebel Imtarfa.

Echinodermata.

Echinolampas Hayesianus, Desm.
Schizaster Desori, Wright.
—— *Parkinsoni*, Defrance.
Euspatangus de Konincki, Wright.
Spatangoidea, sp. indet.
Cidaris, spines.
Pentacrinus Gastaldi, Michelotti.

(All these are common to every horizon, but rare in the upper ones.)

Anthozoa.

Ceratotrochus, sp. indet. Common.
Flabellum Fuchsii. Common.

Foraminifera.

To the 122 species contained in Dr. John Murray's list, the following 31 should be added:—

Miliolina agglutinans, d'Orb.
—— *Auberiana*, d'Orb.
Textularia carinata, d'Orb.
—— *rugosa*, Reuss.
Bulimina aculeata, d'Orb.
Lagena marginata, W. & B.
Nodosaria consobrina, d'Orb.
Lingulina costata, d'Orb.
Marginulina Behmi, Reuss.
——, sp.
Vaginulina margaritifera, Batsch.
—— *Bruckenthali*, Neugeb.
—— *legumen*, Linn.
—— *reticulata*, Cornuel.
Frondicularia interrupta, Karrer.
——, 3 sp. indet.
Cristellaria convergens, Bornem.
—— *variabilis*, Reuss.
—— *radiata*, Bornem.
—— *Kubingii*, Hantken.
—— *cassis*, F. & M.
Polymorphina communis, d'Orb.
Sagrina Raphanus, P. & J.
Planorbulina mediterranensis (var.?), d'Orb.
Truncatulina lobatula, W. & J.
Nonionina umbilicatula, Montagu.
Polystomella crispa, Linn.
Nodosaria soluta, Reuss.
Orbitolites complanata, Lamarck.

9. *The* PETROGRAPHY *of the* ISLAND *of* CAPRAJA. By HAMILTON EMMONS, Esq. (Communicated by Sir ARCHIBALD GEIKIE, D.Sc., LL.D., For.Sec.R.S., F.G.S. Read January 11th, 1893.)

CONTENTS.

1. TOPOGRAPHY OF THE ISLAND.

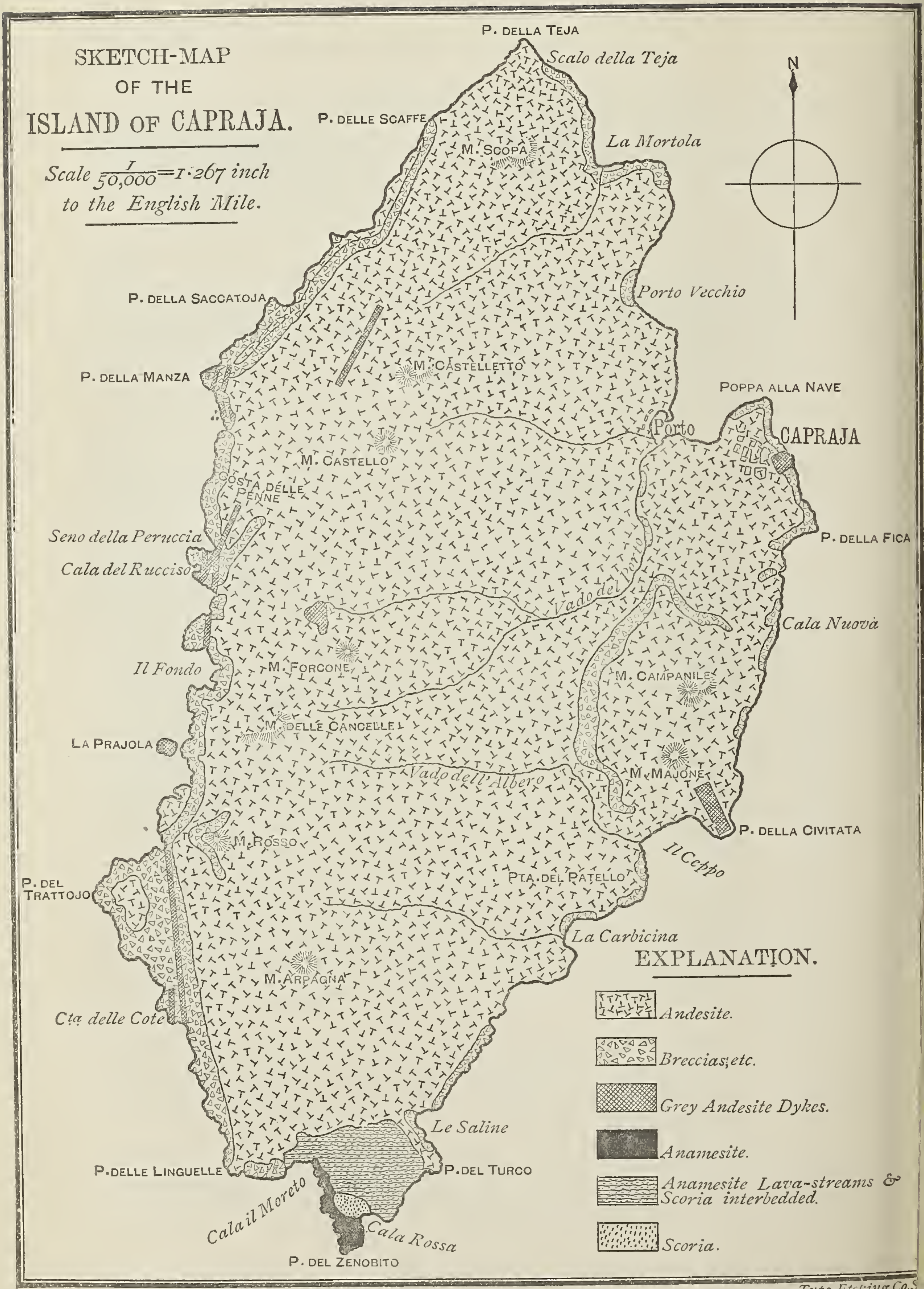
THE Island of Capraja, situated 43° 2′ 35″ lat. N. and 9° 50′ 45″ long. E. of Greenwich, according to the Admiralty chart, constitutes one of the northernmost members of the Tuscan Archipelago. From it on a clear day the observer can easily see the Island of Elba to the south-east, Monte Cristo and Pianosa to the south, Corsica to the south-west, and Gorgona to the north, besides a long stretch of Apennines ranging east and north-east.

The island is roughly oval; its longest axis, lying almost north and south, measures, according to the Italian Ordnance Map, 8 kilometres (5 miles); and from east to west nearly 4 kilometres ($2\frac{1}{2}$ miles) in the broadest parts. A chain of hills, ranging in height from 350 to 450 metres (1150 to 1475 feet), traverses its entire length; the eastern slopes of these hills fall away gradually, while the western plunge abruptly to the sea, often in precipitous cliffs, or deep ravines, exposing the structure of the island remarkably well. The east coast also is bounded by a line of cliffs; and these, though generally much lower than the western cliffs, offer equal facilities for study. Only at one point on this side of the island do they reach a height comparable with the cliffs on the west, *i. e.* beneath the twin hills of Monte Campanile and Monte Majone.

Inland, the slopes are everywhere cut into by little valleys, which present a chequered colouring of green and grey, due to the weathered boulders of andesite standing out above the stunted, broom-like vegetation.[1]

In general terms the island may be said to consist of a number of andesitic outflows, resting on andesitic breccias and agglomerates. The latter doubtless owe their origin to the eruption from which the main mass of andesite subsequently sprang.

[1] Except for a few garden-patches around the town of Capraja, and a few vineyards in the Penal Settlement at the northern end, the island is devoid of cultivation.



Typo. Etching Co. S

The accompanying map indicates roughly the results of my geological observations during a three weeks' stay on the island in the year 1892, but is not put forth as complete. The short time at my disposal rendered it impossible to follow out in detail every andesitic outflow, or to trace all the dykes with which the western coast in particular is seamed. The main object of my visit was petrographical; and I must leave the special geological details to some future observer who may have more time at his command.

I may remark here that I have purposely omitted a number of small patches of breccia inland: in a map on this scale they would hardly appear so large as a pin's head, and their insertion would in all probability only tend to create confusion.

2. Geological Features of the Island.

Without entering into a detailed description of the geology of Capraja, it will perhaps be advisable to mention some of its most interesting features—and firstly the southern end. Here seems to have been situated a distinct centre of volcanic activity, whose products are younger in age and more basic in character than the rest of the Caprajan rocks. Its various phases may be briefly summarized as follows:—

(*a*) Breccias, which in Cala il Moreto seem to rest unconformably on the northern breccias (the strata are inclined at about 45° from the vertical at the line of contact).

(*b*) One or two lava-streams of anamesite.

(*c*) Highly scoriaceous ejectamenta; these in Cala Rossa are piled up in such a way as to give the impression that here was a small cone or parasitical crater.

(*d*) More than forty thin lava-streams; each one separated from the other by a few inches of scoriæ similar to those of phase (*c*).

(*e*) A mass of anamesite, which has forced its way up, cutting through the cone, and sending out apophyses into the lava-streams.

It is worthy of note that these lava-streams everywhere lie horizontally, even when in contact with the cone. This would seem to indicate that they must have flowed from a distance. They cannot have issued from the same vent as the scoriæ; for otherwise there would be more evidence of interbedding than is the case, and the lava-streams would have the same inclination as the beds of scoriæ. From the fact that the lava-streams seem thicker in Cala il Moreto than in Cala Rossa I am inclined to locate this vent to the westward.

The unconformity above mentioned in Cala Rossa proves that the southern breccias are younger than the northern. Absolute proof that they are also younger than the andesite is wanting; we have, however, evidence of a less positive character. There are a number of faults at this end of the island, whose upthrows lie to the south. If, as is reasonable to suppose, this upheaval of the southern end was caused by the formation of the cone or outburst of anamesite, then we must also conclude the latter to be younger

K 2

than the andesite, for the faults run through breccia and andesite alike, proving them to have been *in situ* when the southern eruption took place.

No evidence could be gathered regarding the relative ages of the anamesite and the andesite-dykes of the western coast, because nowhere do they come in contact with each other. From a chemical point of view such evidence would have been particularly interesting.

The next feature of interest is a stretch of about 1 kilometre ($\frac{3}{4}$ mile) on the western coast, including the Seno della Peruccia and Cala del Rucciso. Here the breccia and overlying andesite have been pierced by dykes of grey andesite,[1] the salbands of which have developed a columnar structure perpendicular to the walls of the dyke. These salbands also offer greater resistance to weathering than the centre of the dyke, a circumstance undoubtedly due to the larger quantity of porphyritic constituents in the latter.

In Rucciso Bay we have three dykes. The main dyke, starting opposite the Scoglio del Rucciso, cuts through the headland and reappears in the Seno della Peruccia. Thence it is easily traceable with the naked eye, thanks to its salband-columns, up over the ridge of Le Penne in a north-north-easterly direction. Measured with a clinometer, from the boat, it seems to strike N.N.E. and S.S.W., and to have a dip of 58° to the N.N.W.

The second dyke, which I consider to be an offshoot of the larger one, strikes almost due north-and-south, and dips 40° E. It is first easily visible on the northern side of Rucciso Bay; appears again on the southern side; and, cutting through the headland of Il Fondo, reappears for the last time in the angle of Il Fondo Bay. The third dyke starts in the northern indentation of Rucciso Bay, and is traceable a short distance inland in an east-south-easterly direction. A small apophysis is visible, high up in the cliff, near by.

Following the coast northward from here for about 1 kilometre ($\frac{3}{4}$ mile) along cliffs consisting mostly of breccia, we come to a little bay bounded on the north by Punta della Manza. Here again we meet with two dykes of grey andesite in the breccia, besides other masses of the same rock in different parts of the bay. The first dyke runs northward through the headland and appears in the angle on the other side, but seems to go no farther. It resembles very closely, both in the direction of its course and angle of inclination, the second dyke already described in Rucciso Bay.

The second Punta della Manza dyke, situated a little to the eastward of the first, is traceable only a short distance inland. The two islets and the masses opposite them on the shore may belong to a third dyke; petrographically, at any rate, they belong to these dykes, and not to the original andesite-eruptions.

From Punta della Manza the coast bends slightly eastward, showing sections of breccia with thin beds and injected masses of andesite. On reaching Cala della Saccatoja we come upon a fine example of complex faulting on a miniature scale. The bluff con-

[1] In order to distinguish the massive andesite of the island from the andesite-dykes, which are younger, I shall call the latter 'grey' andesite, as that colour is macroscopically its chief characteristic.

sists of alternating breccias and andesites, with a small dyke of grey andesite near the headland. It is interesting to notice that the inclination of the main fault-lines here coincides appreciably, not only with the small dyke at this point, but also with most of the other dykes along the western coast. And it is not improbable that these dykes—which are petrographically so similar—all owe their origin to the same period, viz. that of the development of the plane of weakness corresponding with the faults.

From Punta della Saccatoja all round the northern coast as far the harbour of Capraja, there is perhaps less to arrest the attention of the geologist. Thick masses of andesite rest on breccia, or project into the sea. Apophyses and ramifications of andesite have forced their way into the breccia; and in places the latter has been eaten into by the waves, forming caverns. Worthy of notice are the thin bands and patches of bright-red and yellow tuff which occur sporadically between the andesite and the breccia. One band runs uninterruptedly from La Mortola to Scalo della Teja, and another along the coast by Punta delle Scaffe. Other patches may be found just south of Punta della Fica, and under Mounts Campanile and Majone.

The profile sketched on the following page will suffice to give an idea of the geological structure of the eastern coast, southwards from the harbour of Capraja as far as Cala Rossa.

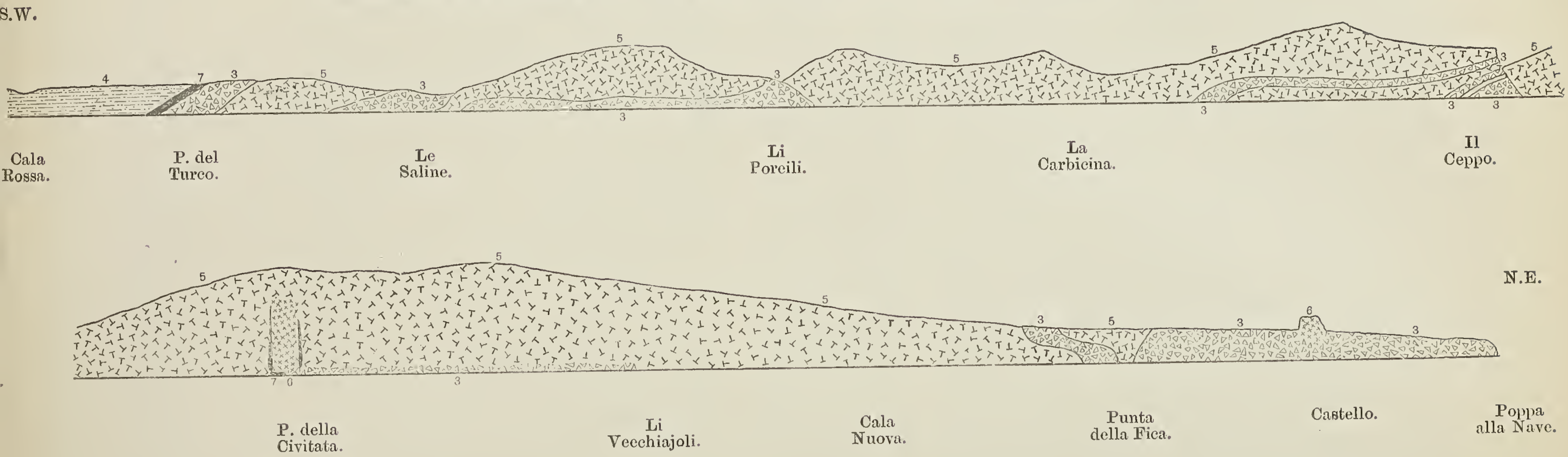
As to the field geology inland, there is not very much to be said. Almost everywhere andesite may be found, and in the valley-bottoms are seen patches of the underlying breccia, especially in the Vado del Porto.

Except for what may be called a small parasitical cone at Punta del Zenobito, as before mentioned, there are no traces of any centre of volcanic activity to be found on the island. An 'extinct crater' is marked on the Admiralty chart; but there is no confirmatory evidence to be gathered on the spot. I suspect that the so-called 'crater' is merely the saddle between the peaks of Monte delle Cancelle and Monte Forcone. The rocks here are as compact as anywhere on the island; that would hardly be the case if we were dealing with an extinct crater. The fact that the underlying breccias at the northern end of the island dip northward and appear to strike eastward, while at the southern end they dip southward, would seem to indicate that the chief centre of activity lay west of the centre of the island. Moreover, the fact that the beds of tuff are both thin and sparse goes to prove that the present island is a part of the outermost rim of the parent volcano—otherwise we should expect to find the tuffs thicker and more frequent. Evidence of a more definite character I was unable to obtain.

3. Macroscopic Characters of the Rocks.

Macroscopically the rocks of Capraja present great differences, in texture, in colour, and in porphyritic constituents; but, as will be seen later, they may be classified microscopically under two heads, namely:—andesite and anamesite.

Profile of the Eastern Coast of Capraja, from Cala Rossa to Poppa alla Nave.



1. Anamesite.
2, Scoria.

3. Breccias, etc.
4. Lava and Scoria, interbedded.

5. Andesite.
6. Grey Andesite Dykes.

7. Contact-phenomena.

(i) *The Andesite.*—The typical andesite, when fresh, has a texture varying from medium-compact to porous, and a dark-coloured groundmass in which felspar is porphyritically developed in great abundance. Black mica and olive-green pyroxene are also generally recognizable with the naked eye: the former in hexagonal flakes, often in the felspar; the latter, when monoclinic, as well-crystallized prisms with the faces

$$\infty \mathrm{P}\infty \{100\}, \infty \mathrm{P}\infty \{010\}, \infty \mathrm{P} \{110\}, \mathrm{P} \{11\bar{1}\},$$

easily determinable. In some varieties yellowish grains of olivine can be detected.

Where decomposition has reached a certain stage, tridymite may be found in the clefts and cracks, and more seldom fine deposits of opal. So-called Szaboite (hypersthene) was observed in well-developed, bronze-coloured crystals at Punta della Fica in a very porous piece of rock.

As soon as decomposition sets in—especially in the darker varieties—fine streaks and patches of a reddish colour make their appearance in the groundmass, and these spread as decomposition advances until the whole groundmass becomes red. This change of colour is due to a passage from the ferrous to the ferric state, and can be traced—firstly to the decomposition of fine grains[1] of Fe_2O_3 in the groundmass, and secondly to the reddening of the mica, augite, and hornblende. It brings out admirably some of the chemical and physical differences in the rock. For instance, flow-structure, which in the fresh rock is invisible, makes itself conspicuous by long red bands, from 1 to 30 or more centimetres ($\frac{2}{5}$ to 12 inches) thick, running for great distances through the mass. This decomposition must proceed very rapidly, for the felspar is still fresh after the whole groundmass has turned red. In the next stage of decomposition the red colour fades to pink, and then to yellowish grey, with kaolinization of the felspar and total bleaching and disintegration of the ferro-magnesian minerals.

(ii) *The Andesite-dykes.*—The above remarks do not apply, however, to the andesite-dykes. These have almost universally, when fresh, a grey colour, compacter texture, and somewhat smaller porphyritic (though equally abundant) felspar. Biotite always, and pyroxene generally, may be detected without the aid of a lens. As one approaches the salbands, the rock becomes darker; along the line of contact it is almost black and semi-vitreous. The same porphyritic constituents, however, are visible, but in less abundance. The pyroxene is the first to suffer from the effects of weathering, fading to greenish-grey superficially; then the groundmass becomes lighter in colour and friable, while the mica and felspar are the last to disintegrate. The dykes never turn red on weathering.

(iii) *The Anamesite.*—The anamesite occurs macroscopically in two varieties. The first variety, which forms the Punta del Zenobito, is a grey, fairly compact rock, mottled with black specks. Under a

[1] More rarely in hexagonal flakelets. The source of the grains is undoubtedly to a great extent magnetite.

hand-lens these may be occasionally resolved into octagonal prisms, whose cleavage-faces often have a metallic iridescence. The mineral proves under the microscope to be olivine. Decomposition turns the rock to a dark-green mass, and the olivine to rusty-brown spots.

The second variety, of which all the thin lava-streams of the southern end of the island consist, is very hard and compact, and of a dark grey-blue colour, the olivine-mottling being as well marked as in the first variety. It, like the andesite, shows the first effects of weathering by reddish streaks and patches, which increase until the whole rock becomes red. This variety, in all but the thickest of the lava-streams, has an amygdaloidal structure; the cavities have been either filled or encrusted with carbonate of lime.

4. Microscopic Characters of the Andesites.

As already noted, these rocks may be divided, microscopically as well as macroscopically, under the heading of andesites and anamesites. The andesites, however, taking both the outflows and the dykes together, may be subdivided according to the quantity and variety of the minerals present.

Mica is always present, and generally in a very considerable quantity; so also a monoclinic pyroxene, though less abundantly. In addition to these, hornblende, olivine, and hypersthene may be present. The rocks, then, are primarily augite-mica-andesites, and may be classified as follows:—(1) Augite-mica-andesites; (2) Hornblende-bearing augite-mica-andesites; (3) Olivine-bearing augite-mica-andesites; (4) Hypersthene-bearing augite-mica-andesites.

In one instance only, *i.e.* in the rock from the top of Punta del Trattojo, is the hypersthene developed, at the expense of the augite and mica, to such an extent as to suggest the classification of that rock as a hypersthene-andesite.

At the same time, there is no intention on the writer's part to lay very much stress upon the above subdivisions. The same dyke, which in one place is an augite-mica-andesite, becomes a few yards off an olivine or hornblende-augite-mica-andesite. The presence of a small quantity of olivine or hornblende does not alter the general character of the rock, and is doubtless attributable to slight local variations in the basicity of the magma during consolidation.

I now describe the chief characteristics of the minerals occurring in the andesites.

(i) *Felspar.*—The felspars are, without exception, triclinic, and belong in the majority of cases to the more basic varieties. Occasionally, however, crystals are found with a very small extinction on P (001). Zonal structure is frequent, the number of zones being ften very great; but the exterior zones do not seem to indicate that the felspar as a whole has become more acid. Crystalline contours are generally well-preserved and, except in some of the dykes, show but slight traces of magmatic corrosion, still less of fracture. The faces M, P, T, 1, x, y are those most frequently recognizable. The general habit is prismatic along M, P. Albite-twinning is universal, often in conjunction with the pericline, and less frequently with the Carlsbad-twinning. Except in the case of some of the dykes, the felspars do not contain very many inclusions: often, indeed, they are quite free from them. Glass is of most frequent occurrence, either with the contours of its host—and then generally with the immovable bubble—and arranged parallel to the boundaries of the crystal, or in irregular patches scattered at random. More seldom, and then often accompanied by evidences of magmatic resorption, is the felspar completely filled with what looks like fine dust under low powers; or else a broad band of the same envelopes a clear felspar-kernel. In either case there is an outermost zone of limpid felspar-material, showing evidences of an attempt on the part of the crystal to regain sharp outlines. In places where the 'dust' is coarser, it can sometimes be resolved into long, narrow, glass inclusions, which show a tendency to arrange themselves with their axes parallel to the edge M, P. Next to glass, mica is the commonest inclusion, and is often macroscopically recognizable. Augite and magnetite occur much less frequently.

(ii) *Mica.*—This mineral occurs in hexagonal plates, with well-defined crystalline boundaries. The colour ranges from light straw yellow to dark red; the former generally in the dykes, the latter only in those andesites whose groundmass is turning or has already turned red. The pleochroism is strong, and in the lighter varieties the polarization-colours are brilliant. In directions at right angles to the cleavage the twinning is often very well marked, between crossed nicols, by the difference in the angle of extinction in neighbouring lamellæ. In many cases basal sections are traversed by three systems of cracks intersecting each other at an angle of 60°—as pointed out by Hussak in the Gleichenberg trachyte. The mica carries magnetite, apatite, augite, and felspar as inclusions. The latter is by no means uncommon, and is interesting as showing the contemporaneous crystallization of felspar and mica. The same may be said of the augite, which both carries mica as an inclusion and itself occurs in mica. In many cases, as usual, the mica is entirely or in part replaced by magnetite and augite, or has only an exterior ring of them.

(iii) *Augite.*—The crystal-faces have already been mentioned as macroscopically visible. Twins after the orthopinacoid are very common; those after a hemipyramid much less so. Sections are either colourless or of the palest green, without a trace of pleochroism. Inclusions are not very abundant, as a rule; where they occur, they are either glass, mica, augite-microliths, or magnetite. A faint opacite-ring was observed in one or two cases. As already pointed out, mica, felspar, and augite, each occurs as the including or included mineral, proving that all three must have crystallized from the molten magma at about the same time. Augite also occurs as an inclusion in felspar, but I was unable to find a single instance of a felspar in the augite.

(iv) *Hypersthene.*—This mineral has a prismatic habit, with the pinacoid and domes most often developed. Less frequently it occurs in irregular grains and fragments. Its optical properties call for no special comment: the pleochroism is weak. Inclusions of glass, apatite, magnetite, and hæmatite-flakes are somewhat commoner than in the augite. In those andesites whose groundmass has already turned red, the hypersthene has developed a thin, superficial film of hæmatite.

(v) *Hornblende* plays a very secondary part as a rock-forming mineral in the rocks of Capraja. In some cases it belongs to the oldest group of porphyritic constituents, in others to the youngest. In the latter case, the crystals are always small, prismatic in habit, of a light green colour, with very little pleochroism, and showing a great tendency to twin after $\infty P \bar{\infty}$ $\{100\}$. Between crossed nicols, the colour is light yellow, and the extinction-angle a very small one. The only inclusions are glass, and these generally in the form of long, narrow bands or streaks (sometimes with an immovable bubble) running parallel to the prism-faces. On the other hand, where the hornblende belongs to the earlier crystallization, it is either entirely or almost entirely changed into magnetite and augite by magmatic metamorphism, like the mica. Where a central patch of hornblende-substance remains, it generally shows by its strong red colour the change of iron from the ferrous to the ferric state (Vado del Albero, slopes of Monte Forcone). Very occasionally it is to be found quite fresh, as in the grey andesite (Punta della Civitata, northern spur of Monte Campanile).

(vi) *Olivine* occurs both in the massive andesites and in the dykes, in grains and granules, more rarely with crystal-boundaries, which are then the pinacoids and domes. It is never entirely fresh. The exterior and cleavage-cracks are generally tinged yellow (Poppa alla Nave, Vado del Porto, Monte Scopa). Further weathering brings on serpentinization, and the secretion of opal (northern dykes in Cala del Rucciso).

(vii) *Tridymite* occurs abundantly, both macro- and microscopically (Monte Patello, Punta della Teja, Cala del Rucciso). It is, as usual, grouped in tile-like aggregates, and calls for no further remark.

(viii) *Apatite* is scattered throughout the andesites in small quantities, generally as an inclusion in the older minerals. It often carries the well-known dust-like interpositions or inclusions, and then has a light brown colour.

(ix) *Magnetite* in some of the rocks is almost entirely wanting (Patello, Punta della Civitata, and Punta della Manza dyke); in others it occurs sparingly; generally, however, it is found in considerable quantities both as a constituent of the groundmass and as a replacement-mineral in mica and hornblende.

(x) *Epidote* is to be met with only in one rock, *i. e.* from the headland just south of the Island of Prajola. It occurs in bands and patches, without a trace of crystal-boundaries. Its colour is a muddy yellow, and pleochroism is very weak. The augite is its chief source and may be found in all stages of alteration, from that in which a thin film of epidote has just made its appearance on the surface and along the cleavage-cracks, to that in which all but a small central kernel has been 'epidotized.' Where the original mineral has been completely decomposed, the epidote has a core of calcium carbonate. Besides calcium carbonate, zeolites and opal are almost invariably present: the former as an exterior zone round the epidote, reminding one of the green zone in certain gabbros round olivine in contact with felspar; the latter in small, irregular patches in close proximity to the epidote, its presence recognizable with certainty only after treating the slide with hydrate of potash and fuchsine. Much less frequent is the occurrence of epidote in felspar, where it presents several striking characteristics. Here it is always clear and colourless, and unaccompanied by any of the other above-mentioned products of decomposition. It is to be found only in felspar with zonal structure, and then always in the more basic part towards the centre of the crystal. In one instance the epidote was seen to follow the contours of one of the interior basic zones, without extending into the acid zone beyond. The felspar, beyond the presence of epidote, shows no signs of decomposition; in fact, everything points towards the conclusion that this epidote cannot be referred to augite as its source, but is either an original inclusion of unknown origin in, or an alteration-product of, the felspar, contemporaneous with its growth. In the latter case, it might be due to magmatic influences during consolidation.

The Groundmass plays a very important part in all the Caprajan andesites. In it are always found glass, felspar, augite, generally magnetite, and not seldom mica and hornblende. The relative proportions of glass and crystalline constituents vary within wide limits. The glass is light brown to colourless, and may be almost free from microliths or very rich in them. Where the brown varieties of glass come into contact with felspar they sometimes lose their colour, and become almost as clear as the felspar along the line of contact; at the same time the microliths disappear entirely or almost entirely.

The felspar of the groundmass is idiomorphic and generally lath-shaped. Crystals are single or once twinned, but too small to admit of any determination of the nature of the felspar from extinction-angles. The augite occurs in long, narrow prisms, which often group themselves together by twos and threes. The hornblende has already been described as it occurs in the groundmass (see p. 138). Mica is not infrequently present, generally well crystallized in minute hexagonal flakes.

Besides the above-mentioned constituents, there often occur small patches of a perfectly colourless, isotropic substance, which was at first mistaken for sodalite. The excellent micro-chemical reactions for sodalite, proposed by Lemberg,[1] proved, however, that it was not

[1] The slide is treated with dilute nitric acid and a few drops of silver nitrate in the cold for ten to twenty minutes, and then washed. Where sodalite is present, a film of silver chloride has been deposited, which soon darkens and reveals the mineral with certainty. I have used this method with the greatest success on the trachytes of Ischia and the Phlegræan Fields.

that mineral. Experiments with hydrochloric acid and hydrate of potash also gave negative results. These facts, together with the total absence of crystal-boundaries, impelled me to consider it as glass, which, in distinction from the normal groundmass-glass, is quite free from inclusions.

Order of Crystallization.—So far as the structure of the andesites is concerned, there is very little to be said. With regard, however, to the order of crystallization of the various constituents, I could find no evidence of an 'intratelluric period.' Beyond the fact that magnetite and apatite are the oldest, the relative ages of the rest of the constituents can hardly be fixed with certainty.

As already remarked, the frequency with which inclusions of felspar occur in mica, and of mica and augite in each other, indicates that all three minerals must have begun to separate about the same time. The felspar seems to have continued to crystallize without appreciable interruption throughout the entire period of consolidation of the rock, as is shown by the gradual diminution, without any abrupt break, in the size of the crystals. In the case of mica and augite, however, there seems to have been an interruption in the course of crystallization, giving rise to two generations, the second of which belongs to the groundmass.

Where olivine and hypersthene occur, they seem older than the other ferro-magnesian minerals. So also is the hornblende of the first generation. With regard to the hornblende, it should be remarked that it never occurs in two generations in the same rock; if it is present in the groundmass, there are no porphyritic crystals of an earlier age, and *vice versâ*.

5. Microscopic Characters of the Anamesites.

These are a holocrystalline variety of rock, composed of a groundmass of felspar, augite, and magnetite, and porphyritic crystals of olivine. Here and there mica-leaflets may be found, and a little nepheline. The felspar, which is by far the commonest constituent of the rock, occurs in lath-shaped individuals, and is generally well crystallized. Each individual has two or three twinning-lamellæ, seldom more, parallel to its longest axis. The smallness of the crystals, however, made it impossible to determine the nature of the felspar from its extinction-angle. The augite, though next in abundance to the felspar, is always very small, and seldom shows crystal-boundaries. It occurs generally in the shape of small round 'drops,' which occasionally arrange themselves, together with magnetite, along the outer surfaces of felspar-crystals, or even penetrate for small distances into their mass.

The olivine presents no unusual characteristics. Nowhere is it absolutely fresh. The yellow film of iron oxide has already made its appearance on the surface and along the cleavage-cracks of every crystal. When crystal-faces are observable, which is the exception, they are the domes and prisms; as a rule, however, the olivine occurs only in grains and fragments. Here and there may be detected small quantities of a doubly-refracting colourless mineral in the interstices of the felspar-crystals, which gives between crossed nicols the characteristic polarization-tints of nepheline. That it really is this mineral can be shown micro-chemically by the use of hydrochloric acid and fuchsine. The nepheline was undoubtedly the last constituent to crystallize out.

As regards the age of the various constituents, I should arrange them as follows, beginning with the oldest:—(1) Magnetite, (2) Olivine, (3) Augite, (4) Mica, (5) Felspar, (6) Nepheline.

6. Chemical Analyses of the Rocks.

In choosing specimens for analysis, I have endeavoured as far as possible to select representatives of all the different varieties of andesite.[1]

	I.	II.	III.
SiO_2	56·82	60·39	60·63
Al_2O_3	16·68	16·96	16·96
Fe_2O_3	3·84	1·50	2·87
FeO	4·57	3·42	2·31
CaO	6·36	5·41	6·41
MgO	3·93	3·81	3·27
Na_2O	3·39	3·37	3·58
K_2O	2·81	2·01	2·44
TiO_2		0·21	
Cl_2	traces	traces	
P_2O_5	traces	traces	
H_2O	1·48	2·03	1·98
	99·88	99·11	100·45
	Sp. Gr. at 22° C. 2·657.	Sp. Gr. at 22° C. 2·580.	Sp. Gr. at 22° C. 2·594.

No. I., from Monte Scopa, is an average sample of the darker, less glassy variety. Felspar, augite, mica, olivine, and magnetite are porphyritically developed in a groundmass, consisting chiefly of microliths and a small quantity of interstitial glass.

No. II., from Monte Patello, is a good representative of the more glassy varieties. The felspar, mica, and augite are very fresh and well crystallized. The groundmass is rich in light-brown isotropic glass, and microliths of felspar, augite, and mica. The rock is almost free from magnetite.

No. III., from Poppa alla Nave, resembles microscopically a basalt. The porphyritic constituents are comparatively scarce: plagioclase, olivine, and an occasional mica-flake are scattered in a black and very compact groundmass, which, under the microscope, is resolved into augite- and felspar-microliths and a little interstitial glass.

[1] All the following analyses were made for me by Dr. Röhrig, in his private laboratory at Leipzig.

	IV.	V.	VI.
SiO_2	62·27	59·06	59·29
Al_2O_3	16·92	16·40	15·27
Fe_2O_3	2·40	2·88	5·21
FeO	2·59	4·18	2·08
CaO	4·78	4·32	6·15
MgO	2·87	2·63	4·42
Na_2O	4·72	5·29	3·31
K_2O	1·47	1·49	2·61
TiO_2	0·16	......	......
Cl_2	0·07	traces	0·036
P_2O_5	traces	traces	0·18
H_2O	1·22	2·06	1·46
	99·47	98·31	100·016
	Sp. Gr. at 22° C. 2·584.	Sp. Gr. at 22° C. 2·606.	Sp. Gr. at 22° C. 2·614.

Nos. IV. and V. are analyses of grey andesite-dykes—No. IV. from Punta della Civitata on the eastern, No. V. from Punta della Manza on the western coast. In appearance, the rocks are very similar; under the microscope, however, an interesting difference is observable. The chief porphyritic constituents in both are felspar, mica, and augite; both also contain hornblende, but under different conditions. In No. IV. it is one of the first constituents that has crystallized out, but in small quantities; in No. V. it is one of the last, and is in fact to be found only in the groundmass, but there in considerable quantities.

The groundmass of both contains much glass,[1] felspar, augite, and very little magnetite; while in No. IV. some mica is to be found.

No. VI. is an andesite in which the groundmass has turned red, but which in other respects is still fresh. Felspar, hornblende, mica, augite, and magnetite are richly distributed throughout the rock. The hornblende and mica are very red; the porphyritic augite is still fresh or has only a thin red crust; the augite of the groundmass, however, has turned completely red. The groundmass shows everywhere a deposition of hydrated ferric oxide.

Three of the rocks whose bulk-analyses have just been given, namely, Nos. I., II., and V., after having been reduced to coarse powder, were fractionated by means of Thoulet's solution, in order to separate the groundmass. The latter, after careful purification, was subjected to analysis, with the following results:—

	I A.	II A.	V A.
SiO_2	64·54	68·60	68·11
Al_2O_3	17·36	17·27	15·56
Fe_2O_3	2·33	2·09	0·96
FeO	2·50	0·585	2·12
CaO	3·97	1·72	2·91
MgO..................	1·56	0·396	1·10
Na_2O	3·58	3·30	3·43
K_2O	2·54	4·61	2·61
H_2O	1·50	2·08	2·82
	99·88	100·651	99·62

Of Cl_2 and P_2O_5 there were traces only, in all three analyses.

[1] No. V. was taken from the salband of the dyke, where the proportion of groundmass was greater, an analysis of the latter being thought desirable.

The amount of material at present published does not warrant the drawing of positive conclusions concerning the relations between rock and its groundmass. But it is interesting to compare the above results with those published by Lagorio[1] for rocks of similar acidity, and to see how nearly they agree with his deductions.

Here, as with him, there is a marked increase in the percentage of silica in the groundmass, and a decrease of iron, calcium, and magnesium. In two of the analyses (II A and V A) there is an increase of potassium, as was to be expected; the third (I A), however, shows a slight decrease, for which I am unable to account, unless it be due to the fact that the groundmass of this rock contains much less glass—in other words, has cooled more slowly—than the other; or that the hand-specimen under analysis came from a part of the outflow which, for some local reason, had been rendered poorer in potassium than the main mass.

During the fractionation of Nos. II. and V., those portions that sank between the specific gravities of 2·6 and 2·75 were set aside and afterwards refractionated to obtain the felspar. The greater portion remained suspended in a solution of sp. gr. 2·67. This, after careful purification, was subjected to analysis with the results tabulated below. They approximate to a labradorite of the composition Ab.An., the theoretical composition of which is given for comparison. Lime is the only constituent that shows much deviation from the required percentage.

	II B.	V B.	Theoretical Ab. An.
SiO_2	55·92	56·25	55·92
Al_2O_3	28·58	28·56	28·10
Fe_2O_3	1·00	0·77	......
CaO	6·65	6·54	10·06
MgO	0·55	1·06	......
Na_2O	5·66	5·42	5·92
K_2O	0·66	0·61	......
H_2O	0·69	0·33	......
	99·71	99·54	100·00

The following three analyses are from specimens collected at the southern end of the island:—

	VII.	VIII.	IX.
SiO_2	53·86	50·34	44·40
Al_2O_3	16·44	16·72	12·98
Fe_2O_3	8·02	15·12	7·36
FeO	1·96	......	......
CaO	8·53	8·00	......
MgO	5·44	3·96	11·60
Na_2O	4·52	3·78	......
K_2O	0·067	1·83	......
Cl_2	0·035	......	......
P_2O_5	0·15	.....	......
H_2O	1·27	0·72	24·04
	100·292	100·47	100·38

Sp. Gr. at 22° C. 2·894.

[1] 'Ueber die Natur der Glasbasis,' Tscherm. Min. u. Petr. Mitth. vol. viii. 1887, p. 467.

No. VII. is an anamesite from Punta del Zenobito.

No. VIII. is a piece from the cone of scoria in Cala Rossa. When in place, the cavities of the scoria are filled with the secondary mineral 'bole.' The piece analysed, however, was a fragment on the beach, from whose pores all the bole had been leached by the action of the sea. It was deemed more advisable to analyse the scoria thus free from bole, as a separate analysis of the bole was also undertaken, the results of which are given in No. IX. Both it and the scoria were carefully washed, after pulverization and before analysis, so as to eliminate any sodium chloride which might have been absorbed from the sea-water.

Lastly, I may mention the occurrence of a mineral in small quantities just north of Punta del Trattojo, called by the Caprajans 'vitreol,' and used by them for healing purposes. It is found sometimes in a silky, fibrous form, and sometimes botryoidal; it is white, except when tinged yellow from traces of iron. Qualitative analysis showed it to be a magnesian alum.

I cannot conclude without expressing my warmest gratitude to Herr Prof. Zirkel for the kindly interest which he has evinced and the valuable assistance which he has given me during my work on the rocks of Capraja; my thanks are also due to Herr Dr. Lenk, assistant in the Mineralogical Institute at Leipzig; and last, though not least, to Herr Dr. Röhrig, for his willingness to set aside other work in order to complete my analyses.

Discussion.

Dr. Du Riche Preller gave an outline of the leading geological and the analogous petrological features of the several islands of the Tuscan Archipelago, of Corsica, Sardinia, the Carrara Mountains, and the Maremma Hills. These groups, he said, were the remains of the old post-Tertiary and subsequently submerged Tyrrhenian Continent, which connected Southern France and Liguria with Africa: the continuance of the ancient Alpine 'greenstone'-chain and the curved axis of the Alps being, moreover, demonstrated by the pre-Silurian serpentines of the various islands. Dr. Preller showed that, with the significant exception of the Trias, which only appeared in the Carrara Mountains, and of the Cretaceous Series, the Tuscan Archipelago, conjointly with Corsica, Sardinia, and the Maremma Hills, included every formation from pre-Silurian to post-Tertiary, and that the eruption of the andesitic rocks of Capraja probably took place in the early, and that of the lava in the same island in the more recent post-Tertiary period.

The President also spoke.

10. VARIOLITE *of the* LLEYN, *and* ASSOCIATED VOLCANIC ROCKS.

By Miss CATHERINE A. RAISIN, B.Sc. (Communicated by Prof. T. G. BONNEY, D.Sc., LL.D., F.R.S., V.P.G.S. Read January 11th, 1893.)

[PLATE I.]

CONTENTS.

I. INTRODUCTION.

ALTHOUGH much has now been written about the igneous rocks of the Lleyn, especially in Mr. Alfred Harker's valuable essay,[1] yet, as he expressly excludes most of the district of which I am treating, and as it receives only slight mention in other writings, some of the most interesting examples from the part coloured on the Geological Survey map as 'metamorphosed Cambrian' have remained unnoticed. I have therefore put together a few notes on the rocks which I have collected in the course of many visits during the last six years. The specimens not hitherto described include a variolite —a spherulitic, somewhat basic rock. A short summary of its occurrence will at least serve to show that we have on the mainland of our island (apart from any example in Anglesey[2]) a mass of variolitic diabase with characters very similar to those of German and Alpine localities, corresponding closely in many particulars with that graphically described by Mr. J. W. Gregory from the Fichtelgebirge,[3] and also, although perhaps less markedly, with that of the Durance, as shown by Prof. Cole and Mr. Gregory.[4] I am limiting myself mainly to the rocks which can be clearly recognized as igneous, and have given only a short notice of others in the last section of the present paper. The extensive masses of a rather indefinite and schistose character in many parts are ashy or

[1] 'The Bala Volcanic Series of Caernarvonshire and Associated Rocks,' Cambridge, 1889.

[2] See Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 331, note; also 'The Variolite of Ceryg Gwladys, Anglesey,' G. A. J. Cole, Sci. Proc. Roy. Dub. Soc. vol. vii. (1891) p. 112.

[3] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 45.

[4] *Ibid.* vol. xlvi. (1890) p. 295.

agglomeratic, but include crushed examples of igneous origin. The exact nature of some rocks, however, even when illustrated by microscope slides, is difficult to determine precisely. I have been obliged also to leave the geological age of the variolites an open question, since even the associated limestone, quartzose rocks, and others which are possibly sedimentary, give no trustworthy evidence bearing upon this point.

As much of my work was done at University College, London, I had the advantage of submitting doubtful points to Prof. Bonney, and have to thank him for valuable advice and assistance.

II. Lithological Characters of the Igneous Rocks.

Among the holocrystalline rocks, some at least are most probably intrusions belonging to a later period. The well-defined dolerite of Trefgraig, Hendrefor, Tyhen, and Methlan is one type[1]; this has been already described, and very similar to it is a greenish diabase forming the headland of Trwyn Glâs; certain other green porphyritic rocks may be related, although they are not identical.[2] A gabbro is found east of Porth Witlin which perhaps is another protrusion of the Craig-y-fael mass described by Mr. Harker.[3] It consists of plagioclase felspar, much decomposed, and of diallage, sometimes connected in an ophitic manner. The rock has been more or less affected by pressure, as even the most normal specimen exhibits bending of the cleavage-planes and other signs of strain, while much of the mass is markedly schistose. The dykes along the shore vary somewhat in character, but many are a compact diabase with fluidal structure;[4] microporphyritic felspars are crowded near the edge, ranging roughly parallel, as if they had been floated to the side.[5]

The igneous rocks which remain to be considered appear from the microscopic characters to have a certain uniformity in composition, and to belong to the class of rather basic andesites or not very basic basalts; but it is not always easy to decide how far we are dealing with two distinct magmas, or with one lava in which subsequent

[1] J. V. Elsden, Geol. Mag. for 1888, p. 304; C. A. Raisin, *ibid.* 1892, p. 409; also Alfred Harker, 'The Bala Volcanic Series, etc.' p. 87.

[2] A diabase at Careg contains white augite; see Geol. Mag. for 1892, p. 412. Others occur at Porth-din-lleyn, and at the beach between Dinas-fach and Porth Oer.

[3] Quart. Journ. Geol. Soc. vol. xliv. (1888) pp. 447, 448; and 'The Bala Volcanic Series, etc.' pp. 89–92.

[4] See 'The Bala Volcanic Series, etc.' p. 111; also J. F. Blake, Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 531. As Mr. Harker states, it cannot be proved that these dykes are of the age to which he inclines to attribute them, but I fail to understand Mr. Blake's suggestion that, if contemporaneous with the volcanic ashes, they are in some cases 'actual flows,' in others 'due to infiltration.'

[5] Compare Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 310. A felstone-dyke occurs near Porth Meudwy, which is lithologically similar to the felstones of Pwllheli. This dyke, however, is to the eastward of the boundary-fault, and cuts the black shales, which are probably of Ordovician age.

differentiation has taken place. Of the two extreme types, the one is a dull-greenish, compact rock, the groundmass including lath-shaped microliths of felspar, accompanied by more or less viridite, opacite, and minute granular augite or epidote. Generally where the viridite is an important constituent, the iron oxide and the augite are absent or small in quantity. Certain more compact rocks (consisting mainly of palagonite or chlorite) were probably originally glassy, and in some the traces of a fluidal structure are still retained. (See Pl. I. fig. 3.) One slide contains rich brown, isometric crystals, often imperfect, probably an early formation of chromite or picotite.[1] The second type of rock is best illustrated in a variety, the microscopic characters of which seem to justify the designation of basalt or ferruginous basalt. (Pl. I. figs. 1, 2, 5.) It is compact, of a dull reddish colour, and consists of opacite or ferrite separating lath-shaped microliths of felspar. These are not infrequently pseudomorphosed, so that the original composition of the mass must have undergone alteration. The two types seem to be connected, for one and the same rock may show a development of each kind.[2] Both forms also exhibit spherulitic growth, and include similar porphyritic or microporphyritic crystals. Some of these are felspar, others a serpentinized mineral, the form and general aspect of which suggest a ferro-magnesian silicate, probably bastite,[3] and there seem to be two varieties present, the one being crossed and outlined by bars of granular opacite. Microliths of a similar nature occur, either yellowish or pale greenish, with a thick border of iron oxide. They are acicular or shuttle-shaped, such as have been often figured.[4]

Thus petrological study suggests that the rocks represent two varieties, with only slight differences in composition and structure, and that they were probably formed by differentiation in a magma originally homogeneous. Owing to this, the ferrite may have crystallized, and consolidation have begun, in one mass rather earlier than in the other. This view seems to accord with the field evidence. While in certain parts the green diabase or dark ferruginous basalt can be easily recognized, elsewhere they are more or less intermingled, and even cannot be separated. Thus a mottled red and green rock (at Porth Orion) appears to have been formed by a second magma intruding into the mass of diabase before it was solidified. Also a junction of two varieties within the heart of a spheroid proves that these were distinguished before the cooling and contraction were complete.[5] As will be presently described, frag-

[1] The crystals are too small to allow of the hardness being tested.

[2] As in the green and purplish rock from west of Hendre-uchaf, see Geol. Mag. for 1892, p. 412.

[3] Fouqué et Michel-Lévy, 'Minéralogie Micrographique,' 1879, pl. xxvi. figs. 1, 2, & pl. xxvii.

[4] U.S. Geol. Explor. of the 40th Parallel, vol. vi. 'Micr. Petrogr.' 1876, F. Zirkel, pl. i. fig. 20; J. J. H. Teall, 'Brit. Petrogr.' p. 14, fig. 5 (after Zirkel); F. Rutley, 'Notes on Crystallites,' Min. Mag. vol. ix. (1891), p. 268, fig. 17 (Crenulites).

[5] This junction was examined microscopically.

ments of purple basalt have been enclosed at places in a later magma. In other examples where the two types are not clearly separated, a tendency in this direction is indicated by a development of spherulites, and is even slightly marked in fluxion-bands.

Partial analyses of two of this rather varied group of rocks have been prepared in the laboratory at University College, through the kindness of Dr. Plimpton. The first apparently belongs to the class of not very basic basalts, and this is representative of my 'ferruginous' type of rock (the other type has not been analysed). The second represents an abnormal variety, a kind of palagonite.

	I.	II.
SiO_2	52·43	29·78
Al_2O_3	23·84	17·72
Fe_2O_3		11·34
FeO	0·00	2·68
CaO	7·55	7·88
MgO	1·11	12·77
CO_2	6·00	6·80
Hygroscopic water ...	...	0·35
Alkalies and water by difference ...	9·07	10·68
	100·00	100·00

I. Variolite from cliff north of Porth Oer.[1]—This rock exhibits a narrow zone of distinct spherulites, with gradations to a mass confusedly crystallized, as shown in Pl. I. fig. 5. The specimen analysed came from the latter part, in which small amygdules occur at intervals, consisting largely of a carbonate. This deposit, however, would form only a small proportion of the mass, and would not very materially affect the results of the analysis.

II. Green palagonitic rock limiting dull red basaltic spheroids, from the boss on the beach north of Porth Oer (see p. 151).[2]

III. Spheroidal Structure.

The igneous rocks are often jointed into rhomboidal columns weathering to roughened ends; and spheroidal structure, which was noted by Prof. Bonney at Porth-din-lleyn,[3] is well shown at many

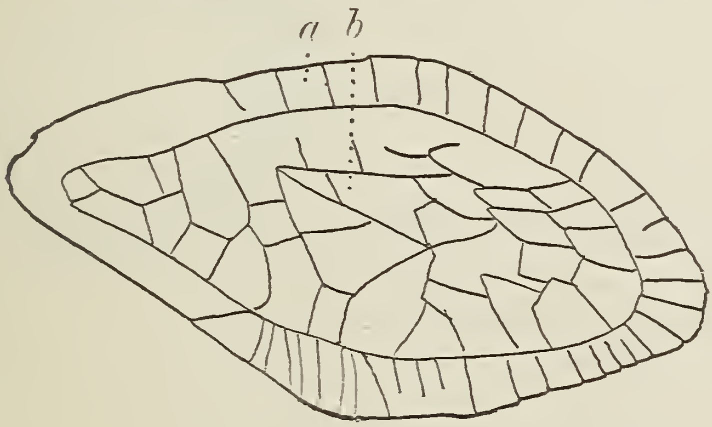
[1] Separate analyses of this rock were obtained by Mr. C. J. Nix and by Mr. W. Gathorne Young, the two results being to a great extent corroborative. I am further indebted to Miss E. Aston, B.Sc., for kindly making an independent estimate of the quantities in a hydrochloric acid extract:—Fe_2O_3 $+Al_2O_3$ 3·73, CaO 6·87, MgO 1·06, CO_2 6·00.

[2] For the analysis of this rock I have to thank Miss J. M. Hayward, B.Sc., who also made a separate calculation of the carbonates present in the rock. These amounted to 20·88, and, on the hypothesis that they were all infiltrations, the percentages in the original rock would be:—SiO_2 38·22, $Al_2O_3+Fe_2O_3$ 34·67, MgO 13·30, with alkalies and water amounting to 13·70. As the quantity of water (not determined with precision) was not more than about one third of this last amount, the high percentage of alkali with a low percentage of silica suggests the enquiry whether nepheline could have been an important constituent in the original rock.

[3] Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 50. For a general account of such structures, see *ibid.* vol. xxxii. (1876) pp. 140–154.

places, the spheroids being sometimes as much as 6 feet in length, and often cushioned in appearance.[1] Their exterior is distinguished generally by characteristic fracture and colour.[2] It is fissured in concentric and radial directions, the interior being traversed by an irregular rhomboidal jointing (fig. 1). Many spheroids also contain

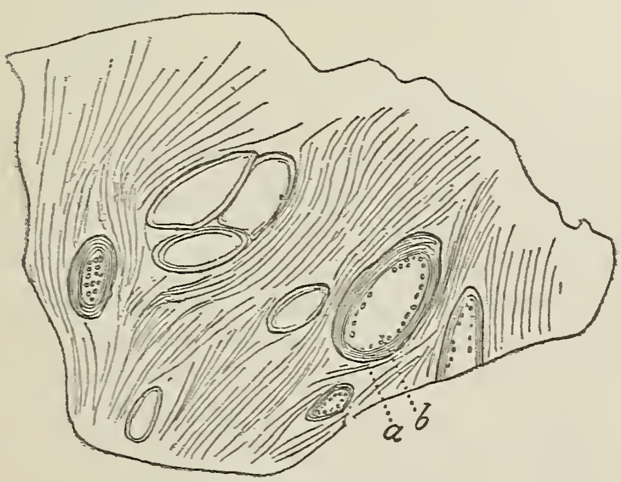
Fig. 1.—*Spheroid of basalt from the beach north of Porth Oer, showing the general direction of the cracks.*



About $\frac{1}{4}$ natural size.

a = outer zone, with radial fissures; *b* = interior, with irregular rhomboidal jointings.

Fig. 2.—*Green spheroidal diabase, as exposed on the surface of a rock in the farmyard at Dwyrhos.*



About $\frac{1}{36}$ natural size.

a = green schistose rock; *b* = spherulitic zone near the exterior of the spheroid.

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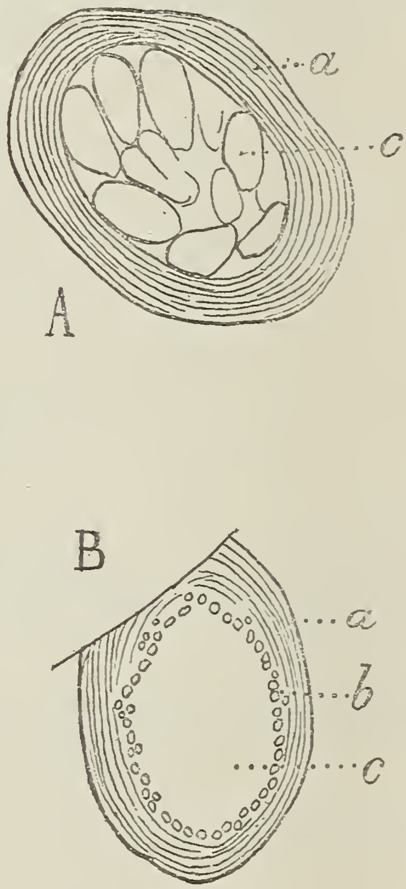
[1] Cole and Gregory, *op. cit.* vol. xlvi. (1890) pp. 311, 312, and fig. 4.

[2] Variolitic structure is often connected with this part of the spheroid; see below, p. 155.

a zone of vesicles radially elongated, as if gases had been prevented from escaping. Thus, evidently, a crust was formed at an early period, before the structures were completely solid. Smaller spheroids also are enclosed within larger (fig. 3, B), illustrating successive

Fig. 3.—*Spheroids from the cliff south of Porth Orion.*



a = outer, greenish schistose zone.

b = zone with reddish spherulites.

c = interior, of purplish basalt.

A and B are, roughly, about $\frac{1}{10}$ natural size, but the spheroids vary considerably in magnitude.

stages in contraction, as was demonstrated by Prof. Bonney;[1] while in a green diabase (probably an ash) north of Porth Oer the enclosing shells are rhomboidal.[2] The outer layers of a spheroid are generally schistose and shining, consisting of palagonite or of a chloritic or serpentinous aggregation, which doubtless represents an originally glassy exterior. A similar matrix surrounds fragments in certain breccias. The foliated structure is not necessarily due to subsequent pressure, but might originate by slight rolling of the spheroids, if the crust were not completely solid.[3] The still plastic magma would be squeezed out along surfaces of weakness.

[1] Quart. Journ. Geol. Soc. vol. xxxii. (1876) pp. 151, 153, and fig. 13.

[2] Compare a structure in shale altered by contact, described by Mr. Harker, *ibid.* vol. xliv. (1888) p. 450.

[3] J. W. Gregory, *ibid.* vol. xlvii. (1891) p. 60.

IV. Fluidal Structure and Flow-brecciation.

Structure which is probably fluidal can be traced in many, more or less palagonitic, green rocks, where streaming groups and streaky blotches of minute epidote or augite-granules are drawn up to wave-like points. Some of these rocks have in the field an appearance of flow-brecciation, while certain microscopic sections prove that subsequent movement has taken place, breaking and displacing spherulites,[1] so that fluxion is partly masked by the effects of mechanical deformation. I attribute to some kind of fluidal action several more obscure examples of breccias found associated with volcanic masses. Thus a dull green rock, probably a devitrified andesite rather acid in composition, encloses compact fragments which prove to be more definitely crystalline, and appear to have been carried within the surrounding magma.[2] Another mass,[3] in the field resembling an agglomerate, when examined microscopically seems to be a flow-breccia, since almost all the fragments are alike, and are cracked and slightly divided, as if broken by the effect of the heated magma (now represented by palagonite or replaced by tufted chlorite). Possibly from the same cause a separation of iron oxide and of a clear crystalline substance has taken place along the edges. The rock is a compact porphyritic diabase, rarely exhibiting fluidal structure or a few amygdules, and including one or two pieces of a brownish glass. In another breccia, with fragments of a reddish slate, sectors of spherulites are embedded, as if these had been snapped along planes of weak cohesion by a sudden flow of lava at a high temperature.[4] (Pl. I. fig. 4.) I have described a rock from Careg in which purple spheroids (4 to 5 inches in diameter) seem to have been separated and broken by a second influx of lava.[5] Some fragments have a roughly concentric fluidal structure, as if they had been moved while still plastic, and towards their exterior are clearer spots bounded by opacite, which possibly are incipient spherulites. (Pl. I. fig. 3.)

The most interesting breccia, however, is found north of Porth Oer. Elongated spheroids (9 to 15 inches long) of a dull-red ferruginous basalt, fractured as previously described, are surrounded by a green, schistose matrix. A few blocks of limestone are also included, possibly broken from a small mass associated with the basalt. This has been affected by calcareous infiltration and veining; while the limestone has acquired a colour somewhat similar to that of the igneous rock; but it can be distinguished easily by its duller texture and fracture, its paler tint, and by being broken into more irregular blocks.[6] The spheroids of basalt appear

[1] In a slide prepared from the variolite, Afon Sant, Aberdaron.

[2] This rock is exposed at lowest tide, below the lime-kiln north of Porth Oer.

[3] Above Pared-llech-y-menyn.

[4] From the isthmus, Dinas-fach.

[5] Geol. Mag. for 1892, p. 412.

[6] This breccia appears to be somewhat similar to the mass at Careg Gwladys, Anglesey, described by Mr. J. F. Blake, Quart. Journ. Geol. Soc. vol. xliv. (1888) pp. 510–11, and fig. 17; but at Porth Oer the inclusion of limestone-blocks is a very subordinate feature, and no crystals resembling andalusite occur. The spheroidal and variolitic structures are exhibited in more than one mass on the beach. One of these shows a few inclusions of limestone on its north-eastern

here, as at other places, to become green and palagonitic at the exterior, especially where segregation of the iron oxide marks a tendency towards the formation of spherulites. But several adjacent rocks, although like this mass affected by subsequent crushing, seem to be examples of flow or flow-brecciation. A separation in the magma was probably followed by a second movement of lava. Although this did not violently displace or carry along the spheroids of basalt, it seems possible that it partially thrust itself between them. If not, we have first to account for the difference in microscopic structure and in fracture as being due to the glassy and the cryptocrystalline characters of the outer and inner parts of the spheroid respectively, and to the different results of crushing upon each. But, secondly, the analyses given previously suggest that the two rocks might be found to have a marked difference in chemical composition. On this point further investigation would be necessary.

In certain neighbouring masses, which are probably flow-breccias, the fragments are more separated, irregular, and smaller, but some are rounded, possibly from being moved while still plastic. These indicate a gradation towards a variolite, although they have not a radial structure.[1]

V. Variolite.

(a) *General Microscopic Structure.*—Corresponding to the two types of rock are two forms of variolite.[2] One is a compact green diabase exhibiting light-coloured spots, which on microscopic examination prove to be spherulites, generally elliptical, greyish, and duller than the surrounding matrix. They include a felspathic constituent showing radial aggregation in polarized light; also minute, brownish, brightly polarizing granules, probably augite; and a fine dust, which is much less abundant in the central and consequently clearer part. Towards the periphery a zone of pseudo-crystallites occurs. The brecciated spherulites at Dinas-fach are similar, but are much clearer. In the second type (Pl. I. fig. 5) needles of brownish iron oxide are grouped in feathery tufts or elongated sheaves. The radiate character is found only at the centre of the spherulite, or both there and at the periphery, or it is

face or edge, while the larger surface exposed to the north-west might be roughly represented by the figure given by Mr. Blake, if the 'fragments' were less angular, more uniformly fractured, more irregularly disseminated, and consisted entirely of dull red basalt. From the details given in the description of the Careg Gwladys variolite by Prof. Cole, Sci. Proc. Roy. Dub. Soc. vol. vii. (1891) p. 112, I gather that the calcareous inclusions are mainly modified igneous rock, and that the mass is therefore probably very similar to this from Porth Oer. Owing to bad weather during my visits to the Anglesey district, I did not reach the particular boss figured by Mr. Blake, but a general lithological similarity was evident.

[1] I may here refer to my description in a former paper of structures connected with pyromerides in acid rocks, Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 255, 267 (2nd group).

[2] The first type is illustrated in rocks from near Aberdaron by Afon Sant and at Deunant; the second from Porth Orion, Dinas-fach, and Porth Oer.

traceable over the whole, but interrupted by pseudocrystallites. The iron oxide usually is concentrated towards the centre, and sometimes the outer rim is clear.

The spherulitic habit, however, is not confined to structures which can be distinguished in hand-specimens. In very many slides, radial clusters of felspars are more or less regular near their centre, but have no definite boundary, adjacent groups being confusedly intercrystallized. In the green diabase the crystals are long, narrow, and straight. In the basalt they are narrow and long, but generally bent or curved, often undulating, and bordered by ferrite-granules or bars. (Pl. I. fig. 2.) Even in some of the defined spherulites the felspars are wavy, lath-shaped crystals with iron oxide along their edges. Possibly this is the cause of the peculiar bending, for, if iron oxide were separated in any great quantity at an early stage, it might interfere with the development of the felspars.

Thus the spherulitic growth exhibits roughly three or four different modes [1] :—

1st, without radial structure ;
2ndly, with sheaf-like felspar radiating from a centre and giving a black cross in polarized light—the felspathic type :
3rdly, with radiate feathery arrangement of iron oxide, which gives the reddened colour to most examples—the ferruginous type.
4thly, with grouped arrangement of distinct crystals. Although in the spherulites indications of these may be found, they are best shown in the confused, interlocking aggregates of the groundmass.

(b) *Distribution.*—The variolite occurs in small bosses near Aberdaron and at places along the coast; it is well seen north of the beach of Porth Oer, near the small isthmus of Dinas-fach, and in the cliff south of Porth Orion.

Towards the mouth of Afon Sant, near Aberdaron, the diabase appears to form two or more patches, suggesting intrusion amid the ordinary schistose rocks.[2] The spherulites are only $\frac{1}{16}$ inch across,

[1] See Quart. Journ. Geol. Soc. vol. xli. (1885) *Proc.* pp. 90–91, Prof. T. G. Bonney's Pres. Address; see also J. P. Iddings, 'Spherulitic Crystallization,' Bull. Phil. Soc. Washington, vol. xi. (1891) p. 448.

[2] It occurs west of the line of fault, as a low crag overlooking the small valley or rift along the line of the streamlet, and it crops out in the fields above in some furze-covered plots. I could find only a single and very rotten junction with the schistose rocks, and at that part the diabase seemed to be compact and without spherulites. The variolitic structure appeared not to be necessarily developed at the exterior of the mass, but often to be connected with a kind of lamination, which I was inclined to attribute to a movement in the magma. As previously stated, in one part at least the rock suggested flow-brecciation, and the spherulites are usually elliptical with a definite orientation.

In the black micaceous shales quarried south of the fault, east of the stream, I found a fragment of a small trilobite. Dr. Hicks very kindly examined this, and stated that it was probably the pygidium of an *Æglina*. The specimen, in conjunction with others from another locality, seemed to him suggestive of the Arenig Group.

and stand out as whitish pimples on the weathered surface. A diabase is also exposed in the farmyard at Dwyrhos, where the variolitic structure seems to be connected with spheroids (fig. 2, p. 149). In one of these, about $1\frac{1}{2}$ foot in diameter, the interior is compact and pale green, surrounded by a spherulitic zone, outside which the spheroid-crust and the intervening matrix are shiny, dark green, almost black, consisting of interfelted chlorite or of palagonite. The variolite at Deunant is best seen in the quarry behind the farm, where the rock is compact, dark green, jointed, and slickensided. The pale-green oval spherulites, about $\frac{1}{4}$ inch in length, are often ranged end to end, and microscopic examination supports the idea that the elongation is in the direction of a flow-structure, but this would not in itself disprove the intrusive character of the mass.

North of Porth Oer beach, as previously described, a purple basalt, somewhat calcareous and veined, is brecciated, probably by a second lava-flow. Both rocks exhibit variolitic structure. I could not always connect it with the exterior of spheroids, although it is often thus developed. Some varioles, perhaps $\frac{1}{4}$ inch in length, not radial in their structure, appear to consist of small fragments of the breccia. On other surfaces, the spherulites appear as small knobs, densely crowded, about $\frac{1}{16}$ inch across, which in the field bear a resemblance to amygdules contained within the basalt. In the weathering of some of these examples, a greenish or greyish envelope flakes off from a reddened centre.[1] This inner kernel is traversed by radial bars of iron oxide, sometimes grouped like iron filings about a magnet. The deposit is wanting in the outer zone, where the felspathic sheaves are more distinct, although they extend over the whole spherulite, giving a black cross in polarized light. An outer boundary, roughly elliptical in shape, is marked by a deposit of brightly polarizing granules, and similar granules are sparsely scattered over the section. These spherulites are grouped along a narrow zone in the rock, and gradations can be traced to a mass confusedly intercrystallized (Pl. I. fig. 5). The specimen bears much resemblance to the felsite of Arran described by Prof. Bonney;[2] but in the Lleyn slide the radial structure can be traced over both the centre and the external zone; and the granular boundary-line is not polygonal as in the Arran specimen, although I attribute it to the same cause—contraction of the rock and deposition along surfaces of weakness. The conditions of formation in all probability were similar, since here the second flow of lava may have caused renewed heating of rock partially consolidated, as described by Prof. Bonney in Arran.

At Dinas-fach, on a weathered surface of dark red basalt are small, rather elliptical bodies (averaging $\frac{1}{4}$ inch in length) paler in colour or surrounded by a paler border.[3] The microscope shows that iron

[1] The partial analysis of this specimen is given on p. 148. It was taken from the low cliff, near the isolated boss on the beach described on p. 151, note.

[2] Geol. Mag. for 1877, p. 510 and fig. 3.

[3] Part of the surface exhibited radiate coral-like markings, which were probably limpet-tracks similar to those noted by the Rev. Edwin Hill; see Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 387, note.

oxide is concentrated in the centre; but the spherulite has very little radial structure. The variolite is found between the mass of green diabase forming the islet and the breccia containing spherulitic fragments, so that here also it appears to have relations with a complex of igneous rocks.

In the promontory south of Porth Orion the varioles are clearly connected with spheroids of the rock, recalling the description given by Mr. J. W. Gregory of a similar mass at Berneck.[1] The interior of the spheroids is purplish in colour or mottled: the exterior is generally green, surrounding a reddened zone. Spherulites developed quite at the outside are small and close, but the examples which at once attract attention on the cliff and on scattered blocks belong to that part of the spheroid where the green zone is passing to the next redder band (fig. 3, A, p. 150). These spherulites average about $\frac{1}{4}$ inch in diameter, standing out like peas on the weathered surface, and they are divided generally into a green rim and a red interior, but the red colour in some is confined to a central speck, in others extends over the whole.[2] The spherulites possess a shadowy radial structure, but no distinct mineral forms, while in the interior of the spheroid the constituents of the rock become better defined, but closely intercrystallized.[3] Radial groups starting from adjacent centres are confusedly interlocked, and the spherulitic habit is only discovered by microscopic examination.

The same relations in more rudimentary structures are found in the spheroidal diabase of Porth-din-lleyn on the north, and of Pared-llech-y-menyn on the south. At the former place, the spherulitic tendency in rocks which are not variolites was noted by Prof. Bonney, and he also described the spheroidal character well exhibited at certain parts. The two structures are sometimes related. Near the outer boundary in one spheroid,[4] a greenish palagonite includes small microporphyritic felspars, around which granular aggregations are clustered. These seem to form incipient spherulitic or axiolitic structures (Pl. I. fig. 6). Within this narrow peripheral zone, the spheroid is a confused mass of similar microlithic growth, as if the crystallization took place more slowly and uniformly; and about an inch from the outer surface is a band of small, irregular, sometimes radial cavities.

(c) *Development.*—Variolite has been defined as a "devitrified spherulitic tachylyte, typically coarse in structure."[5] I take the last phrase to mean:—with spherulites visible macroscopically, since the microscope shows complete gradations to rocks with no spherulitic tendency. The term thus retains its original connotation given in pre-microscopic days. Distinct spherulites, whether in acid or

[1] *Ibid.* vol. xlvii. (1891) p. 48, fig. 2.

[2] These appear to be very similar to those of Annalong, Co. Down, judging from Prof. Cole's description, Sci. Proc. Roy. Dub. Soc. vol. vii. (1892) p. 513.

[3] Cole and Gregory, Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 313 and pl. xiii. fig. 5.

[4] Obtained from the cliff near the boathouse.

[5] Cole and Gregory, *op. cit.* p. 330.

basic rocks, are bounded either by mutual planes of weakness or by an intervening magma differently consolidated.[1] An example of the first case is the Arran felsite, in which the polygonal boundaries, as was pointed out by Prof. Bonney, were probably due to the contraction which followed a renewed heating of the rock.[2] Where spherulites are separated by intervening palagonite, this is likely to be a modification of the original glass. If the temperature had been much raised subsequently, we might expect some marginal devitrification and the development perhaps of half-spherulites, as in the artificial example described by Prof. Bonney.[3] But the modified glass which borders cracks forms a zone outside any spherulitic or devitrified structure. Thus, although in a spheroid the fissures formed by contraction might allow the passage of residual heat, causing a secondary devitrification in the way suggested by Prof. Cole in Lipari obsidian,[4] I think that in these examples the formation of spherulites was generally a result of the original cooling. Structures developed in the two ways could not always be distinguished, but, as in the experiments of dry cooling,[5] it would seem that both conditions occur.

Considering the origin of acid spherulites, Mr. Iddings attributes the crystallization of certain portions of the magma to their being places of greater hydration;[6] Mr. Whitman Cross to the aggregation of a colloid substance.[7] In these andesites or basalts of the Lleyn we note frequently that spherulites have a concentration of iron oxide towards the centre, and since this substance is an early deposit, it is possible that, in somewhat basic magmas, its segregation might help to induce the formation of spherulites at certain spots.[8]

As original constituents, the spherulites seem to form in a mass where the rate of cooling is not uniform, and neither slow enough to allow of the development of well-formed crystals, nor so rapid as to give rise to a homogeneous glass. As Prof. Bonney has said, the conditions are probably found in a mass kept for some time at a

[1] See J. P. Iddings, 'Spherulitic Crystallization,' Bull. Phil. Soc. Washington, vol. xi. (1891) p. 451.
[2] Geol. Mag. for 1877, p. 510.
[3] Quart. Journ. Geol. Soc. vol. xli. (1885) *Proc.* p. 92.
[4] Min. Mag. vol. ix. (1891) p. 274.
[5] Quart. Journ. Geol. Soc. vol. xli. (1885) *Proc.* p. 93.
[6] Bull. Phil. Soc. Washington, vol. xi. (1891) p. 447.
[7] 'Constitution and Origin of Spherulites in Acid Eruptive Rocks,' *ibid.* pp. 436, 437.
[8] The iron oxide in these rocks often is not in its original condition, but although oxidation and hydration may have occurred, it seems probable that the spherulites are marked by an excess of the ferruginous constituent. In the well-known pyromeride-bearing felstone of Lea Rock, Shropshire, the iron oxide which causes the red-brown colour of the small spherulites may be only the result of subsequent change; but it is possible that a smaller proportion of iron is present in the surrounding matrix, in which no large amount of viridite or of any iron-containing constituent can be recognized on microscopic examination. It would seem to be impossible here to apply the final test of chemical analysis. Compare also some of the pyromerides of Boulay Bay, Jersey.

low temperature.[1] They would often occur where some freedom of motion is possible, as near the exterior of the rock-mass, at the boundary of contraction-spheroids, or along the lines of flow in a glassy magma.

In spheroids, which we may consider as a typical case, the order of changes might be something like the following:—The exterior forming a thin film, the rate of cooling in the next shell is so checked that crystallites begin to develop. In the viscid crust, iron oxide segregates at places constituting centres of growth. Radial and concentric cracking takes place, and further cooling causes the glass to 'set' along the fissures. In the ferruginous aggregates within the crust, the constituents group themselves, and a radial arrangement dominates the growth, thus giving rise to spherulites. The interior of the spheroid is still in a plastic condition,[2] and as soon as the crust is sufficiently solid, the fall of temperature in the part within takes place doubtless at a fairly uniform and somewhat slower rate, so that a confused intercrystallization of its elements results. At certain parts they are connected together in radial groups, but these are not definitely bounded, thus they do not weather out, and the rock where they occur is not a variolite.

The same succession of conditions would be found towards the exterior of a rock-mass, so that a variolite is limited sometimes to that part. A somewhat analogous case might occur in a moving lava-stream, where semi-plastic fragments are embedded in a more fluid part. The movement would tend to prevent the proper formation of spherulites, but the curious aggregations along the exterior of included pieces might be an incipient development.[3]

Some of the Lleyn variolite is thus a development of a lava; and where the magma was not an actual flow, it seems very probable that it cooled at no great depth below the surface, but was formed towards the exterior of an intrusive mass.[4]

Certain of the spherulites (as for example that from Deunant) are not unlike the variolite of Briançon, a specimen of which was kindly lent me for comparison by Prof. Bonney; but in the Durance rock the crystallization is more definite, and a chloritic constituent has developed, which seems to have been cleared out of the spherulite, so that this is paler, but is surrounded by a darker rim.

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 105. Compare also experiments of M. Claudet, referred to *ibid.* vol. xli. (1885) *Proc.* p. 90, note; Cole and Gregory, *ibid.* vol. xlvi. (1890) p. 326; J. W. Gregory, *ibid.* vol. xlvii. (1891) p. 61.

[2] This agrees with Mr. J. W. Gregory's suggestion, *ibid.* vol. xlvii. (1891) p. 60. See also Cole and Gregory, *ibid.* vol. xlvi. (1890) p. 316, and Delesse, 'Métamorphisme des Roches,' Paris, 1858, pp. 371–374.

[3] Some structures at Porth Oer are probably due to similar conditions. The development is shown clearly in a specimen from Boulay Bay, which I received from Prof. Bonney for comparison with nodules obtained near Pwllheli. See Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 264.

[4] See Prof. Cole's suggestion as to the Annalong dyke, Sci. Proc. Roy. Dub. Soc. vol. vii. (1892) p. 513.

The variolite is also similar in many respects to pyromeride-bearing rocks. Among the differences, we find that the more basic spherulites do not tend to become so large, the usual maximum in the Lleyn examples being about $\frac{1}{2}$ inch. The pyromerides also are generally distinguished by a smaller proportion of ferrite, and by clearer crystallization, due to the different chemical composition. As to form, the variole, although sometimes nearly spherical, has an elliptical outline more commonly than the acid spherulites, and this (and other characteristics) may be connected possibly with the more fluid character of a basic magma. In some examples veins and circular cracks occur,[1] similar to those seen at the exterior of pyromerides; but here the mode of formation is clear and indisputable, since the material of the spherulite is sharply different from that of the vein. In the more acid rock, the greater similarity of the two gives an appearance of gradation, which may have seemed to lend support to another inference.

VI. Pseudocrystallites.[2]

Microscopic examination reveals occasionally a clear network across spherulites or other parts of the greenish diabase. The bars of the net appear under a high power to be free from minute augite and epidote, and to be formed of felspathic granules, thus presenting some similarity to spherulitic rays. In the ferruginous variolite, bars of granular iron oxide are similarly developed, bordered by a clear isotropic substance, and where they cross the rays, these (for a short distance) are free from the brown deposit. This colouring material might have been withdrawn to any system of contraction-cracks if such existed; or in the crystallization of the felspathic constituent, iron oxide would be extruded, as occurs along spherulitic rays. Ferrite is aggregated around other crystals, probably pyroxene, which in one slide vary from a square to an oblong or lath-shape, sometimes so narrow that the dark border becomes a bar; and in other cases feathery tufts grow out on either side of the pseudocrystallite-axis. I am thus inclined to revert to the earlier explanation of these structures, and not to follow Mr. J. W. Gregory's idea of their being caused by contraction.

VII. Secondary Minerals.

Among the secondary minerals are the usual aggregates replacing felspar. Other crystals, probably originally pyroxene, enclose serpentinous, chloritic, or similar products, and are surrounded and crossed by deposits of iron oxide. A similar border of opacite is seen in two slides of trachyte from Auvergne, which were kindly

[1] See Mr. Iddings's description of a crescent-shaped area filled with felspar, in a spherulite from the Yellowstone Park, Bull. Phil. Soc. Washington, vol. xi. pp. 453, 454, pl. vii. fig. 4.

[2] Cole and Gregory, Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 313, 314; J. W. Gregory, *ibid.* vol. xlvii. (1891) pp. 56–58; Michel-Lévy, Bull. Soc. Géol. France, 3^{me} sér. vol. v. (1877) p. 238.

lent me for comparison by Prof. Bonney.[1] The minerals within amygdules and veins include epidote, quartz, a sheaf-like zeolite, calcite and other carbonates, and iron oxides. Doubtless in many cases these substances have been transferred from the rock, as in a dull-greenish diabase (north of Porth Oer) which has the structure of the basalt but not its colour, and contains small red amygdules, apparently filled by material drawn from the surrounding mass.[2] Some of the secondary deposits have been modified subsequently, and one veined specimen was described by Prof. Bonney, as illustrating the effects of pressure upon calcite.[3]

A carbonate of lime, magnesia, or iron, is one of the commonest secondary products. From microscopic study much of this appears to be dolomite or chalybite, although calcite is also present.[4] In many diabase-tuffs, it is scattered through the slide in small, clearer, rhomboidal spaces, often including reddish hæmatite. In the microcrystalline basalts, the secondary development is discovered only on application of polarized light, when a number of bright-coloured rhomboids suddenly start into view. These consist of the carbonate replacing lath-shaped felspars, but interrupted by the iron oxide. The deposit seems at places to creep up the felspar-microliths, so as to project beyond—and cause a slight irregularity in—the boundary-line of the rhomboid (Pl. I. fig. 1). Similar crystals are deposited in the Dinas-fach breccia within the felspathic rays; while elsewhere the wavy felspar-microliths of a small radial group have been replaced.[5] These pseudomorphosed spherulites, in polarized light, contrast with the surrounding duller mass by their bright pink and green tints.

Much of the change described is evidently due to infiltration, since rhombohedra of a carbonate, sparsely scattered in the mass, are thickly clustered along fissures or veins. Sometimes the rock appears to have been saturated throughout, the interchange of substance causing in both masses alterations of colour which can easily be recognized. The limestone generally assumes a pale peach tint, and fragments of basalt cemented by calcareous veins exhibit an outer zone of thin alternating laminæ, then a band of deep red, while the interior retains a normal duller tint.

The limestones which belong, as I believe, to the original series of rocks, would probably be a sufficient source for the calcareous deposits, without imagining the extension of Carboniferous or other masses of more uncertain age, and iron oxide must have been present in large proportion within the basalts.

[1] Compare Fouqué & Michel-Lévy, 'Minéralogie Micrographique,' 1879, pls. xxviii. and xxix.; U. S. Geol. Explor. of 40th Par. vol. vi. 'Micr. Petr.,' 1876, F. Zirkel, pl. iv. fig. 2, & pl. v. fig. 2.

[2] Radiate clusters of lath-shaped crystals project into the vesicles along their edge, the remainder of the space being filled with hæmatite.

[3] Geol. Mag. for 1889, p. 485.

[4] It has generally a granular texture, absence of cleavage and twinning, rhomboidal form in section, and high polarization-tints.

[5] This is seen in a Porth-felen basalt, and also within the spheroid described from Porth-din-lleyn.

VIII. Stratigraphical Summary of the District.

For study of the rocks in the field we are limited generally to exploration of the coast. Only rarely is any mass exposed inland above the surface of the drift, and most of such isolated outcrops were marked as the so-called 'serpentines.'[1] (See Map.)

My examination of Bardsey Island was somewhat hurried, and I did not explore the cliffs along its north-eastern coast, but its rocks are evidently similar to those in the neighbouring parts of the mainland. From a boat a good view is obtained of the coarser agglomerates (including large compact blocks and streaky laterite) which form the eastern cliffs north of Yr-henllwyn. The lower part of the island to the southward, on which the lighthouse is built, consists of well-banded, ashy rocks, sometimes fine-grained, with associated quartzose and calcareous masses. This series apparently forms the lowest strata exposed, since the dip is fairly steady over most of the island, as marked on the Geological Survey map. The extreme southerly point exhibits agglomerate, and also a purple basaltic tuff and a limestone included within a green diabase. At three places I found a coarsely crystalline rock, more or less crushed, probably intrusive and allied to the granitoid mass near Llangwnadl.[2] The most northerly of these includes a green mineral which is probably an altered biotite, while in the next example the compact pinkish mass is interrupted by large plates of silvery mica, doubtless a primary constituent subsequently modified. The third rock (on the west coast) has a wavy and interrupted lamination probably caused by pressure, the results of which can be recognized also in the microscopic section. Patches of a greenish, vermiform chlorite (doubtless prochlorite) extend in thin strings among the grains of quartz, which present the appearance of having been crushed and redeposited.

On the mainland, the eastern boundary-fault at Parwyd Cave brings down strata, probably of Ordovician age, against the contorted quartzose and micaceous schists of Mynydd Cristion. These have the appearance of an ancient series, and are probably related to the schists of Anglesey. Since similar types are found on Mynydd Ystum,[3] it is possible that an axis of Archæan rock strikes roughly north-eastward near the boundary-fault.[4] Along the south coast, westward of the schists, are rocks which appear to belong to the volcanic series. Some at least seem to be tuffs. The cliffs westward and northward most largely consist of ashy and agglomeratic strata, often schistose, and including grit and limestone (see Map). Over the hills of Mynydd-y-gwyddel and Mynydd Annelog, the rock

[1] T. G. Bonney, 'On the Serpentine and Associated Rocks of Anglesey; with a Note on the so-called Serpentine of Porth-din-lleyn,' Quart. Journ. Geol. Soc. vol. xxxvii. (1881) pp. 40–50. See Geol. Mag. for 1892, p. 408, and literature there quoted.

[2] Alfred Harker, Quart. Journ. Geol. Soc. vol. xliv. (1888) pp. 444–446.

[3] J. F. Blake, *ibid.* p. 533.

[4] I found near Tociau a similar specimen; it was loose, but close to the débris thrown up from the shaft of a small boring made in search of coal!

The outcrops of igneous rocks beyond the important lines of fault, which extend east of Llangwnadl, are copied from Mr. Alfred Harker's map in 'The Bala Volcanic Series of Caernarvonshire,' p. 59. The areas marked 'Lower Silurian,' with their faulted boundary, are taken from the Geological Survey map: these strata are probably of Ordovician age. The country west of the main faults which is left blank is generally covered with drift. Numerous diabase dykes cut the rocks along the coast of the Lleyn, but it is impossible to show them on a map of this scale.

is a banded hälleflinta, in which the layers are developed by weathering. A fine-grained argillaceous tuff can be seen near Porth Merin, and at other places north of it. These beds have a fairly continuous dip to the north-west and run out to sea in low points, while their truncated edges form a flattish platform, sometimes at the foot of low grassy cliffs of Drift. Small volcanic centres are perhaps marked by coarse agglomerates associated with igneous masses (as at Pared-llech-y-menyn and Maen-melyn-lleyn).[1] Elsewhere the diabase or basalt, sometimes standing as an isolated reef or islet, may have formed part of the pipe or reservoir of a small volcano, as at Dinas-fach, Dinas-fawr, and south of Porth Oer, while the extensive mass of variolite at Porth Orion probably is also connected with a centre of eruption. Lava-flows can be recognized in green palagonitic rocks (as at Careg, Porth Oer); also in vesicular basalt containing amygdules of calcite, as in a much-crushed specimen between Dinas-fach and Porth Oer, and in a very coarsely-vesicular rock west of Porth Witlin.

Volcanic rocks, massive and fragmental, have thus been traced from Bardsey Island to Porth-din-lleyn. They appear on the whole to form one series, apart from those intrusions which, judging from their lithological character, are probably of post-Ordovician age.[2] Green and purple layers among the schistose tuffs seem to be homologous with the two types of igneous rock, and the hälleflinta of the two southern hills is represented occasionally in interstratified bands of similar character. Grit and limestone, often in lenticular patches, varying from microscopic size to many yards in length, appear to be contemporaneous with the volcanic series, although the layers have been subsequently broken and squeezed. Gradations can be traced from limestone to ashy bands (as above Braich-y-pwll), or to a laminated basaltic mud, as if the finer volcanic débris was washed into calcareous waters. At Porth-din-lleyn, as I have shown,[3] small igneous fragments appear to be embedded. Limestone is also included in large blocks within the basalt, and in these and other examples the microscopic slide consists of very regular, uniform rhombohedra, suggestive of contact-alteration. It resembles the structure shown to me by Prof. Bonney in a piece of Trenton limestone, which had been caught up in a dyke at Corporation Quarry, Montreal. The grit consists mainly of quartz and of felspar, often plagioclase, sometimes microcline. It occasionally contains flakes of chlorite or mica, fragments of mica-schist or of a compact scoriaceous or igneous rock; and a grain of tourmaline occurs in one slide. The grit has evidently been derived partly from old granitoid rock and schists, and thus its accumulation must

[1] At this place, where the streamlet falls into the sea, is St. Mary's Well, of ancient repute. The trough-shaped pool of clear water, wherein grow delicate green algæ, is hollowed out at the foot of a vertical cliff of coarse agglomerate. The water is fresh and sweet, although the surface is a very few feet above the level of a calm sea at high tide.

[2] Geol. Mag. for 1892, p. 409.

[3] *Ibid.* p. 410.

have been separated from their formation by a long interval of time, such as everywhere parts the old Archæan from Pebidian or early Palæozoic rocks.[1]

The question of the geological age of these rocks is extremely difficult. Lithologically some of them resemble the Pebidians of Caernarvonshire or the northern district of Anglesey. At one place I found two badly preserved fossils in an indurated argillite,[2] which reminded me of Ordovician strata; but this may be a case of interfolding, and thus it gives no absolute proof of the age. I submitted the rock to Dr. Hicks, who kindly gave me his opinion, that it seemed "to belong to the Arenig Series,"[3] and that the organisms resembled phyllopod crustaceans.[4] Unless further details should be obtained, we must leave undecided the geological position of these volcanic rocks, and the question whether they belong to very late Archæan or to early Palæozoic time. But the uncertainty hardly seems to justify us in erecting a new system to contain these and other similarly dubious masses.

The stratigraphical interest of the area consists in its volcanic characters. Basaltic lavas occur, of which, as Mr. Harker points out, no other examples have been described in Caernarvonshire;[5] and a variolite is connected with contraction-spheroids, as in German and Alpine localities. The cliffs and low crags along the coast exhibit clear dissections of volcanic structures. Some igneous rocks seem to mark the remains of the reservoir or the vents from which lava flowed or fragments were ejected;[6] but most of the widely extended ashy deposits, especially the finer ashes, have probably come from more distant centres. The igneous masses and coarser agglomerates in the south-west and at places along the coast suggest that important vents were probably situate in parts now covered by the sea. The volcanic formations seem to have accumulated near a shore-line, where limestones were formed in shallow lagoons,[7] and where the waters deposited grit and mud, derived partly from ancient granitoid rock, partly from later volcanic materials.

[1] In several places, Prof. Bonney has pointed out the contrast shown by these Archæan and later series of rocks.

[2] Associated with the volcanic rocks of Pared-llech-y-menyn on the south coast.

[3] Dr. Hicks reported that this specimen and two from another locality were 'probably of Llanvirn age like the Pont Seiont Beds at Caernarvon.'

[4] The fossils were afterwards submitted to Prof. T. Rupert Jones, F.R.S., who has kindly favoured me with the note appended to the present paper, p. 164.

[5] 'The Bala Volcanic Series, etc.,' 1889, p. 75. Mr. Harker points out that the rocks at Porth-din-lleyn, previously described by Prof. Bonney, might include such examples. See papers quoted.

[6] The fine-grained clastic rock near the spring, north of Mynydd Annelog, possibly represents material thrown out from the small vent to the northward, since the constituents are similar, except in size. See Geol. Mag. for 1892, p. 413.

[7] The possibility of precipitation of carbonate of lime in shallow pools among volcanic detritus on land, as at the well-known Temple of Serapis, must not be overlooked.

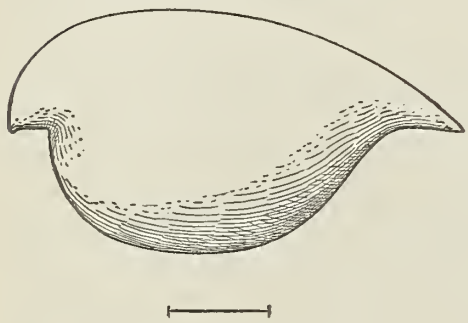
NOTE *on a* FOSSIL CYPRIDINAD *from the* SOUTH *of the* LLEYN.

By Prof. T. RUPERT JONES, F.R.S., F.G.S.

The two counterparts of a hæmatitic cast, one convex and one hollow, in the bluish-grey schistose mudstone, weathering brown, are too rough and imperfect in surface and in outline to give quite satisfactory evidence of the little organism they represent. It appears, however, to be a badly preserved ostracod of Cypridinad affinity, having a suboval or obovate body, with a hook and notch at the anterior end, and a strong caudal process posteriorly. It measures 9 by 5 millim.

Cypridina Raisiniæ, sp. nov.

[Enlarged 4 diameters.]



Analogous features in various degrees, and associated with other characteristics, exist in *Cypridina Reynaudii*, Milne-Edwards, *C. elongata*, Brady, *C. Bairdii*, Brady, *C. japonica*, Brady, and other hooded and apiculate members of the genus; but none of these have the hinder end tapering away to so long and strong a point. A fossil form, however, from the Carboniferous series of Sicily, described and figured by Prof. G. G. Gemmellaro (*Philomedes acanthoides*, Gemm., Mem. Soc. Ital. Sci. ser. 3, vol. viii. 1890, p. 37, pl. v. figs. 16 and 17), is very similar, but is too attenuate, and measures 6·5 by 3 millim.

Having a sufficiently distinctive form, this little fossil may be regarded as of specific value; and, in honour of Miss C. A. Raisin, the discoverer, I call it *Cypridina Raisiniæ*.

As far as I remember, the oldest Cypridinad yet published is the "*Cypridina*? Internal cast of a right valve, mag. about 4 diam. From a pebble of Palæozoic quartzite [1] in the Triassic conglomerate of Budleigh Salterton, Devon." Geol. Mag. for 1881, pp. 337 and 347, pl. ix. fig. 7.

EXPLANATION OF PLATE I.

Fig. 1. Ferruginous basalt, from the cliff at Maen-melyn-lleyn. Dolomite is seen by polarized light to replace felspar, and to form rhombohedral crystals, represented in the drawing by spotted rhomboids. The groundmass consists of felspar, of minute crystals (left blank), which are probably augite, and of dark granules and microliths of opacite. (Magnified 30 diam.)

Fig. 2. Ferruginous basalt, from the beach of the small cove north of Porth Oer. This slide shows the bent and wavy character, and somewhat spherulitic arrangement, of the felspar-microliths. The dark granular deposit is opacite, which partially separates the felspars of the groundmass. Parts of two amygdules are shown: these consist of quartz and dolomite or ankerite. (Magnified 30 diam.)

[1] Devonian or Lower Silurian.

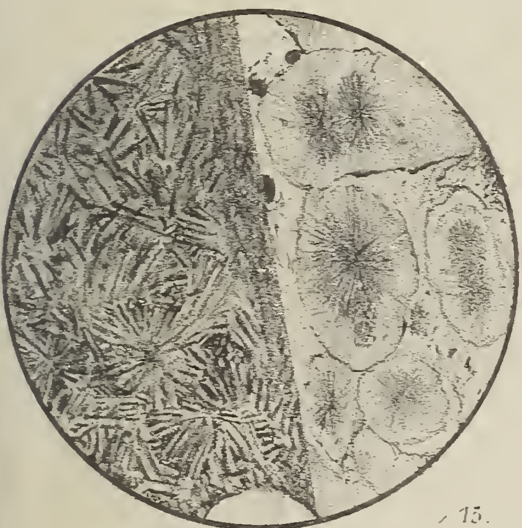
1.

2.

3.

4.

5.



6.

H. Michael del. et lith.

Mintern Bros. imp.

VARIOLITES AND ASSOCIATED VOLCANIC ROCKS OF THE LLEYN.

Fig. 3. Breccia, from a small quarry on the hillside west of Careg (north of Aberdaron), probably due to flow. The fragments show a tendency to fluxion-structure: they are bordered by small incipient spherulitic formations, within a thick deposit of opacite. The part left clear is mainly palagonite, probably an altered basic glass. A small crystal of felspar is contained within one fragment. (Magnified 8 diam.)

Fig. 4. From rock on the beach, at the eastern part of the isthmus of Dinasfach. A breccia, including fragments of a spherulitic andesite and of slate or argillite. The radial structure represents the spherulitic fragments, consisting mainly of felspar. The dotted parts represent pseudomorphic dolomite. The darker shaded fragments consist of argillite. The part between the fragments represents mainly palagonite, and the rock is probably a flow-breccia. (Magnified 30 diam.)

Fig. 5. Variolite, from the cliff north of Porth Oer. The spherulites shown on the right of the figure have a central part darkened by ferrite, and are contained within rings of granular deposit, somewhat similar to the boundaries in the specimen which was described from Arran by Prof. Bonney (see p. 156). This structure passes gradually to the part without distinct spherulites, shown on the left of the drawing. The groundmass here consists of granular opacite, and of felspar-microliths. (Magnified 15 diam.)

Fig. 6. Exterior zone of a spheroid from near Porth-din-lleyn, south of the lifeboat-house. This part of the spheroid shows incipient spherulitic structure in the form of non-radial aggregates, which in many cases are grouped around felspar-microliths. The slide is crossed by a vein filled with a secondary deposit or palagonite. The small group of spherules to the left of the vein, which is less shaded in the drawing, is seen under polarized light to be pseudomorphosed, showing the bright pink-and-green colours of dolomite. (Magnified 20 diam.)

Discussion.

Prof. Judd complimented the Authoress on the evidently great amount of labour and patient research devoted to this investigation. He thought the occurrence of the spherulitic structure round the surfaces of 'pillow-like masses' similar to those described by Prof. Dana was exceedingly interesting, especially when one considered the probably very great antiquity of these Caernarvonshire rocks. He thought, also, the suggestion that early crystallized magnetite-grains had formed the nuclei of the spherulites was a very interesting and probable one.

Mr. Harker expressed satisfaction at the further discovery of variolites in Britain—rocks presenting interesting points of resemblance to those known in Savoy, Hesse, and Bavaria. He anticipated that the detailed researches of the Authoress would throw light on the nature of these spherulitic structures in basic igneous rocks.

Prof. Bonney said he believed that the variolite described by the Authoress was the third example in the United Kingdom, that discovered by Mr. Blake in Anglesey being the first, and that found by Prof. Cole in Ireland the second. He referred to the question of the origin of spherulites, and stated his opinion that this paper, the fruit of much labour, would prove a valuable contribution to our knowledge of the subject.

Prof. Hull and Prof. J. F. Blake also spoke.

11. NOTES *on the* GEOLOGY *of the* DISTRICT WEST *of* CAERMARTHEN. *Compiled from the Notes of the late* T. ROBERTS, Esq., M.A., F.G.S. (Communicated by Prof. T. McKENNY HUGHES, M.A., F.R.S., F.G.S. Read February 8th, 1893.)

THE following paper has been written by Mr. J. E. Marr, M.A., F.R.S., Sec.G.S., from notes made by the late Mr. Thomas Roberts, M.A., F.G.S. The value of the work is guaranteed by the fact that so competent an authority as Mr. Marr has thought it desirable to place Mr. Roberts's observations on record, and has given much of his valuable time to the verification of the facts and the arrangement of the notes in a form suitable for communication to this Society.

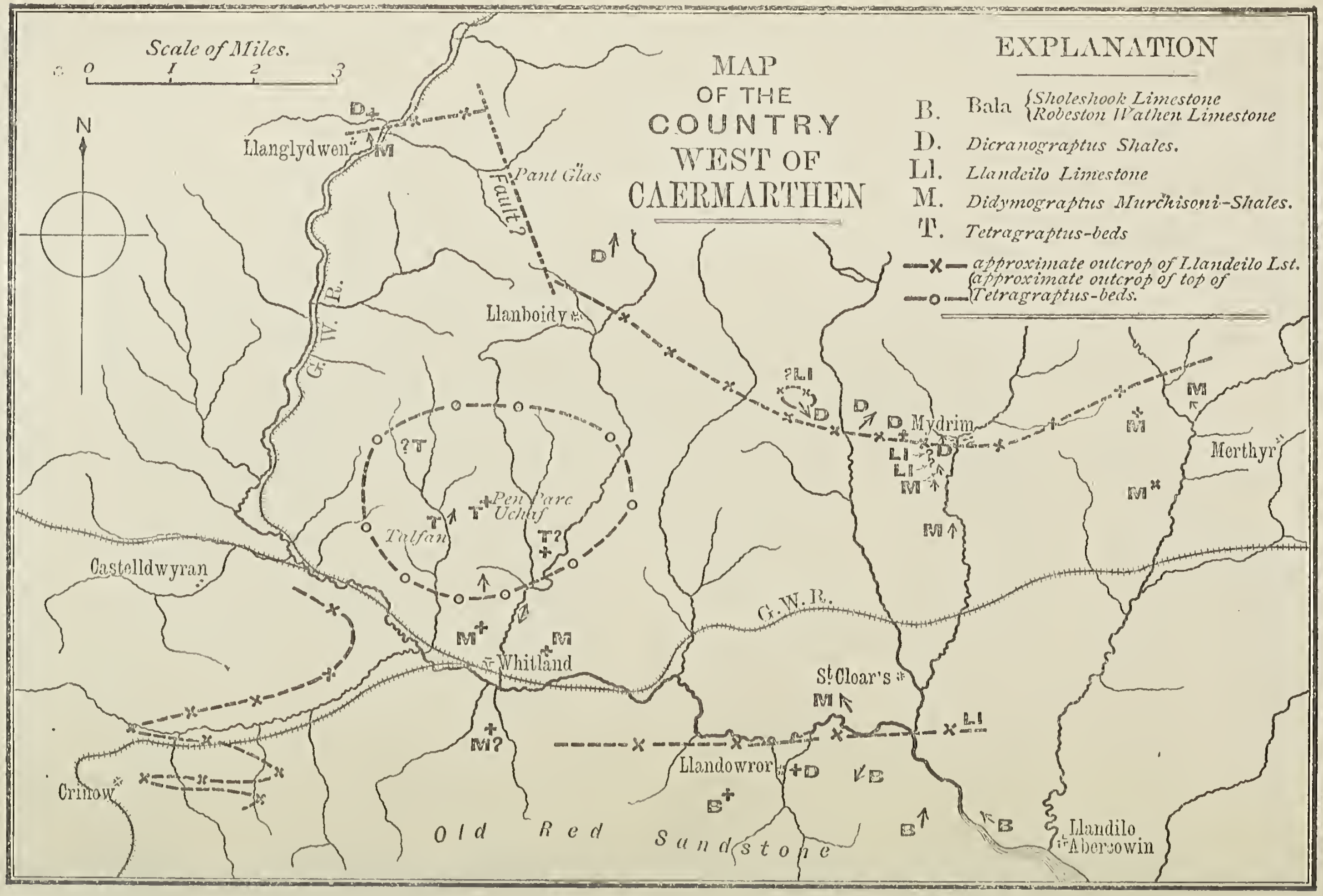
T. McKENNY HUGHES.

In a paper published in the Society's Journal in the year 1885 [1] a complex synclinal of Lower Palæozoic rocks occurring in the neighbourhood of Haverfordwest was described. Owing to the occurrence of a fault at the northern side of that synclinal, no strata of Arenig age were noticed in the paper, the oldest Ordovician beds referred to being the *Didymograptus Murchisoni*-shales below the Llandeilo Limestone in the neighbourhood of Narberth, at the south-eastern end of the synclinal. It seemed important, therefore, to work the strata lying east of Narberth in order to try and discover Arenig Beds in the district between that town and Caermarthen. This was accordingly done in some of the vacations between 1886 and 1890, and a complex anticlinal was discovered lying north-east of the Haverfordwest synclinal, having its oldest beds exposed north of Whitland. The accompanying map shows the general distribution of the beds in this anticlinal, no attempt being made to trace accurate boundary-lines; but two approximate boundaries are drawn at the top of the *Tetragraptus*-beds (to be presently described) and along the line of outcrop of the Llandeilo Limestone respectively, in order to show the general distribution of the strata and the nature and direction of the anticlinal. The beds may be described, in ascending order, as follows :—

1. *Tetragraptus*-beds.—These beds consist of alternating conglomerates, shales, and grits, seen at Talfan, Pen-parc-uchaf, and probably near Whitland Abbey, all places lying generally north of Whitland. The shales have yielded graptolites, kindly determined by Prof. Lapworth, as follows :—

Dictyonema	North of Talfan.
Dendrogaptus, sp.	*Ibid.*
Didymograptus nitidus, Hall	*Ibid.*
—— *patulus*, Hall	North of Talfan and Pen-parc-uchaf.
Tetragraptus Headi, Hall	North of Talfan.
—— *serra*, Brongn.	*Ibid.*
Callograptus Salteri, Hall	*Ibid.*
—— *persculptus*	*Ibid.*
Dichograptid	*Ibid.*

[1] Marr and Roberts, Quart. Journ. Geol. Soc. vol. xli. p. 476.



MAP
OF THE
COUNTRY
WEST OF
CAERMARTHEN
EXPLANATION
B. Bala {Sholeshook Limestone / Robeston Wathen Limestone
D. Dicranograptus Shales.
Ll. Llandeilo Limestone
M. Didymograptus Murchisoni-Shales.
T. Tetragraptus-beds
approximate outcrop of Llandeilo Lst.
approximate outcrop of top of Tetragraptus-beds.
Scale of Miles.
0 1 2 3
N
Llanglydwen
Pant Glas
Fault?
Llanboidy
G. W. R.
Pen Parc Uchaf
Talfan
Castelldwyran
Whitland
Crinow
Mydrim
Merthyr
St. Cloar's
Llandowror
Llandilo Abercowin
Old Red Sandstone

The fossils enumerated above prove the Arenig age of these rocks.[1]

2. Beds with 'tuning-fork' *Didymograpti.*—These strata have been noted in a previous paper,[2] as passing beneath the Llandeilo Limestone of the neighbourhood of Narberth. In the district now being described we meet with them in many places around the dome of the *Tetragraptus*-beds, and they must immediately succeed these beds, though the arrows shown on the Geological Survey map in the neighbourhood of Whitland suggest the occurrence of an overfold or fault, owing to which the black shales with 'tuning-fork' graptolites dip at or under the *Tetragraptus*-beds.

Didymograptus Murchisoni and other 'tuning-fork' graptolites have been chiefly found in localities which, for convenience, may be referred to three north-and-south lines. The first of these runs from Whitland in a northerly direction to Llanglydwen, and graptolites have been obtained at Pen-y-coed, $\frac{1}{2}$ mile north-east of Whitland, and at Llanglydwen itself. Along this line also black shales occur south-west of Middleway (south of Whitland) containing nodules showing cone-in-cone structure, and with several species of *Bellerophon.* These shales possibly belong to the beds under consideration, as do almost certainly some shales by the roadside north of Pwll-y-rhwyaid, south-west of Whitland Abbey, with a small *Caryocaris* and tails of the same, or a *Theca.*

The second line runs from St. Clear's in a northerly direction to Mydrim. 'Tuning-fork' graptolites have been collected from the shales of Pen-y-craig, 1 mile west of St. Clear's, and from those of a quarry $\frac{1}{4}$ mile north of Plas-parcau, between St. Clear's and Mydrim. They have also been discovered in the following places in the neighbourhood of the third line near Merthyr:—Melin-ricket, Penllwynbach, and Cwm Treharn.

No attempt has been made to separate the Upper Arenig Beds from those of Lower Llandeilo age, though this may be done by further work. All that can be said is that we are here dealing with beds corresponding to Dr. Hicks's Llanvirn Group, and that they are newer than the *Tetragraptus*-beds of Arenig age, and older than the Llandeilo Limestone.

3. Llandeilo Limestone.—This rock is well shown north of Pant-dwfn, near St. Clear's, where it is of the character usual in this Southern Welsh area, and contains:—

Asaphus tyrannus, Murch.
Homalonotus.
Calymene cambrensis, Salt.
Beyrichia complicata, Salt.
Orthis testudinaria, Dalm.
Strophomena compressa, var. *llandeiloensis*, Dav.

It doubtless passes beneath the Old Red Sandstone at no great distance from this section, on both the east and west sides.

[1] [Other rocks, probably of Arenig age, occur at and near Henllan Amgoed, somewhat farther north. These are grits with *Orthis*, and trilobite-shales with abundant specimens of *Ampyx*; the specimens obtained from these localities cannot be found.]

[2] Marr and Roberts, *op. cit.*

On the northern side of the anticlinal, the presence of the Llandeilo Limestone has not been absolutely determined. At Llanglydwen the beds with 'tuning-fork' graptolites are found on the southern side of the 'Castell,' while *Dicranograptus*-shales are seen on the northern side. The Llandeilo Limestone should come between these, and may be faulted out, or it may be present and not exposed. The rock at Llanglydwen marked as limestone on the Geological Survey map is an ash. A sandy limestone is seen by the roadside north of Penlan, near Mydrim, dipping N.E. At Mydrim, where the *Dicranograptus*-beds occur north of the village and dipping northward, the church stands on black shales with nodules of limestone, which may represent the Llandeilo Limestone.

South of Mydrim, some gritty shales are found in a quarry south of Pant-rhendref. They contain many *Trinuclei*, together with *Acidaspis* and *Bellerophon*, and, as they intervene between the shales with 'tuning-fork' *Didymograpti* and the *Dicranograptus*-shales north of Mydrim, they may be parts of the Llandeilo Limestone Series. The species have not been determined, but the rock does not closely resemble any member of the Llandeilo Limestone in the vicinity, and beds of a different age may possibly be folded or faulted in here. These beds certainly merit a further examination.

4. *Dicranograptus*-shales.—On the southern side of the anticlinal, these shales with characteristic graptolites are found near St. Clear's, where a list of fossils was long ago recorded by Prof. Lapworth from the graptolitic shales of that place.[1] Graptolites may also be seen in the shales of a section on the second 'l' of Llandowror (on the Survey map), where *Climacograptus tubuliferus*, Lapw., is abundant.

On the northern side of the anticlinal the *Dicranograptus*-shales occur at Dyffryn-pwdrim, near Llanboidy, with *Dicellograptus* and *Orthis argentea*, His., also in the following places at and near Mydrim:—North of Mydrim Church, Maenllwyd, Llangarth-gynin, and north of Penlan. Much work remains to be done in these highly convoluted shales, which have already yielded so many Hartfell species, and which will no doubt furnish characteristic Glenkiln forms after further search.

5. Robeston Wathen and Sholeshook Limestones.—These Caradoc and Upper Bala Limestones are often welded together, so that it is difficult to separate them, without minute examination of the forms. The two formations are possibly represented at Llandowror, near St. Clear's, where the following fossils have been found in a limestone which is like the Sholeshook Limestone:—

Calymene senaria, Cour.
Cheirurus juvenis, Salt.
—— *bimucronatus*, Murch.
Cybele verrucosa, Dalm.
Illænus Bowmanni, Salt.
Stygina.
Orthis calligramma, Dalm.

The same formations may also be present (one of them certainly is)

[1] Ann. & Mag. Nat. Hist. ser. 5, vol. iv. (1879) pp. 339–340.

both at Feynor, south-west of Llandowror, where *Cybele verrucosa*, Dalm., *Illænus Bowmanni*, Salt., and an *Orthoceras* have been found, and at Foxhole, 2 miles south-east of St. Clear's, where *Cybele verrucosa* has also been obtained.

No representatives of these beds have yet been seen on the northern side of the anticlinal, and no higher beds of the Lower Palæozoic succession have been definitely determined in either limb of the anticlinal, unless a series of grits and conglomerates north of Cerrigwyn, about 3 miles east of St. Clear's, should belong to a higher group.

The rock marked *Fs* b 2 on the Survey map, near Llangynog, appears to be a diabase.

It is hoped that these brief notes may assist anyone engaged in working out the details of this district. They furnish a connecting link to unite the better-known strata around Llandeilo with those in the district about Haverfordwest.

Discussion.

Dr. Hicks said he felt sure he was expressing the feelings of the Fellows in referring to the serious loss which the Society had suffered by the death of Mr. T. Roberts, who certainly was one of the most promising palæontologists in this country. The important researches which he carried on, in conjunction with Mr. Marr, had made it now comparatively easy to understand some intricate and extensive districts in Pembrokeshire and Caermarthenshire, which previously were little more than blanks on the Geological Map.

12. *On some* Additional Remains *of* Cestraciont *and* other Fishes *in the* Green gritty Marls, *immediately overlying the* Red Marls *of the* Upper Keuper *in* Warwickshire. By the Rev. P. B. Brodie, M.A., F.G.S. (Read December 21st, 1892.)

So brief a notice on so limited a subject may seem hardly worthy of the Geological Society, but as a supplement to my former paper published in this Journal in 1887[1] on the section and fossils from the Upper Keuper Sandstone at Shrewley, three miles north-west of Warwick, it may perhaps be acceptable.

Immediately below the lowest bed of rock, the best and thickest of the sandstones, about 9 feet of grey and green, coarse, sandy marls succeed, resting on red marls. In these green marls no fossils had been hitherto found, except the tests of *Estheria minuta*, often in good preservation; but I have now to record the discovery of numerous large and small spines (ichthyodorulites) of cestracionts, besides palatal teeth of *Acrodus keuperinus*, which are abundant, ganoid fish-scales, and many broken bones, including a fragment of a cranial bone, some of which may belong to fishes and others to labyrinthodonts. These occur in a very thin band of marly, friable, gritty sandstone, full of many small rolled pieces of grit,[2] lying between two beds of green marl; but at a little distance east the same bed is a green marl without any intermixture of sand, containing similar fossils.

The entire length of the section exposed is 115 yards: the green marls predominate, but alternate with six thin layers of sandstone, a thicker one coming just below the 'bottom-rock.' The total thickness of these strata, between the latter and the underlying red marls, is about 8 or 10 feet; while the Ichthyodorulite-bed does not exceed 2 inches, and is 10 inches above the red marls, though not so thick at the eastern end near the tunnel. Towards the middle of the section it does not exceed 1 inch, and is replaced by green marl with bones of fishes, but without any admixture of gritty particles.

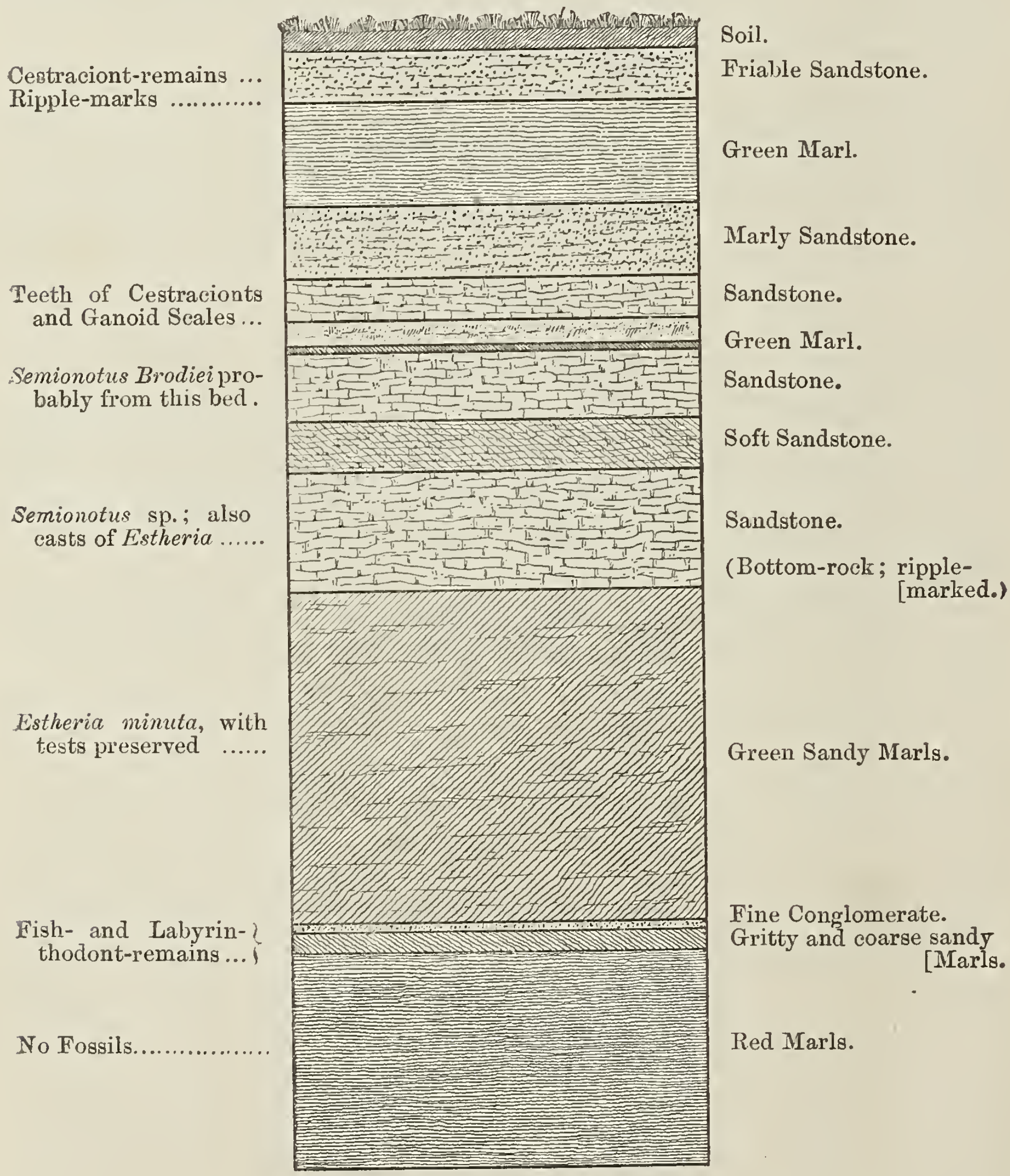
The indurated green and red marls have a somewhat irregular surface, and, including the overlying sandstones, have a slight easterly dip. In the fossiliferous gritty marl, bones and teeth are so numerous that it might almost be called a bone-bed; it does not exceed 3 inches in thickness. It extends across the canal, and no doubt could be traced farther northward beneath the sandstones. It is impossible to obtain any large slabs, or indeed any considerable quantity of pieces, otherwise many more interesting organisms (probably in better preservation) might be found. Unfortunately,

[1] Vol. xliii. p. 540.

[2] I forwarded some of these rolled fragments to my friend, Prof. Rupert Jones, F.R.S., who reports that, although some of them are not unlike Entomostraca, he could not positively affirm that they were identical, and they rather appear to be rolled relics of some organism, such as shell- or test-fragments, or perhaps in one or two cases crinoid-ossicles; while the smooth, shining particles of grit seem as if they had come from windworn sandbanks into shallow water.

these coarse sandy marls are so saturated with water and so excessively friable that no entire specimens, but only mere fragments can be secured, though they appear to belong to the same species as the well-preserved spines in the sandstones, and the acrodont teeth certainly are much more numerous. The occurrence of these abundant remains of cestracionts and other fishes (ganoids) lower

Section in the Upper Keuper at Shrewley, Warwickshire.



Vertical Scale: $\frac{1}{8}$ inch = 1 foot.

[The total height of the section is about 33 feet.]

Note.—Several of the sandstones are good building-stones; some are current-bedded, with footprints of *Labyrinthodon.* These footprints appear to be confined to one hard, fine-grained sandstone, the exact position of which I have never been able to ascertain.

down in the section proves their existence at a somewhat earlier date in the Upper Trias hereabouts, and therefore the section has a certain amount of interest for the palæontologist. It is more especially worth recording, considering the remarkable absence of life in the British Trias as a whole.[1] Only a few remains of fishes have been found in it, and those chiefly in Warwickshire, though *Semionotus* was discovered by Mr. Edw. Wilson near Nottingham, and the remarkable and unique *Dipteronotus* in the Lower Keuper Sandstone at Bromsgrove. Footprints of *Labyrinthodon* are frequent in various places in the New Red Sandstone generally, but notably in Warwickshire, Staffordshire, and Cheshire, and a fine collection of reptilian and labyrinthodont remains is preserved in the Museum of the Natural History Society at Warwick.

No remains of the possible Lacertilian *Rhynchosaurus* have been as yet detected in that county, and they appear to be confined to Grinsill in Shropshire, where a few skulls and some footprints are preserved. The last apparently existing *Palæoniscus* (*P. superstes*, Egerton), which I found many years ago at Rowington, was obtained from a rubbly sandy marl associated with the sandstones, and higher up than the green gritty marls above referred to. *Semionotus Brodiei*, Newton (Quart. Journ. Geol. Soc. vol. xliii. 1887), was discovered at Shrewley in the sandstones above the 'bottom-rock.' In the latter another, better-preserved, and larger fish was found, measuring about 5 inches in length, the head and scales being well shown, which has yet to be figured and described, if the owner will lend it for that purpose, and which Mr. A. Smith Woodward, Assistant Keeper of the Department of Geology in the British Museum (Nat. Hist.), has lately had the opportunity of seeing. I may also add that, in looking over my collection from the New Red Sandstone, the same palæontologist noticed a specimen of selachian cartilage which he thinks is probably the upper jaw of a hybodont: this was associated with other cestraciont-remains in the Upper Keuper Sandstones at Shrewley. He moreover recognized from the Lower Keuper at Coten End, Warwick, a tooth of *Ceratodus*: the only other one, from Ripple, in Worcestershire, is now in the British Museum (Natural History).

So far as I know at present, the quarry at Shrewley is the only one open in this part of the county, and although the sandstone was largely quarried in the olden times, especially at Rowington, for building purposes, it is unfortunately no longer worked. There is plenty of useful stone there, the best being the 'bottom-rock,' still available.[2]

[1] There are so few sections in the Keuper anywhere in Warwickshire that, scarce as fossils generally are, many perhaps might be obtained if more quarries were opened. The quarry at Coten End, Warwick, has lately been worked, and a nearly perfect jaw of *Hyperodapedon* was found, showing most of the teeth in place and the underside well exposed. It is probably the best specimen as yet discovered here, and is now in the possession of Mr. Gavin Jack, by whom, at my suggestion, it was sent to Mr. E. T. Newton, of the Geological Survey, for examination.

[2] Messrs. Richards and Jack, two ardent young geological students at Warwick, were present with me when we first detected the Ichthyodorulite-bed, and drew my attention to the fossils mentioned in this paper. They also, at my request, traced the bed on the opposite side of the canal, and obtained numerous teeth and spines. Many of the latter could have been got out entire, if the bed had been more accessible.

[*Note.*—Since the foregoing communication was read, Mr. Richards, who accompanied Mr. Jack and myself in examining and working out the section at Shrewley, has detected the thin fossiliferous bed immediately overlying the red marl at three other places a few miles off, in a south and south-westerly direction; and he states that it covers there an area of about six square miles. He has also traced it at other spots in the north-west. It differs slightly in thickness, varying from one to three-quarters of an inch. The lithological characters agree generally with those at Shrewley. The 'bottom-rock' with *Estheria* was observed at one spot; and in each section palatal teeth of *Acrodus keuperinus* were abundant, also a few fish-scales were found, but no spines. The further extension of this thin stratum over a wider area is of some interest, and now it may be looked for in other directions where the Upper Keuper is exposed.—February 25th, 1893.]

Discussion.

The Chairman (Prof. Judd) congratulated the Society on the presence of one of its Fellows who had been connected with it for nearly sixty years, and had read his first paper almost half a century ago. He hoped that the Society would still continue to receive communications from the same source of like interest and value.

Mr. J. W. Davis congratulated the Author on the discovery of another horizon containing the remains of fossil fishes and labyrinthodonts. In the Keuper strata of Yorkshire no such beds had yet been discovered, and this addition was peculiarly interesting on account of its rarity. Only a short time ago the Author discovered *Semionotus* in the beds a little higher in the series; and it was a great pleasure to find that Mr. Brodie still retained his love for field-work, and was able to bring the results of his observations before the Society. He hoped this would not be the last opportunity the Fellows would have of listening to Mr. Brodie's description of his work.

Mr. H. B. Woodward referred to some specimens of a bone-bed collected by Mr. A. Strahan and himself, from Gold Cliff, near Newport, in Monmouthshire. This bone-bed (to which attention had first been directed by J. E. Lee) occurred 3 feet down in the green marls below the black *Avicula contorta*-shales, and it contained remains of *Gyrolepis*, *Saurichthys*, and *Hybodus*. It thus occurred in the debatable region between the red Keuper marls and the Rhætic shales. The discovery by Mr. Brodie of another bone-bed at a lower horizon was of much interest in showing the intimate connexion between Keuper and Rhætic Beds.

Mr. E. T. Newton also spoke.

The Author, in reply, expressed his gratitude to the Fellows for their kind reception of himself and his paper. He was sorry that there was not much likelihood of his being able to carry on many further researches in his district, there being now so little chance of making new discoveries in the Warwickshire area.

13. *On* INCLUSIONS *of* TERTIARY GRANITE *in the* GABBRO *of the* CUILLIN HILLS, *Skye: and on the* PRODUCTS *resulting from the* PARTIAL FUSION *of the* ACID *by the* BASIC ROCK.

By JOHN W. JUDD, F.R.S., V.P.G.S., Professor of Geology in the Royal College of Science, London. (Read January 25th, 1893.)

[PLATES II. & III.]

CONTENTS.

1. THE LITERATURE OF INCLUSIONS IN IGNEOUS ROCKS.

THE striking results of extreme contact-metamorphism, displayed by fragments of rock which have lain for a time in the bath of a molten igneous magma, have been frequently described by geologists and petrographers. Among sedimentary materials which have been thus acted upon, we may refer to the more or less perfectly vitrified products formed from arenaceous rocks (*verglaster sandstein*); the greatly altered and highly crystallized forms of argillaceous masses—so often mistaken for basalts, before the application of the microscope to their study—(*jaspisschiefer, kieselschiefer*, 'phthanite, lydite, hydrotachylyte,' etc. of different authors); and the calcareous or dolomitic rocks, so wonderfully rich in beautifully crystallized minerals that have resulted from the action of molten lavas or fragments of limestone entangled in them. Such extreme results of contact-metamorphism may be studied, either in the localities where the operations have taken place, as at Monzoni in the Tyrol;[1] or among the fragments thrown out from volcanic vents, as at Monte Somma and the Eifel.

The phenomena displayed, when fragments of an igneous or other crystalline rock are caught up and enveloped in a molten material of different chemical composition, have received no less attention from petrographers. Some of the results of this extreme action have been regarded as so anomalous that they have given rise to much discussion. Without attempting to make an exhaustive list of works on this question, I may refer to the following memoirs as especially bearing on the point discussed in the present paper.

[1] Geol. Mag. for 1876, pp. 211–213.

As long ago as 1859 Mitscherlich brought forward the results of his studies of the rock-fragments entangled in the lavas of the Eifel, though his memoir was not published in full till 1865.[1]

Between the years 1862 and 1865 an animated controversy was carried on with respect to some of the very highly-altered materials found enclosed in igneous rocks of the Kaiserstuhl by H. Fischer, von Hochstetter, and Kenngott:[2] and in 1880 John Arthur Phillips very fully discussed the points of distinction between greatly altered and recrystallized foreign inclusions and the remarkable segregation-nodules found in many granites.[3]

We are indebted to J. Lehmann for a very interesting memoir, published in 1874, in which he fully described the alteration of the several minerals in the various aqueous and igneous rocks found among the ejected materials, or enclosed in the lavas, of the Eifel volcanoes:[4] a subject which had, as we have seen, earlier engaged the attention of Mitscherlich. In 1880, L. Van Werveke returned to the discussion of the foreign fragments enclosed in the igneous masses of the Kaiserstuhl, and described a clear case of gneiss caught up in nephelinite.[5] In 1884, F. von Sandberger gave an account of fragments of rock caught up in the basalt of Naurod:[6] in the following year von Chrustschoff described the enclosures of granite in the basalt of Striegau,[7] while still more recently, in 1890, A. Lacroix has given a very full and interesting account of fragments of foreign igneous rocks contained in the lavas of Auvergne.[8] In the same year there appeared the valuable memoir of H. Bäckström on the inclusions of augite-granite and other rocks in basic eruptives in Scandinavia.[9] Within the last year (1892), Fr. Graeff has again taken up the discussion of the included masses in the Kaiserstuhl eruptives.[10]

A series of phenomena somewhat similar to those found in natural lavas were described by E. Hussak, in 1880, as resulting from the fusion of basalt and the enveloping of pieces of granite by

[1] E. Mitscherlich, 'Ueber die vulkanischen Erscheinungen in der Eifel, und über die Metamorphie der Gesteine durch erhöhte Temperatur,' Abhandl. d. königl. Akad. d. Wissensch. Berlin (Phys.), 1865, pp. 1–68.

[2] See Verh. Naturf. Gesellsch Freib.-i.-B. vol. ii. p. 407, vol. iii. pt. 2, p. 1, pts. 3 & 4, p. 165, and also Verh. d. k. k. geol. Reichsanst. 1865, pp. 3–7.

[3] 'On Concretionary Patches and Fragments of other Rocks contained in Granite.' Quart. Journ. Geol. Soc. vol. xxxvi. (1880) pp. 1–22.

[4] 'Untersuchungen über die Einwirkung eines feurig-flüssigen basaltischen Magmas auf Gesteins- und Mineral-Einschlüsse, angestellt an Laven und Basalten des Niederrheins.' Verh. des Naturh. Vereins der preuss. Rheinl. u. Westf. 1874, pp. 1–40.

[5] 'Gneiss-Einschlüsse aus Nephelinit von Oberbergen am Kaiserstuhl,' Neues Jahrb. 1880, vol. ii. p. 283.

[6] 'Neue Einschlüsse im Basalt von Naurod bei Wiesbaden.' Verhandl. d. k. k. geol. Reichsanst. 1884, p. 17.

[7] 'Mikropetrographische Mittheilungen.' Tschermak's Mineral. u. Petrogr. Mitth. vol. vii. (1885) p. 295.

[8] 'Sur les Enclaves Acides des Roches Volcaniques de l'Auvergne,' Bull. des Serv. de la Carte Géol. de France, No. 11 (vol. ii).

[9] 'Ueber fremde Gesteinseinschlüsse in einigen Skandinavischen Diabasen.' Bihang till Svenska Vetensk.-Akad. Handlingar, vol. xvi. pp. 1–38.

[10] Mitth. der Grossherzogl. Badischen Geol. Landesanst. vol. xiv. p. 405.

the fused mass, which was observed by him in the walls of a disused limekiln.[1] Mr. Rutley's investigations upon various rocks which had been submitted to the action of heat in a glass-furnace for considerable periods of time,[2] and Doelter and Hussak's researches on the action of molten magmas on various minerals,[3] also throw light upon some of the questions raised by the study of rock-inclusions in liquid lavas; nor are the well-known observations of Sir James Hall, Gregory Watt, Sorby, Waller, and many others who have experimented on the fusion of rocks, without bearing on these enquiries.

These observations have made tolerably familiar to geologists the nature of the changes which are induced in the several minerals of rocks, when they are exposed to a temperature sufficiently high to produce partial fusion; they have at the same time shown how frequently spherulitic structures are developed in the groundmass of rocks placed under such conditions, and caused to soften if not actually to fuse.

The interesting question of the changes produced in igneous rocks that have been subjected to partial re-fusion has also been discussed in some other memoirs to which I must call especial attention, seeing that the phenomena described have a very close analogy indeed with those that are considered in the present paper. In 1877 Prof. Bonney showed that, at two points in the Island of Arran, a remarkable spherulitic structure has been developed in acid rocks (quartz-felsites) where they are in contact with other igneous masses that have been intruded into them.[4] On the Corriegills shore this effect has been produced by the intrusion of a mass of pitchstone; while north of Drumadoon the agent of alteration is a basic protrusion. At both localities I have been able to verify the very interesting observations of Prof. Bonney.

2. The Products of the Re-fusion of Quartz-Felsite Fragments by the Basalt of Ascherhübel, Saxony.

The geologists of Saxony have long been acquainted with a remarkable case of the enclosure of fragments of an acid rock in one of basic composition, and the results in that case are so similar to those here described from the Western Isles of Scotland that I must refer to it at somewhat greater length: more especially is this necessary as the details which enable us to make the comparison have only very recently been laid before the scientific world.

More than twenty years ago, when visiting Freiberg, I obtained

[1] 'Umgeschmolzene Basalte und Granite von Edersgrün bei Karlsbad,' Verh. d. k. k. Reichsanst. 1880, p. 314.

[2] 'Notes on the Alteration induced by Heat in certain Vitreous Rocks, based on experiments of Douglas Herman and G. F. Rodwell,' Proc. Roy. Soc. vol. xl. (1886) pp. 430–441.

[3] 'Ueber die Einwirkung geschmolzener Magma auf verschiedene Mineralien,' Neues Jahrb. 1884, vol. i. pp. 18–44.

[4] Geol. Mag. for 1877, pp. 505–509.

from E. Neumann, an optician in that town, who was one of the earliest makers of microscopic slices of minerals and rocks, a thin section which at the time arrested my attention and has often since been referred to with interest. It bore the label *Dopp. geschm. Porphyr, Grillenburg*; but the maker of the section was unable to afford me any information concerning the origin of the specimen or the authority on which it had been described as a 'doubly-melted porphyry.' The microscopic examination of the specimen, however, seemed to indicate that it had been correctly labelled, and that it was indeed a rock of very considerable interest. While parts of the section show the characters belonging to the well-known 'quartz-porphyry' of Specthausen and Tharandt, there are other portions which pass into a perfect glass. In this glassy part there are traces of flow-structure, with incipient spherulites and perlitic cracks. Every gradation, indeed, can be traced from nearly unaltered 'porphyry' to a perfectly vitrified material, and from a clear glass to one in which all the earlier stages of devitrification can be unmistakably recognized.

For a long time I was quite foiled in my endeavours to obtain any trustworthy information concerning this remarkable specimen—of the source from whence it was derived, or the authority on which it was labelled. Some time ago, however, Prof. Zirkel and Prof. Credner kindly interested themselves in the matter, and as a consequence of the communications which they have made to me I have been enabled to clear up my doubts on the subject. The specimen must evidently have been obtained, not from the locality named, but from Ascherhübel, which lies about 3 kilometres north of a village now known officially as Grüllenburg, but which was formerly called Grillenburg. This locality is in the kingdom of Saxony, and is nearly equidistant from Freiberg and Tharandt.

At Ascherhübel, the well-known *quarz-porphyr* and the *quarzarmer-porphyr* of the Tharandt Wald are partially covered by Quadersandstein, the whole being penetrated by basaltic outbursts which form the cupola (*quellkuppe*) of Ascherhübel, and the lava-current of Landberg. In the midst of the Ascherhübel basalt there are found numerous inclusions of 'porphyry,' in all stages of vitrification and fusion up to a perfect glass, and it is one of these which has yielded the interesting section to which I have referred.

Subsequently to receiving this information from Prof. Zirkel, I was favoured by the same friendly correspondent with an advance copy of the 'Erläuterungen zur geologischen Specialkarte des Königreichs Sachsen—Section Tharandt, Blatt 81.' In this work Herr A. Sauer has given a short but very interesting account of the eruptive mass of Ascherhübel and its inclusions, from which the following particulars are derived.

Ascherhübel is a small *quellkuppe* of an elliptical form, with a diameter of from 200 to 300 metres. The rock of which it is composed is a nepheline-basalt, and consists of a groundmass almost wholly made up of microlites of augite and grains of magnetite, between which a few particles of nepheline can be be detected.

Very sparsely scattered through this groundmass are small phenocrysts of augite and olivine, seldom more than 1·5 millimetre in length, the former sometimes exhibiting the hour-glass structure, and the latter forming interpenetrant twins. The rock is so poor in alumino-alkaline silicates that it approaches an augitite in composition.

Very great interest attaches to this rock from the circumstance, pointed out by Herr Sauer, that it contains inclusions of pyrrhotite (magnetic iron-pyrites) and, in addition, one fragment, the size of a walnut, of *native iron* covered by an oxidized crust. This iron is perfectly malleable and of a tin-white colour, but it does not exhibit the Widmanstätten figures when etched. The mode of occurrence of iron in this basalt appears to resemble that in the basalt of Ovifak and other localities in Greenland, and those of the nickel-iron alloys of New Zealand (Awaruite) and of Oregon (Josephinite).

The basalt of Ascherhübel is described by Herr Sauer as being so rich in inclusions of foreign rock that it is scarcely possible to find a large fragment of the igneous material which does not contain one or more foreign fragments. These belong in part to the Pläner- and Quadersandstein and in part to the underlying 'porphyry,' while the formations which form the foundation of the surrounding country are also represented: all these rock-masses having been penetrated and replaced by the basalt. Among the foreign fragments, those of the 'porphyry' are most numerous, though they are generally small in size. They are for the most part perfectly vitrified, but nevertheless often show indications of the characteristic structures of the 'porphyry.' The whitish grey, dirty violet, or reddish spotted fragments are compact or bubbly, and near the basalt are generally bounded by a greenish-coloured seam of augite-microlites. On the surface they are covered with a thin weathered crust resembling kaolin.

On a microscopic examination, we find a glass with distinct perlitic structure and colourless or brownish spherulites. This glass contains felspars which are occasionally still recognizable, and are generally changed into a granular substance sometimes acting uniformly under polarized light; there are also minute crystals of magnetite with particles of hæmatite, and more rarely crystals of spinel. Besides the glass there are dull, undefinable patches representing the 'porphyry' in a less changed condition. Herr Sauer's description so completely agrees with the section to which I have referred as being obtained at Freiberg that there is no room for doubt as to the origin of the specimen from which it was cut.

I have noticed at some length the enclosures at Ascherhübel, for here we have, as in the Cuillin Hills, masses of acid plutonic rocks entangled and altered by a magma of basic material. In this rock, as in the cases so well described by Prof. Bonney from the Island of Arran, we get clear proof that not only are characteristic alterations produced in the porphyritic crystals, but that spherulitic structures are developed in the groundmass of such acid rocks when re-fused, a conclusion which has also been arrived at by Whitman Cross,[1] Bäckström,[2] and other authors.

In the Cuillin Hills, however, the phenomena are exhibited on a far grander scale than in Saxony or in Arran. The enclosures are of much larger dimensions, and the mass of molten basic rock in which they have been enveloped is of much grander proportions, while the period during which it has retained its high temperature must have been far longer—as is shown by the highly crystalline character of the gabbro.

3. The Granites and Gabbros of the Cuillin Hills.

The Tertiary granitic rocks of Skye, Mull, Rum, and St. Kilda, with their southern developments in Arran and the Mourne Mountains, were carefully described by Zirkel in 1871, under the names of 'quartz-syenite' and 'quartz-porphyry,'[3] and in 1874 I gave some further account of their nature and relations, referring them to granites and quartz-felsites.[4] More recently, in 1888, Mr. Teall referred to one of the most widely-distributed types of the rock, his notice of it being illustrated by an excellent figure and a full petrographical description;[5] in the same year, too, Sir Archibald Geikie and Dr. Hatch contributed interesting details concerning many of the varieties assumed by these rocks.[6]

As I hope shortly to lay before this Society an account of the whole series of acid rocks of Tertiary age as developed in Scotland, the study of which has occupied much of my time and attention during the last twenty years, I will content myself here with a short summary of their principal characters.

In some of the more central parts of their mass, these rocks present themselves as true biotite-granites, but there is a constant tendency for the biotite to be replaced wholly or in part by hornblende. When, as not unfrequently happens, the quantity of plagioclase increases in amount, the biotite- or hornblende-granite passes into a common granitite or a hornblende-granitite. Towards the peripheral portions of the intrusive masses, however, a very marked change takes place in the characters of the rock. Micropegmatitic ('granophyric') intergrowths of felspar and quartz make their appearance between the phenocrysts of the rock, the mica and hornblende are gradually replaced by augite, magnetite becomes a prominent constituent of the rock, and a remarkable drusy ('miarolitic') structure is developed in it. It is this variety of the rock, which is indeed the most widely distributed, that has been called by Mr. Teall and Sir Archibald Geikie (following the nomen-

[1] Bull. Phil. Soc. Washington, vol. xi. (1891) p. 433.

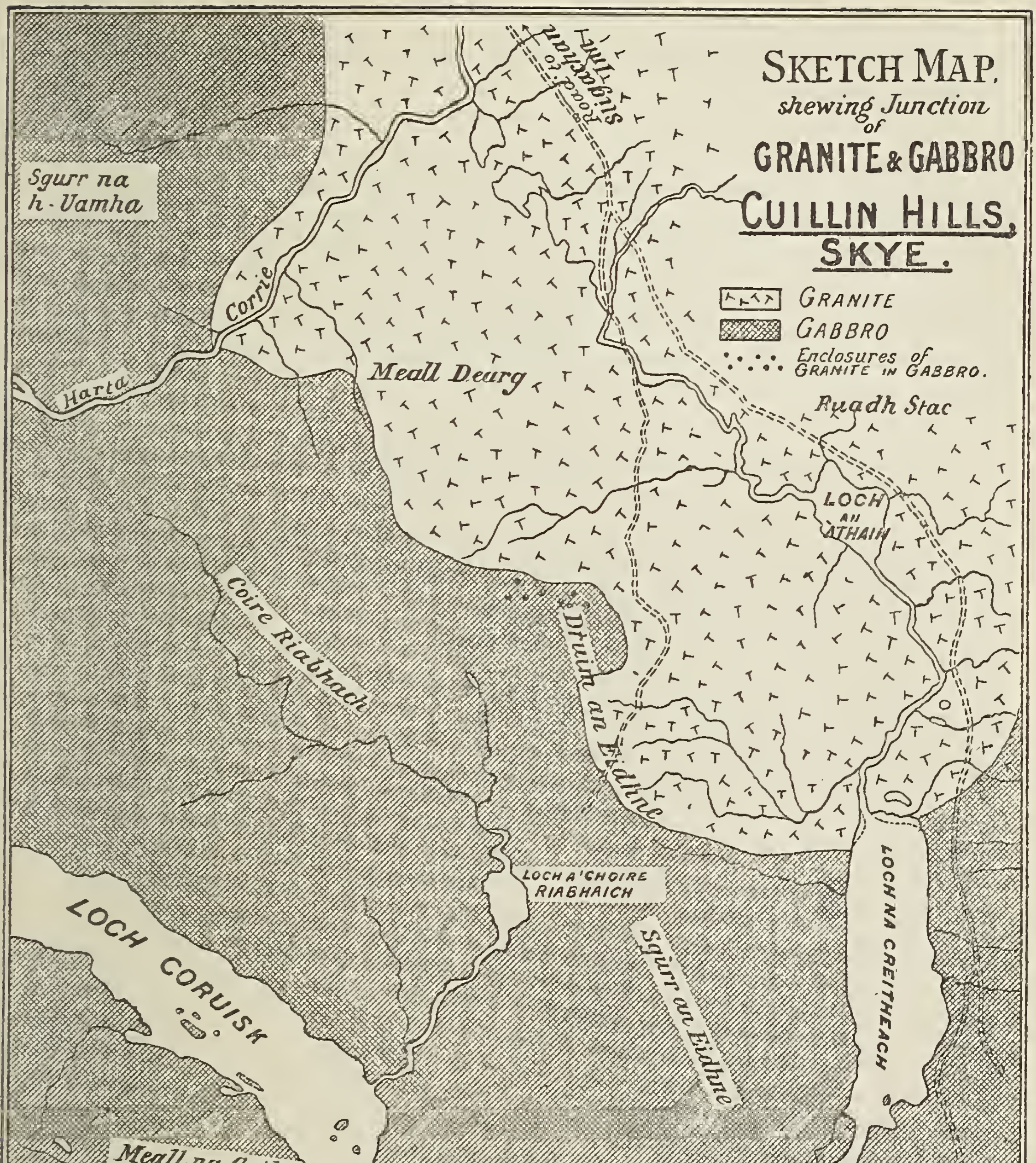
[2] *Op. supra cit.*

[3] 'Geologische Skizzen von der Westküste Schottlands,' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxiii. (1871) pp. 1–124.

[4] Quart. Journ. Geol. Soc. vol. xxx. (1874) pp. 234–236.

[5] 'British Petrography,' 1888, p. 327, pl. xxxiii. fig. 1.

[6] Trans. Roy. Soc. Edinb. vol. xxxv. (1888) p. 148.


SKETCH MAP.
shewing Junction of
GRANITE & GABBRO
CUILLIN HILLS,
SKYE.
GRANITE
GABBRO
Enclosures of GRANITE IN GABBRO.
Road to Sligachan
Sgurr na h-Uamha
Corrie
Harta
Meall Dearg
Ruadh Stac
LOCH AN ATHAIN
Coire Riabhach
Druim an Eidhne
LOCH A'CHOIRE RIABHAICH
LOCH NA CREITHEACH
LOCH CORUISK
Sgurr an Eidhne
Meall na Cuilce
Sgùrr na Strì
Camasunary
N
LOCH SCAVAIG
0
1/4
1/2
3/4
1
MILE

clature of Rosenbusch) 'granophyre.'[1] This drusy and micropegmatitic variety of the rock passes in turn into ordinary quartz-felsites (*quarz-porphyr*).

The gabbros of the same district have been already described at some length in a former volume of this Journal, and I may therefore refer to that memoir for full petrographical details.[2] The rocks are very typical gabbros, exhibiting every gradation from augite-gabbro to common or diallage-gabbro; and the monoclinic pyroxene is to a greater or less extent liable to be replaced by a rhombic variety (bronzite or hypersthene), so that the rocks pass into norites.

4. The Position and General Characters of the Granite-inclusions in the Gabbro.

The locality where the inclusions of granite can be seen lying in the midst of the gabbro of the Cuillin Hills is known as Druim-an-Eidhne (see the sketch-map on the preceding page, which has been reduced from the latest edition of the six-inch Map of the Ordnance Survey). That ridge, which is rather more than 1000 feet in height, is situated in the angle formed by the valley in which the well-known Loch Coruisk lies, by the scarcely less famous Harta Corrie, and by the continuation of Glen Sligachan called Strath-na-Creitheach. The ridge itself is composed of a great intrusive sheet of gabbro overlying the acid rocks, which rise from beneath it northward into the mountain of Meall Dearg. At many points the junction between these bare and strongly-contrasted rocks may be easily followed. The gabbro at this locality presents all its usual features; the only noteworthy peculiarity being the great abundance in it of contemporaneous or segregation-veins, an occurrence long ago pointed out by Macculloch. The granitic rock of Meall Dearg is the drusy and micropegmatitic variety of augite-granite, so widely developed in this district, and it passes in places into a true quartz-felsite or 'quartz-porphyry' with idiomorphic crystals of quartz and felspar.

Well within the boundary of the gabbro, and sometimes at the distance of many yards from it, there occur a number of irregular patches of pale granitic rock, which are seen to be completely enclosed in the gabbro mass. These enclosed patches are sometimes at least 20 or 30 yards from the line of junction between the

[1] Unless the terminology of petrography is to be allowed to fall into a state of utter confusion, a confusion ten times worse confounded than that which has characterized it in the past, a protest and a firm stand must be made against the practice—especially prevalent in Germany—of taking old names and re-defining them so as to express ideas totally different from those of the original authors. It may now be too late to restore to 'gabbro' and 'syenite' their original significations; but 'granitite' and 'granophyre,' if used at all, must surely be employed with the meaning given them by their respective authors, Gustav Rose and Vogelsang. See on this point the admirable remarks of Whitman Cross (Bull. Phil. Soc. Washington, vol. xi. p. 430, note).

[2] Vol. xlii. (1886) pp. 49–97.

granites and gabbros. As the granite weathers so much more readily than the gabbro, these patches of granite form depressions in the great rusty-brown mass of the basic rock, which are usually filled with *débris*; some of the patches show a section several square yards in area. Within these depressions the acid rock can be clearly traced, while the boundary of the surrounding gabbro may be followed without difficulty, and the complete isolation of the patches of granite is very obvious. The acid rock within the depressions is at once seen to present a very different appearance from the normal granite: although the phenocrysts of quartz and felspar are often conspicuous, the rocks exhibit the general aspect of a *rhyolite* rather than that of a granite. They are compact in texture and splintery in fracture, and sometimes almost glassy in appearance. The greatly weathered surfaces reveal the peculiar structures of the rock in a most admirable manner. Banding is very manifest on these weathered surfaces, and in many instances the banding can be seen to be due to a parallel disposition of spherulites in the mass (see Pl. II. figs. 1 & 2). Spherulitic structures, of all dimensions from a pin's head to a small orange, are everywhere conspicuous (Pl. II. figs. 3, 4); they often show the characters of lithophyses (hollow spherulites; see Pl. II. fig. 5), and not unfrequently exhibit the crushed and distorted appearances which have been so well described in the case of the very fresh rhyolitic rocks of the Western Territories of the United States. On breaking open the larger nodules, they are seen to present the arborescent forms characteristic of the complex spherulites of the districts just referred to. These spherulites often weather out as perfectly rounded bodies like 'marbles,' which can, in places, be collected in considerable numbers. The general examination of the enclosed masses indicates that they are rocks originally of a glassy character, but converted into 'lithoidite' by the development throughout the mass of every variety of spherulitic structure, while scattered through the whole may often be seen the phenocrysts of quartz and felspar. At one or two points I have found the same phenomena displayed, though in a less striking manner, at the junction of the gabbro with the granite.

The general conclusions concerning the nature and origin of these beautiful rocks, which we arrive at from their macroscopic study, are fully confirmed when we apply the microscope to the examination of thin sections prepared from them; while many new and remarkable facts about their structure are then revealed.

The rocks are seen to contain in many places phenocrysts of quartz, felspar, and magnetite, embedded in a more or less devitrified, glassy base. These phenocrysts exhibit many interesting features, showing that they have been exposed to a high temperature. The micropegmatitic groundmass, the last to solidify among the constituents of the original rock, has been the first to fuse; and the liquefaction has often been sufficiently perfect to allow of the development of flow-structures in the mass. It is worthy of notice, however, that certain of the larger micropegmatite groups have in places escaped complete fusion, and some of these masses of micropegmatite form the nuclei of large composite spherulites. Re-solidification, however, has been accompanied by devitrification, resulting in the development of a great variety of the spherulitic structures, often on a very grand scale. During and after the fusion, new minerals (pyrites, fayalite, etc.) have been formed, and the whole rock has undergone sufficient change to lead to the formation of many secondary products, such as chalcedony, chlorite, etc.

5. The Alterations which the Minerals in the Inclusions have undergone.

Beginning with the characters of the phenocrysts, we find the grains of *quartz*, as we might expect, the least altered of all the minerals. Their contours, whether the idiomorphic and corroded forms of 'quartz-porphyries' or the allotriomorphic forms characteristic of granite, are admirably preserved, and the crystals appear quite clear and transparent. Careful examination, however, shows that the crystals are not unfrequently traversed by a number of fine cracks, though these cracks have only occasionally been developed in such numbers as to seriously impair the transparency of the quartz (Pl. III. fig. 1). That these cracks are new features which have been developed by the heat to which the crystals have been exposed is unquestionable. Occasionally the crystals have opened along these cracks, and the glassy matrix has penetrated through them, breaking up the quartz-crystal into a number of isolated fragments, in the manner so well described by Lehmann in his account of the Eifel rocks (Pl. III. fig. 2; compare Lehmann, *op. supra cit.* Tab. I. figs. 1 & 2). When we come to examine the enclosures, we find that the granitic quartz sometimes shows cavities containing liquids with moving bubbles, which occur in streams and bands traversing the crystals. In some cases, however, these cavities appear empty or filled with a black opaque substance. The idiomorphic quartzes have cavities, sometimes of considerable size, which are filled, not with *stony* matter, as in the original rock, but with *glassy* material. This glass sometimes occupies well-marked negative crystals, and at other times cavities of most irregular form, the connexion of which with the surrounding matrix is sometimes clearly visible.

The glass-cavities in the idiomorphic quartz-crystals are so big and so numerous that it is scarcely possible to avoid the conviction that some of them have been enlarged during the re-fusion of their contents, and there is at least a suspicion that new cavities may have been formed, like the secondary glass inclusions described by Chrustschoff as occurring in the quartzes of *verglaster sandstein.*[1] The corrosion of the outside of these crystals by the surrounding glass may also have been produced, or at all events increased, during the second fusion to which the rock has evidently been subjected.

[1] Tschermak's Min. u. Petr. Mittheil. 1882, p. 473, and 1885, p. 64.

Some of the quartz-crystals are surrounded by radiating filaments of brown oxide of iron ('ferrite') which greatly resemble the products of alteration of the pyroxene, and it seems very probable that they indicate the former existence of zones of augite and magnetite, like those which surround the quartzes in the 'quartz-basalts.' In some cases I have found distinct evidence of the formation of zones of secondary quartz around the corroded fragments of the mineral. This is precisely similar to the *pyrogen-quarz* which Lehmann[1] and Chrustschoff[2] have shown to be so characteristic of inclusions (see Pl. III. fig. 3). It is, of course, not necessary to suppose that the secondary quartz has been produced by direct fusion, as the evidences of the presence and action of water are sufficiently obvious in these rocks.

The *felspars* of these included masses are almost always kaolinized and more or less opaque, as indeed is the case in the original rock. The most conspicuous feature about them is the occurrence of cracks, parallel to the orthopinacoid (010), to the basal plane (001), and perhaps also to the clinopinacoid (100), which have opened and been filled with a secondary deposit of felspar (see Pl. III. fig. 4). A similar rim of secondary felspar also surrounds the whole crystal in some cases, the secondary felspar being in approximate, but seldom in complete, optical continuity with the original and altered material. Occasionally the whole crystal is broken up into a multitude of dice-like fragments, and these are in some cases displaced, the circumstance being revealed by the mass behaving like a mosaic in polarized light. These altered felspars with their infilled 'contraction-rifts' offer a close analogy with the 'perthites,' but there does not appear to be a very marked difference in character between the original and altered portions and the new and infilling veins which traverse the crystal. Bäckström and other authors have frequently described a similar alteration of the felspars in inclusions.

The large 'stone cavities' which occasionally occupy considerable spaces in the original crystals have sometimes been fused and partially or wholly devitrified. In some cases the whole of the centre of the crystal has been honeycombed by the surrounding matrix, and in these cases the mixture of felspar and glassy material has easily fused and then become devitrified. It is in this way that the interesting appearances illustrated in Pl. III. fig. 5 have evidently been produced. The felspars, like the quartzes, are sometimes surrounded with radiating trichites, now converted into limonite (Pl. III. fig. 6).

With respect to the optical properties of the felspars, I have made many attempts to determine the position of the optic-axial plane, but, owing to the opacity of the crystals, have not succeeded in obtaining trustworthy results.

The *ferro-magnesian silicate* in this particular variety of the

[1] Verh. des Naturh. Ver. d. preuss. Rheinl. u. Westf. 1877, p. 203.
[2] Tschermak's Min. u. Petr. Mittheil. 1885, p. 295.

granite is a green pyroxene. As a rule, however, few traces of this mineral remain in the fused product, it having for the most part been broken up into various secondary minerals, among which magnetite is usually very prominent. The magnetite thus produced can always be distinguished from the original magnetite and titanoferrite of the rock; the secondary mineral tends to form branched and radiated filaments, and not unfrequently gives rise to the extremely delicate trichites which, as we shall see hereafter, are so conspicuous in many of the spherulitic growths. The change is very similar to that produced in the hornblendes of the Corriegills pitchstone by the long heating of that rock in a glass furnace, as shown by Mr. Rutley. Bäckström, in the work already quoted, has pointed out that the ferro-magnesian minerals of inclusions of granite in basic rocks are less capable of resisting the action of the molten magma around them than are the felspar-fragments, and that they are often entirely dissolved, leaving scarcely a trace of their former existence. The cores left by the removal of these minerals are, he says, sometimes surrounded by magnetite, and possibly also by secondary quartz and biotite.

The original magnetite and titanoferrite are apparently unaltered, except that the latter mineral sometimes shows the beginnings of change into sphene ('leucoxene'), and the crystals are scattered through the vitrified mass. Some of the magnetite may, however, be acted upon to produce the pyrite which is in certain cases tolerably abundant.

The condition of the minerals in these masses of curiously altered rock will thus be seen to be strikingly different from that of the former minerals in the granite and its apophyses, and the changes they have undergone are precisely those which have been described as occurring in enclosures of acid in basic rocks by Mitscherlich, Lehmann, Bäckström, Sauer, and other authors.

6. The Spherulitic Growths developed in the Inclusions.

If we now turn our attention from the porphyritic crystals to the base or groundmass, we shall find in the fusion of the micropegmatite and the development of spherulites in the glass resulting from this fusion an exact parallel to the changes which have been produced in plutonic acid rocks by the action of heat, as described by Sauer, Bonney, Bäckström, and others.

In studying the remarkable spherulitic growths which have been formed in the glassy mass produced by the fusion of the micropegmatitic groundmass of the acid rock I have been greatly aided by the valuable memoirs of Mr. Iddings[1] and Mr. Whitman Cross,[2]

[1] J. P. Iddings, 'Obsidian Cliff, Yellowstone National Park,' Washington, 1888, issued with the Seventh Annual Report of the U.S. Geological Survey for the years 1885–6; 'Spherulitic Crystallization,' Bull. Phil. Soc. Washington, vol. xi. (1891) pp. 445–464.

[2] Whitman Cross, 'Constitution and Origin of Spherulites in Acid Eruptive Rocks,' Bull. Phil. Soc. Washington, vol. xi. (1891) pp. 411–444; see also F. Rutley, 'On a Spherulitic and Perlitic Obsidian from Pilas, Jalisco, Mexico,' Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 530–533.

of the U.S. Geological Survey, on the spherulitic rocks of Obsidian Cliff in the Yellowstone Park, and on the similar rocks of Silver Cliff, Custer County, Colorado. The former gentleman has greatly facilitated my task by supplying me with a series of specimens illustrating the chief types which he has so well described.

The spherulites of the Cuillin Hills sometimes attain a diameter of nearly $2\frac{1}{2}$ inches (60 centimetres); they present examples of all the varieties described by Messrs. Iddings and Whitman Cross, with some forms not previously noticed. So far as size goes, they fall far short of the spherulites described by the latter observer from Silver Cliff, which are said to sometimes attain a diameter of 10 feet; the Cuillin-Hills spherulites, however, I believe, surpass in size any hitherto described in the British Isles, with the exception of the fine hollow spherulites of Boulay Bay, Jersey, while they are in a much less altered condition than these latter.

Many of the spherulites in question are beautiful examples of what Mr. Rutley has proposed to call 'composite spherulites,'[1] in which globular spherulites formed round a number of sporadic centres have been enclosed in other radially-formed masses of much larger dimensions—they are, in short, spherulites within spherulites.

The smaller spherulites nearly all belong to the ordinary type (the 'compact spherulites' of Iddings), in which microlites, arranged radially, give with crossed nicols the usual black cross or sometimes a greater number than four dark brushes not at right angles to one another (the so-called 'pseudo-spherulites').

Not unfrequently, these ordinary spherulites consist of several concentric layers, the microlites of each of which exhibit some differences in colour, opacity, or other characters. These spherulites are found to be involved in peculiar arborescent growths, which have been compared to foxes' tails; and these start from one or sometimes several centres, and involve alike the ordinary spherulites and the phenocrysts of the original rock, which have escaped fusion. The bodies built up by these arborescent growths constitute the 'porous spherulites' of Iddings[2] (see Pl. III. fig. 7).

When the curious plume-like or brush-like bodies are examined, especially in polished surfaces of the spherulites, which can be viewed by reflected light, we see that there are two varieties of them, which are strongly contrasted in colour (Pl. III. fig. 7). In one case the colour is bluish grey, while in the other it is creamy white. Microscopic sections of extreme thinness show that the blue-grey plumes are composed of felspar and quartz, through which grains of magnetite are uniformly distributed (Pl. III. fig. 8). The creamy white plumes are also composed of felspar and quartz, but are destitute of the scattered grains of magnetite; they exhibit, however, a quantity of hydrous brown oxide of iron lying between the felspar-fibres of the plumes (Pl. III. fig. 9). Careful study of very thin sections with high powers shows that this brown oxide

[1] 'Composite Spherulites in Obsidian, from Hot-Springs, near Little Lake, California,' Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 423, 424.

[2] 'Obsidian Cliff, etc.,' p. 278.

of iron, which is so uniformly distributed, has been produced by the oxidation and hydration of trichites of magnetite which have clearly been formed at the same time as the felspar-needles between which they lie. These plumes, which are now of a creamy white colour, are evidently identical with the 'trichitic spherulites' described by Mr. Whitman Cross.[1]

The foxtail-like plumes all exhibit the beautiful radial structure combined with a concentric arrangement so well described, alike by Messrs. Iddings, Whitman Cross, and Rutley (Pl. III. figs. 8 & 9). Between the portions of the mass formed by the phenocrysts, the ordinary spherulites, and the two kinds of plumes, we sometimes find other growths which would seem to be analogous to the 'supplemental spherulitic growths'[2] of Whitman Cross.

The centres of all the spherulites, both large and small, appear to be very generally formed by original crystals of quartz or felspar, or sometimes by well-developed micropegmatite groups which have escaped fusion. In some very interesting cases, however, masses of the original micropegmatitic rock, from 8 to 10 millimetres in diameter, seem to have almost entirely escaped obliteration, and they form the centres of great compound spherulites (Pl. III. figs. 10 & 12). These masses of micropegmatite are usually surrounded by a crust of glass with fluidal structure, which is stained by iron oxides, while outside the whole we find the great mass of the complex spherulitic growth (Pl. III. figs. 11 & 13).

If any doubt existed as to these spherulitic masses having been formed by the partial fusion of the micropegmatitic granite of the Cuillin Hills, such doubt would be at once removed by the examination of those fragments of granite which are thus curiously preserved as the nuclei of spherulites. In the drawing on the opposite page, Miss M. Reeks has succeeded in giving an admirable representation of one of these granite-fragments, as seen with a low-powered objective.

There is considerable diversity in the general appearance of the sections of these complex spherulites. This is caused by the varying extent to which the several kinds of spherulitic growth take part in the formation of the compound masses. In some cases rounded and irregular masses are found to be built up of an aggregation of ordinary spherulites, with only a small amount of intermediate or 'supplementary' spherulitic growth between them. In other cases, like that figured in Pl. III. fig. 7, a few scattered spherulites of the ordinary type are seen to be enclosed in the plume-like masses building up the 'porous spherulite.' Others, and these perhaps constitute the most abundant type, consist wholly of plume-like or arborescent masses radiating from one or several centres and enclosing the phenocrysts of the original rock.

In some cases the oxidation of the outer zones of a spherulite has given rise to a very marked contrast between its brown outer

[1] 'Constitution and Origin of Spherulites, etc.,' Bull. Phil. Soc. Washington, vol. xi. (1891) p. 423.

[2] *Ibid.* p. 424.

portion and the bluish-grey mass in the centre, which appears to be coloured by magnetite and finely-divided pyrite.

Spherulites from less than 1 millimetre up to 60 centimetres in diameter and of all intermediate sizes can be found; and sometimes, as may be well seen in weathered surfaces of the rock, the mass is made up of crushed and distorted spherulitic growths like those occurring in Silver Cliff, Colorado[1] (Pl. II. fig. 3). These indicate, as has been shown, that the mass was subject to internal

Section of the Granite-nucleus of a Spherulite (see Pl. III. figs. 12 and 13), *as seen with a magnifying power of* 14 *diameters.*

The quartz and the micropegmatite groups are almost unaltered and retain their relative position, only a small quantity of glass having been produced by the fusion of intervening materials.

movement during the time that the spherulites were being formed. Hollow spherulites or lithophyses, especially types like the beautiful forms that have been compared to an expanding rose,[2] are by no means uncommon (see Pl. II. fig. 5). There are examples in which globular aggregates of small spherulites up to 25 millimetres

[1] Whitman Cross, *op. supra cit.* pl. v. fig. 1.
[2] J. P. Iddings, 'Obsidian Cliff, etc.,' pl. xii.

(1 inch) in diameter have been formed, and then a complete change in the mode of development has taken place, the outer zones of the spherulite being formed by the separating concentric layers of a lithophyse (see Pl. II. fig. 4).

Although the state of preservation of the plume-like masses in the spherulites of the Cuillin Hills is very much inferior to that of the spherulites from the western districts of the United States, microscopical study proves that they are identical in character and origin with the objects so well described by Messrs. Iddings and Whitman Cross. I have no doubt that those observers are correct in referring all the fibres of these arborescent growths to felspar; they have shown, by the use of the quartz-plate *à teinte sensible*, in the manner suggested by M. Michel-Lévy, that the positive or negative character of the spherulitic growth may be accounted for by regarding the former as felspars elongated parallel to the vertical axis and with the so-called 'anomalous' optical orientation, and the latter as being also felspar-crystals, but elongated parallel to the clino-axis and with the normal optical orientation. These felspar-microlites are frequently Manebach twins, and this accounts for the very regular forking of the fibres at definite angles. The whole character of the spherulites of the Cuillin Hills is in complete harmony with this explanation.

Although quartz does not enter directly into the composition of these spherulitic growths, as was formerly supposed, free silica takes a small, but by no means unimportant part in the building-up of such structures. Mr. Iddings has shown that the fibres of felspar entangle numerous, small, rosette-like aggregates of tridymite, while Mr. Whitman Cross points out that the spaces between such fibres may be filled in with colloid silica, probably hydrated. Both tridymite and colloid silica have of course long since disappeared in the altered spherulites of the Cuillin Hills; but the crystallized quartz between the felspar-fibres probably represents the silica which has been redissolved and has crystallized in the stable form. We find an interesting proof of the former existence of the tridymite rosettes when we attempt to polish the sections of these spherulites, the polishing powder finding its way into and rendering very conspicuous the cavities formerly occupied by tridymite.

There are two minerals formed in these spherulites which are of especial interest. The first of these is iron pyrites. In my paper of 1874 I pointed out how frequently this mineral is present in the Tertiary igneous masses of the Western Isles of Scotland.[1] At a later date, I described the propylitic modification of the older andesites by the intrusion into them of the granitic rocks.[2]

The masses of fused granite enclosed in the gabbro of the Cuillin Hills all contain sulphur; this has been shown by a series of careful tests with the blowpipe made for me by Mr. Gilbert Cullis, one of the Demonstrators of the Geological Division of the Royal College of Science. But in addition to the finely-divided iron sulphide we

[1] Quart. Journ. Geol. Soc. vol. xxx. (1874) pp. 236–237.

[2] *Ibid.* vol. xlvi. (1890) pp. 341–384.

have pyrites-crystals, sometimes of considerable dimensions. These, in all probability, have been formed at the expense of some of the magnetite of the rock and are found, sometimes attached to comparatively unaltered centres of the spherulites, and at other times scattered promiscuously through their mass. The pyrites-crystals often show every stage of the conversion of their substance into limonite. Bäckström has also found pyrites to be among the secondary minerals developed in the inclusions of granite in diabase.

There are, moreover, grounds for believing that fayalite, the iron-olivine, was a constituent of the spherulites. Mr. Iddings has shown how commonly this mineral occurs in the spherulites of acid rocks.[1] In some of the spherulites of the Cuillin Hills there are masses of brown oxide of iron, which are evidently the product of alteration of another mineral. In the midst of these, particles may sometimes be detected which under the microscope exhibit the lustre and cleavage of partially altered fayalite, like that of the Mourne Mountains. In spite of the minute size of these particles, they can be extracted by a needle-point, and, on boiling with hydrochloric acid, they are seen to be decomposed with separation of gelatinous silica.

7. Bearing of the Evidence afforded by these Inclusions on the Question of the Relative Ages of the Igneous Rocks in the Western Isles of Scotland.

There is one important inference from the phenomena exhibited at Druim-an-Eidhne, which is so obvious that it would not be necessary even to call attention to it, but for the circumstance that opposite conclusions have been persistently and authoritatively put forward. It is perfectly clear from the study of these inclusions that the gabbro of the Cuillin Hills was erupted *after* the granites of the Red Mountains of Skye, and it is further indisputable that the acid rocks must have consolidated and acquired their existing features, including the remarkable micropegmatitic structure, before the gabbros were forced through them and caught up these 'horses' of granite.

As long ago as 1819, Macculloch discussed the relative ages of these two series of igneous rocks, and, although he hesitates about giving a final and definite opinion on the subject, it is clear that he leans towards the view that the granites are the *older* rocks of the two.[2]

In 1846 Principal J. D. Forbes made a very careful study of

[1] 'On the Occurrence of Fayalite in the Lithophyses of Obsidian and Rhyolite in the Yellowstone National Park,' Am. Journ. Sci. ser. 3, vol. xxx. (1885) p. 58; see also Iddings and Penfield, 'Fayalite in the Obsidian of Lipari,' *ibid.* vol. xl. (1890) p. 75; 'The Minerals in Hollow Spherulites of Rhyolite from Glade Creek, Wyoming,' *ibid.* vol. xlii. (1891) p. 39.

[2] 'A Description of the Western Islands of Scotland,' 1819, vol. i. pp. 362–393. See the order adopted in the legend to the Map of Skye, vol. iii., and also the legend to his general Map of Scotland published in 1832, where 'Diallage Rock' (gabbro) is placed last of all the formations except Alluvium.

the junctions of the two sets of igneous rocks, and the result he arrived at, after a very able and candid discussion of the whole question, was that the gabbros were erupted *after* the granites.[1]

In 1871, Prof. Zirkel, after examining the rocks both in Skye and Mull, came to the same conclusion.[2]

Between the years 1870 and 1874 I repeatedly examined the junctions between the two rocks, and found that there was abundant evidence in support of the conclusions published by my predecessors in the same field, while I failed totally to discover any facts which were opposed to those conclusions. Consequently, in my interpretation of the structure of the district, I adopted the same views (as to the relative ages of these rocks) as those which had been already announced by Forbes and Zirkel.[3]

In 1888 Sir Archibald Geikie published a memoir in which, while abandoning many of his previous conclusions on the subject, and adopting in their place the views I had put forward in 1874, he nevertheless strongly maintained that all previous observers had been mistaken as to the relative ages of the acid and basic rocks, and that the granites are really *younger* than both the basalts and gabbros of the district.[4] He, indeed, went much further than this, and intimated that the opposite opinion arrived at by his predecessors was not only one for which there was no foundation, but could be maintained only by those who had not properly examined the evidence.

In his recent Presidential Address to this Society, the Director-General of the Geological Survey has forcibly reiterated these conclusions, and has summed them up in the following words:—"There can be no doubt that they" (*i. e.* the granites and other acid eruptives) "are the last of all the Tertiary volcanic series, except the latest basalt-dykes which traverse them."[5]

I cannot, perhaps, better indicate how absolutely crucial is this question of the relative ages of the granite and the gabbro, with respect to the two interpretations that have been given of the structure of the district, than by quoting the remarks on the subject made by Prof. A. H. Green. In an article which claims to be a perfectly impartial statement of the case, and which no one who reads it can possibly tax with undue leanings to my own side of the controversy, we find the following passage:—

"So far then the views of Dr. Geikie and Prof. Judd may admit of modifications which render them less conflicting than they seem at first sight. But there is one point on which reconciliation is impossible, viz. the nature and relative date of the eruptions of acid composition. Prof. Judd recognizes not only acid eruptions of the

[1] 'Notes on the Topography and Geology of the Cuchullin Hills, etc.,' Edinb. New Phil. Journ. vol. xl. (1846) pp. 76–99.

[2] 'Geologische Skizzen von der Westküste Schottlands,' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxiii. (1871) pp. 1–124.

[3] Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 249.

[4] 'The History of Volcanic Action during the Tertiary Period in the British Isles,' Trans. Roy. Soc. Edinb. vol. xxxv. pp. 21–184.

[5] Quart. Journ. Geol. Soc. vol. xlviii. (1892) *Proc.* p. 167.

massive type—granites and their allies—but he speaks of thick bodies of felstones, disposed in regular sheets and of amygdaloidal structure, which alternate with beds of scoriæ, lapilli, and ashes, that lie upon the skirts of the central bosses of granite. These he believes to be the remnants of a volcano formed mainly of acid lavas, which was piled up and largely ruined by denudation before the discharge of the plateau-basalts began. The existence of the granite-bosses admits of no doubt, but Dr. Geikie has depicted numerous sections which leave no doubt that these rocks intrude into the basalts and gabbros, and are therefore of later date than them. Now that all these details are before us, the question of relative age can admit of only one answer, but it is evidently a point on which observers, who had not opportunities of entering minutely into details, were apt to go wrong. Both Principal J. D. Forbes and Prof. Zirkel seem to have come to the same conclusion as Prof. Judd, and Dr. Geikie has supplied the explanation. 'That there should ever have been any doubt,' he says, 'about the relations of the two eruptive masses is possibly explicable by the facility with which their junction can be observed. Their contrasts of form and colour make their boundary over crag and ridge so clear that geologists do not seem to have taken the trouble to follow it out in detail. And as the pale rock (granophyre or granite) underlies the dark (gabbro), they have assumed this infraposition to mark its earlier appearance.' All this is graphically brought out in fig. 43 of Dr. Geikie's memoir. . . . Anyone trusting to surface-feature might well fancy that the basalts . . . lay upon, and were newer than, the granophyre. . . . Let us all take warning thereby." [1]

How anyone reading the memoirs of Principal Forbes and Prof. Zirkel could possibly imagine that they had jumped to conclusions which they published concerning the relations of the two sets of igneous rocks in question, without properly examining the evidence, I am at a loss to conceive. Their memoirs exhibit proofs of the most careful and painstaking study of the lines of junction, and it seems to me needless to combat the idea that they published statements based only on hasty views of the ground from a distance.

For myself, I may add that, before adopting the conclusions of my predecessors, I carefully studied the sections they described, as well as others, and satisfied myself that these two authors were perfectly accurate as to their facts and rigidly logical in their conclusions.

The confident statements of our critic led me, however, to re-examine the whole of the junctions again with the greatest care. It then soon became evident how the mistake on the part of Sir Archibald Geikie—for that it was a mistake no one who examines the evidence now adduced can for one moment doubt—has arisen. In his memoir in the Transactions of the Royal Society of Edinburgh there are given a number of sketches—most of them necessarily taken from a distance, as they represent whole mountain-sides—in which the granites are shown as sending off veins into the 'bedded basalts.' On reference to the text, it is seen that the 'basalts' near

[1] 'Nature,' vol. xxxix. pp. 132–134 (Dec. 6th, 1888).

these igneous intrusions are said to be strangely altered, and converted into a splintery rock which weathers with white surfaces. These rocks, it is obvious, are the lavas which I described under the name of 'felstones' in 1874, and into which, as I then showed, the granites send numerous veins. Two years ago I gave full petrographical details concerning this remarkable series of rocks, and I showed that, so far from their being basalts, they are for the most part andesites, many of them with a very high percentage of silica, but usually converted by solfataric action—probably connected with the intrusion into them of the granites—into the 'propylitic' modification.[1]

The description of the beautiful and unmistakable inclusions of granite ('granophyre' of some authors), lying within the gabbro in the area of its best development, now completes the evidence as to the younger age of the latter rocks which has been disputed by Sir Archibald Geikie. I may mention, however, that, when I describe in detail the acid rocks, I shall be able to add many other facts which are scarcely less decisive than this in their bearing on the question.

8. Postscript.

[In the discussion which followed the reading of this paper complaint was made that no notice had been taken of the alleged existence—at the locality described—of veins proceeding from the granite into the gabbro. It was a desire not to complicate the very definite issue raised in the title of the paper, with questions upon which a remarkable conflict of testimony exists, that led to my avoidance of the subject; but, as my motive has been misunderstood, I will as briefly as possible state what that testimony is.

Macculloch and Forbes alike called attention to the profusion of pale-coloured, contemporaneous or segregation-veins in the gabbro of the Cuillin Hills; they both assert, however, that veins are never found passing from the granite into the gabbro. The results of my own observations, at this and other localities in the Western Isles of Scotland, were, as I stated in 1874, in complete accord with those of my predecessors. Fragments of basic rock can of course be easily found which are traversed by white veins; but there is no difficulty, especially under the microscope, in distinguishing between the white segregation-veins of the gabbro, composed as they are of lime-felspars, and apophyses of the granite. containing alkali-felspars. It was not until 1888 that Sir Archibald Geikie made the statement that veins of granite do cut through the gabbro at Meall Dearg and other points. I can only add that since this assertion was made I have revisited all the localities referred to, but have never succeeded in finding true granite-veins penetrating the gabbro. It was, in fact, while vainly engaged in searching for such veins that I discovered the very conclusive evidence of the inclusions described in this paper. It appears to me that the existence of these inclusions of granite in the gabbro is absolutely irreconcilable with the occurrence of veins of the same granite cutting through the gabbro.—March 17th, 1893.]

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 341–384.

EXPLANATION OF PLATES II. & III.

In Plate II. the very characteristic weathered surfaces of the fused granite of the Cuillin Hills is represented, all the figures being of the natural size.

Fig. 1. Shows a mass, probably from near the edge of an inclusion, in which the most perfect flow-structure is exhibited. The fine bands, which are slightly different in colour, can in places be seen to be formed of drawn-out spherulites. Microscopic examination shows that, in this case, the phenocrysts have been almost completely absorbed in the glass.

Fig. 2. A somewhat similar banded spherulite, in which the bands have, by the movements of the molten mass, been made to assume beautiful puckerings and contortions, so well exemplified in some of the rhyolites of Hungary, the Ponza Islands, and many other districts.

Fig. 3. A very striking example of a banded mass, with spherulites of very different sizes, drawn out and crushed. This rock greatly resembles certain varieties of rhyolite from Obsidian Cliff.

Fig. 4. A rock showing the puckered banding in union with large spherulites, which are sometimes 'lithophyses.'

Fig. 5. Very characteristic 'hollow spherulites,' exposed by weathering.

(In the last two figures the phenocrysts of the original granite are very conspicuous and stand out in relief.)

In Plate III. microscopic sections of the altered minerals and the spherulitic growths of these inclusions are represented.

Fig. 1. Shows quartz-crystals with large glass enclosures, the crystals being much cracked, while in places the surrounding glass has penetrated along and opened out the cracks.

Fig. 2. Shows a quartz-crystal which, by the corrosive action of the glass penetrating along cracks, has been broken into four fragments. The action of these fragments under polarized light shows that they are parts of the same crystal.

Fig. 3. A greatly cracked quartz-crystal which has had developed around it a shell of secondary 'pyrogene' quartz. The secondary quartz is seen filling a crack which traverses both crystal and matrix. The secondary and original quartz show perfect continuity in polarized light.

Fig. 4. Two orthoclase-crystals, twinned and untwinned, with 'contraction-rifts,' along which secondary felspar-substance has been developed.

Fig. 5. Orthoclase-crystal similarly altered, but with a nucleus, probably containing stone-cavities originally, which has been completely fused.

(Figures 1–5 are represented as seen with a power magnifying 30 diameters.)

Fig. 6. Small oligoclase-crystal lying in a mass of glass containing trichites, now converted into hydrous iron oxide ; many of these are attached to the edges of the felspar.

Fig. 7. Section of one of the largest of the complex spherulites, natural size ; the dark parts represent the ordinary spherulitic growths (see fig. 8), and the paler-coloured portions the 'trichitic spherulites' (see fig. 9). These spherulitic growths radiate from and enclose smaller spherulites and the original phenocrysts of the granite.

Fig. 8. Ordinary spherulitic growths forming the smaller dark portion of this spherulite, and showing radiating and concentric structure, with numerous scattered grains of magnetite which give them their dark colour ; magnified 30 diameters.

Fig. 9. Trichitic spherulitic growths, with similar radiating and concentric structure, which make up the larger part of the spherulite. High powers show that the pale creamy tint is due to innumerable trichites which have been converted into brown oxide of iron. The figure shows a tuft seen with a magnifying power of 30 diameters.

Fig. 10. Spherulite, with nucleus of micropegmatitic granite ; natural size.

Fig. 11. Nucleus of micropegmatitic granite magnified, showing the surrounding vitrified crust with crystals of pyrites.

Fig. 12. Spherulites, natural size, with two nuclei of micropegmatitic granite.

Fig. 13. Enlargement of the upper and larger of these nuclei, with its glassy crust. (It is this granite mass which is shown as seen under the microscope in the figure on p. 189.)

Discussion.

The President remarked that those who had followed the subject attentively were well aware that the Author had made the Western Islands of Scotland his own particular study, and the Society was glad to be again favoured with an interesting memoir from him. The paper was distinctly separable into two portions, the first of which, purely petrological, afforded a useful definition of the processes of fusion of acid by basic rocks. The second portion was peculiarly interesting, since it conveyed a direct challenge to those who took opposite views (to those of the Author) as regards the relative age of acid and basic rocks. The geology of the Highlands had ever been fruitful of controversy. It was, however, impossible for any one not thoroughly acquainted with the district to say how matters stood. He was sure that all present were now anxious to hear the other side of the question.

Sir Archibald Geikie observed that a doubt might well be entertained whether the so-called 'inclusions' of the Author were really such; for the petrographical description of them was suggestive rather of obsidian and rhyolite-veins. No account had been given of the structure of the surrounding rock with relation to the 'inclusions' and their supposed metamorphism. He was willing, however, for the sake of argument, to allow them to be actual blocks enclosed within the gabbro. But surely the sweeping generalization drawn from them by Prof. Judd, as to the age of the great acid protrusions of the Western Isles, was not warranted. Geologists have been in the habit of believing that all that can be demonstrated from such evidence is that an enclosed block must be older than the rock immediately enclosing it. Beyond that point all attempt to fix more precisely their relative dates is inference, which may be probable or not according to the circumstances of the case. But the speaker was again ready, for the sake of argument, to waive this objection and to concede that the 'inclusions' were not ancient rocks, but portions of some of the acid masses of the Tertiary volcanic series in the Hebrides. Yet, even with this admission, was the Author entitled to say that he had brought forward any valid proof of the relative ages of the basic and acid bosses of the West of Scotland? Most assuredly not. Sir Archibald Geikie stated that he had shown that there were traces of acid protrusions at an early part of the volcanic history of that region, and that blocks of various acid rocks were abundant in the volcanic agglomerates and in some of the tuffs intercalated among the plateau-basalts. The alleged 'inclusions' of the Author, if truly such, would thus be most naturally assigned to this early series of acid rocks, of which only ejected fragments had yet been found. Hence, even on the Author's own ground, the supposed demonstration that the granitic bosses are older than the gabbro masses entirely failed.

But the true state of the case had not been put before the Society. Quoting from his memoir in the Transactions of the

Royal Society of Edinburgh (which the Author refers to), Sir Archibald Geikie pointed out that from the same neighbourhood where the 'inclusions' are said to occur he had cited a remarkable portion of the junction-line between the granite and gabbro, and had described the occurrence of numerous veins proceeding from the mass of granite there and traversing the gabbro. Why had Prof. Judd kept silence as to these observations? If they were true, they afforded a complete demonstration that he had reversed the order of appearance of the two rocks. Until they were disproved it was idle to bring forward such weak evidence and inconclusive reasoning as had been offered in the present paper. But the case against the Author rested, not on the testimony of this one locality only, but on that of many others throughout the Western Isles. The speaker referred to numerous examples described in his memoir, where, by similar proofs of intrusion, he had demonstrated the posteriority of the granitic masses. The granitic veins and dykes of Skye, Mull, Rum, etc., not only traverse the plateau-rocks which Prof. Judd originally called felstones and now terms propylites, but also the great cores and sills of gabbro. The great granitic bosses are cut only by the youngest basic dykes. Whether these dykes were accompanied by the intrusion of sills or bosses of basic material had not yet been ascertained.

No man could pretend to have exhausted a subject or a region, and Sir Archibald Geikie said he well knew that an observer coming after him, with more time and maps on a larger scale than he had been able to obtain, would correct mistakes into which he himself had fallen, and would supply a multiplicity of detail which he had missed. He could only claim to have sketched an outline of a great subject; but he felt well assured that when this outline was eventually filled in, the position which he had assigned to the granitic bosses of the Inner Hebrides would be amply confirmed.

Dr. Du Riche Preller said that a striking analogy existed between the Tertiary gabbros and granites of Mull and those of Elba, with which latter he was acquainted. In Elba, however, the granite was clearly injected both into gabbro and diabase, and was therefore of a more recent Tertiary period than either of these rocks. These rocks occurred in the schists and associated calcareous strata which Signor Lotti had shown to be Eocene. If the igneous 'greenstone' rock of St. Kilda to which Sir Archibald Geikie referred, and of which he exhibited a specimen showing a distinct intrusive granitic vein, was a true gabbro, the case of Elba undoubtedly tended by analogy to strikingly confirm Sir Archibald's view of the Skye rocks; but the question was whether Sir Archibald and Prof. Judd really referred to the same rocks. Dr. Preller showed, by several sections, the intrusion of the Elban Tertiary granite into diabase and gabbro, and also of diabase into gabbro: both these last-named rocks being in many cases altered into serpentine, which always underlies either one or the other, or both where all three occur together. Some geologists still held that the eruption of diabase was confined to the Palæozoic period, but the case of Elba demonstrated that there the

Tertiary diabase erupted even after the Tertiary gabbro, and that the Tertiary granite erupted after the diabase, and was thus the last eruptive member of all in that island.

Mr. Rutley commented on the close resemblance between the microscopic structures described by the Author and those occurring in vitreous lavas.

Mr. W. W. Beaumont and Mr. Geo. Barrow also spoke.

Prof. Bonney being unavoidably absent, the Author of the paper asked permission (in accordance with a precedent that had recently been established) to read the following statement which had been received from him :—

"The specimens which you showed me recalled to memory certain felstones which had been affected by the heat of later intrusive rocks; they differed from felstones which had cooled in the usual way. The differences became more marked on microscopic examination. It seems impossible to deny that these rocks represent a variety of granite which has been partially melted down again *in situ*. Portions of the granitic original remain here and there, and form nuclei in the spherulites. This does not resemble the ordinary granites of Scotland, such as that of Ballachulish, but appears to be identical with the Tertiary granite (often called 'granophyre') of the Western Isles. So the latter must be earlier in date than the gabbro."

The Author, replying to Sir Archibald Geikie's suggestion that the masses of altered rock might be *veins* and not *inclusions*, pointed out that not only were the forms of the masses lying enclosed in the gabbro quite different from those of veins, but the petrographical evidence—such as the remarkable alteration of the minerals and the occurrence of fragments of micropegmatitic granite as nuclei in the spherulites—were altogether irreconcilable with such an idea. To the assertion that the occurrence of these inclusions at one locality is not sufficient to prove the relative ages of these two great rock-masses, he rejoined that a single and indisputable case of one rock enclosed in another did prove, beyond all controversy, that the enclosing rock is *younger* than the enclosed masses. In this case the inclusions occur near to the line of junction of the largest and most typical areas of granite and gabbro in the whole region—those of the Red Mountains and the Cuillin Hills of Skye, and at a locality selected by Sir Archibald Geikie himself as a most perfectly representative one. With respect to the assertion that, at this place, veins proceed from the granite into the gabbro, earlier writers on the district had looked for and failed to discover such evidence. He had himself gone again and again to the very spots indicated by the Director-General of the Survey, and could find nothing of the kind, while he did obtain abundant evidence opposed to this view. He maintained that loose fragments, like those picked up on the shore at St. Kilda, and now exhibited by Sir Archibald Geikie, do not support his views. They show a dark rock traversed by veins of a light one, but the dark rock is not a gabbro, and the light rock is not a granite.

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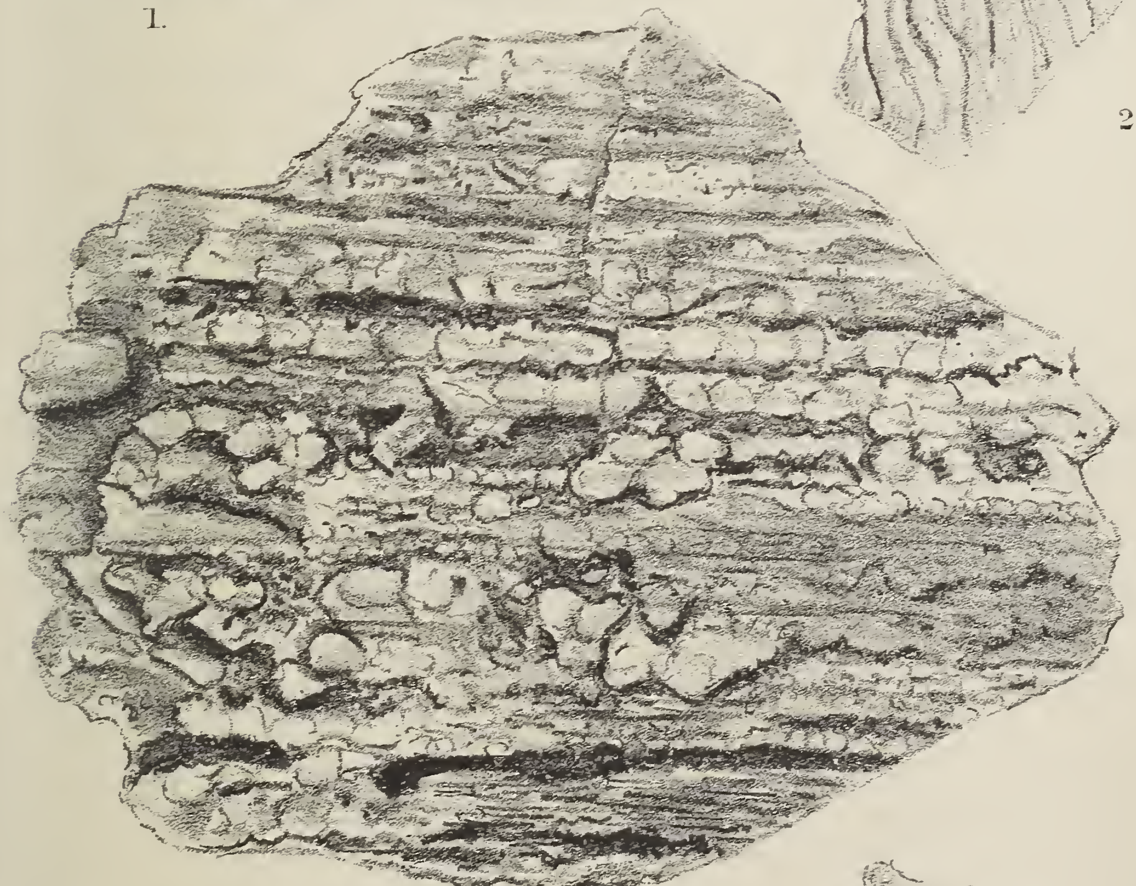

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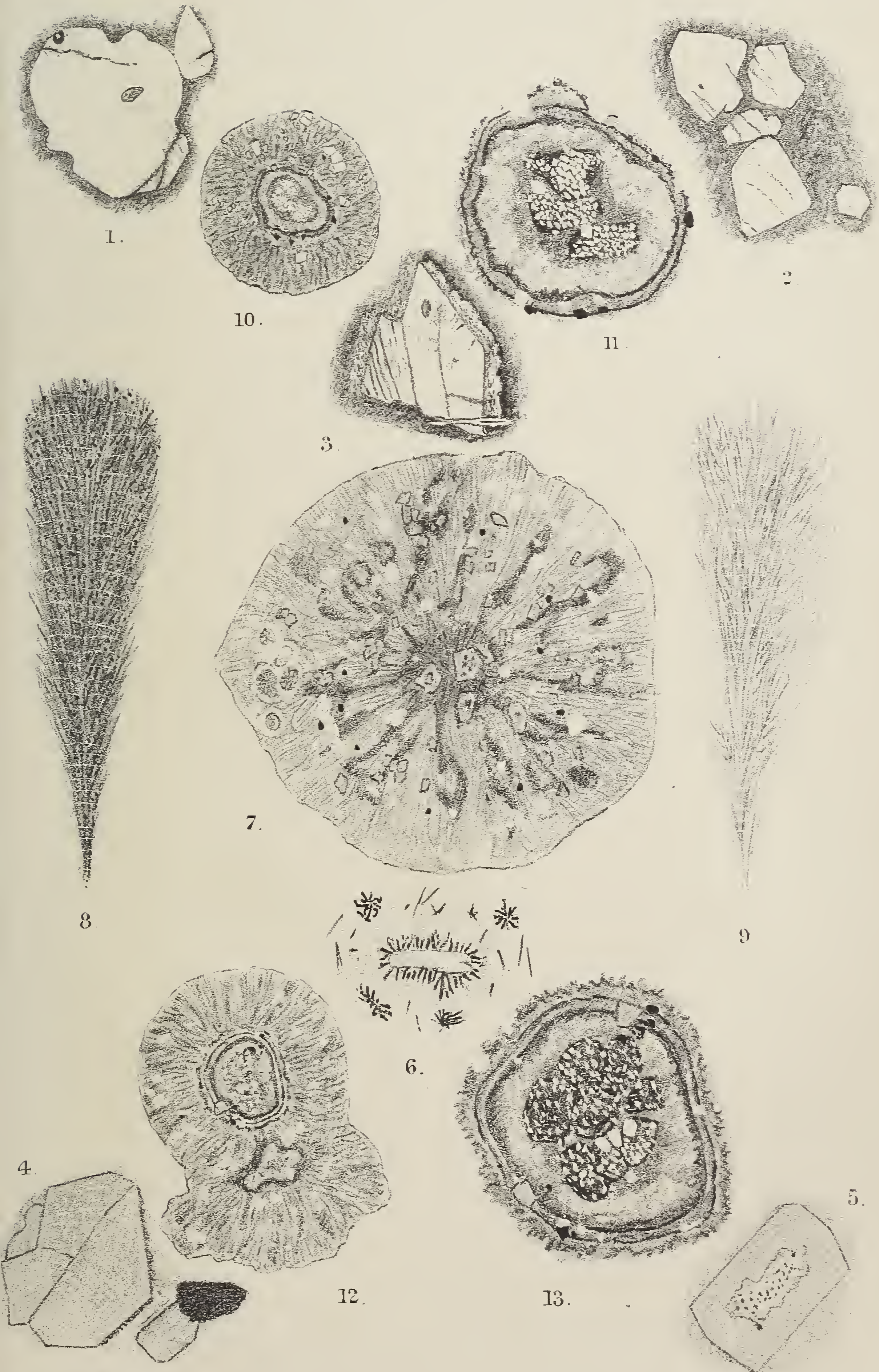
WEATHERED SURFACES OF GRANITE-INCLUSIONS.



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MINERALS & SPHERULITIC GROWTHS IN GRANITE-INCLUSIONS.

14. Notes *on some* Coast-sections *at the* Lizard. By Howard Fox, Esq., F.G.S., and J. J. H. Teall, Esq., M.A., F.R.S., F.G.S. (Read February 8th, 1893.)

Contents.

I. Introduction.

The well-known serpentine of the Lizard may be seen in contact with hornblende-schist, and also with the rocks for which Prof. Bonney proposed the term 'Granulitic Series.' The object of the present communication is to describe two small portions of the western coast, where phenomena which throw important light on the nature of the relations of the serpentine to the adjacent rocks may be observed. The first is in the neighbourhood of Ogo Dour, and the second east of the Lion Rock, Kynance.

II. Relations of Serpentine to Hornblende-schist at Pol Cornick.

In his classic 'Report on the Geology of Devon, Cornwall, and West Somerset,' De la Beche says (p. 30):—"It [the hornblende-slate] supports the great mass of the Lizard serpentine, with an apparent passage of the one into the other in many places. . . . . In contradiction to this apparent passage, we find a mass of serpentine amid the hornblende-slate between Dranna Point and Porthalla, on the north of the principal mass of serpentine, which has every appearance of having been thrust up among the hornblende-slate, twisting and contorting the laminæ adjoining it in directions which we should consider consistent with the passage of the serpentine in a state of igneous fusion through them." In these sentences De la Beche shows that he had observed facts which apparently contradicted each other, and with characteristic candour he states the two more or less opposed views, leaving the question undetermined.

In 1877 and 1883 Prof. Bonney communicated to this Society important papers in which he maintained that the serpentine was the result of the alteration of somewhat different types of rock, all of which belonged to the peridotite family, and that it, or rather the original rock of which it is the altered representative, had been intruded into the hornblende-schist. In the years 1879 and 1884 Mr. J. H. Collins joined issue with Prof. Bonney, and finally summed up his conclusions as follows:—"Of an originally differing series of conformable bedded rocks, some beds have been converted into that peculiar variety of hornblende-schist which characterizes the locality [Porthalla], others have been converted into true serpentine, and others again into a rock of intermediate character."[1] Thus the two opposing views which had been indicated by De la Beche were supported, with some modifications, as independent hypotheses by Prof. Bonney and Mr. Collins.

During portions of the summers of 1890 and 1891 we devoted some time to the examination of the coast near Ogo Dour—a locality which seemed likely to furnish important evidence on the vexed question of the relations of hornblende-schist to serpentine. As the results at which we have arrived do not precisely agree with those of previous observers, and yet at the same time tend to bring the conflicting views into more or less harmony, we venture to hope that a description of the facts which have influenced us will be of interest to this Society.

Briefly stated, our conclusions are as follows:—We agree with Prof. Bonney that the serpentines have in all cases been produced by the alteration of rocks in which olivine was an important constituent, but we believe that these rocks formed part and parcel of the foliated series to which the hornblende-schists belong, and that the apparent evidences of intrusion of serpentine into schist, in the district in question, are consequences of the folding and faulting to which the rocks have been subjected since the banding was produced. Whether these conclusions will be found to apply to all portions of the Lizard district or not, is a question on which we desire at present to offer no definite opinion.

In treating the subject we will in the first place deal with the original relations of the serpentine and hornblende-schists, and then with the effects of folding and faulting.

(*a*) Interbanding of Schist and Serpentine.

Absolutely undisturbed junctions of hornblende-schist and serpentine are extremely rare in the Lizard District, especially when both rocks present their typical characters, and are developed on a large scale. In the district in question the definite interbanding of these rocks may, however, be observed in more than one locality, and hand-specimens may be obtained in which both rocks are represented.

As an illustration we may refer to the promontory at Potstone Point (see Map, p. 203). Serpentine is here the prevailing rock, but it contains thick and thin bands of schist. The interbanding or interlamination, as it may be termed, is often on so minute a scale that microscopic sections may be prepared to illustrate it. One hand-specimen, from which a section has been cut, shows a conspicuous band of hornblende-schist, about $\frac{1}{4}$ inch in thickness, traversing the specimen throughout, and other much thinner and less persistent folia. The main mass of the specimen is composed of olivine, hornblende, serpentine after one or both of these minerals, the charac-

[1] Geol. Mag. for 1885, p. 299.

teristic network of magnetite, and a few grains of picotite. The hornblende-schist is composed of pale-brown hornblende, colourless malacolite, and more or less altered felspar. Another specimen from the same locality illustrates the interbanding of the two types of rock in a still more perfect manner. Numerous laminæ, no thicker than sheets of cardboard, alternate with each other. The bands of schist are composed of hornblende, malacolite, and turbid felspar. In some bands the hornblende is pale green in colour, in others brown. Detached olivines with strings of magnetite may be observed along certain planes, and by the increase in the number of these olivines and in the thickness of the zone in which they are developed bands of peridotite have been formed, and from these serpentine has been produced in the usual way. As the olivine increases the felspar diminishes, but the hornblende of the serpentine is absolutely identical in structure and mode of development with that of the schist.

The hornblende of the schist associated with the serpentine is usually brown, and not green, as in the common type of hornblende-schist; but we have found brown hornblende in the schists of this locality, even when they are developed on a large scale, and have the macroscopic characters of the typical hornblende-schist of the Lizard. The white augite (malacolite), first recognized by Lieut.-Gen. McMahon, is a feature of these rocks, and one band of the zone marked *a* (see Map, p. 203) contains it to the exclusion of hornblende. A hand-specimen of this band is massive, grey, and fine-grained. Under the microscope it is seen to be a granular aggregate of malacolite, altered felspar, and iron ores, with biotite occurring as an unimportant accessory. This rock is connected with the normal schists by intermediate varieties, and must, therefore, be regarded as forming a band of exceptional composition. The serpentines interbanded with the schists belong to the olivine-hornblende variety. They are themselves frequently well banded, in consequence of variations in the relative proportions of the two principal constituents; and this banding, so far as we have been able to determine, is parallel with that of the schist, when allowance is made for the effects of disturbance.

So far we have been referring only to banding; but occasionally lenticles of serpentine may be observed in the schist, and when this is the case the foliation-planes in the schist wind round the lenticles.

It is no part of our present purpose to enter into a discussion of the causes which have produced the banded complex. They were probably similar to those which have given rise to banded gneisses of igneous character all the world over. The occurrence of banded peridotites as an integral part of gneissose formations is known in the north-west of Scotland and in Norway.[1] The last-mentioned occurrence is particularly interesting, because the peridotite would give by alteration a serpentine closely resembling, if not identical with, that of the district under consideration.

[1] W. C. Brögger, 'Ueber Olivin-fels von Söndmöre,' Neues Jahrb. 1880, vol. ii. p. 187.

(*b*) Folding and Faulting of the Complex.

We have now to consider the effects of folding and faulting in the banded complex of schist and serpentine. These may be studied in the neck at the small promontory which for convenience of description we have called Potstone Point, and also on the cliff-slopes

Fig. 1.

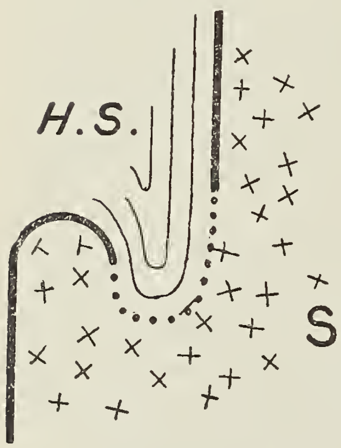
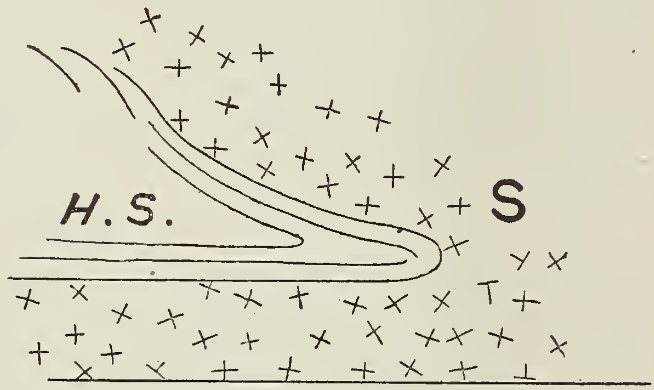


Fig. 2.



Folding of Serpentine and Schist at + *on eastern border of* a (see Map).

south-east of it. On the eastern margin of the banded schist *a* at + in the Map, the serpentine is distinctly seen to be folded with the schist as represented in fig. 1, and a little to the right the schist tongues out as indicated in fig. 2. The most conclusive evidence of interfolding is, however, furnished by mapping portions of the cliff-slopes, an operation attended with some difficulty on account of the movement which is going on, and the quantity of loose talus which covers certain areas. In Trans. Roy. Geol. Soc. Cornwall, vol. xi. part iv. p. 215, one of us published a map showing the mutual relations of serpentine, schist, and basic dykes at Potstone Point. We have since then extended our observations, and the result is given in the Map which is seen on the opposite page. The phenomena are represented as they actually appear on the sloping face, and not as they would appear on a horizontal plane.

We wish to direct special attention to a small area in the central portion of the Map, which we have drawn on a scale of 50 feet to the inch. At *e* is a patch of schist surrounded on all sides by serpentine. To the east, at *f*, schist again appears. The junction between schist and serpentine is of a wavy character, tongues of the latter run out into the former, and the patch *e* might be taken for an inclusion, so that at first glance the hypothesis of an intrusion of serpentine into schist seems a perfectly natural one. Careful examination shows, however, that the patch *e* is not an enclosure, but the summit of a gentle dome which has been exposed by the removal of the once overlying band of serpentine; and, further, that the wavy character of the junction is the result of folding, so that

MAP OF A PORTION OF THE WESTERN COAST OF THE LIZARD NEAR POL CORNICK for every tongue of serpentine into schist there is a corresponding tongue of schist into serpentine. The relations of the two rocks are further complicated by small faults, some of which are represented in the Map. As these are in no way remarkable, it is unnecessary to do more than refer to them.

We have examined other localities on the western coast where hornblende, schist, and serpentine are in juxtaposition, and in no case have we found appearances which were incompatible with the view suggested by the facts above described.

III. Basic Dykes, and the Conversion of Dolerite into Hornblende-schist.

In concluding this part of our paper, we desire to offer some additional remarks on the porphyritic and non-porphyritic dykes which are so well seen in this part of the coast. Starting from Ogo Dour on the north, and walking over the boulders and rocks to Potstone Point at low water, we find both coarse and fine-grained porphyritic epidiorites [1] cutting the hornblende-schist and themselves passing into hornblende-schist, which closely resembles that of the district. Extremely coarse-grained gabbros, or gabbro-pegmatites as they may be termed, also occur. Crossing a ridge, we reach the narrow gully on the northern side of Potstone Point. The cliffs on the north-east are formed of well-banded serpentine with a south-westerly dip of about 60°, and the face of the cliff is determined by the slope of the banding. The floor of the gully is formed of porphyritic epidiorite and dolerites, which are here intimately interblended with white and grey, banded, saussuritic rocks.

The porphyritic epidiorite varies, from the massive variety with well-marked idiomorphic crystals of felspar, to a fissile variety in which the crystals appear merely as narrow white streaks. Every intermediate phase may be observed within a few feet. The south-western face of the gully is formed in its lower part of porphyritic epidiorite with large and very numerous porphyritic felspars, and in its upper part of a more compact non-porphyritic variety of the same rock. The junction between the intrusive igneous rock and the schist of the country may be observed near the top. Two gabbro-dykes containing pseudophite, from 6 to 12 inches thick, traverse the serpentine on the north-eastern side of the gully. The head of the gully is crossed by a small fault, producing a shift of about 10 feet in one of the gabbro-dykes.

We now come to Potstone Point. Here the porphyritic epidiorite, containing numerous large white crystals of felspar, has on its western side a 'chilled' margin in which very few crystals are seen. The dykes *c* and *d*, and the coarse porphyritic epidiorite *P D*, which is merely a thicker dyke of the same age and character,

[1] We use the term 'epidiorite,' because there is reason to believe that all these rocks were once dolerites. Some portions are dolerites even now, but it is impossible to distinguish the dolerite from the epidiorite in the field.

have been traced 50 yards farther south-east (see Map, p. 203). The fact that these cut the banded series is clearly established by tracing the junctions. The hade of the dykes is nearly at right-angles to that of the foliation-planes. It will be seen by the map that there are other dykes besides those which have been especially referred to. Potstone, similar to that described in a former paper by one of us, has been observed at many points east and south-east of the locality where it was first recognized. It is well seen at *g*, where it is associated with schist and serpentine in such a way as to suggest that it forms a part of the banded complex.

In describing the dykes, we have frequently referred to their passage into hornblende-schist. In the porphyritic varieties the foliation-planes wind round the large felspars which have often been squeezed out into lenticular folia. Fluxion-structures are, moreover, strongly marked under the microscope. Are these structures original or secondary? In previous communications one of us has maintained the latter view, and more extended observations have not yet led him to change his opinion. A description of a specimen from a foliated portion of one of the dykes near Potstone Point may here be given in support of this view.

It is a rock possessing linear foliation. White porphyritic felspars still showing traces of idiomorphism, but usually more or less rounded and lenticular, lie in a compact, dark greenish matrix. Under the microscope the large felspars can be seen to have suffered distortion and fracture by the movement which produced the fluxion-structure. Seeing, however, that these felspars were almost certainly present in the magma when the dyke was intruded, their distortion does not prove that the rock was deformed after final solidification. We turn then to the groundmass. This presents a somewhat confused appearance. Lath-shaped felspars are still recognizable, but it is clear that they have been bent, broken, and converted into a microcrystalline aggregate in which the original form is partially or wholly lost. In other words, cataclastic structures are as clearly discernible in the felspars of the groundmass as they are in those which occur as porphyritic constituents. It is evident, therefore, that the deformation which produced the fluxion-structure took place after the lath-shaped felspars had been produced. We have thus pushed the operation one stage nearer that of final consolidation.

Now, the two generations of felspar and their broken fragments lie in a fine-grained, crystalline aggregate, of which a pale-green, more or less fibrous hornblende is the principal constituent. It is in this aggregate that the differential movement has mainly taken place. Fluxion-structure is common in basaltic lavas and occurs even in dykes, but in no case known has the unconsolidated interstitial matter, which allowed the structure to be produced, solidified as an aggregate of fibrous hornblende; whereas such hornblende unquestionably arises in consequence of the alteration of augite. To make the case still stronger we want evidence that the original rock was a dolerite, and that it did not possess a parallel structure.

This evidence is furnished by the very slide we are describing. Ragged cores of unaltered augite lie in some of the hornblende-aggregates, and apparently shade off into them. *These cores polarize as individuals, and are penetrated by lath-shaped sections of felspar, whereas the hornblende polarizes as aggregates and shows fluxion round the felspars.* We conclude, therefore, that the original rock was a massive ophitic dolerite, that the parallel structure is the result of fluxion due to earth-stresses after the consolidation of the last mineral—that is, after the consolidation of the augite—and, finally, that the superinduced plasticity was connected with the replacement of augite by hornblende.

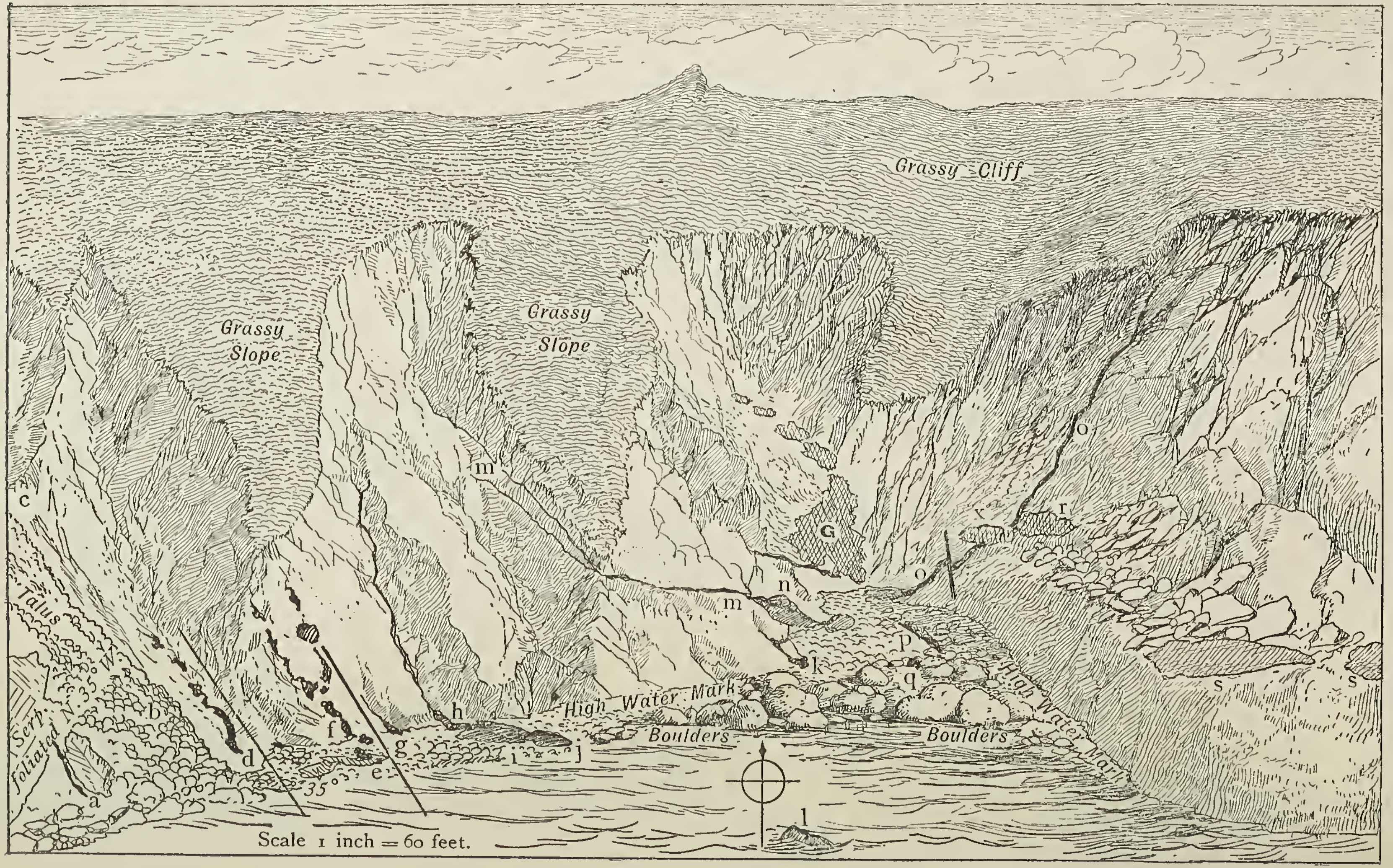
IV. Relation between the Serpentine and the Granulitic Series east of the Lion Rock.

The general structure of the coast for a distance of about 120 yards (from west to east) is indicated in fig. 3. The main mass of the cliff is formed of serpentine. The common variety weathers red, and contains numerous crystals of bastite. It is therefore markedly different from the olivine-hornblende serpentine of the Ogo Dour district.

The chine *c*, at which our section commences on the west, is evidently determined by a plane of disturbance, and the brecciation which may be observed at this point is probably connected with the disturbance. It is only seen in a narrow band, measuring a few feet across, and running in the general direction of the chine. The dyke *d* is only visible for a few yards, and does not maintain a constant thickness for any considerable portion of that small distance. It is formed of a compact, grey, massive rock, too much decomposed for precise determination. In its upper part it has been converted into a series of lenticles by a number of small oblique faults. The gabbro-vein *e* can be traced only for a few yards among the fallen blocks. It must have been of the extremely coarse type for which the term 'gabbro-pegmatite' seems appropriate. Pseudomorphs after diallage, sometimes measuring 1 inch or more across, lie in a matrix of pseudophite. The vein is about 1 foot thick, and it may be seen to cut across the foliation of the serpentine, which is here fairly well marked.

The dyke *f* occurs at a place where there has been much disturbance. The lower portion (6 feet) is bordered by rotten serpentine and varies in thickness. Where the dyke is narrow, foliation is strongly marked. Like most of the small dykes along this coast, it is so altered as to make a precise petrographical determination impossible. The freshest portions are, however, rich in biotite, and it is probable therefore that the rock most nearly resembles some of the darker members of the Granulitic Series. The mass *h* is fine-grained and well foliated in places. It runs parallel with the shore for about 18 or 20 feet, and then turns up the cliff. At its lowest part it attains a thickness of about 3 feet, but as it is followed up the cliff it is seen to diminish rapidly in thickness, and finally to disappear. In its thicker portions it closely

Fig. 3.—*View of Cove east of the Lion Rock, Kynance (partly diagrammatic).*



resembles parts of the Granulitic Series. Close to the southern end of this dyke is a mass of the typical Granulitic Series (*i*), with both the basic and the acid varieties well developed. The relation of this to the dyke could not, however, be observed, owing to fallen blocks. Some of the blocks at *j* are greenish-grey serpentine, containing crystals of picotite similar to those seen at Lankidden and elsewhere. Another basic mass, which is connected with a dyke, may be seen at *m*; although it is, on the whole, fairly uniform in composition, thin veins of an acid rock may be observed in one or two places. The eastern junction with the serpentine is exposed for about 6 feet; it is wavy in outline, and the schistosity in the serpentine is cut by the junction-surface, as is also the foliation in the schist.[1]

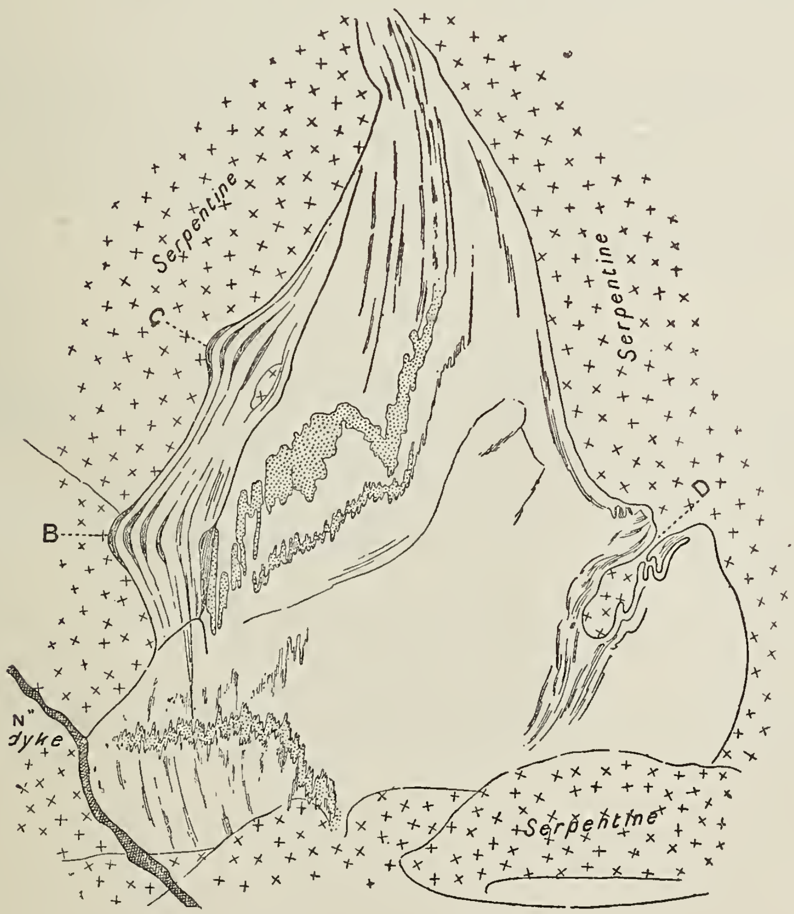
We next come to the wedge-shaped mass of granulitic rock *G*, which forms the most interesting portion of the section. The thickness of the wedge at the base is about 20 feet, but this rapidly diminishes as it rises in the cliff, and at a height of about 25 feet is only 1 or 2 feet. A narrow band of the same material may be traced at intervals up the slope, but its relations to the surrounding rock cannot be made out in a satisfactory manner. The wedge is made up of two types of rock, a dioritic type and a granitic type, the former of which occasionally contains small porphyritic felspars. The relations of the two types are too complicated to be accurately represented in a diagram. The granitic type occurs in puckered bands, streaks, and lenticles. Microscopic examination confirms the view that we have in this wedge a genuine representative of the Granulitic Series, which was formerly supposed to occur only on the east coast of the Lizard.

We have now to describe the most important point of all in connexion with this wedge. The junction with the serpentine is well exposed. On the left side are two rounded protuberances (*B* & *C*, fig. 4, p. 209), so that the junction-line presents a wavy appearance. The granulitic mass is here well banded, and the banding is conformable with the junction. On the right-hand side, at *D*, there is a tongue-like process of rotten serpentine, and indications of the same feature may also be observed on the left. Now these phenomena seem to contradict the view that the original rock of the serpentine was intruded into a solid granulitic complex. They appear to indicate that the granulitic complex was either intruded into the serpentine, or that the two have been folded together while the granulitic complex was in a state of plasticity, so that bosses and tongues of serpentine could be pushed into the yielding mass of granulitic material; or finally, and this we regard as the least probable, that the serpentine was intruded into the granulitic complex while this was in a plastic state.

[1] The letters *a*, *k*, *l*, *p*, *q* in fig. 3 indicate dykes which do not differ in any essential particular from those above described. The mass *l* is not seen when the tide is so high as shown in the figure: it lies on the floor of the foreshore, with boulders of serpentine on the top of it.

East of the granulitic wedge, a dyke *o*, varying from 18 to 24 inches in width, is seen cutting the serpentine and running to the top of the cliff in a north-easterly direction. About 40 feet from the base of the cliff a fault crosses the dyke, throwing it down 2 feet. Fifteen feet above this fault a reddish rock *X* is seen to emerge from the turf and join the dyke. On the other side of a talus 20 feet wide, it becomes banded with the basic rock of the dyke, and runs along in a banded state for 20 feet at *r*. The reddish rock is of medium grain, crystalline in texture, and is composed of orthoclase and plagioclase, with a few small flakes of biotite. At *s* there

Fig. 4.—*Wedge G in the view* (*fig.* 3).



[Diagrammatic.]

Scale : 1 inch = about 9 feet.

The serpentine at the base is in the form of loose blocks lying in front of the wedge.

is a cake-like mass resting on the serpentine. It is a fine-grained, dark greyish schist, composed of hornblende and felspar, with small grains of iron ore. Foliation is well marked and its strike is north-east.

V. Summary of Results.

Ogo Dour District.

(1) The hornblende-schist and serpentine of the Ogo Dour district form together a banded complex of crystalline foliated rocks.

(2) The relative ages of hornblende-schist and serpentine cannot be satisfactorily determined, but the occurrence of lenticles of serpentine in hornblende-schist points to the conclusion that, if there be any difference in age, the serpentine is the earlier.

(3) The complex of schist and serpentine has been folded after the banding was produced, and before the dykes were intruded. Some, if not all, of this folding probably took place when the complex was formed.

(4) The schist and the serpentine have been traversed by dolerite-dykes.

(5) These dykes have themselves been converted into schists which are macroscopically indistinguishable from portions of the normal hornblende-schist of the Lizard Peninsula.

(6) The district has been faulted after the dykes had reached their present condition.

Lion Rock District.

(1) Basic dykes and a gabbro-vein may be observed traversing the serpentine in the cliff immediately east of the Lion Rock.

(2) These dykes pass in places into hornblende-schist.

(3) They vary in thickness, and in some of the thicker portions put on appearances which are characteristic of the Granulitic Series.

(4) One wedge-shaped mass of typical granulitic rock is seen in the section.

(5) The structure of this mass appears to be incompatible with the theory that the serpentine was intruded into solid granulitic rock.

15. *On a* Radiolarian Chert *from* Mullion Island. By Howard Fox, Esq., F.G.S., and J. J. H. Teall, Esq., M.A., F.R.S., F.G.S. (Read February 8th, 1893.)

Contents.

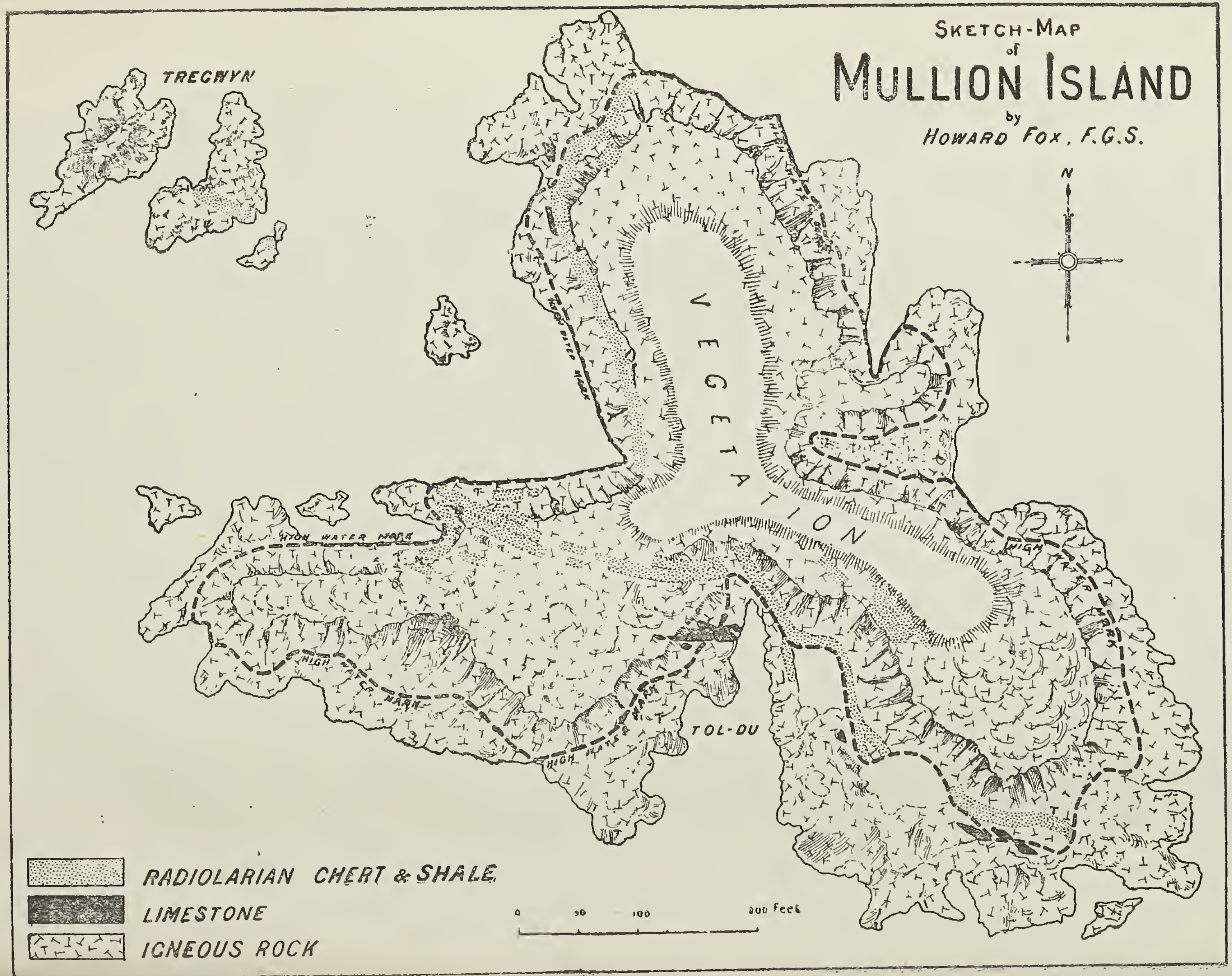
I. Description of the Island and its Predominant Rocks.

Mullion Island lies off the western coast of the Lizard Peninsula, a little south of Mullion Cove. The channel separating it from the mainland is only about 250 yards wide at its narrowest part, and yet the rocks of which the island is composed are quite distinct from those of the adjacent coast.

The island somewhat resembles in shape the leaf of the trefoil. From the central part three promontories, each 150 yards in length, answering to the three lobes of the leaf, run out into the sea; one towards the north, another towards the west, and a third towards the south-east. The coast-line is almost everywhere backed by cliffs which vary in height from 20 to 100 feet. The culminating point lies at the extreme edge of the western promontory, facing the open sea. The upper portions of the cliffs in this part of the island glow with brilliant orange and yellow tints, owing to the luxuriant growth of the ubiquitous lichen *Parmelia parietina*. The lower part of the island is covered in places with miniature forests of tree-mallow. Sea-beet and other marine plants abound.

The predominant rock is of igneous origin. It is greenish, fine-grained, much jointed, and often highly decomposed. The old term 'greenstone' may be appropriately applied to it. In the mass it is separated into rude rolls by curvilinear joints. These rolls show circular or elliptical outlines in cross-section and measure from a few inches to 2 feet in diameter. Flat surfaces of this rock, such as are exposed in many places at the base of the cliff, remind one somewhat of the appearance of a lava of the *pahoehoe* type. A few spherical amygdaloids are scattered through the mass.

Under the microscope the common type of rock is seen to consist of felspar, augite, iron ores, and secondary products, such as carbonates and chlorite, derived from these minerals. The felspar may occur as porphyritic crystals sparsely scattered through the groundmass, or as long, slender microlites forming a constituent of the groundmass. The augite occurs as small grains and microlites, and is sometimes only represented by secondary minerals. Iron ores are comparatively scarce. In structure the rock is more allied to a lava than to an intrusive mass. Small veins filled with calcite are very common.


SKETCH-MAP
of
MULLION ISLAND
by
HOWARD FOX, F.G.S.
N
TREGWYN
VEGETATION
HIGH WATER MARK
TOL-DU
RADIOLARIAN CHERT & SHALE
LIMESTONE
IGNEOUS ROCK
0
50
100
200 Feet

One somewhat exceptional variety may be described as a fine-grained, dark greenish-grey dolerite. It is composed of pale brown augite showing a strong tendency to form long, slender prisms, lath-shaped felspars, and iron ores (scarce).

The stratified rocks, which form only a very small portion of the island, consist of cherts, shales, and limestones. They occur in thin strips which cannot be traced continuously across the island, and are both underlain and overlain by igneous rocks. They are seen at different horizons from the foreshore to the summits of the northern and south-eastern promontories. The chert is the most interesting lithological type, on account of its radiolarian origin. It is interstratified with shale, and occurs in bands which vary from $\frac{1}{4}$ inch to several inches in thickness. As many as thirty bands may occur in a thickness of 3 feet. In some places where movement appears to have taken place before the final consolidation of the cherts, some layers have been pinched out, while others have been thickened into nodules. That these nodules are not of a concretionary character is shown by the presence of radiolaria. The colour varies from black to grey or brown, and very frequently the thinner layers have a central dark band, bordered by lighter-coloured margins. The radiolaria may often be observed with a pocket-lens on the surfaces of cross-joints, but they are most perfectly seen on the upper surfaces of some of the layers where the shale has been removed by the weather. Here they appear as rounded protuberances, often thickly crowded together, and their true nature can be at once determined by placing such a surface under the microscope. The reticulated character of the test can then be often clearly seen. The chert bands are generally traversed by a network of white quartz-veins.

The shale varies in colour from buff or brown to nearly black. We have searched this shale for fossils, but up to the present time only one microscopic form has been detected, and that one has not been identified. The limestones are grey in colour and crystalline in texture. Their precise relations to the series of cherts and shales cannot be very clearly made out. Not unfrequently they occur as more or less isolated lenticles in the greenstone.

An excellent exposure of the rocks of the island is seen in Tol Du, the inlet on the southern side. The foreshore is formed of 'greenstone,' and the exposed surface shows the peculiar appearance above referred to. The more or less distinct rolls exhibit a tendency to elongation in a north-westerly and south-easterly direction, and there are indications of a dip towards the north-east. Small patches of chert and shale may be seen sticking on this surface, and bits of limestone occur between the rolls of igneous material. At the base of the cliff facing south-west is a band of chert and shale measuring a few feet in thickness. It is covered by another mass of rock precisely similar to that which forms the foreshore. As the section is followed round the south-eastern part of the island patches of the chert-shale series are seen at different levels in the igneous rocks.[1]

[1] [A subsequent visit has enabled me to obtain evidence that the band of radiolarian chert traverses the third islet of Tregwyn, as well as the two where it is shown on the map facing this page.—H. F., March 21st, 1893.]

The northern promontory also shows an excellent exposure of the igneous and stratified rocks. The latter are here from 8 to 10 feet thick at the base of the cliff, where it faces towards the north-west. The thickness rapidly diminishes as the band is followed towards the south. The cherts are here associated with black shales, which certainly look as if they should yield fossils. The igneous rock possesses the same structure as at Tol Du, with the same rude N.W.-and-S.E. strike in the rolled masses. The cherts and shales are again exposed on the upper surface of the south-eastern arm near the central part of the island, and two bands may also be seen on the western arm. The latter occur in the cliffs facing north, but cannot be traced to the other side of the promontory.

II. Relation of the Igneous and the Stratified Rocks.

An important question arises as to the relation between the igneous and the stratified rocks. Must the 'greenstone' be regarded as intrusive or contemporaneous? The fact that the stratified rocks appear to have been completely enclosed in igneous material, and that there is no trace of a floor over which a lava could have flowed, are points which may be urged in favour of the former view. But there are other facts which are difficult to explain on this hypothesis. Thus the igneous rock is uniformly fine in grain, although developed on a very extensive scale. There are no marked signs of metamorphism in the sedimentary rocks. The ropy structure is quite unlike that of any known intrusive mass of equal size. In these circumstances we are tempted to ask whether the phenomena may not be due to the injection of igneous material between the layers of the stratified series near the surface of the sea-bed, and possibly while deposition was actually going on. In this way thin sheets of deposit might be detached and moved on by the flow of igneous material. The phenomena might be explained by the simple flow of a submarine lava, if such a lava possessed the power of insinuating itself between layers of deposit and tearing them up during its onward march.

III. The Rocks of the Neighbouring Mainland contrasted with those of the Island.

The rocks of Mullion Island have not been found on any portion of the adjacent coast. The opposite cliffs are formed of hornblende-schist and serpentine. Stratified rocks make their appearance at Polurrian Cove, rather less than a mile N.N.E. of Mullion Island. The junction at this point has been described by Prof. Bonney, in vol. xxxix. of this Journal (1883), p. 10. The change from hornblende-schist to a sedimentary series consisting of dark slates with sandy beds is abrupt, and the fault which hades to the south, so as to carry the sediments beneath the schists, is marked by a breccia. The strike of this breccia, as it is exposed on the coast, points to Mullion Island. We endeavoured to trace the fault inland on the six-inch map, but, as it does not make a feature, and as there are few exposures, this is by no means an easy task. The first point where the fault can be fixed within a few yards is at La Frowder, and if this point be joined to the exposure on the coast and the line continued, it would pass to the north of the island. The trend of the junction-breccia on the coast, therefore, appears to indicate that the fault curves somewhat towards the south. If this curvature were continued for a short distance, it would carry the boundary-fault between Mullion Island and the mainland, and such is the view we take. We have examined the coast from Polurrian Cove to the cliffs north of Gunwalloe in the hope of finding the rocks of Mullion Island, but without success. They must apparently be looked for in other parts of Western Cornwall.

IV. Note *on the* Radiolaria *in the* Mullion Island Chert. By George Jennings Hinde, Ph.D., V.P.G.S.

[Plate IV.]

As already mentioned by the Authors, the radiolaria in this chert are partially weathered out on the surface of some of the beds, and, when examined under a lens or under the microscope, they appear like so many millet-seeds, thickly covering the rock. In this condition they usually show the lattice-like structure of the test, of a light or dark-brown tint; when this has been weathered off, only the solid cast of translucent silica which has filled up the originally hollow test projects above the surface. The majority of the forms thus shown appear to be simple spheres belonging to the genus *Cenosphæra*, Ehrenberg (Pl. IV. fig. 1.), but as only the upper portion of these weathered-out forms can be distinguished, it is quite possible that some of them may be oval instead of spherical.

In thin microscopic sections of the chert, the radiolaria are shown in some portions nearly in contact with each other, while in others they are less thickly distributed. Most of them appear as transparent bodies with circular or oval outlines, only marked off from the enclosing matrix by the clearness of the silica which has filled in their inner cavities. The lattice-structure of the tests in these forms has completely disappeared, and only the chalcedonic casts of the interior remain. Sometimes the tests are shown in section as circular or oval rings of a brownish tint, in which the apertures are indicated by alternate lighter spaces (Pl. IV. figs. 4, 5). In a few rare instances the tests have become stained by an opaque dark material, and these show the structure fairly well; but unfortunately this dark substance has often infilled the interior of the tests, so that only their outlines can now be distinguished. In their general condition of preservation the radiolaria in this Cornish chert strikingly resemble those in the Ordovician[1] chert of Scotland, but they are less favourably preserved in the specimens which have as yet been obtained.

Owing to their imperfect preservation, it is not possible to give

[1] Ann. & Mag. Nat. Hist. ser. 6, vol. vi. (1890) p. 40.

more than an approximate determination of the genera to which the radiolaria belong, and in some cases even the generic position is doubtful. The genera recognizable are *Cenosphæra*, Ehrenberg, *Carposphæra*, Haeckel, *Cenellipsis*, Haeckel, *Lithapium*, Haeckel, and *Lithatractus*, Haeckel, belonging to the two sub-orders of the Sphæroidea and Prunoidea. The commonest forms present are simple, spherical or oval lattice-tests belonging to *Cenosphæra* (Pl. IV. fig. 1) and *Cenellipsis* (Pl. IV. figs. 4–7). The tests range from ·16 to ·30 mm. in diameter. The genus *Carposphæra*, in which there are two concentric lattice-tests, is represented by a few small forms (Pl. IV. figs. 2 and 3) which may perhaps belong to two species. A specimen with an elliptical lattice-test and a single spine (Pl. IV. fig. 8) is included under *Lithapium*, and other examples with two concentric tests and with a spine at each pole (Pl. IV. fig. 9) belong to *Lithatractus*. Forms with spines are comparatively rarely shown in sections; in the two examples figured (Pl. IV. figs. 10 and 11) only the outlines are seen, and they do not appear to belong to any genus yet described. The recognizable forms belong to simple generic types which are all represented in Palæozoic strata, and with one exception as low as the Silurian, but they do not afford any trustworthy indication of the age of the chert in which they occur.

With the exception of the radiolaria, the only other microscopic organic remains in sections of the chert are some ill-defined spicular bodies, shown only in the dark-stained portion of the rock; some of these may be fragmentary spines of radiolaria, while others are perhaps spicules of siliceous sponges.

The following is a technical description of the forms which can be recognized:—

Sub-order Sphæroidea, Haeckel.

Cenosphæra, sp., Pl. IV. fig. 1.

Spherical tests, ranging from ·145 to ·305 mm. in diameter, are numerous in the chert, but the lattice-structure is shown only in those weathered out on the surface. The holes in the test appear to be subequal, about ·015 mm. in breadth, while the lattice-work is from ·005 to ·010 mm. wide. In the size and disposition of the apertures of the test, this form resembles *C. gregaria*, Rüst ('Palæontographica,' vol. xxxi. 1885, p. 286, pl. xxvi. fig. 10), which is common alike in Devonian, Jurassic, and Cretaceous strata.

Carposphæra, sp. *a*, Pl. IV. fig. 2.

The outer test is ·145 mm. in diameter and ·009 mm. in thickness, and the inner ·045 mm. in breadth. The structure is not preserved. There are three rays visible, connecting the inner with the outer test. It resembles in outline *C. pygmæa*, Rüst, from the Lower Carboniferous of the Harz ('Palæontographica,' vol. xxxviii. 1892, p. 135, pl. vi. fig. 13), but it is distinctly larger. The form is rare.

Carposphæra, sp. *b*, Pl. IV. fig. 3.

The outer test is ·095 mm. in diameter and ·007 mm. in thickness; the inner, ·030 mm. in diameter. There are from seven to eight rays connecting the inner with the outer test. No pores are shown. Rare.

Sub-order Prunoidea, Haeckel.

Cenellipsis, sp. *a*, Pl. IV. fig. 4.

Test regularly oval, long diameter ·220 mm., breadth ·185 mm. Surface apparently smooth, the holes circular or oval, about ·015 mm. in width, the lattice-work less than the width of the holes. Wall, ·020 mm. in thickness.

Cenellipsis, sp. *b*, Pl. IV. figs. 5, 6.

Test regularly oval; length, ·20 mm.; breadth, ·165 mm.; thickness of wall, ·015 mm. The lattice-structure is not clearly shown. It is smaller, and the wall is thinner than in the preceding species.

Cenellipsis, sp. *c*, Pl. IV. fig. 7.

Test elongate oval; length, ·25 mm.; breadth, ·18 mm. The apertures are circular or oval, unequal in size, from ·010 to ·025 mm. in breadth; the lattice-work is less than the width of the apertures. Fairly common. In form and proportions the specimens agree with *Cenellipsis perovalis*, Rüst ('Palæontographica,' vol. xxxviii. 1892, p. 151, pl. xvi. fig. 4), from the Lower Carboniferous of the Harz, but the apertures of the test are smaller and less crowded.

Lithapium, sp., Pl. IV. fig. 8.

Test elliptical; length, ·18 mm.; breadth, ·15 mm. At one end is a short conical spine, ·045 mm. in length. Structure very imperfectly shown.

Lithatractus, sp., Pl. IV. fig. 9.

The elliptical outer test is ·110 mm. in length and ·085 mm. in breadth. The inner test is ·040 mm. in diameter; it is connected by four or five rays with the outer test. Only one spine, ·050 mm. in length, is preserved, but there are traces of another at the opposite end of the test and of some minute blunted spines (or tubercles) as well. The lattice-structure is not shown.

Forms undetermined, Pl. IV. figs. 10, 11.

Fig. 10. Test nearly circular in outline; length, ·195 mm.; width, ·155 mm.; with three radial spines: the longest preserved is ·195 mm. in length. No structure shown.

Fig. 11. Test circular in outline, ·2 mm. in diameter, with two long, tapering, radial spines, about ·2 mm. in length, and two short secondary spines. No structure shown.

EXPLANATION OF PLATE IV.

Fig. 1. *Cenosphæra*, sp. Drawn from a specimen weathered out on the surface of a slab of chert. × 200 diameters.
Fig. 2. *Carposphæra*, sp. *a*. Drawn from a microscopic section. × 200.
Fig. 3. *Carposphæra*, sp. *b*. × 200.
Fig. 4. *Cenellipsis*, sp. *a*. Showing the wall in section. × 200.
Figs. 5, 6. *Cenellipsis*, sp. *b*. One specimen showing the wall in section, and the other showing traces of the lattice-work. A quartz-vein traverses a portion of this latter. × 200.
Fig. 7. *Cenellipsis*, sp. *c*. A specimen showing the lattice-structure preserved in dark material. × 200.
Fig. 8. *Lithapium*, sp. Showing indistinct traces of the lattice-structure. × 200.
Fig. 9. *Lithatractus*, sp. Showing the form in section. × 200.
Fig. 10. Outline of undetermined form with three radial spines. × 100.
Fig. 11. Specimen undetermined, the outline only shown. × 100.
Fig. 12. A portion of a slab of chert, showing radiolaria partially weathered out on its surface. × 50.
Fig. 13. Section illustrating the structure of the greenstone associated with the chert of Mullion Island. Two porphyritic crystals of felspar and acicular microlites of the same mineral are clearly recognizable in the figure. × 50.

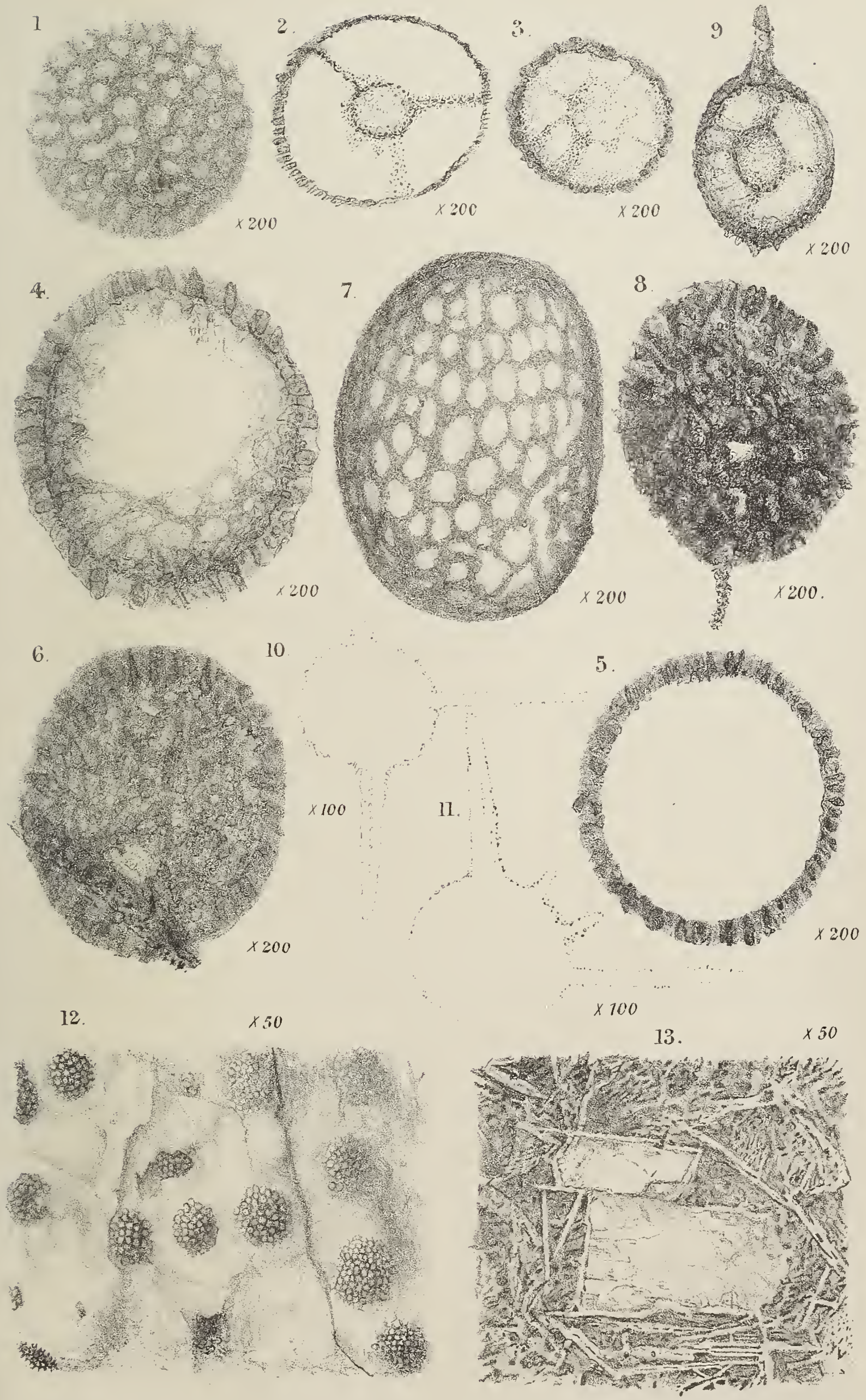
All the specimens are from the chert at Mullion Island, Cornwall.

DISCUSSION (ON THE TWO PRECEDING PAPERS).

The PRESIDENT commented on the many difficulties felt by De la Beche which were still unsolved. It was difficult to know whether the serpentine was intrusive in the hornblende-schists, or *vice versa*. At the previous Meeting a similar question was being discussed with regard to the Hebrides, viz. whether there the acid rock was intrusive in the basic or *vice versa*. If he might venture on a surmise, might not the Lizard rocks form an igneous complex, where each observer paid particular attention to those points bearing on his own views? The position had been advanced a point further by the Authors. He suggested that the discovery of organisms in Mullion Island might throw light on the period to which the complex belonged, though it was not clear that the Mullion Island rocks were of the same age as those of the mainland. It seemed that Dr. Hinde could not determine the age of the radiolaria.

Rev. EDWIN HILL spoke of the interest of this paper on Mullion Island. The Lizard serpentine seemed ringed in by other rocks; in this respect it resembled an igneous 'plug,' and such was the impression left on him by the general view of the aggregate of evidence. While these papers on a small area were most valuable, he hoped that the Authors would some day furnish a view of the Lizard as a whole. A harmony of diverse views had been suggested; he doubted if it were desirable to attempt this.

Prof. BONNEY said that the discovery of radiolarian chert at Mullion Island (which he had not visited) was of great interest, but it would never help, as the President seemed to think, in determining the age of the Lizard schists. He believed there was a



A. T. Hollick del. et lith.

Mintern Bros. imp.

RADIOLARIA FROM MULLION ISLAND.

volcanic complex at the Lizard; but if the last-named rocks belonged to one, then there were two complexes of different dates.

As regards the case of the granitoid rock and the serpentine, south of the Lion Rock: difficulties were caused in this district by the fact that there was an intrusive granite, which sometimes brought up fragments of an older dark rock, and a granulitic rock, included as large fragments in the serpentine, and the two were often very like one another. Without examining on the ground the instance described by the Authors, he was not prepared to say to which of these rocks he should attribute it; going by the diagram, there were difficulties in either reference. If intrusive granite, then its form and structure were very strange; if caught up in the serpentine, then we must suppose the heat of the latter to have produced a slight plasticity.

He had not examined the particular section of banded schist and serpentine found in the cliffs near Ogo Dour, and it was doubtless a puzzling one. But that the Lizard serpentine at several places was distinctly intrusive in the Hornblendic or the Granulitic Series, he was convinced—for instance, in Ogo Dour Bay (farther north), at Henscarth, Porthalla, Kildown Point, etc. Moreover, he had repeatedly obtained proofs of the intrusive nature of serpentine in other regions, and did not believe the same rock could have two modes of origin. The Norway case he knew as a rock, and believed it was only a 'sill' made schistose by pressure. As regards the case at the Lizard, was the hornblende-rock associated with the serpentine the normal hornblende-schist of the district? Of this he felt doubts. If it were, we might have only a peculiar case of intrusion; if not (as he suspected), then this might be a case of fluxion-banding, the peridotic magma being either exceptionally ill-mixed with a more felspathic one (cases of which did occur), or possibly having locally half-dissolved some fragments of hornblende-schist. There were certainly no signs, in the rocks themselves, that they had been modified by pressure, indications of which at the Lizard were only local. Banded structures caused by fluxional movements in igneous rocks, leading sometimes to an apparent stratification of material with considerable differences, were now becoming familiar. To some of these the speaker referred. The case discussed was a curious and interesting one, and he reserved a final opinion till he had seen it in the field; but it did not alter his view (for he agreed with Mr. Hill's remarks) that the Lizard serpentine was an altered peridotite, intrusive in the hornblendic and granulitic groups.

Dr. Hicks said he was glad that there were some reasons for believing that the radiolarian chert might be of Ordovician age; and he hoped that this important discovery would lead to the detection of similar bands in neighbouring areas, where no doubt could arise as to the geological horizon. He would be inclined to place the beds towards the base of the Ordovician, for many years ago he arrived at the conclusion, as stated in papers read before the Geological Society in 1875 and 1876, that the Arenig and

Llandeilo Beds had been deposited in comparatively deep water. His conclusions, however, were then severely attacked by the late Sir Andrew Ramsay and others; but evidence was now accumulating to show that they were correct.

Dr. Hinde also spoke.

Mr. Teall did not think that a determination of the age of the Mullion Island sediments would throw any light on that of the crystalline schists of the Lizard. The main object of the first paper was to show that certain hornblende-schists were interbanded with foliated serpentine. It must be remembered, however, that the hornblende-schists of the Lizard were certainly not all of the same age. Some of the foliated portions of the dykes in the area under consideration bore the closest resemblance to parts of the hornblende-schist of the South.

He agreed with Prof. Bonney that there were intrusive peridotites, but he thought there were others which formed integral portions of gneissose formations. He commented on certain points of resemblance between the Lizard District and the North-west of Scotland. In both there were foliated crystalline rocks cut by basic dykes, and in both these later dykes passed into schists. He thanked the speakers for the kind way in which they had received the papers.

Mr. Howard Fox said it would be gratifying if the discovery of the Mullion Island radiolarian cherts led to that of other beds in England and Wales. Some of the less accessible points and outlying rocks in Cornwall had yet to be examined. Prof. Bonney had kindly informed him that west of Conway marine mud was seen to be partly caught up by Bala lava as the Mullion Island chert and shales appeared to have been, and south of Clermont Ferrand Prof. Bonney had seen a lava-stream with many large lumps of marl picked up by it. The interest of their second paper was largely enhanced by Dr. Hinde's most valuable note.

16. NOTE *on a* RADIOLARIAN ROCK *from* FANNY BAY, PORT DARWIN, AUSTRALIA. By GEORGE JENNINGS HINDE, Ph.D., V.P.G.S. (Read February 8th, 1893.)

[PLATE V.]

ABOUT two years ago, Capt. Moore, of H.M.S. 'Penguin,' brought home to this country and forwarded to the Admiralty a block of a white rock obtained from the cliffs at Fanny Bay, Port Darwin, in the Northern Territory of the Colony of South Australia. The specimen was forwarded by Capt. W. J. Wharton, F.R.S., the Hydrographer to the Admiralty, to Sir Archibald Geikie, For. Sec. R. S., Director-General of the Geological Survey, who, with Capt. Wharton's consent, kindly allowed me to make a microscopical examination of it, and the results seem of sufficient interest to communicate to the Society.

The rock in question is of a dull-white or yellowish-white tint, in places stained reddish with ferruginous material; it has an earthy aspect, like that of our Lower White Chalk, but it is somewhat harder than chalk, though it can be scratched with the thumb-nail. There are no signs of stratification, and it appears as a fine-grained, homogeneous material. Unlike chalk, however, it gives no reaction either in cold or heated hydrochloric acid. When thoroughly dry it readily breaks up into flakes with uneven surfaces. Though somewhat soft, thin microscopical sections of it can be prepared without much difficulty, and these show a fairly transparent groundmass containing numerous very minute granules and subangular mineral-fragments ranging up to ·075 mm in breadth. The groundmass itself is quite negative in polarized light, and appears to be made up of amorphous silica, but the minute grains and angular particles with which it is filled readily polarize, and some of them appear to be of quartz, while others are probably rutile.

Besides these microliths, the rock contains numerous small circular and elongate bodies of a clearer aspect than the matrix, owing to the fact that the silica composing them is largely free from the mineral particles. These bodies are very irregularly distributed through the rock; in some portions they are so crowded as to be in contact with each other, while in others they are sparsely scattered here and there. The greater number of these bodies show nothing more than mere outlines; in a few the structural details are preserved, though in a very faint and imperfect manner, yet these are sufficient to prove that the organisms are radiolaria, and that the rock is really a radiolarian earth, intermediate in character between soft, incoherent, radiolarian material (like that from the Tertiary strata of Barbados) and compact chert (like that from the Ordovician strata of the South of Scotland and that described by Messrs. Fox and Teall from Mullion Island, Cornwall).

Though there is a considerable difference between the outer aspect of this earthy rock and that of the older chert, a microscopical examination shows an unexpected resemblance both in the character and condition of the minute organisms, and in the nature of the matrix.

The following is a chemical analysis of this white rock, for which I am indebted to the kindness of Mr. A. Dick, Jun. It has been executed in the Laboratory of the Geological Survey :—

	Per cent.
Silica	84·20
Iron	Trace
Alumina	10·70
Lime	......
Magnesia	......
Soda }	not determined.
Potash }	not determined.
Loss on ignition	5·00
	99·90

Unfortunately, details of the extent of the deposit whence this radiolarian rock was obtained, and its relationship to the other rocks of the country, are as yet unobtainable. The only published information respecting the rocks of the district, which I can find, is contained in a Report by the late Rev. J. E. Tenison-Woods,[1] in which it is stated that nearly all the cliffs in the Northern Territory or Arnheim's Land, as it is called, are capped by beds, from 16 to over 100 feet in thickness, of a compact, white or yellowish-white, sometimes ferruginous rock, which is stated to be for the most part magnesite, but intermingled with silicate of magnesia. No fossils were found in this white rock, and it was considered by Mr. Tenison-Woods to be a decomposed volcanic ash of Miocene age. There is a very fair correspondence in general character between the Fanny Bay Cliff specimen and the rocks described by Mr. Tenison-Woods, and it remains to be seen whether the beds described as consisting of silicate of magnesia may not really be of radiolarian origin.

In spite of the generally imperfect state of preservation of the radiolaria in this white rock, the generic characters can in many cases be ascertained, and in some the species as well. As shown in the description given below, the three sub-orders of the Prunoidea, Discoidea, and Cyrtoidea are represented; but the first named is only indicated by a single species of *Cenellipsis*. Of the Discoidea, there are the following genera :—*Astrophacus*, 2 sp., *Lithocyclia*, 1 sp., *Amphibrachium*, 4 sp., *Spongodiscus*, 3 sp., and *Spongolena*, 1 sp.; while the following are the genera included in the Cyrtoidea :—*Dictyomitra*, 2 sp., *Lithocampe*, 1 sp., and *Stichocapsa*, 2 sp. One peculiar feature in this assemblage is the general absence of forms with freely-projecting spines; in only three instances are there short secondary spines round the margins of discoidal forms. From

[1] 'Report on the Geology and Mineralogy of the Northern Territory,' No. 122, 1886, South Australia.

these radiolaria it is not practicable at present to determine the geological horizon of the rock; with one exception, all the genera represented occur from Palæozoic times to the present.

Class Radiolaria, Müller.

Sub-order Prunoidea, Haeckel.

Cenellipsis, sp. (Pl. V. fig. 1.)

Test regularly oval in outline; ·160 mm. in length, by ·115 mm. in breadth. Occasional traces of circular pores, about ·011 mm. in breadth. Oval tests of this character are by no means uncommon in the deposit, but it is seldom that pores are shown.

Sub-order Discoidea, Haeckel.

Astrophacus, sp. *a*. (Pl. V. figs. 4, 5.)

Tests nearly circular in outline, with two medullary tests connected by rays, and numerous small, subequal, marginal spines; in fig. 4 the spines are only partially preserved. Diameter of test, from ·13 to ·16 mm.; of the outer medullary test, ·06 to ·07 mm.; and of the inner, ·02 mm. The pores in the test are not shown. Rare.

Astrophacus, sp. *b*. (Pl. V. fig. 3.)

Test regularly oval in outline; ·13 mm. in length, by ·10 mm. in breadth; the outer and inner medullary tests are ·06 and ·03 mm. in diameter. There is a border of small spines. Rare.

Lithocyclia exilis, n. sp. (Pl. V. fig.8.)

Test circular in outline, with from 6 to 8 rings surrounding the medullary sphere. Diameter of test, ·150 mm.; of the central sphere, about ·028 mm.; distance between the rings, ·010 mm. The surface-pores of the test are faintly shown. Not uncommon.

Amphibrachium crassum, n. sp. (Pl. V. fig. 9.)

Test elongate, with the ends slightly inflated and rounded. Structure of minute pores irregularly disposed. Length, ·245 mm.; breadth, ·041 mm. Not uncommon.

Amphibrachium truncatum, n. sp. (Pl. V. fig. 10.)

Test elongate, biclavate; the arms either truncate or slightly furcate at the ends. Structure of minute pores. Length, ·21 mm.; thickness at the ends, ·05 mm.; in the centre, ·03 mm. Rare.

Amphibrachium fragile, n. sp. (Pl. V. fig. 11.)

Test biclavate, with a slight inflation in the centre. Structure of minute pores, partly arranged in longitudinal series. Length, ·245 mm.; thickness at the ends, ·050 mm.; in the centre, ·030 mm. Rare.

Amphibrachium, sp. (Pl. V. fig. 13.)

Test elongate, biclavate, with a sub-circular central disc; the arms have rounded ends and are divided by five or six curved partitions. Surface characters are not shown. Length, ·265 mm.; thickness near end of arms, ·060 mm., in the centre, ·040 mm. Rare.

Spongodiscus expansus, n. sp. (Pl. V. fig. 6.)

Test sub-circular in outline, with an apparently minutely reticulate or porous structure throughout. There is no differentiation shown in the central area. Diameter of the test, ·28 mm. Not uncommon.

Spongodiscus, sp. (Pl. V. fig. 7.)

Test circular, the structure minutely reticulate, as in the preceding, but there are traces of a medullary test. Diameter of the test, ·18 to ·20 mm.; of the central area, ·05 mm. Not uncommon.

Spongodiscus, sp. (Pl. V. fig. 2.)

Test oval, with a marginal border of small triangular spines. The surface is very imperfectly shown; it appears to be minutely reticulate. Diameter, ·14 mm.; breadth, ·11 mm. Rare.

Spongolena symmetrica, n. sp. (Pl. V. fig. 12.)

Test in form like a dumb-bell; the ends of the arms are inflated and rounded, while the central portion is nearly cylindrical. Structure minutely reticulate. Length, from ·210 to ·345 mm.; breadth of the ends, ·055 to ·070 mm.; of the central portion, ·035 mm. Common.

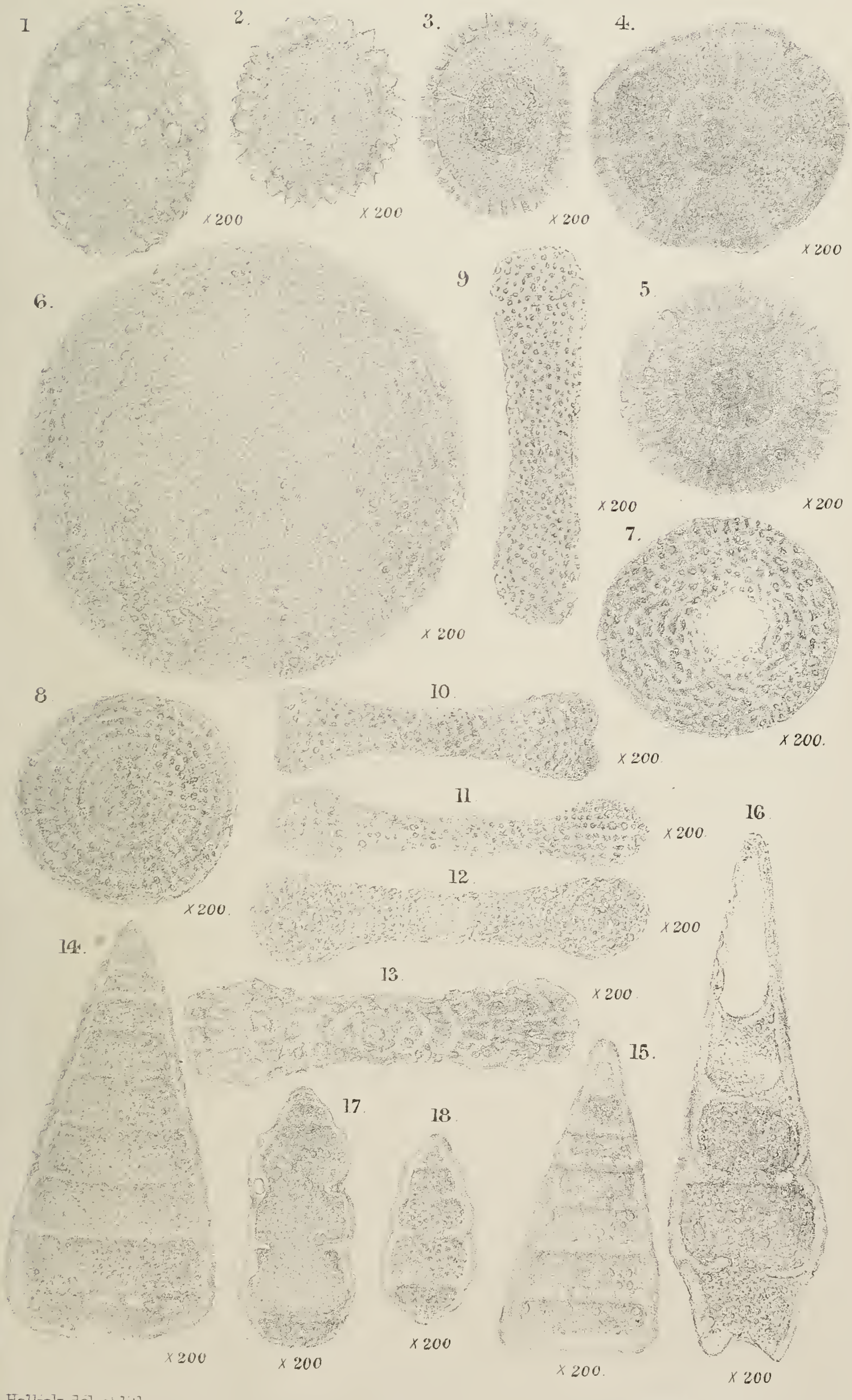
Sub-order Cyrtoidea, Haeckel.

Dictyomitra australis, n. sp. (Pl. V. fig. 14.)

Test conical, gradually increasing in width to the base, with from eight to ten, nearly horizontal, transverse partitions or constrictions, marking off as many segments. In the sections only the outlines and the partitions can be seen. Length, ·27 mm.; width at base, ·13 mm. This form is somewhat larger and wider at the base than *Dictyomitra* (*Lithocampe*) *cretacea*, Rüst ('Palæontographica,' vol. xxxi. p. 313, pl. xxxix. fig. 3, and vol. xxxviii. p. 187) from the Lower Devonian in the Southern Ural, and from different horizons of the Cretaceous in Italy and Switzerland.

Dictyomitra triangularis, n. sp. (Pl. V. fig. 15.)

Shell conical, gradually increasing in width to the base, with from seven to eight horizontal partitions. Length, ·19 mm.; width at base, ·10 mm. The surface-pores are faintly shown in places. Rare.



T. Hollick del. et lith.

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RADIOLARIA FROM PORT DARWIN.

Lithocampe fusiformis, n. sp. (Pl. V. fig. 16.)

Test elongate, fusiform, increasing in breadth to nearly the last partition, then contracted. There are four nearly horizontal, transverse partitions; the terminal aperture is narrow and apparently retracted, but not closed by a perforate plate. Length, ·335 mm.; greatest breadth, ·10 mm. Rare.

Stichocapsa pinguis, n. sp. (Pl. V. fig. 17.)

Test subcylindrical, with five partitions, the first two segments small, the next three rounded and subequal; traces of a perforate plate below the last segment. Pores not shown. Length, ·165 mm.; greatest breadth, ·075 mm. Rare.

Stichocapsa chrysalis, n. sp. (Pl. V. fig. 18.)

Test spindle-shaped, with four segments; the partitions are nearly straight; the fourth segment is the largest, and below this a perforate plate is faintly shown. Length, ·11 mm.; greatest breadth, ·055 mm. Rare.

EXPLANATION OF PLATE V.

Fig. 1. *Cenellipsis*, sp. × 200.
Fig. 2. *Spongodiscus*, sp. × 200.
Fig. 3. *Astrophacus*, sp. *b*. × 200.
Figs. 4, 5. *Astrophacus*, sp. *a*. × 200.
Fig. 6. *Spongodiscus expansus*, n. sp. × 200.
Fig. 7. *Spongodiscus*, sp. × 200.
Fig. 8. *Lithocyclia exilis*, n. sp. × 200.
Fig. 9. *Amphibrachium crassum*, n. sp. × 200.
Fig. 10. *Amphibrachium truncatum*, n. sp. × 200.
Fig. 11. *Amphibrachium fragile*, n. sp. × 200.
Fig. 12. *Spongolena symmetrica*, n. sp. × 200.
Fig. 13. *Amphibrachium*, sp. × 200.
Fig. 14. *Dictyomitra australis*, n. sp. × 200.
Fig. 15. *Dictyomitra triangularis*, n. sp. × 200.
Fig. 16. *Lithocampe fusiformis*, n. sp. × 200.
Fig. 17. *Stichocapsa pinguis*, n. sp. × 200.
Fig. 18. *Stichocapsa chrysalis*, n. sp. × 200.

All the specimens are from the white rock in the cliff, at Fanny Bay, Port Darwin, Australia.

[*Note*.—After the paper had been set up in type I received a letter from P. W. Bassett-Smith, Esq., Surgeon R.N., of H.M.S. 'Penguin,' who assisted in obtaining the radiolarian rock from Port Darwin, giving the required information as to the occurrence of the deposit in this locality. Mr. Bassett-Smith states that the white radiolarian rock forms a very prominent feature in the steep cliffs, from 30 to 50 feet in height, which border the harbour of Port Darwin. The rock is exposed for many miles on the Fanny Bay side of the harbour, and extends continuously on the beach from point to point across the bay. A section in the cliff at Fanny Bay consists at the base of mica-schists and quartz, on which discordantly rests a narrow band of soft ochre-like clay, followed above by the white radiolarian rock, which varies in places from 10 to 30 feet in thickness. It is covered by a layer of ironstone conglomerate, of a few feet in thickness, which caps the cliff. The white rock appears to be nearly horizontal; it contains, more particularly in the upper portion, numerous nodules, varying in size from that of a walnut to that of a cocoanut. In weathering it becomes soft and shows a great variety of tint, from pure white to deep red. No fossils could be found in it. It is used extensively for building purposes, and it is eaten by the natives, probably on account of its purgative properties. Mr. Bassett-Smith further states that the white radiolarian rock is unaffected by heated hydrochloric or nitric acid, and it is the same as that designated 'magnetite' in Tenison-Woods's Report. It thus seems probable that this material, so widely distributed in the northern area of Australia, and reaching in places a thickness of 130 feet, may prove to be, as already suggested, a deep-sea deposit of radiolarian origin.[1]—April 3rd, 1893.]

Discussion.

The President said that the Author had been wise in exercising caution as to the age of the rock. It probably came from an area where considerable oscillations had taken place.

Mr. E. T. Newton called attention to the extremely unpromising nature of the material which the Author had to work upon, and to the very satisfactory results which he had nevertheless obtained.

The Author briefly replied.

[1] [Captain Wharton, F.R.S., has also kindly forwarded to me information of a similar character from Capt. W. W. Moore and from Mr. J. J. Walker, F.L.S., both of H.M.S. 'Penguin.']

17. Geological Notes on certain Islands in the New Hebrides.

By Lieut. G. C. Frederick, R.N. (Communicated by Sir Archibald Geikie, D.Sc., For.Sec.R.S., V.P.G.S. Read February 22nd, 1893.)

[Abridged.]

So far as can be judged at present from the soundings obtained, it appears that the New Hebrides are probably situated on a bank lying from 350 to 400 fathoms below the surface of the ocean and running in a N.N.W. and S.S.E. direction, with a deep valley between it and New Caledonia. The only soundings obtained between these two groups are 2375 and 2730 fathoms respectively, the former within a short distance of the New Hebrides.

1. *Tanna.*—On the east side of this island is situated a volcano which has been in constant activity for many years, and on ascending its sides one is struck by the fact that so little lava is to be seen. The cone itself, which rises to a height of nearly 1000 feet above the sea, appears to be formed entirely of more or less fine ash, and there are no signs of any lava-flow.

In November 1890 the crater appeared to be about 300 feet deep, and was split into two nearly equal parts by a kind of rocky wall or partition which rose to a height of about 100 feet from the bottom.

There were five fire-holes, three on one side and two on the other side of the partition, where the molten materials were bubbling and pulsating with a subdued roaring sound; but every few minutes a tremendous explosion took place, throwing up the molten scoriæ, etc., to heights varying from 100 to 300 feet above the summit of the crater.

Clouds of sulphurous fumes arose from the surface of the crater, many yards back from the lip, whenever these explosions took place, as if forced up through the porous material by the violence of the outburst.

2. *Efaté Island* is about 24 miles long and 18 miles broad. It is chiefly made up of coral-limestone. The north-western portion of the island is the most elevated, rising into mountains and ridges to a height of 2203 feet, and thence sloping down in long spurs to the south-eastward, where the land assumes the features of a plateau some 200 or 300 feet in height, in which are carved deep, narrow valleys, with steep, and in many places almost perpendicular sides.

In some parts natural terraces appear to rise one above the other, denoting distinct periods of upheaval; this is most noticeable in the vicinity of Havannah Harbour.

Coral was found in Efaté Island at the remarkable height of 1500 feet above sea-level.

Lying off the northern coast of Efaté are several smaller islands, Nguna, Pelé, and Mau, which are of volcanic origin. No coral was found on them above sea-level. On Mau and Nguna are the remains of extinct craters, but, so far as could be ascertained, the natives have no traditions as to when they were active. This volcanic formation extends across to a small part of Efaté, where there are several hills on which nothing but volcanic specimens were obtained.

The small islands of Moso, Protection, and Erradaka, on the western side of Efaté, are of coral-formation.

In the vicinity of the volcanic islands there is very little coral-reef, especially where the shores are steep. At the western end of Nguna, where the water shoals out gradually, and also near its south-eastern end, coral has begun to grow; and there is a fringe of coral-reef round the whole of Efaté.

While sounding in the vicinity of Efaté, live coral was brought up on the lead from depths of 28, 39, and 42 fathoms off Moso, 37 fathoms near Mau, and 40 fathoms off Mataso. They were generally a species of small, delicate coral comparable to *Oculina*, one of them being probably a Pocilloporid in its flattened form.

3. *Mataso* is a small island, consisting of two distinct hills joined by a low beach of sand and coral, on which cocoanut palms and other trees are now growing. The higher of the two hills is a very remarkable peak, 1669 feet in height, and only 1870 yards long by 1000 yards broad. Though so steep, its sides are covered with trees and grass, and the bare rock can only be seen in one or two places. The lower hill is 485 feet high, and has a rich red soil which is very productive. The whole island is of volcanic origin, and as yet but little coral is growing round the base of the steep hills, though on either side of the low beach there is a narrow fringing-reef.

One mile eastward of Mataso rises a remarkable pyramid of bare rock, 412 feet in height and only 130 yards in diameter at the base, called Monument Rock. This rock is evidently volcanic, but the present writer found it impossible to obtain any specimens.

4. *Makura Island*, lying 6 miles north of Mataso, is also volcanic, nearly 1000 feet in height, and covered with a coarse grass. At the base of the steeper sides of the island are masses of volcanic boulders, but near the western end, which is low, there is a narrow fringing coral-reef.

5. *Mai Island* is formed of three high, conical hills, evidently of volcanic origin, and is surrounded by a fringing-reef. No coral was found elevated above the sea-level, but on the flat portion of the western side of the island it is easy to trace how the land has been extending, for there is evidence of a beach some 50 yards or more inside the edge of a belt of thickly-growing trees, with coral cropping up here and there on the same level as the present beach.

On the eastern side of this island a piece of dead coral, apparently the Alcyonarian coral (*Heliopora cærulea*), weighing about 30 lbs. was found. The bright blue colour extended right through the whole block. Only once before had I seen a specimen of the same species, and that was on the southern side of Efaté in the previous year.

A short distance to the westward of Mai Island is an outlying reef of atoll-formation, called Cook Reef. The outer edge shows dry patches at low water, while the lagoon has a general depth of about 6 feet, with numerous scattered coral-heads almost awash at low water.

6. The *Shepherd Islands* form a group extending south-eastwards from Epi. They are all of volcanic origin, and apparently of recent formation. No coral was found growing round the shores of any of these islands or on the adjacent coast of Epi, and on but few occasions was any coral brought up on the lead.

Native tradition states that a great earthquake accompanied by a volcanic eruption took place some 250 or 300 years ago, when these islands, which then formed part of Epi, were broken up into their present form. Their relative position and appearance add weight to the report.

7. Near the north-eastern point of *Tongoa Island*, which on the above supposition would be on the south side of the crater, is a district some 20 to 25 acres in extent, where the ground is heated almost to water-boiling-point. It is situated close to the coast, upon a cliff rising some 50 feet above the sea. There is little vegetation over this area, plant-growth being restricted to some coarse grass and a few stunted bushes. But in the immediate vicinity, vegetation is luxuriant in the extreme, and cocoanut palms were producing ripe fruit when only 2 or 3 years old. Steam and other vapours rise from the ground at several different spots, especially in the hollows of the surface. Unfortunately, no thermometer was available for testing the temperature, but in several places the exposed surface was too hot for the palm of the hand to rest on for more than a second or two. The natives take advantage of this natural oven to cook their food in holes dug for the purpose.

8. *Mallicolo Island*, known as *Malekula* by the natives, one of the largest of the New Hebrides, has both coral and volcanic formations.

On the hills overlooking Port Stanley, on the north-eastern coast of the island, coral-limestone was found at a height of about 500 feet above sea-level. The rock is described in Appendix II., and no doubt may be found in other parts of the island.

Appendix I.

Volcanic Rocks *from the* New Hebrides.

By J. J. H. Teall, Esq., M.A., F.R.S., Sec.G.S.

Tongoa Island, from the 'hot ground.'—A black rock with resinous lustre, containing numerous small, glassy, porphyritic felspars.

Microscopic characters.—Plagioclase and augite occur as porphyritic constituents. The plagioclase is allied to labradorite, and shows the usual characters of that mineral as it occurs in the andesites. Inclusions of glassy matter are common. The augite is monoclinic and faintly pleochroic in greenish and brownish tints. The groundmass is thickly crowded with minute, ill-defined granules, and contains a few acicular microlites of felspar. Iron ores occur as grains, and also as extremely minute granules scattered through the groundmass.

The rock is an augite-andesite. Similar rocks are common in the volcanic regions surrounding the Pacific.

Tongoa Island. Lava from summit, 1584 feet above sea-level.—A dark brown, massive rock, containing a few small porphyritic felspars.

Microscopic characters.—The porphyritic constituents consist of basic plagioclase, often honeycombed with inclusions, pseudomorphs after olivine, and augite (scarce). The groundmass is an aggregate of lath-shaped plagioclase, granular augite, and magnetite.

The rock is a basalt.

Makura Island.—A dark, medium-grained, massive, crystalline rock.

Microscopic characters.—Basic plagioclase, a pale green augite, dark brown pseudomorphs after olivine (?), and opaque iron-ores.

The rock is a dolerite.

Appendix II.

[*The* Microscopic Structure *of some of the* Organic Rocks *from the* New Hebrides. By George Jennings Hinde, Ph.D., V.P.G.S.

Efaté, Havannah Harbour. From the summit of a peak at 1274 feet above sea-level.—The rock is a brownish, porous or cavernous limestone, consisting principally of nullipore (*Lithothamnion*), apparently in its position of growth, with a few foraminifera (*Amphistegina*) and, rarely, fragments of polyzoa. The spaces between these organisms are partly occupied by finely-comminuted organic débris cemented by calcite.

Erradaka. From the summit of the island, at 345 feet above sea-level.—A white, hard limestone consisting of *Lithothamnion* and corals, apparently in their position of growth. The interspaces are filled in with calcite. The minute structure, both of the nullipore and of the corals, is well preserved.

Mallicolo or *Malekula Island*, *Sasun Bay.* From Rocky Point, about 3 feet above sea-level.—A brownish compact claystone, in which are scattered a few specimens of *Globigerina.* The matrix consists of very minute mineral particles, some of which can be recognized as volcanic. The slight reaction which the rock gives with acid is probably due to the foraminifera present therein.

From the shores of the same Bay, about 10 feet above sea-level, there is a greyish, granular, soft limestone-rock, consisting almost entirely of foraminifera, with a few fragments of nullipore, cemented by calcite. The greater portion of the foraminifera belong to *Globigerina*, and there are also forms of *Amphistegina* and *Polystomella.*

From the spur at Port Stanley in the same Island of Malekula, at 500 feet above sea-level, there are some specimens of a white, cavernous limestone mainly consisting of *Lithothamnion*, with a few fragments of coral and some scattered foraminifera (*Globigerina* and *Amphistegina*). Another specimen is a fine-grained calcareous rock in which fragments of corals and foraminifera (*Rotalia* and *Globigerina*) are obscurely shown in places.

From the above description it appears that the so-called coral-rock, from elevations of 345, 500, and 1274 feet in different islands of the New Hebrides, is mainly built up of nullipores and corals with an admixture of foraminifera, and it therefore corresponds in character with the fossil coral-rocks described from Barbados, the Solomon Islands, and other localities. The rocks occurring at lower levels on the shores of Sasun Bay, in Malekula Island, are of quite a different character; in one instance they consist of a claystone, probably of volcanic débris, in which there are a few foraminifera, and in another the rock is distinctly foraminiferal, with only a slight admixture of nullipore-fragments. In another part of Malekula Island, a greenish-white, porous claystone occurs nearly at the sea-level, but no organic remains could be recognized in it, and it is probably made up of volcanic débris. The fine-grained claystones quarried at Port Sandwich, at 400 feet above sea-level, are apparently of a similar character. *In none of the rocks of this group, so far as at present examined, is there any evidence of a deep-water origin.*—March 10th, 1893.]

Discussion.

The President said that it was very gratifying to have a communication from an officer of H.M. Navy. He regretted that the Geological Society had no officers of the Royal Navy amongst its Fellows. The area was interesting, on account of the oscillations in level which had taken place, and also because of the commingling of coralline and volcanic rocks. He observed that no mention was made in the paper of oceanic deposits similar to those described by Dr. Guppy as occurring in some neighbouring islands.

Sir Archibald Geikie, referring to the encouragement given by the present Hydrographer of the Admiralty to the officers of surveying vessels of the Royal Navy to make scientific observations, congratulated Lieut. Frederick on having so worthily carried out the designs of his chief. One of the main points of interest in the present paper lay in its bearing upon the theory of the origin of coral-reefs. In the region described by the Author there seemed to be no evidence whatever of subsidence, but abundant and striking proofs of elevation, fringing-reefs occurring at various heights up to 500 feet above the sea, and coral-rock even at the remarkable height of 1500 feet. A solitary atoll observed by the Author lay in the midst of these proofs of elevation, and afforded no indication of a contrary movement. The 'claystones' referred to in the paper had not been examined microscopically, but he suggested that they should be carefully studied with the view of ascertaining whether or not, like the somewhat similar material of Port Darwin, they might show the presence of radiolarian deposits in some of the upraised tracts on which the modern volcanic cones stand.

Dr. Du Riche Preller observed that the very fact mentioned by the Author, of three, clearly defined, successive coral-walls or banks having, in one of the localities specified, been upheaved by volcanic action from a depth of 200 feet and more, tended to show that these banks marked three distinct phases of a previous subsidence, whether it was due to a gradual sinking of the bottom of the sea, or to that of a submarine volcano. Thus the conflicting theories of Darwin and Dana on the one hand, and of Murray, Semper, and Studer on the other, did not, after all, appear to be irreconcilable. The occurrence of living coral at a depth of 240 feet appeared to upset existing views.

Mr. Teall said that he had examined some of the igneous rocks collected by the Author. One was an augite-andesite of a type common in the volcanic regions surrounding the Pacific; another was a fairly typical basalt, and a third a dolerite. A peculiar rock crowded with glassy crystals of labradorite, or a more basic felspar, must also be referred to the augite-andesites.

The Author observed, with reference to the specimens of augite-andesite alluded to by Mr. Teall, that one of them was obtained at the summit of the crater on Tanna Island, while the other was brought from the 'hot ground' on Tongoa Island.

He stated that the coral cliffs or terraces on Efaté Island were composed of coral from top to bottom, madrepores and many other species being most distinct among the mass of coral-detritus and limestone which formed the cliffs.

As regards the atoll called Cook Reef, he could only suppose that during some period of great upheaval the floor of the sea had been elevated to within such a distance of the surface that coral polyps had been able to commence operations, and covered the shoal with various forms of coral life.

The specimens of living coral brought up from a depth of 200 to 250 feet were not of the reef-building species, but small branching corals like the species of *Oculina*.

He further said that the temperature of the surface-water in this region was from 82° to 84° Fahr., but no observations of serial temperatures had been obtained.

18. *The* Pambula Gold-Deposits. By Frederick Danvers Power, Esq., F.G.S., M.Am.Inst.M.E. (Read November 9th, 1892.)

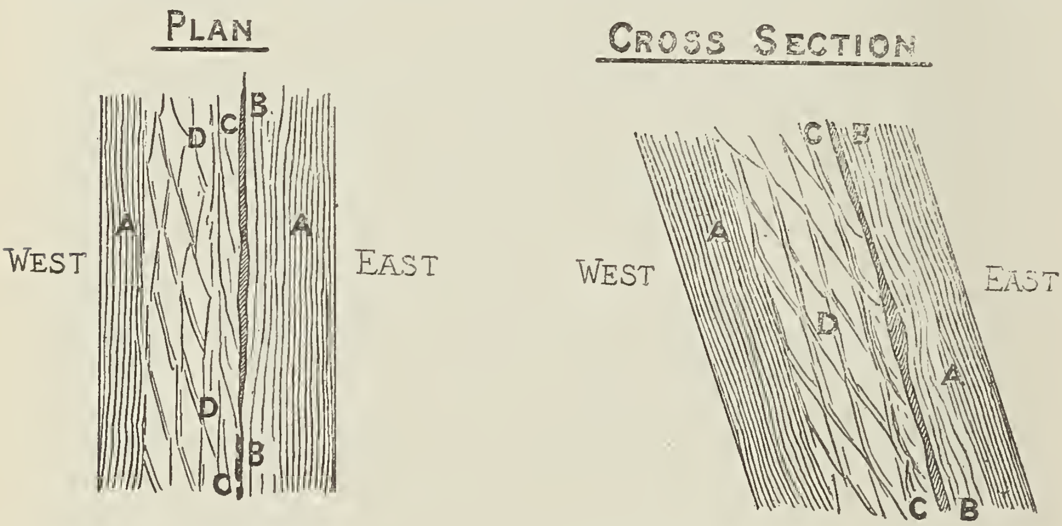
[Abridged.]

The Pambula Goldfield is situated in the parish of Yowaka, county of Auckland, in the south-eastern corner of New South Wales, and is about 11 miles north of Twofold Bay.

Most so-called 'practical' miners, especially those accustomed to well-defined quartz-reefs, acknowledge that these deposits are quite different from anything they have ever met with, and admit that they do not understand them. This is not surprising, for, if the observer takes a cursory view, without giving due weight to minor details, these lodes do indeed appear different from the general run of auriferous deposits, chiefly owing to the fact that the material filling the ore-channels does not differ much in appearance from the enclosing rock ('country'), and is but slightly impregnated with metallic sulphides.

The ore-deposits of Australasia are for the most part confined to certain belts of country, running more or less parallel with the sea-coast and with the main ranges of hills. The rocks which contain the Pambula gold-deposits are no exception to the general rule, their average strike being 12 deg. W. of N. The enclosing rock or 'country' is pyrophyllite-schist, interbedded with felspar-porphyry, sometimes merging into quartz-porphyry, the whole of which is tilted at a high angle; near the surface the rocks dip considerably to the east, while deeper down they are almost perpendicular. The planes of cleavage and the planes of bedding of the 'country' appear to be coincident.

Examined microscopically, the structure of the schist is lenticular, and this is repeated on a macroscopical scale, more especially in those zones of disturbance which now form the lodes. The lenticular structure is carried still further, for the lodes themselves, while tending to a north-and-south strike, cut up the field and form a network; but of the whole system, it is only the main or central lode which has been worked at a profit. Some of the lodes are accompanied by a quartz 'indicator': that is to say, either a succession of small detached veinlets of quartz or one continuous vein ('leader'), 9 inches wide, as shown in the figure on p. 234. Curiously enough, however, this quartz contains little or no gold, the precious metal being found in the shattered 'country' lying on the 'footwall' side. This shattered zone always has a good 'hanging wall,' whether the quartz indicator is present or not, but on the footwall side it gradually merges into the normal rock. The width for which it may be profitably worked varies from a few inches to 5 feet, and is not defined by any sharp line. In Faulkner's Claim there are rich lenticular parts of the shattered zone which measure as much as 18 feet long and 18 feet deep. The richness of these lenses varies, but several of them in succession will form a 'shoot.' These shoots have a southerly 'pitch,' and as a rule are short, but one at Faulkner's, running into the Pambula Company's ground, has so far proved to be from 400 to 500 feet long. The more broken and wider the lode, the richer it is found to be. The spaces between the lenses, where they overlap one another, are occupied by clay, and when this material is scraped out it has at times yielded as much as 1 lb. of gold to the 'dish.'[1] On the



AA = Pyrophyllite-schist.
BB = Well-marked hanging wall.
CC = Quartz indicator.
DD = Shattered rock containing gold, not separated by a well-defined plane from the schist on the footwall-side.

surface the lode material is bleached by organic matter: a little lower down it is tinted red, owing to the decomposition of iron pyrites; while still deeper the rock has a greenish hue, and is more or less impregnated with iron pyrites. In Pipe Clay Creek, a dyke of clay running E. and W. diverts the course of the lodes where it cuts them, but the latter eventually return to their original direction. This dyke is 2 or 3 feet wide, and 'underlies' slightly to the south.

From the above data it will be observed that there are many points in common between these deposits and those which are universally acknowledged to be lodes. These deposits have a general course parallel to the sea-coast, but individually run in such directions as to divide the district into large, irregular lenses, which together form a system of gold-deposits. Those zones of disturbed rock which are off the main line are poor in gold. The deposits have at least one good wall, and are made up of shattered 'country,' sometimes showing a brecciated structure, the broken particles having been more or less rounded, perhaps by corrosive liquids. Evidences of motion are also to be seen in the striations on the quartz forming the indicator, and in the clay between the lenticular masses of rock. The gold occurs in 'shoots' which 'pitch'

[1] The 'dish' is a measure of capacity=572 cub. ins.

southerly (the most usual direction for shoots in Australia), and these are richest in loose or soft 'country,' but gradually become poorer towards the footwall-side, where the stone becomes 'tighter.' Iron pyrites, though not in a massive form, is associated with the gold. The course, 'underlay,' and width vary in these lodes, within certain limits, as in others, and they are also affected by a dyke which crosses them. The country is hilly and disturbed, as is generally the case where lodes occur.

Some observers term these deposits 'true fissure-lodes'; but many miners believe that the word 'fissure' suggests an open crack of some importance. In the gold-bearing portion there is no evidence that such an open crack ever took place; the rupture was caused by pressure, which would not allow of an open crack existing. The minute joints between the lenses cannot, with the greatest stretch of the imagination, be called 'fissures.' The quartz indicator runs parallel with the cleavage of the surrounding rocks, and evidently occupies a cleavage-joint which was gradually filled with quartz; for the grooves on the face of the quartz, where it has rubbed against itself, prove that motion has taken place since some of the quartz was deposited. Lodes in soft rocks are not so likely to be well defined as those in hard, so the merging of one 'wall' into the enclosing rock was to be expected. The foliated structure of this enclosing rock is not obliterated in the ore-channel, except in very rare instances. The difference between these lodes and lodes abundant in sulphides is due more to degree than to any fundamental character; it seems greater than it really is, on account of the difficulty of distinguishing between the ore-channel and the enclosing rock, a distinction rendered less easy because the ore-channel is for the most part a 'bedded lode,' and has not been subjected to a metasomatic change, nor had it wide interstices which could be filled by extraneous minerals.

These lodes are worked with profit on the top of Mount Gahan (named after one of the original prospectors), where rock has been crushed, yielding 1 oz. 12 dwt. to the ton, and also in Pipe Clay Gully, 493 feet below, where the picked stone sent to the battery gives 11 oz. per ton. The rock is naturally looser on the surface than deeper down, and therefore it is to be feared that, since the spaces between the lenses are so minute on the surface, they will be still smaller as the depth increases, until finally the 'country' becomes so 'tight' that there will be no place for the gold to lodge.

Discussion.

Mr. H. Bauerman said that the condition of occurrence noticed by the Author was characteristic of a considerable area in North America, in the States of North and South Carolina and Georgia, where gold has been obtained from pyrophyllite and other soft schists associated with quartzite and irregular quartz-veins, the latter not being always gold-bearing. As a particular instance, he mentioned the Brewer Mine in South Carolina.

19. *On the* Microscopic Structure *of the* Wenlock Limestone, *with* Remarks *on the* Formation generally.

By Edw. Wethered, Esq., F.G.S., F.C.S., F.R.M.S. (Read February 22nd, 1893.)

[Plate VI.]

Contents.

I. Introduction.

The general features and fossils of the Wenlock Limestone have been described by several geologists, but I am not aware of any endeavour to make a systematic examination of the microscopic structure. The value of such work has been greatly underestimated; for investigations which I have made show that, although much information as to the formation and structure of the rock may be gained by observations made without the assistance of a microscope, yet the use of this instrument brings into view important facts which are not perceived by the unassisted eye.

In this paper I do not attempt an exhaustive enquiry; to do this it would be necessary to make several visits to the localities from which specimens for examination were collected, and this I have been able to accomplish only in the case of the Wenlock Limestones exposed within a convenient distance from Cheltenham. I have therefore selected what I regard as typical sections of the limestone in the neighbourhood of May Hill in Gloucestershire, and in the adjoining portion of the county of Hereford.

The procedure has been to take samples from several beds in each exposure of the rock, and to grind down the usual thin sections for examination under a microscope. These I prepare myself, and I mention the fact because it seems to me important for this reason: very many slides require to be made for a paper like the present one, and each must be adjusted, with regard to actual thinness, according to the structure which occurs. This can be determined only by a person conversant with the organisms, the calcareous remains of which have built up the limestone.

I may mention that to bring out obscure structure in slides it is important to give a final polish to the section before removing it to a permanent glass slide. This is best done by rubbing, on a moist thick flannel sprinkled with putty powder. In this way structure is developed which would otherwise be lost.

II. May Hill Series of the Wenlock Limestone.

On the south-eastern slope of May Hill, about 1 mile above Longhope in Gloucestershire, the Wenlock Limestone is exposed for a little less than $\frac{1}{4}$ mile, in a line of quarries originally worked for lime-burning. The following section gives details of the beds:—

Section of the Wenlock Limestone at May Hill.

	Thickness.	
3. Irregularly-bedded Limestone, and Nodules, containing from 8·1 to 17·2 per cent. of residue insoluble in hydrochloric acid.	18 feet.	Favositidæ, which are often of large size, are numerous.
2. Thin-bedded Limestone Series, the respective beds separated by 'paper shales' seldom more than 1 foot thick. The limestones contain as much as 12·4 per cent. of residue.	14 feet.	Numerous polyzoa. Favositidæ, *Strophomena rhomboidalis*, *Omphyma subturbinatum*. *Heliolites interstinctus*, and fragments of trilobites.
1. Massive Limestone, containing as much as 6·9 per cent. of residue.	12 feet.	No fossils found; but there are fragmentary remains in the slides.

From the above section it will be seen that the Wenlock Limestone in the neighbourhood of May Hill shows three divisions: (*a*) the massive limestone at the base in which no fossils, other than fragments, have, so far, been collected: (*b*) the thin-bedded limestones with numerous fossils, especially characterized by polyzoa and Favositidæ: (*c*) the irregularly-bedded and nodular limestones.

I propose to examine the microscopic structure of each division separately.

(i) *Slides from the Massive Bed.*

Slide No. 1.—Numerous, very fragmentary, calcareous remains, chiefly those of ossicles of crinoids, valves of ostracoda, fragments of shell, echinoderm-spines (?), *Girvanella problematica*, and a quantity of infilling calcite.

A feature in the slide is that many of the organic fragments are enclosed by a brown crust. This for the most part is structureless, except that in some instances tubules of *Girvanella* can be detected. The fragments surrounded by this crust resemble the oolitic spherules in the basement-beds of the Inferior Oolite near Cheltenham, to which I have on a previous occasion called attention.

Slide No. 2.—This slide, viewed through a 2-inch object-glass, is seen to contain ossicles of crinoids and fragments of polyzoa. Some of these are enclosed by a crust similar to that mentioned in the previous slide. The most noticeable feature is, however, the number of dark, granulated masses, which would be structureless but for the occasional appearance of tubules of *Girvanella*, and streaks and spots of calcite. I have been considerably puzzled to account for these masses, but the fact that in several of them the tubules of

Girvanella can be detected leads one to infer that some at least have originated from these tubules. Nevertheless I may state, though I shall refer to the subject again, that *Girvanella*-tubules are clearly defined only when the interior has been filled in with calcite. The walls of the tubules usually present the same minutely-granulated appearance as that noticed in the structureless masses just referred to; and this constitutes further, though not conclusive evidence in support of the view that the masses represent original aggregations of tubules, the outlines of which have not been preserved by the infilling of calcite. If some of the tubules had been partially filled in with calcite, that infilling would account for the streaks and spots of the mineral which the masses so frequently contain.

Slide No. 3.—Fragments of polyzoa, ossicles of crinoids, aggregations of *Girvanella problematica*, and granulated masses in which occasional tubules appear.

(ii) *Slides from the Thin-bedded Limestones.*

Slide No. 1.—Some of the organic fragments are so crystalline that their true nature cannot be determined, but among them are polyzoa and ostracoda. The slide is remarkable for the number of aggregations of *Girvanella* which occur. Of these at least two types can be distinguished: (*a*) that of *G. problematica*, the tubules measuring ·017 millim. in diameter, and sometimes encrusting foreign objects: (*b*) a form of *Girvanella*-tubules of irregular size, with a maximum diameter of ·03 millim. These latter also grow around fragments of organisms which occur in the limestone.

Slide No. 2.—In this the remains of organisms are for the most part obscure. They include those of crinoids, aggregations of *Girvanella problematica*, spicular objects, and inorganic material (consisting chiefly of very small, angular grains of quartz and mica, apparently of detrital origin). There are also numerous minute spherules of pyrites, which are presumably of organic origin.

Slide No. 3.—In this we see fragments of polyzoa and ostracoda, but the limestone is chiefly made up of remains of crinoids. Tubules of *Girvanella problematica* occur, and in one instance are most beautifully preserved. The tubules form a granule, having a nucleus in the centre which has passed into calcite, and their preservation is due to the interiors having been filled in with the same mineral, against which the walls of the tubules stand out in relief.

Slide No. 4.—The organic fragments here are similar to those noticed in previous slides. Two types of *Girvanella* are represented, the tubules of the largest having a maximum diameter of ·07 millim. In all cases they collect round a nucleus, forming a spherule. There are also spherules which show no structure.

Slide No. 5.—Fragments of polyzoa and obscure masses of *Girvanella*. In some of the latter the tubules are seen passing into the minutely-granulated structure, so characteristic of the spherules in which tubules are absent or the outlines obscured.

(iii) *Slides from the Nodular Beds.*

Slide No. 1.—Numerous, very fragmentary remains of organisms, including polyzoa, ossicles of crinoids, valves of ostracoda, and several other remnants. There is also a quantity of anisotropic mineral matter, probably detrital.

Slide No. 2.—In this the organic remains are larger than those noticed in No. 1. They are those of polyzoa, small fragments of shell, and a variety of *Girvanella*.

Slide No. 3.—The nodule from which this slide was made was selected as representative of the smallest type of nodules, and has a maximum diameter of 2·20 centimetres. In the centre there is a nucleus, the original nature of which is not easy to determine. Around this there is an immense number of very fragmentary calcareous remains, cemented together, apparently by extremely fine material of detrital origin. Among the organic fragments are portions of crinoids and tubules of *Girvanella*; but the great majority of the organic remains are too fragmentary to be determined.

Slide No. 4.—This is representative of the irregularly-bedded limestones. It shows a quantity of detrital material enclosing a rather large fragment of shell, and numerous other remains too obscure to be determined. This bed yielded 17·3 per cent. of residue insoluble in hydrochloric acid. The insoluble residue consists of small grains of quartz, mica, and cryptocrystalline siliceous aggregations. There is also a still finer residue which is little else than a siliceous paste; it appears to have originated from the breaking-up of the last-enumerated material during the process of boiling with acid.

(iv) *Summary of the Evidence obtained from the Wenlock Limestone at May Hill.*

The evidence obtained from the slides shows that the Massive Limestone at the base is largely made up of the remains of crinoids, polyzoa, valves of ostracoda, portions of shell, and tubules of *Girvanella*, the latter sometimes forming oolitic spherules.

The Thin-bedded Limestone Series differs from the Massive Limestone, inasmuch as it contains a smaller proportion of crinoid-remains and a larger proportion of polyzoa. Remarkably fine forms of *Girvanella* are seen in it, and to them I shall refer later on.

The Nodular and Irregularly-bedded Limestones, constituting the upper division, are very arenaceous and argillaceous. The calcareous element is made up of remains of organisms similar to those mentioned in the beds below, but for the most part they are more fragmentary.

The most interesting result of the microscopic study of these rocks was the discovery of new and interesting forms of *Girvanella*, and the fact that this organism has taken so important a part in building up the limestone. In Pl. VI., figs. 1, 2, 3, 4 *a* and 4 *b*, are represented the forms which have been discovered.

In fig. 1 we have a spherule with a fragment of a polyzoan as a nucleus; this is in part surrounded, or encrusted, by a stratum of tubules measuring ·03 millim. in diameter. These are again enclosed by an outer stratum (which envelops the whole inner stratum and the nucleus) of well-defined tubules measuring ·14 millim. in diameter.

In fig. 2 we have a spherule containing a nucleus, the nature of which is not apparent, surrounded by tubules measuring ·10 millim. in diameter. These are very like the larger tubules in fig. 1, but the smaller forms are not represented. The interiors of the tubules are filled in with calcite, against which the walls stand out in relief.

In fig. 3 a very interesting spherule is depicted. Here are two strata of tubules which are to some extent divided by finely-granulated material. The tubules included in the inner stratum average about ·02 millim. in diameter, while those in the outer average ·05 millim.; the latter are therefore the larger of the two. The tubules in the inner stratum are not continuous around the entire nucleus, but pass into finely-granulated material, in which only obscure and occasional outlines of tubules, and streaks and spots of calcite can be detected. At first sight, I thought this finely-granulated material was of organic origin, but after further examination I have come to the conclusion that there is doubt as to this. I am disposed to regard the granulated material as a calcareous residuum, proceeding from the decay of those tubules which have not been preserved by the infilling of calcite. This explanation, however, does not account for the difference in size of the tubules in the two 'strata.' There are two possible explanations of the occurrence:—(*a*) That the smaller forms are the same as the larger, but of younger growth; (*b*) That the two sets of tubules have no relation one with the other. That is to say, the inner stratum first formed a spherule around the original nucleus, and later on this first spherule became the nucleus for the outer set of tubules. If the first explanation be the right one, then, I think, we ought to find the order of the 'strata' reversed; that is to say, the smaller tubules, as the younger, would be in the outer or more recent stratum, and the larger or older tubules in the inner one, next to the nucleus. I should, therefore, be disposed to take the second view, namely, that there is no relation between the two strata of tubules, but that there was a first-formed spherule of the smaller ones, and finally this first spherule became the nucleus for the larger *Girvanella*.

Fig. 4, *a* and *b*, represents a form of *Girvanella* of a rather complex structure. The tubules average ·03 millim. in diameter, and in some instances have the appearance of branching; the ramification, if such there be, is obscured by lines which traverse one or more tubules at right angles. It is, however, very difficult to believe that there is not some evidence of branching in this specimen, and, if so, the discovery is a decided advance in our efforts to determine the true nature of *Girvanella*.

III. Wenlock Limestone at Purley, near West Malvern.

The late Prof. Phillips observed[1] that "the lower limestone at Colwell Copse, Winning Farm, and Whitman's Hill abounds in a large pisolitic structure, which is of great beauty." Sir R. Murchison figured one of the pisolites under the name of *Stromatopora nummulitisimilis* in the 3rd edition (1859) of 'Siluria,'[2] but in the 4th edition (1867) of that book the name is changed to 'Pisolite' (see pl. xli. there, and explanation).

In 1890 I tried to find some of this pisolite, but all the quarries mentioned by Phillips, where he saw the pisolite, are either partially or entirely filled in. Thus the quarry at Colwell Copse is now a plantation, and only the upper series, of Nodular Limestones, are exposed. I was therefore disappointed in my efforts to trace the object of my search till the following year, when I found a small quarry at Purley, near West Malvern. I collected specimens of limestone for microscopic examination, and in one of these I discovered pisolite. Returning to the quarry early in the spring of 1892, I was rewarded by obtaining a weathered block of limestone full of pisolites.

The strata in this quarry at Purley give a vertical section very similar to that at May Hill, but the three divisions, so well marked at the latter locality, are not so clearly defined here. When I visited the quarry, about 12 feet of rock was exposed. At the base was a massive bed of limestone, which passed up into thin-bedded limestone, and then again into thin-bedded and nodular rock. Fossils are not so numerous as at May Hill, but such fossils as there are belong to similar species.

The microscopic examination of the Massive Bed at the base shows that it is more or less pisolitic,[3] the spherules averaging about 3 millim. in diameter; therefore 'oolitic' would perhaps be the more correct term. In some of the spherules there is an irregular concentric arrangement, in others simply a crust around the nucleus. That some of these are of organic origin cannot be doubted; and Pl. VI. fig. 5 affords a proof of it. Of the great majority of the spherules, however, all that can be said is that there are in some indications of *Girvanella*-tubules (Pl. VI. fig. 6); others are quite structureless or show only a concentric arrangement. Had the two latter types of spherules been the only spherules found, no one would have ventured to ascribe to them an organic origin. But the fact that in some instances tubules can be seen, and that in Pl. VI. fig. 5 they show a decidedly concentric growth, makes one hesitate to pronounce against the probability of organic origin. In support of this probability let me ask the question, what would be the appearance of the spherule represented in fig. 5, had not the tubules been filled in with calcite, or had they only partially been filled in with it? All outline of the tubules would be obliterated or at least rendered very obscure; but there would be a rude concentric arrangement or crust,

[1] Mem. Geol. Survey, vol. ii. part i. (1848) p. 86.
[2] Pl. xli. fig. 32.
[3] I use the term because of Phillips's reference, mentioned above.

with streaks and spots of calcite representing those tubules which had in part been filled in with the mineral. This is just what we see in the spherule represented in Pl. VI. fig. 6.

The oolitic bodies do not constitute the whole of the limestone; there are, in addition, fragments of polyzoa and of shells, joints of crinoids, valves of ostracoda, and aggregations of *Girvanella problematica*.

The Thin-bedded Limestones which follow the Massive Bed at the base contain the remains of ostracoda, portions of shell, polyzoa, small ossicles of crinoids, and numerous aggregations of *Girvanella*.

Sections of the nodules show that they are made up of remarkably fine detrital material, with fragments of calcareous organisms similar to those noticed in the beds below. These nodules are therefore identical with those at May Hill.

IV. Wenlock Limestone at Ledbury.

Let us now proceed to examine the Wenlock Limestone at Ledbury, selecting two exposures as being fairly typical.

The first of these is a quarry, belonging to M. Biddulph, Esq., M.P., on the left-hand side of the road leading to Eastnor. The following section is seen in the quarry :—

Section of the Wenlock Limestone. Biddulph's Quarry, Ledbury.

[Top of Quarry.]	Approximate thickness. ft.	in.
6. Argillaceous Beds, with some few calcareous nodules	9	0
5. Nodular Argillaceous Limestone, with regular Nodules in Argillaceous Bands	10	0
4. Argillaceous Band terminating the Massive Limestones	4	8
3. Dark Limestone	5	0
2. Crystalline Limestone	10	0
1. Slate-coloured, Argillaceous Nodular Limestone	8	0 (?)
[Base of Quarry. Not fully exposed.]		

The first thing which strikes one on reviewing the above section is the difference between it and that at May Hill (see p. 237). I had great doubts as to whether the beds are those of the Wenlock Limestone Series, and the difficulty is increased by the absence of fossils. The beds are marked as Wenlock Limestone on the Geological Survey map, and the correctness of the mapping is confirmed by Mr. Geo. H. Piper, F.G.S., of Ledbury, who is an acknowledged authority on the geology of the district. The variable nature of the Wenlock Limestone was also noted by the late Prof. Phillips, who said: "It has been already observed that the Wenlock Limestone, in some places a single solid bed, covered by calcareous nodules, is accumulated in other localities, to a double or even triple series, all more or less suitable for the lime-burner."[1] He also stated that

[1] Mem. Geol. Survey, vol. ii. part i. (1848) p. 81.

"when completely developed, this group of rocks [*i. e.* the Wenlock Limestone] is of considerable thickness, and appears in two, three, or more stages, alternating with shales, and occupying, with these, altogether as much as 280 feet of thickness."[1] In the section which I have given of Biddulph's Quarry at Ledbury there is only 46 feet 8 inches of strata, and this is the greatest development that I have met with. It is, however, exceedingly probable that Prof. Phillips's statement is correct, for when he surveyed the district the limestone was much more extensively worked for lime-burning than is now the case; and, consequently, he was better able to arrive at a correct estimation of the maximum thickness than any observer at the present day.

Slides from the Ledbury Limestone (1*st Quarry*).

The Slate-coloured Nodular Limestone at the base of the section contains as much as 30·4 per cent. of residue insoluble in hydrochloric acid. This residue is made up of very small flakes of mica and quartz, with a quantity of amorphous and cryptocrystalline siliceous aggregations, and pyrites.

The calcareous portion consists of valves of ostracoda, some of them well preserved, ossicles of crinoids, fragments of shell, and polyzoa. As a whole this limestone is exceedingly compact, and there is little infilling calcite.

The Crystalline Limestone which follows contains a great quantity of organic fragments, and only 4 per cent. of residue insoluble in hydrochloric acid. Among the organic fragments are those of shells and polyzoa, and some few ossicles of crinoids. These remains of organisms are, on the whole, well preserved, and the crystalline nature of the rock arises from the quantity of infilling calcite.

The Dark Limestone, No. 3 in the section (see p. 242), is very hard and compact, with little infilling calcite. It contains 13·9 per cent. of residue insoluble in hydrochloric acid. This residue is made up of a quantity of amorphous and cryptocrystalline siliceous aggregations, some little felspar, and a paste full of crystallites, which originates from the breaking up of the cryptocrystalline matter. The organic fragments are chiefly ossicles of crinoids, with some portions of shell and valves of ostracoda.

The nodules in Bed No. 6 contain, like the Dark Limestone, 13·9 per cent. of insoluble residue, made up of the same material as the residue in the beds below. The calcareous portion consists of very fragmentary remains of crinoids, shells, and a few broken valves of ostracoda. In addition, however, there are a few aggregations of *Girvanella problematica* which, strange to say, have not been noticed in the limestones below.

The nodules which occur in the uppermost Argillaceous Beds contain as much as 20 per cent. of residue insoluble in hydrochloric acid, and the calcareous portion is made up of very obscure fragments of shell and crinoids, etc.

[1] *Op. cit.* p. 78.

The second exposure of the Wenlock Limestone at Ledbury, which I have selected for examination, is a quarry belonging to W. A. H. Martin, Esq., about ½ mile distant from the last-mentioned quarry, on the road to Eastnor. The following is the section:—

Section at Martin's Quarry, Ledbury.

[Top of Quarry.]	Approximate thickness. ft.	in.
4. Nodular Limestone and Argillaceous Bed...	1	0
3. Crystalline Blue Limestone.....................	2	6
2. Blue Limestone....................................	3	0
1. Massive Blue Limestone	8	0
[Base of Quarry.]		

It will be observed that the above section differs materially from that given of Biddulph's Quarry (see p. 242). This is partly accounted for by the fact that Martin's Quarry is not so extensively worked.

Slides from the Ledbury Limestone (2nd Quarry).

Bed No. 1 is a massive limestone, made up chiefly of small ossicles of crinoids, with fragments of polyzoa, valves of ostracoda, and occasional aggregations of *Girvanella*. An estimation of the residue insoluble in hydrochloric acid gave 2·9 per cent., a percentage lower than that obtained from any other previous estimation. This insoluble residue is made up of grains of quartz, numerous small flakes of mica, some felspar, zircon, cryptocrystalline siliceous aggregations, and a quantity of pyrites.

Bed No. 2 is also a crinoidal limestone, but, comparing it with No. 1, the remains of ostracoda and small aggregations of *Girvanella*-tubules are more numerous. The bed yielded 7·3 per cent. of residue insoluble in hydrochloric acid, made up of minerals similar to those mentioned in the residue from the previously described bed, but there is less pyrites.

Bed No. 3 is more crystalline than the beds below, and the organic fragments are larger. It yielded 7·6 per cent. of insoluble residue.

The calcareous element in the nodules at the top of the section is chiefly derived from the ossicles of crinoids, some few fragments of polyzoa, and aggregations of *Girvanella problematica*. Some of the nodules are almost entirely calcareous: estimations of the residue in two nodules gave respectively 2·7 and 9·5 per cent. The residue contains well-rounded grains of quartz (measuring ·10 millim. in diameter), crystals of zircon, fragments of partially decomposed felspar, mica, and cryptocrystalline siliceous aggregations. The very fine residue is made up of a vast number of crystallites, some of which give brilliant polarization-colours. Among them are crystallites of quartz, which originate from the breaking up of the cryptocrystalline siliceous matter, probably during the process of boiling the residue in acid.

The Wenlock Limestone at Ledbury is remarkable for the small variety of organisms which have contributed to its formation. Crinoidal remains are by far the most numerous: next in importance come fragments of shell, valves of ostracoda, and polyzoa. The latter, however, are not common, a scarcity which contrasts strongly with the great number of polyzoan remains found at May Hill. Moreover, the almost entire absence of *Girvanella* is remarkable: occasional aggregations of *Girvanella problematica* have been noticed, but the varieties seen at May Hill and Purley are wanting.

V. General Summary.

The evidence recorded in this paper points to the Wenlock Limestone as having been deposited under varying local conditions. At May Hill, as before stated, three successive stages are clearly defined. They are:—(1) What I have termed 'Massive Limestone,' at the base of the quarry; (2) Thin-bedded Limestones; (3) Nodular and Irregularly-bedded Series. These stages are indicated at Purley, but are less clearly defined, and the Massive Bed at the base is here more or less oolitic. At Martin's Quarry, near Ledbury, the Massive Limestone and Nodular Beds do indeed occur, but the Thin-bedded Limestones are absent. With the beds in Biddulph's Quarry correlation is difficult; still we have in the Crystalline and Dark Limestones (Nos. 2 & 3) what may be termed Massive Beds followed by a thick development of the Nodular Series.

I have from time to time, during the course of this paper, mentioned the proportion of residue which is left after boiling portions of the limestone in hydrochloric acid. This, to some extent, is a guide to the amount of detrital material deposited with the limestone, but allowance must be made for the disappearance of decomposable minerals such as felspar. The estimations show a larger proportion of residue than is usual in most limestones, and as there is evidence that the mineral-grains in the original sediment have undergone decomposition, it is clear that the amount of sediment deposited was considerable. The evidence of this decomposition is seen in the fact that, with the exception of occasional fragments of felspar, the mineral constituents still existing in the residue are not easily decomposable. I have now had some considerable experience in the examination of insoluble residues, and in my opinion the amorphous and cryptocrystalline silica in the residues under consideration is the residuum of decomposed minerals such as felspars; the alkaline constituents, of course, would be removed by percolating waters before the limestones attained their present compactness and crystalline condition. The quantity of detritus appears to have increased as the formation went on, until so much was deposited that calcareous organisms were unable to accumulate, and the limestone-forming process ceased. This latter stage is represented by the Nodular and Irregularly-bedded Limestone constituting the uppermost division. It would appear as though the calcareous fragments tried, as it were, to accumulate, but that the process was interrupted, the fragments were rolled about with sediment, and hence arose the nodules.

The remains of crinoids enter largely into the structure of these limestones. In making this statement I am not in accord with the late Prof. Phillips, who, referring to the Wenlock Limestone, remarked that "it is rarely composed of fragments of crinoidal columns."[1] Thin slides of the limestone, however, show that crinoid-remains are abundant, but they are very fragmentary, and for the most part small. Shell-fragments come next in importance, then valves of ostracoda, and lastly polyzoa, more especially in the thin beds at May Hill.

The organism known as *Girvanella* has contributed largely to some of the beds at May Hill and Purley, and the process seems to have been as follows:—Fragments of organisms were deposited on the sea-floor; around these the *Girvanella*-tubules collected, sometimes entirely enclosing a fragment with a crust of tubules, and thus giving rise to a spherule or granule, the determination of which depended on the shape of the fragment enclosed. To such an extent did this process go on that, in some of my slides, almost every fragment is either enclosed or has some tubules attached to it.

It is curious to note how very local the various forms of *Girvanella* are. Thus some of the thin-bedded limestones at May Hill seem to have been deposited under conditions especially favourable to the growth of certain forms of *Girvanella*, represented in Pl. VI. figs. 1, 2, and 3. These have not been noticed in the beds at Purley; but on the other hand a form appears there (Pl. VI. fig. 5) which has not been found at May Hill.

Girvanella problematica seems to constitute an exception to what I have just stated, and to be a most persistent form. It occurs in the beds at May Hill, Purley, and Martin's Quarry, and in the nodules obtained from Biddulph's Quarry; in the two last-named localities it is the only *Girvanella* found.

Whether *Girvanella* is to be regarded as an animal or a plant is a question which is not absolutely settled. Rothpletz has figured[2] several forms of fossil algæ, among which he includes *Girvanella*. I certainly think that the forms which I have discovered in the Wenlock Limestone seem more favourable to the vegetable theory of the origin of this fossil than those described in my former paper,[3] and possibly it may be allied to the calcareous algæ; more than this, however, I cannot say. Further investigation may throw light on this interesting question, but whether it be a vegetable or an animal it is certainly a very low form of life, perhaps the lowest of which we have knowledge in a fossil state.

[1] *Op. supra cit.* p. 78.
[2] See Zeitschr. d. Deutsch. Geol. Gesellsch. for 1891, p. 295.
[3] Quart. Journ. Geol. Soc. vol. xlvi. (1890) pl. xi.

EXPLANATION OF PLATE VI.

Fig. 1. Spherule of *Girvanella*. Wenlock Limestone, May Hill, × 16 diam. There are two strata of tubules surrounding a polyzoan fragment. The smaller tubules measure ·03 millim. in diameter, and do not surround the whole of the nucleus. The larger tubules measure ·14 millim.

Fig. 2. A remarkably fine spherule of *Girvanella* from the Wenlock Limestone. May Hill, × 32 diam. The tubules are nearly all of the same size. and measure about ·10 millim. in diameter.

Fig. 3. Spherule of *Girvanella*, also from the Wenlock Limestone of May Hill. × 32 diam. In this there are two strata of tubules surrounding a nucleus of calcite; the smaller tubules measure ·02 millim in diameter, and the larger ·05 millim. The inner stratum of tubules is not continuous around the entire nucleus, but passes into a granulated material, in which, however, the outlines of tubules can be detected.

Figs. 4 *a* (× 32 diam.) & 4 *b* (× 65 diam.). Wenlock Limestone, May Hill. Portion of a *Girvanella*-spherule remarkable for the complicated structure of the tubules. Apparently they are branching, but there are some markings which it is difficult to account for. The tubules measure ·03 millim. in diameter.

Fig. 5. *Girvanella*-spherule from the Wenlock Limestone, Purley, near West Malvern. The spherule is remarkable for the concentric growth of the tubules. These measure ·02 millim. in diameter. × 65 diam.

Fig. 6. Represents a granule from the Wenlock Limestone of Purley, near West Malvern, in which there is no well-defined tubular structure. × 65 diam. The nucleus is an ossicle of a crinoid.

Discussion.

The President remarked upon the very great interest of the paper. It appeared that the Wenlock, like most other Palæozoic limestones, was largely composed of crinoids. The Author seemed to be less certain with regard to the origin of *Girvanella* than he had been in a previous communication, which, if his (the speaker's) memory served him aright, contained a discussion as to the kind of foraminifer to which *Girvanella* should be referred. Now the Author regarded it as probably an organism, but one of very low type.

Prof. Bonney acknowledged the great value of Mr. Wethered's admirable researches. It was very interesting to notice how the action of living organisms was being detected in processes hitherto deemed simply physical; as in the formation of sinter and tufa, described by Mr. W. H. Weed. It had also been found that calcareous algæ were important constituents in the formation of certain more or less pisolitic limestones in the Eastern Alps. The insoluble residues from these Silurian limestones, which, thanks to Mr. Wethered's kindness, the speaker had seen, were of great interest: some largely consisted of the 'clotted' siliceous material. already often noticed in residues; others of fragmental grains—quartz, felspar, zircon, and other constituents of crystalline rocks in good preservation. He thought they indicated that a land formed of such rocks must have existed at no very great distance.

Dr. G. J. Hinde commended the way in which the Author had brought forward his paper: the enlarged photographs exhibited by him very distinctly illustrated the character and variety of organic structure in the oolitic and pisolitic granules which abounded in some of these limestones. He agreed with the Author in believing that the large pisolite-grains, at least, were probably all due to *Girvanella*, although in many of them the organic characters had been subsequently obliterated. With respect to the nature of *Girvanella*, the speaker considered that Dr. Rothpletz had satisfactorily shown its relationship to certain forms of fossil and recent calcareous algæ.

Mr. CLEMENT REID suggested that these tubes might be formed in a variety of ways, and might not be due to the agency of any special organism. He thought it probable that many of them were merely inorganic encrustations on any filamentous plants, such as algæ, growing in water containing much lime. The tubes might be compared with the deposits on the fibres of a common patent apparatus —a sort of mop—used to extract lime from the water in boilers. If the fibres within these artificial encrustations were to decay, there would be left a tangled mass of small tubes, like most of the so-called *Girvanellæ*.

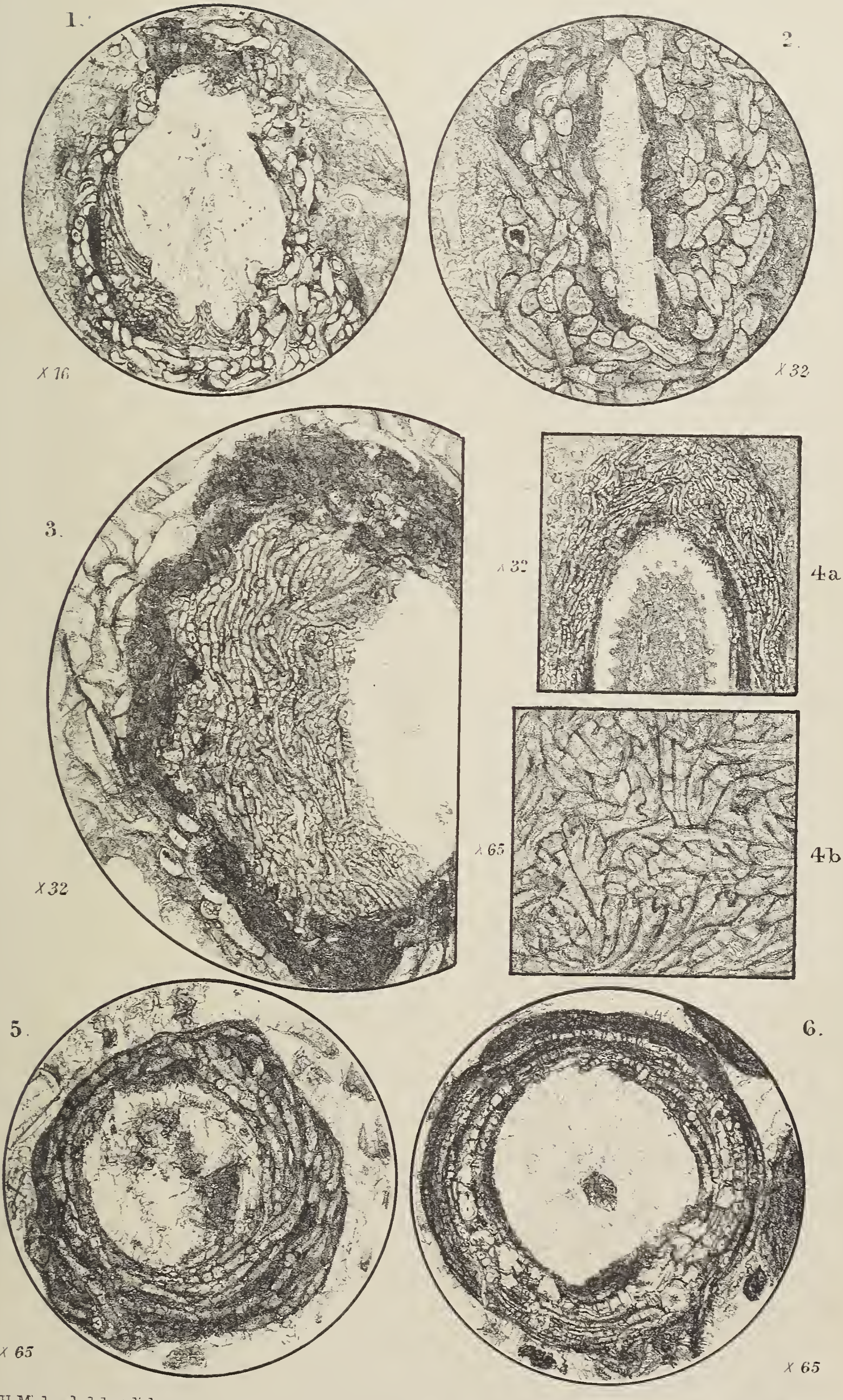
Mr. RUTLEY pointed out that if the suggestion of Mr. Clement Reid were correct, the structure of *Girvanella* would correspond, on a very small scale, with that of *Osteocolla*.

The Rev. H. WINWOOD said that whatever development had taken place in the mind of the Author of the paper as to the character of the organism, he certainly must feel gratified at the progress of development in the views of geologists generally, and the consensus of opinion as to the organic nature of these tubules. He remembered, when the subject was first brought before the Society, that the tubules were of a simpler character—single ones merely, or circling round some nucleus; now, by the Author's further researches, they appeared of different sizes and shapes. One specimen which Mr. Wethered had kindly sent him seemed to branch off into a wisp-like form, which, as Dr. Hinde had just remarked, looked like an alga. He hoped that Mr. Wethered would continue his good work, and bring further developments before the Fellows.

The AUTHOR replied that, as to oolitic structure in general being due to the growth of *Girvanella*-tubules, he had proved to the satisfaction of most people that this was the origin of pisolite; and it would be found to apply to the smaller oolitic granules to a much greater extent than was generally supposed.

In reply to Mr. Reid and Mr. Rutley, the Author said that though there was doubt as to whether *Girvanella* was an animal or a plant, there was absolutely none on the question of its being organic.

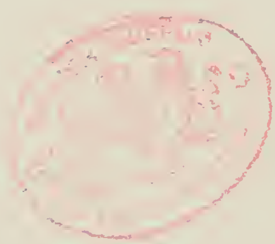
With the other Fellows who had spoken he was in practical agreement, and he thanked them all for their remarks.



F. H. Michael del. et lith.

Mintern Bros. imp.

GIRVANELLA IN WENLOCK LIMESTONE.



20. *On the* Affinities *of* Anthracoptera *and* Anthracomya. By Wheelton Hind, M.D., B.S., F.R.C.S., F.G.S. (Read February 22nd, 1893.)

[Plates VII., VIII., IX., & X.]

Part I.—The Affinities of Anthracoptera.

The first mention of these shells is by Sowerby in Prestwich's memoir on the geology of Coalbrookdale, where four species are figured—one as *Modiola*, a second as *Mytilus*, and the other two as *Avicula*. These were hesitatingly referred to *Myalina* or *Avicula* by Salter, in 'Iron Ores of South Wales,' Mem. Geol. Surv. 1861, where in a footnote (p. 230) he hazards the conjecture that they may belong to *Anthracomya*, a genus then described for the first time to contain shells previously referred to *Unio*. In 1862, in the memoir on the 'Geology of the Country round Wigan,' he proposed the name *Anthracoptera* for certain shells previously described and figured as *Avicula, Modiola*, and *Myalina*; he there detailed the specific characters and gave a diagrammatic woodcut of the genus.

In the Supplementary Chapter to 'Acadian Geology,' 1860, Sir J. W. Dawson proposed the name *Naiadites* to include all Coal Measure shells; he then figured no shell referable to this genus, although Salter, in his paper 'On some fossil Crustacea from the Coal-measures of British North America,' Quart. Journ. Geol. Soc. vol. xix. (1863) p. 79, figured a shell, *Anthracoptera carbonaria*, evidently correctly, but erroneously identified it with Dawson's figure (fig. 42, p. 204), which really represents an *Anthracomya*. Subsequently, in the 2nd edition, in 1868, Sir J. W. Dawson showed that he believed *Naiadites carbonaria* to be synonymous with *Anthracoptera carbonaria*, Salter, and *Naiadites lævis* with *Anthracoptera lævis*, the figures given resembling *Anthracomya* rather than *Anthracoptera*.

In 1852 Ryckholt figured, under *Mytilus*, three specimens from the neighbourhood of Mons. These doubtless belong to the genus under discussion; and Ludwig, as *Dreissenia*, describes four species from the Coal Measures of Germany.

Asiphonida (integropallialia).

Family Mytilidæ.

Genus Anthracoptera, Salter.

Syn. *Modiola*, Sowerby, Trans. Geol. Soc. ser. 2, vol. v. pt. 3, pl. xxxix. figs. 15–18.
Mytilus, ibid. ibid.
Avicula, ibid. ibid.
Myalina, Salter, Geol. Surv. Mem., 'Iron Ores of South Wales,' p. 230.
Anthracoptera, Salter, Geol. Surv. Mem., 'Country round Wigan,' 1862.
Mytilus, Ryckholt, 'Mélanges paléontologiques,' 1852.
Dreissenia, Ludwig, 'Palæontographica,' vol. viii. (1859–1861).

Myalina, McChesney, 'New Sp. of Palæozoic Fossils,' 1860.
" Meek & Worthen, Proc. Acad. Nat. Sci. Philad. 1860.
" " " Proc. Acad. Nat. Sci. Chicago, 1866.
Modiola, Brown, 'Fossil Conchology,' 1849.
" Lea, Journ. Acad. Nat. Sci. Philad. vol. ii. 1853.
No name, R. Garner, 'Nat. Hist. of County of Stafford,' pl. E, figs. 19, 21, 22 (1844).

Generic Description.—Shell modioliform, obliquely triangular, inequivalve, the left valve being most tumid, the right valve flattened, both valves notched for the byssus, the left one slightly more so. Hinge-line straight. Hinge-plate in some species almost obsolete, in others markedly striated. Edentulous. Anterior end small and oblique, forming a lobe anterior to the umbonal ridge. Beaks almost terminal, slightly pointed anteriorly at apices. Umbonal ridge strong in left valve, less marked in right, extending from the umbones to the posterior part of the shell, where it becomes lost in most species before it reaches the posterior border. Surface ornamented with flat concentric lamellæ, and lines of growth and wrinkled periostracum over the posterior end. Below the oblique ridge the striæ are close, and arising from the umbo diverge until they reach the ridge, where they turn upwards at wider and regular intervals, and are continued to the superior border.

Interior.—The pallial line is represented by a dotted line. The post-adductor scar is circular, large, situated near the posterior end, $\frac{1}{3}$ distance from the superior to the inferior border. Anterior-adductor scar small, pit-like, anterior to the umbo. There are two accessory, pit-like scars, for the pedal and byssal muscles—one umbonal, and one midway between the umbo and the anterior-adductor scar. Scars for the pedal and byssal muscles about the centre of the superior border, and just below the hinge-line.

Observations.—I have been fortunate enough to obtain some weathered-out interiors of this genus from the Ten-Feet and Hard Mine seams of the North Staffordshire Coalfield, which possess a well-marked, striated hinge-plate, showing the close affinity of these shells with *Myalina*, under which they were once described. They differ, however, in not possessing triangular septa within the beaks for the insertion of the anterior-adductor muscle. It is in these beds that the genus appears in such profusion, both in numbers and in its specific forms.

Continental authors have described these shells as *Dreissenia*, but they are undoubtedly in error. The absence of the shelf for the anterior adductor, and the shape and position of the posterior-muscle scar, which in *Dreissenia* is riband-like and flat, and is inserted into the shell close to the upper border, show a divergence from *Dreissenia*.

M'Coy, 'Brit. Palæozoic Foss.,' p. 492, thinks that there were two anterior adductors, each arising from the large anterior muscle-pit, but crossing each other to be inserted into the smaller scar near the umbo. This may be so; but from dissections of *Mytilus*, *Modiola*, and *Dreissenia*, I believe the uppermost scar to be that of the anterior pedal muscle. The shells now under consideration closely resemble those described by Mr. R. Etheridge, Jun., as *Myalina*,[1] and he says that his specimens from the Cults Limeworks, Pitlessie, Fife, are covered with *Spirorbis*, a frequent occurrence on North Staffordshire specimens. Sir J. W. Dawson considers these shells to be embryonic forms of *Unio*, to which family he states that the shell is closely allied in structure ('Acad. Geol.' 2nd ed. p. 202).

There is a good deal of variation in size, shape, and tumidity of the shells of the different species to which names have been given, and, indeed, it would be easy to show a series of shells passing gradually from species into species; nevertheless, there are well-marked variations, which may be regarded as being of specific value. They were evidently gregarious in habit. Mr. R. Etheridge, Jun., in his 'Palæozoic Conchology of Scotland,' quotes a specimen of *Calamites* surrounded by a number of individuals of *Anthracoptera*, lying as if attached to it by a byssus.

The specific forms of this genus may be identified as:—

ANTHRACOPTERA MODIOLARIS. (Pl. VII. figs. 1, 1 *a*, 1 *b*, 3, 4, 5, 6.)

Avicula modiolaris, Sowerby, Trans. Geol. Soc. ser. 2, vol. v. pt. 3, pl. xxxix. fig. 18.
? Non *Avicula tenua*, *sic* Brown, Trans. Manch. Geol. Soc. vol. i. (1841) pl. v. fig. 23.
? Non *id.* Brown, 'Fossil Conchology,' pl. lxviii. fig. 9.
Avicula modiolaris, Brown, *ibid.* pl. lxi.** figs. 23, 24.
Mytilus Wesemaelianus, Ryckholt, 'Mélanges paléontologiques' (Mém. couronn. Acad. roy. Belg. t. xxiv. 1852), pl. viii. figs. 11, 12.
Dreissenia inflata, R. Ludwig, 'Palæontographica,' vol. viii. p. 190, pl. lxxi. figs. 8–10.
Dreissenia laciniosa, R. Ludwig, 'Palæontographica,' vol. viii. pl. v. figs. 15–19.
Modiola funata, Brown, 'Fossil Conchology,' pl. lxxi. figs. 12–13.
Modiola wyomingensis, Lea, Journ. Acad. Nat. Sci. Philad. vol. ii. pt. 3, 1853, p. 203, pl. xx. fig. 1.
Myalina modiolaris, Salter, 'Iron Ores of South Wales,' pl. ii. fig. 14.
? Non *Anthracoptera Browniana*, Salter, Mem. Geol. Surv. 'Country round Wigan,' 2nd ed. p. 37, fig. 3, p. 38, fig. 3, *a*, *b*.
Anthracomya modiolaris, Ward, Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x. (1890) pl. i. fig. 13.
R. Garner, 'Nat. Hist. of County of Stafford,' pl. E, figs. 21, 22, no description.

Specific Characters.—Shell triangular, compressed; hinge-line nearly or quite as long as the greatest length of the shell; posterior extremity rounded or straight and somewhat emarginate, meeting the hinge-line at an obtuse angle. The left valve is slightly more convex than the right. There is a flattened ridge starting at the umbo passing backwards parallel to the hinge-line at first, then obliquely downwards and backwards, becoming lost on the lower part of the posterior half of the shell. Beaks almost terminal, curved inwards and forwards, not contiguous, slightly elevated above the hinge-line. Anterior part of shell almost obsolete, with byssal notch. Posterior part expanded, flattened, and obtusely curved at the lower angle. Hinge-plate thick and transversely striated; I have counted as many as ten striæ on one plate.

[1] Ann. & Mag. Nat. Hist. ser. 4, vol. xv. (1875) p. 427, pl. xx.

Interior.—Attachment of mantle marked by a dotted line in casts, corresponding to small pits in the shell. Anterior muscle-scars three in number, pit-like. The anterior is the largest, and is situated in the umbo; the next is situated just below the horizontal part of the ridge, and the most posterior on the ridge, exactly at the point where it changes its direction downwards. The posterior scar is large, obovate antero-posteriorly, situated close to the posterior superior angle of the shell. Faint traces of byssal muscles are seen near the upper border. Two or three slight diverging grooves arise from the upper part of the keel, and are seen as ridges in casts.

Surface ornamented with fine striæ and lines of growth, which arise from the anterior side of the umbo, and pass along the anterior part, until they reach the ridge, when they become separated by regular and wider intervals, and reflected strongly, passing across the shell to the superior border. Periostracum wrinkled. Shell moderately thick.

Dimensions:—Greatest antero-posterior length, 31 mm. ($1\frac{1}{4}$ inch); greatest dorso-ventral depth, 24 mm. (about 1 inch); thickness, 8 mm. ($\frac{11}{32}$ inch).

Remarks.—This form varies very much in the length of the hinge-line, which may even exceed the length of the shell; also in the shape of the posterior end. In many the hinge-line passes by a gentle curve into the posterior border; in others the two borders join at an obtuse angle, in which case the posterior border is slightly sinuated at the upper part. This shell is more nearly triangular than any of the other groups.

Salter's figures in 'Iron Ores of South Wales,' pl. ii. fig. 14, and 'Country round Wigan,' 2nd ed. p. 37, fig. 2, no. 3, and p. 38, fig. 3, have the long hinge-line and emarginate posterior end.

In compressed forms from shales the periostracum is extremely wrinkled. The best-preserved specimens are from ironstone-beds.

Localities.—North Staffordshire Coalfield: roof of Hard Mine, Banbury, and Holly Lane Coals, Moss Shale, Knowles Ironstone; South Wales: Darran Pins; Coalbrookdale: White Flats; Lancashire Coalfield: Rochdale, 30 feet below the Arley Mine; Yorkshire Coalfield: Wakefield.

I am unable to identify Brown's *Avicula tenua* (sic), to which Salter gave the name *Anthracoptera Browniana*, as belonging to this genus. According to Brown's figures (Trans. Geol. Soc. Manch. vol. i. pl. v. fig. 23, and 'Foss. Conch.' pl. lxviii. fig. 9) the shell has a definite *Avicula*-like form. Salter, 'Country round Wigan,' figs. 2, 3, figures what he supposed to be fragments of Brown's shell, dotting in an outline as if it had the shape of an *Anthracoptera*. Both Brown's figures appear to be those of complete shells, and probably represent a species of shell hitherto called *Posidonia* from the Lancashire coalfield. I have therefore dropped both names as synonyms of the shell described above.

Brown's figure of *Avicula modiolaris*, purporting to be a copy of Sowerby's in the 'Geology of Coalbrookdale,' is unrecognizable; but his description, though meagre, is evidently of our shell. The figures of his *A. funata* and *Modiola subtruncata* are much better, and have every appearance of the shell under description. They are both, moreover, from the same locality (Wakefield).

ANTHRACOPTERA TRIANGULARIS. (Pl. VII. figs. 7, 8, 9, 9 *a*.)

Mytilus triangularis, Sowerby, Trans. Geol. Soc. ser. 2, vol. v. pt. 3, pl. xxxix. fig. 16.
? *Avicula modioliformis*, Brown, 'Fossil Conchology,' pl. lxvi.* fig. 19.
Myalina Swallovi, McChesney, 'New Sp. Palæozoic Foss.' p. 57, 1860.
,, ,, ,, Illustrations to same, pl. ii. figs. 6, 6 *a*.
,, ,, Meek & Worthen, 'Geol. of Illinois,' Palæont. vol. ii. (1866) pl. xxvii. fig. 1 *a, b, c, d*.

Specific Characters.—Shell much compressed, obliquely ovate, with pointed anterior end, and the posterior regularly and semicircularly curved into the upper and lower borders. Hinge-line straight, about $\frac{1}{3}$ length of shell, from which point the superior border slopes gently downwards into the curve of the posterior end. Left valve most convex, with a diagonal ridge proceeding from the umbones, which becomes lost when it has traversed $\frac{1}{3}$ the length of the shell. It is not twisted as in previous species. Beaks situated at $\frac{1}{5}$ length from the anterior end of the hinge-line, only slightly curved forwards. Anterior end small and tumid. Inferior border nearly straight. The posterior end, produced, slightly expanded, and flattened, comprises $\frac{3}{4}$ of the shell.

Interior.—Three pit-like, anterior-adductor muscle-scars; one posterior, position uncertain.

Surface-markings as in previous species.

Greatest length, 38 mm. ($1\frac{7}{16}$ inch); greatest dorso-ventral depth, 21 mm. ($\frac{13}{16}$ inch; this is close to the posterior end); thickness, 10 mm. ($\frac{3}{8}$ inch).

Remarks.—The shells form a group, distinguished from *A. modiolaris* by a comparatively short hinge-line, and flatter, more oblique form, with a less-marked diagonal ridge, which has not the obtuse change in direction near its apex. It is distinguished from *A. carinata* by its more expanded and produced form, and less tumid and keeled valves; but intermediate forms exist, connecting all three forms.

Localities.—North Staffordshire: roof of Hard Mine Coal; Coalbrookdale: Crawstone; Woodhall, Water of Leith (Rhind).

ANTHRACOPTERA CARINATA. (Pl. VII. figs. 2, 2 *a*, 10, 10 *a*, 11, 12, 12 *a*.)

Modiola carinata, Sowerby, Trans. Geol. Soc. ser. 2, vol. v. pt. 3, pl. xxxix. fig. 15.
Modiola carinata, Brown, 'Fossil Conchology,' pl. lxi.*** figs. 19, 20.
Myalina carinata, Salter, Geol. Surv. Mem., 'Iron Ores of South Wales,' pl. ii. fig. 15.
Dreissenia dilatata, Ludwig, 'Palæontographica,' vol. viii. pl. lxxi. figs. 5, 6, 7.
Anthracomya carinata, Hull, 'Coalfields of Great Britain,' 4th ed. pl. facing p. 38, fig. 3.
A. carinata, Ward, Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x. (1890) p. 129, pl. i. fig. 9.
No name, R. Garner, 'Nat. Hist. of County of Stafford,' pl. E, fig. 19.

Specific Characters.—Shell obliquely rhomboidal, but the anterior lobe is larger comparatively than in the two foregoing species. Anterior and posterior margins almost parallel; lower margin short and rounded. Hinge-line as long as the greatest length of the shell. Valves convex, with a blunt ridge rising from the superior border at $\frac{1}{5}$ of its distance from the anterior end. This ridge proceeds downwards at an acute angle to the line of obliquity of the shell, and becomes lost near the inferior border. The anterior part of the shell is swollen above, then compressed obliquely, parallel to and in front of the ridge, expanding again into the ridge, and it consists of rather more than $\frac{1}{3}$ of the whole shell. The posterior part is compressed near the hinge-line, more tumid and produced below. The lower border forms a U-shaped curve, obtusely rounded.

Interior.—Three muscle-scars, pit-like, anteriorly; one posterior, rounded near the posterior superior angle. Fine lines of growth starting from the anterior extremity along the inferior border, diverging slightly, reach the ridge and become reflected upwards to the inferior and posterior borders. Periostracum wrinkled.

Size.—Greatest length diagonal, 25 mm. (1 inch); length of hinge-line, 9 mm. (about $\frac{3}{8}$ inch); greatest width from side to side, 8 mm. ($\frac{11}{32}$ inch).

Localities.—North Staffordshire: Hard Mine, Ten-foot, Moss Seams; Coalbrookdale: Crawstone; South Wales: Blue Vein and Darran Pins.

Observations.—This shell is easily distinguished from other groups by its shape and gibbosity. The longer forms approach somewhat to *A. triangularis*, and the flatter, broader forms to *A. quadrata*.

ANTHRACOPTERA QUADRATA. (Pl. VIII. figs. 1–4.)

Avicula quadrata, Sowerby, Trans. Geol. Soc. ser. 2, vol. v. pt. 3, pl. xxxix. fig. 17.
Avicula quadrata, Brown, 'Fossil Conchology,' pl. lxi.** figs. 27, 28.
Myalina quadrata, Salter, 'Iron Ores of South Wales,' pl. ii. fig. 16.
Myalina meliniformis, Meek & Worthen, 'Geol. of Illinois,' Palæont. vol. ii. (1866) pl. xxvii. fig. 3.
Myalina recurvirostris, ibid. pl. xxvi. fig. 9 *a*, *b*, *c*.

Specific Characters.—Shell compressed, quadrate or U-shaped, very slightly oblique. Anterior side almost obsolete. Posterior expanded and flattened. Left valve slightly more convex than right valve. Hinge-line straight, longer than or as long as the greatest antero-posterior diameter. The lower border is almost semicircular. Anterior side narrow, compressed, with sinuated margin at the byssal notch. There is a blunt keel, which starts from the hinge-line at $\frac{1}{6}$ of the length from the anterior end and passes downwards and slightly backwards, becoming soon expanded and lost on the shell. The posterior end is flattened, expanded above its posterior border, being almost straight, meeting the hinge-line at an obtuse angle. Umbones almost terminal, slightly elevated above the hinge-line, and bent anteriorly.

Interior.—Three anterior muscle-scars, pit-like; one posterior, which seems to vary slightly in position, in one specimen being close up to the posterior superior angle, in another midway between this angle and the middle point of the shell. Hinge-plate thickened and striated. Surface-markings as in previous species. Periostracum wrinkled.

Size.—Length of hinge-line, 30 mm. ($1\frac{1}{10}$ inch); greatest dorso-ventral measurement, 25 mm. (1 inch); thickness, 12 mm. ($\frac{7}{16}$ inch). Another specimen: length of hinge, 23 mm. ($\frac{15}{16}$ inch); dorso-ventral measurement, 25 mm. (1 inch); thickness, 5 mm. ($\frac{1}{5}$ inch).

Localities.—North Staffordshire: Hard Mine, Ten-foot, and Banbury Seams; Coalbrookdale: White Flats; South Wales: Darran Pins; Bunker's Hill, W. of Rochdale, 30 feet below the Arley Mine.

Remarks.—This species is easily distinguished from others. It is somewhat rare; but its flat, peculiar U-shaped form, and expanding posterior side, separate it from all others. The oblique ridge, too, is occasionally nearly at a right angle to the hinge-line, but mostly at a very obtuse angle. A series of specimens with slight variations show the close connexion of this form and *Anthracoptera modiolaris.*

ANTHRACOPTERA TUMIDA. (Pl. VII. fig. 13, 13 *a*, 14.)

R. Etheridge, Jun., Mem. Geol. Surv. Scot. Expl. Sheet 31, p. 82, no figure.

Specific Characters.—Transverse, triangular, gibbous, with strong diagonal ridge, dividing the valves into two nearly equal parts. Anterior side well marked, tumid. Sinuated border, with byssal notch most marked in the left valve. The posterior end is obliquely truncate, the margin with the hinge-line forming an obtuse angle, occasionally emarginate. Hinge-line shorter than length of shell; lower margin obtusely rounded. Diagonal ridge and umbonal region very convex, forming the most gibbous part of the shell. Ridge almost median, rather (if anything) anterior, curved forwards along the hinge-line, to become almost terminal. Beaks prominent, separated, raised above the hinge-line.

Interior.—There are three pit-like muscle-scars anteriorly, as in the preceding species; but I have not ascertained the position of the posterior muscle.

Size.—Antero-posterior measurement, 13 mm. ($\frac{1}{2}$ inch): dorso-ventral, 12 mm. ($\frac{7}{16}$ inch); from side to side, 11 mm. ($\frac{3}{8}$ inch).

Localities.—Shale above the Brownstone portion of the Bo'ness Lower Ironstone, Edge Coal Series; Hard Mine, Dividy Lane, Longton.

Remarks.—Mr. R. Etheridge, Jun., observes that the convexity of shell distinguishes this species from *A. triangularis*; the more prominently developed anterior end, the median position of the diagonal ridge, and its more direct course, from *A. carinata* and *A. quadrata.* I have adhered in greater part to his own description.

Two specimens at Jermyn Street, described as *Anthracoptera Sowerbyi* (Etheridge, MSS.), are probably of this species.

ANTHRACOPTERA OBESA.

R. Etheridge, Jun., Quart. Journ. Geol. Soc. vol. xxxiv. (1878) pp. 12–13, pl. i. figs. 12, 13 (& 14 ?).

"*Sp. Char.*—Trigonal, very gibbous, inequality of the valves distinctly marked; anterior side pointed, well marked, and defined by the byssal furrow in each valve; posterior side but little flattened, its margin slightly sigmoidal. Hinge-line straight, as long as the shell, its margin thickened on each valve, leaving in casts two long grooves. Umbones well developed, contiguous, but not touching, anterior, but not quite terminal, with a broad, very obtusely rounded, diagonal ridge proceeding from each, to which the shell owes much of its exceedingly convex form. Byssal furrows shallow, most pronounced in the left valve; marginal notch not deeply excavated. Anterior muscular impressions quite anterior, infra-umbonal. Surface of the shell covered with concentric subimbricating lamellæ, crowded and striiform on the anterior end, but opening out and becoming lamellar on the diagonal ridge and posterior wing."

"*Obs.*—The much more central position of the diagonal ridge, greater convexity of the shell, and the sigmoidal margin of the posterior end at once distinguish *A. obesa* from either *Anthracoptera?* or *Myalina* (*Avicula*) *quadrata*, Sow., *A.*? or *M.* (*Avicula*) *modiolaris*, Sow., *A.*? or *My.* (*Modiola*) *carinata*, Sow."

I personally know nothing of this form, and have copied word for word Mr. R. Etheridge's description and remarks.

ANTHRACOPTERA ELONGATA, sp. nov., Wheelton Hind. (Pl. VII, figs. 15, 15 *a*, 16, 17.)

Specific Characters.—Shell inequivalve, very inequilateral, modioliform, or transversely elongated, tumid. Hinge-line straight, about $\frac{2}{3}$ the length of the shell. Beaks almost terminal, separated, directed forwards. A very tumid ridge extends from the umbones diagonally across the shell to the posterior inferior angle. Anterior end almost obsolete, swollen, with wide byssal sulcus. Posterior end tumid below, flattened upwards and backwards, and somewhat expanded. Posterior border bluntly curved above, truncate below. The inferior border would, if produced forwards, make an acute angle with the hinge-line, is broadly sinuated, and notched for the byssus.

Interior.—All that is known is that there is a very large anterior-adductor muscle and another pit-like scar in the umbo.

Exterior.—Surfaces marked with fine striæ and lines of growth anteriorly, which diverge slightly until they reach the oblique ridge, where they become rapidly reflected upwards and pass to the superior border.

Size.—Greatest antero-posterior measurement, 23 mm. ($\frac{15}{16}$ inch); greatest dorso-ventral measurement, $\frac{1}{3}$ from posterior end, 8 mm. ($\frac{11}{32}$ inch); from side to side, 5 mm. ($\frac{1}{5}$ inch).

Remarks.—This is a rare species, limited, so far as I know, to the Knowles Ironstone of Fenton and Longton. It can be distinguished from all other species by its tumid, elongated, subparallel form. There is a block of Knowles Ironstone in the Museum of Practical Geology, Jermyn Street, which contains a large number of these shells. The younger forms are more oblique and less tumid. This species very closely resembles some species of *Anthracomya*; but the distinctive features of the umbonal region serve to point out the differences.

Locality.—Knowles Ironstone, Fenton Park, North Staffs.

Anthracoptera Browniana, Salter.

In the Trans. of the Manchester Geol. Soc. vol. i. pl. v. fig. 23, in illustration of a paper by Mr. Binney, Capt. Brown figured a specimen from the Pendleton coal-pits, but without naming or describing it. However, in his 'Fossil Conchology,' pl. lxviii. fig. 9, he refigures the specimen and appends a short description. The figures of his shell are in both cases of unbroken specimens, but I cannot say anything further as to their correct affinity. When, however, Salter published his description of *Anthracoptera Browniana* (Geol. Surv. Mem., 'Country round Wigan,' 2nd ed. p. 38, fig. 3 *a*, *b*) he figured a shell evidently, judging from its lines of growth, a complete specimen, and like Brown's ; but he changed it into a form of his new genus by adding parts to the shell where the shape did not agree with his new form.

I have been unable to see in any museum, or to collect, forms of shell like Brown's ; but, if his figure be correct, they probably will be more accurately referred to the *Posidoniæ*, and I have therefore not recognized *Anthracoptera Browniana* as a species of this genus.

I have redescribed the four forms originally figured by Sowerby, though I should be very loth to guarantee the absolute separation of these four species. Probably, had I been describing these forms for the first time, I should have created only two species, considering *Anthracoptera modiolaris* and *A. quadrata* as varying forms of the one, *A. triangularis* and *A. carinata* of the other.

I have been unable to examine Continental and American types, which I have given as synonyms, except from plates and descriptions. These, however, all agree very closely with the forms to which I have suggested their relationship. This reference must be regarded as only tentative, and liable to be modified by the results of further investigations.

Part II.—The Affinities of Anthracomya.

Salter, Geol. Surv. Mem., 'Iron Ores of South Wales,' p. 230.

This genus was established by Salter in 1862 for certain shells which had been described by Sowerby, Trans. Geol. Soc. ser. 2, vol. v., 'Geology of Coalbrookdale,' under *Unio*, and as *Modiola* (Binney) and *Naiadites* (Dawson), possessing a common character in the periostracum, which he considered distinctive of the family Myadæ, hence the name. At that time, however, the interiors were quite unknown, and the correct place of the genus could only be guessed. Sir J. W. Dawson looked upon the fossils as embryonic forms of *Unio*, from the microscopic structure of the shell, which he describes as presenting an internal lamellar and subnacreous layer, a thin layer of vertical prismatic shell, and periostracum. The ligament is external, there are no hinge-teeth or byssal sinus, and he did not think they could have been burrowers ('Acadian Geology,' in which are figured two specimens of *Anthracomya*, *A. carbonaria*, Dawson, *non* Salter, Quart. Journ. Geol. Soc. vol. xix. 1863). Another species of this genus is described by Williamson (1836) in Phil. Mag. vol. ix. p. 351, as *Unio Phillipsii*, and by Phillips in Murchison's 'Silurian System,' p. 88, as a thin compressed shell from the neighbourhood of Manchester; while Ludwig, 'Palæontographica,' vol. viii. pl. iv. figs. 13–15, under *Unio obtusus*, figures one of this genus, and in vol. x. pl. iii. figures *Anodonta obstipa*, *Cyclas obuncula*, *Unio Goldfussanus*, *Anodonta subparallela*, *Unio Eichwaldanus*, and *Anodonta tenera*, which may probably belong to this genus.

Asiphonida (Integropallialia).

Family Unionidæ.

Genus Anthracomya.

Generic Characters.—Shell transverse, slightly inequivalve, inequilateral, the anterior end being small and rounded, posterior produced, compressed and expanded, generally truncate. The umbones are small, and situated near the anterior end, very little raised above the hinge-line, which is straight, long, and edentulous, and has a narrow interior ridge in its posterior portion. There is a blunt oblique swelling which arises at the umbones, and, expanding as it passes downward and backward, is lost on the posterior part of the shell. There is what appears to be a byssal furrow, parallel and anterior to the ridge, but it is extremely doubtful whether it is not an ancestral relic, as I have been unable to find evidence of a byssal notch in any of the species. Ligament external, as in *Anodon*. Many of the species seem to gape at both extremities.

Interior.—Nacreous and smooth, with concentric laminæ, and fine radiating striæ, most marked at the pallial line. No trace of pallial sinus or hinge-teeth. Anterior-adductor impression situated at the extreme anterior-superior angle of the shell, rounded, with a small accessory muscle-scar above it. Posterior-adductor scar also circular, just below and in front of the posterior end of the hinge-line.

Exterior.—Surface marked by fine concentric striæ and lamellæ of growth. Periostracum wrinkled.

Remarks.—I have replaced this genus in the Unionidæ, as a member of which it was originally described by Sowerby ;. writers have since that time included it among the Mytilidæ and Myacidæ.

It may now be taken as settled (specimens having been discovered showing the interior) that *Anthracomya* does not belong to the former, though in some forms the shape approaches somewhat that of certain of the Modiolæ.

As to its affinity to the Myadæ, it is somewhat difficult to understand why so many characteristics of that family were assumed for *Anthracomya*. There were a few points only in common between the two, but these were not of generic value. The gaping ends, produced flattened posterior, and wrinkled periostracum are possessed by members of the Unionidæ, as well as Myacidæ, while the peculiar V-shaped marking on *Anthracomya senex* resembles the ornamentation of some recent Siamese Unios, and is therefore in no way peculiar to the burrowing Myacidæ.

There is no evidence at all that these shells were burrowers; indeed I believe, from the fact that they are always associated with byssiferous *Anthracoptera* and other members of the Unionidæ, that they were not so. They are never found lying at right angles to the lines of stratification in North Staffordshire, but always horizontal. The simple edentulous hinge-line, external ligament (I can find no evidence of an internal one in casts), the absence of pallial sinus, position and shape of the adductor-muscles (though the accessory scars posterior to the anterior adductor appear to be absent, as Prof. King pointed out to be the case in *Anthracosia*) all are characteristic of the family Unionidæ.

The shells approximate closely to *Anodon*, under which name Ludwig has described several Continental forms, but they lack the eroded obsolete beaks, the supplementary anterior-adductor muscle-scar, and the equal valves of this form. From *Anthracosia* (King) they differ in the expanded shape of the posterior end, the small inconspicuous beaks, and the absence of a peculiar hinge-plate and teeth.

D'Orbigny quotes a byssiferous form of *Anodon* as found in the river Paraná, South America. Most forms of the genus have traces of a byssal sinus, although they have no longer a byssus. The sinuation of the inferior border, the obliquity of the valves, and the absence of a byssal notch in *Anthracomya* induce one to suppose that its ancestors or embryos may have been byssiferous.

Salter firmly believed that the beds in which *Anthracosia*, *Anthracomya*, and *Anthracoptera* were found were of marine or highly brackish-water origin, his view being formed by the supposed affinities of the latter two genera. He also quotes Agassiz and De Koninck as authorities for the marine character of *Anthracosia*; but it must be remembered that both these observers confused the shells with *Cardinia*, a typical marine genus, and their view has not been accepted by subsequent writers on the subject.

There are, fortunately, very typical marine beds of various depths in the Coal Measures, which contain an unimpeachable marine fauna, e. g. *Productus*, *Spirifer*, *Lingula*, *Discina*, *Orthoceras*, *Goniatites*, *Nautilus*, *Aviculopecten*, *Posidonia*, *Edmondia*, *Sanguinolites*, etc., not only at the base in the Gannister Beds, but, as occurs in North Staffordshire, much higher up in the Coal Measures proper. In none of such beds do *Anthracosia*, *Anthracomya*, and *Anthracoptera* occur; but, on the other hand, these genera are found associated with a peculiar fauna of fishes and reptiles, annelids and crustaceans, which have a close affinity with recent forms and inhabit fresh water, together with a flora of ferns, *Sigillaria*, *Calamites*, and *Lepidodendron*.

The fact of typical marine fossils being found in a few beds of small extent, intercalated in the coal strata, seems to me to afford strong evidence that the rest of the beds were not of marine origin; it would indeed be unaccountable, if all the beds were marine, that the typical fossils should not be more generally distributed for we may safely assume that the forms were surviving in the seas of that period.

The thick, wrinkled periostracum possessed by these shells was one of the characters on which Salter relied as a generic peculiarity. This feature would be considered typical of a freshwater habitat among recent molluscs; it is indeed necessary in these forms, to prevent excessive erosion by the carbon dioxide dissolved in river and lake waters, and thus it constitutes an additional link in the chain of evidence of the freshwater origin of the Coal Measures.

The other affinities of *Anthracoptera* and *Anthracomya* to recent freshwater shells afford strong presumptive evidence of the freshwater origin of the greater part of the Coal Measures; and the occasional simultaneous presence of fluviatile forms with marine, said to occur in a few beds, may be easily accounted for by the supposition that they inhabited estuarine and tidal rivers, whence some would be washed out seawards, and so become mingled with marine types. I must confess, however, that I have never seen this intermixture of forms, and can obtain no evidence of it from many fellow-workers in various coalfields. Salter, Geol. Surv. Mem., 'Country round Wigan,' 2nd ed. p. 34, quotes the occurrence of *Anthracosia* and *Goniatites* not actually in the same layers, but closely intermixed, and states that *Anthracosia acuta* is found in "undoubtedly marine" beds at Clitheroe. (I cannot understand the last allusion.)

ANTHRACOMYA ADAMSII. (Pl. VIII. figs. 5, 5 *a*, 6, 7, 8.)

Salter, Geol. Surv. Mem., 'Iron Ores of South Wales,' p. 230, pl. ii. fig. 7.
Non Ward, Trans. N. Staffs. Inst. Min. & Mech. Eng. vol. x. (1890) p. 125, pl. i. fig. 2.

Specific Characters.—Shell obliquely ovate, compressed, ventral margin much curved, narrower at the short, rounded, anterior end, broadest at about $\frac{1}{4}$ distance from the posterior margin, which is obliquely truncate. Anterior end short, moderately convex, straight above, rounded and sinuated below. Posterior end flattened and expanded. Valves slightly unequal, the left being more convex. An oblique, obtuse swelling passes diagonally from the umbo, across the valves; the byssal furrow is broad and shallow, but there is no perceptible marginal notch; lunule elongate and narrow. Hinge-line straight, $\frac{5}{6}$ length of the shell. Edentulous cartilage external, in grooves on each side of the hinge. Umbones broad, tumid, raised above the hinge-line, almost contiguous, situated $\frac{2}{5}$ distance from the anterior end of the hinge-line. Shell thin.

Interior smooth.

Exterior marked with fine eccentric lines and folds of growth, starting from the anterior end, close together, but separating as they pass across the shell in regular curves, to reach the posterior part of the hinge-line and the posterior border. Periostracum strongly wrinkled.

Size.—Antero-posterior measurement, 65 mm. ($2\frac{3}{5}$ inches); from side to side, 10 mm. ($\frac{2}{5}$ inch); dorso-ventral measurement at $\frac{1}{3}$ from posterior end (the greatest depth), 45 mm. ($1\frac{4}{5}$ inch).

Remarks.—This is a well-marked form of wide distribution, compressed in comparison with its other proportions. Some of my specimens show distinct bands of colour; it occurs chiefly in ironstone-bands. When young it resembles closely *Anthracomya Phillipsii* in shape.

Localities.—Soap Vein, South Wales; Little Mine Ironstone, Fenton and Longton; New Mine Ironstone, Biddulph.

Anthracomya Adamsii, var. expansa, Wheelton Hind. (Pl. IX. figs. 2, 3.)

Anthracomya Adamsii, Ward, Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x. (1890) p. 125, pl. i. fig. 2.

Specific Characters.—Shell obliquely subquadrate, compressed and expanded. Hinge-line straight. Umbones obtuse, slightly raised above the hinge-line, contiguous, situated at $\frac{1}{5}$ distance from the anterior end. Cartilage external. Anterior end almost obsolete, very obtuse, no oblique sulcus; but an obtuse diagonal swelling starts from the umbones, where it is most pronounced (the thickest part of the shell), to be lost rapidly on the posterior part of the shell. This posterior part is flattened and expanded. The anterior, inferior, and posterior borders are part of one general curve which meets the superior border posteriorly at an obtuse angle. There is no relic of a byssal notch. The left valve is the more tumid.

Interior same as in *Anthracomya Adamsii.*

Exterior.—Surface with fine concentric lines and bands of growth. Periostracum much wrinkled.

Size.—Antero-posterior measurement, 53 mm. ($2\frac{1}{4}$ inches); greatest dorso-ventral, 42 mm. ($1\frac{5}{8}$ inch); from side to side, 8 mm. ($\frac{1}{32}$ inch).

Remarks.—This shell is found in the same beds with the previous species, of which I believe it to be a variety. A very large form, 65 mm. ($2\frac{3}{5}$ inches) long, and measuring 55 mm. ($2\frac{1}{5}$ inches) dorso-ventrally, is found in the New Mine Ironstone, Biddulph. It is distinguished by its produced and rounded inferior border, and obsolete anterior end. It looks very much like the figure of *A. dolabrata*, Sowerby, *op. jam cit.*; but the latter has its anterior end broken off, and is therefore imperfect. It is also very much more convex than the specimen under description.

Localities.—Little Mine Ironstone, Fenton, Longton, and Hanley; New Mine Ironstone, Biddulph.

Anthracomya dolabrata. (Pl. VIII. figs. 9, 9 *a*, 10, 10 *a*; Pl. IX. figs. 1, 1 *a*, 4, 5.)

Unio dolabratus, Sowerby, Trans. Geol. Soc. ser. 2, vol. v. pt. 3, pl. xxxix. fig. 9.
Modiola curtata, Brown, 'Fossil Conchology,' pl. lxxii. figs. 19, 20.
A. dolabrata, Salter, Geol. Surv. Mem., 'Iron Ores of South Wales,' p. 230, no fig.

Specific Characters. — Shell tumid, equivalve, transversely elongated. Hinge-line straight, much raised, about $\frac{5}{6}$ length of the shell. Umbones obtuse and gibbous, raised above the hinge-line, situated at $\frac{1}{3}$ length of the hinge-line from the anterior end.

Lunule long and narrow. The lower border is nearly straight, or very slightly sinuated; if produced anteriorly, it would form an angle of 35° with the hinge-line. At its posterior end it curves rapidly upward into the posterior border, which is bluntly rounded below, but obliquely truncated above its superior border. Anterior end short, much lower than the umbones, somewhat acute, with a broad diagonal sulcus. An obtuse, very tumid ridge passes from the umbones, diagonally across the shell, to the posterior-inferior angle. Posterior to the ridge, the shell becomes flattened upward towards the hinge-line.

Interior unknown.

Exterior ornamented by fine striæ and lines of growth, which become rapidly deflected upward, when they reach the oblique groove, to the superior border.

Size.—Antero-posterior measurement, 45 mm. ($1\frac{4}{5}$ inch): dorso-ventral, 28 mm. ($1\frac{1}{16}$ inch); from side to side, 22 mm. ($\frac{7}{8}$ inch).

Remarks.—This species was the first member of the genus to be figured and described. It is closely allied to *Anthracomya Adamsii*, but differs in its dimensions. The greatest thickness is umbonal, not, as in *A. Adamsii*, at the centre of the shell; while the relatively greater length, compared with its dorso-ventral measurement, also serves to distinguish this shell; the oblique ridge and sulcus are much more marked.

Through the kindness of Prof. Prestwich, I have been able to examine the original type-specimen. It is without the anterior end, the absence of which gives a much more quadrate and subparallel appearance to the fossil. I have, with his permission, figured it again. It is for this reason that Sowerby, in his description of the specimen, says its anterior side is small and rounded, and he is followed by Salter (*op. jam cit.*), who says that the anterior side is almost obsolete. The original type is a little more compressed posteriorly than the specimen from North Staffordshire. The specimens of this species from the Oldham district are somewhat different in appearance; they are shorter antero-posteriorly and altogether more thick-set. The posterior end is obliquely truncate, and not so flattened. I have figured two specimens of this form from the cabinet of Mr. J. Ward, F.G.S., of Longton. This shell is mimicked very closely in North Staffordshire by *Anthracoptera tumida*.

Localities.—The Pennystone Beds, Coalbrookdale; Little Mine Ironstone, North Staffordshire; Black Mine, Middle Coal Measures, Oldham, Lancashire.

ANTHRACOMYA PHILLIPSII. (Pl. IX. figs. 6, 6*a*, 7, 8; Pl. X. fig. 27.)

Unio Phillipsii, Williamson, Phil. Mag. vol. ix. (1836) p. 351 (without description).

Unio linguiformis, Phillips, 1839, Murchison's 'Silurian System,' p. 88.

Modiola sp., Binney, 1855, Mem. Lit. Phil. Soc. Manchester, 2nd series, vol. xii. p. 221, note (without description).

Anthracomya Phillipsii, Huxley and Etheridge, 1865, Cat. Foss. Mus. Pract. Geol. pp. 157 & 160 (without description).

Anthracomya Phillipsii, T. Rupert Jones, Geol. Mag. for 1870, p. 217, pl. ix. figs. 3 & 18.

Anthracomya Phillipsii, R. Etheridge, Jun., Geol. Mag. for 1877, pp. 243–244, pl. xii. figs. 6, 7.

Specific Characters.—Transversely-obliquely oval, modioliform, elongated in the direction of the diagonal. Anterior end obsolete, its margin rounded; posterior end compressed, expanding into the hinge-line, which is elevated posteriorly. Hinge-line straight, almost half the length of the diagonal of the shell. Ventral margin convex, passing with a gentle curve into the anterior end, or becoming straight shortly before it reaches the anterior end. Beaks anterior, almost terminal, very obtusely rounded and inconspicuous; in the uncrushed condition there is no diagonal ridge. The shell is tumid, becoming flattened above posteriorly.

Interior unknown.

Exterior.—The markings consist of concentric lines and fine striæ.

Size.—Antero-posterior measurement, 20 mm. ($\frac{4}{5}$ inch); dorso-ventral, 10 mm. ($\frac{2}{5}$ inch); lateral, 8 mm. ($\frac{3}{8}$ inch); another specimen, 23 mm. ($\frac{7}{8}$ inch), 15 mm. ($\frac{3}{5}$ inch), and 5 mm. ($\frac{1}{5}$ inch) respectively.

Remarks.—This shell has a very wide distribution, both horizontally and vertically. It must have existed in immense numbers, especially in the upper beds of the Coal Measures, and was gregarious.

Prof. T. Rupert Jones, F.R.S., *loc. supra cit.*, points out the general resemblance of this shell to *Estheria*, and suggests that the small shells figured by Salter in 'Iron Ores of South Wales,' pl. ii. figs. 1–5, are forms of this species, the black bands in which it there occurs being very characteristic of its situation; but I describe these forms under *A. minima* below. The Bassy Mine Ironstone and Shale of North Staffordshire are literally filled with compressed shells of this species, with *Stigmaria* and other plant-remains.

Phillips, 'Silurian System,' p. 88, in a letter quoted by Murchison, describes four different shells (Unios) as occurring in these beds. "One, smooth, tumid, with prominent beaks, but with very distinct lines of growth, and rather short, straight hinge-lines, looks like a young *Modiola*; a second form, with nearly elliptical hinge-line, deviating considerably from parallelism with the front, ends in a prominent angle; lines of growth strong, shell very thin, beaks slightly prominent. Mr. Williamson has inaccurately referred this shell to *Unio nuciformis.* It occurs in the red beds above the limestone, Black Bass, and underlying Coal Measures."

A third species, "which I named *U. linguiformis* (*U. Phillipsii* of Williamson), is transversely elongated, three times as wide as long; the hinge-line deviates very little from parallelism to the front lines of growth; shell fine, very thin, and smooth."

The fourth species, "which I named *U. rugulosus*, is of obliquely expanded or semi-elliptical form, the hinge-line forming the diameter [I suppose he means when both valves are lying flattened out, connected with a hinge]; surface concentrically marked with broken undulations, often showing radiations on the posterior slopes; shell exceedingly thin. Unionidæ of the same species occur in the bed of mottled marls above the [*Spirorbis*-] limestones, in the Black Bass or shale above the Main Limestone, and in the shale beneath all the calcareous bands."

Of these four, I suspect the last is the shell figured by Salter, Quart. Journ. Geol. Soc. vol. xix. (1863), as *Naiadites lævis*, and referred to by Prof. T. Rupert Jones, Geol. Mag. for 1870, pl. ix. fig. 15, p. 220; but I refer again to this under *A. scotica.*

The 2nd and 3rd are probably different forms of the shell under description, which does vary in shape as described.

I am indebted to the Curators of the Owens College Museum for the loan of Prof. Williamson's type-specimen, and for permission to figure it.

Localities.—In the blackbands, ironstones, and shales of the North Staffordshire Coalfield, as far down as the Bassy Mine; in the Knowles Ironstone; Upper Coal Measures of the Lancashire Coalfield: Ardwick; Coal Measures, Bradford; Blackband, South Wales.

Anthracomya scotica. (Pl. X. fig. 31.)

R. Etheridge, Jun., Geol. Mag. for 1877, pl. xii. fig. 8, pp. 244, 246.

Specific Characters (Etheridge).—"Obliquely-broad-ovate, flattened, abruptly truncated along the dorsal margin. Anterior end rounded; posterior end produced ventrally, its margin obliquely rounded. Hinge-line not so long as the shell, passing insensibly into the oblique posterior margin. Umbones anterior, but not terminal, inconspicuous. Shell marked with exceedingly close, fine, microscopic thread-like striæ, with a few transverse wrinkles, which at times give it the appearance of being partially radiately striated."

Remarks.—Mr. R. Etheridge, Jun., thinks this form closely resembles *Naiadites lævis* (Dawson), though the latter is much smaller, and the concentric striæ closer, finer, and more numerous; the posterior end is more obliquely truncated, and the beaks more anterior. Salter, Quart. Journ. Geol. Soc. vol. xix. (1863) p. 80, identifies Sir J. W. Dawson's shell with one found in the Upper Coal Measures of Manchester. Dawson's shell was in 1870, by Prof. T. Rupert Jones, Geol. Mag. pl. ix. fig. 15, Appendix, p. 220, described as an *Estheria*, and p. 218, the fragment of a similar shell is mentioned from the Ardwick beds; but in 1877 the same writer is quoted by R. Etheridge, Jun., in the paper from which I take the latter's description of the shell under discussion, as having independently referred the Scottish fossil to Sir J. W. Dawson's species.

I figure a pretty little shell found in the Ardwick Limestone, which may belong to the form in question, but I cannot venture to pronounce on the point until I have been able to obtain specimens of the Scottish and American species for study and comparison. Mr. Etheridge (*op. cit.* p. 245) suggests that Hibbert's *U. nuciformis*, from the Burdiehouse Limestone, is an uncrushed example of *A. scotica*, a particularly convex and globose form, but unfortunately Hibbert's specimen has entirely disappeared.

Localities.—Cement-stone Group, Burdiehouse Limestone; Binn

Hill, Burntisland, Fife; Calder Hall and Calder Wood, Inchkeith (Firth of Forth); Wardie Shales, Water of Leith.

ANTHRACOMYA MODIOLARIS. (Pl. X. figs. 24, 25, and 26.)

Unio modiolaris, Sowerby, Trans. Geol. Soc. ser. 2, vol. v. pt. 3, pl. xxxix. fig. 10.
Anthracomya modiolaris, Salter, Mem. Geol. Surv., 'Iron Ores of South Wales,' pl. ii. fig. 13.
Anthracomya modiolaris, Ward, Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x. (1890) pl. i. fig. 10.

Specific Characters.—Shell inequilateral, equivalve, transversely elongated, convex. Dorsal and ventral margins subparallel, hinge-line straight, somewhat elevated posteriorly. Umbones obtuse, adpressed, situated about $\frac{1}{4}$ distance of the hinge-line from the anterior end. An obtuse oblique ridge, in some forms sub-angular, passes obliquely backwards from the umbones in the direction of the posterior-inferior angle, becoming lost on the surface of the shell, just before it reaches this point. Anterior end short, rounded, much compressed below, with well-marked diagonal sulcus, anterior to the ridge. Posterior end flattened rapidly from the oblique ridge, and expanded; the posterior end is truncate, with rounded superior and inferior angles. The inferior border is straight, and gently curved where it passes into the anterior and posterior borders.

Interior.—Pallial sinus entire. Anterior-adductor scar elongate, at the junction of the hinge-line and the anterior border. Posterior-adductor scar large, ovate, near the posterior-superior angle of the shell.

Exterior.—Surface marked with lines and striæ parallel to the lower border, becoming curved posteriorly, very slightly so anteriorly. Striæ more dense at the inferior part of the shell.

Shell thin. Periostracum strongly wrinkled in some specimens.

Size.—Antero-posterior measurement, 44 mm. ($1\frac{3}{4}$ inch); dorso-ventral, 23 mm. ($\frac{7}{8}$ inch); from side to side, 18 mm. ($\frac{11}{16}$ inch).

Remarks.—This shell somewhat resembles *A. dolabrata*. It occurs at an entirely different horizon, the two species never appearing together in North Staffordshire.

Salter's figure in 'Iron Ores of South Wales,' pl. ii. fig. 13, hardly agrees with Sowerby's shell, but has all the appearance of a small form of *A. Adamsii*. The comparative measurements and shape are very similar; it lacks the straight lower border, the more acute form of the diagonal ridge, and besides its anterior end is too high, joining the inferior border with too great a curvature to belong to the species under description. It does occur in the South Wales Coal-field. I have had the opportunity of examining a shell from the locality in the collection of Mr. J. Ward.

This species is the only member of the genus which has been identified from a Scottish coalfield, though Mr. R. Etheridge, Jun., mentions some crushed specimens from the Bo'ness Series; the former is confined to the Middle Coal Measures.

Locality.—Hard Mine and Ten-foot Seams, North Staffordshire Coalfield; Crawstone, Coalbrookdale; Black Mine, Oldham; ? South Wales; Durham Coalfield; Scotland.

ANTHRACOMYA ELONGATA. (Pl. X. figs. 1–12.) Williamson MSS.

Modiola Williamsoni, Brown, 'Fossil Conchology,' pl. lxxi. figs. 24, 25.
Non *Naiadites* (*Anthracomya*) *elongata*, Dawson, 'Acadian Geology,' 2nd ed. (1868) p. 204, fig. 43.

Specific Characters.—Slightly inequivalve, the left being the larger; inequilateral; transversely elongate; greatest dorso-ventral measurement at the posterior end of the shell. Hinge-line straight, edentulous, raised posteriorly. Umbones small, contiguous, situated at rather less than $\frac{1}{3}$ distance of the hinge-line from the anterior margin. Inferior border nearly straight, slightly sinuated about its centre. Lunule small and elongated. Anterior end sharp, compressed, with an acutely rounded border passing rapidly downward into the inferior border. Posterior end expanded and very slightly flattened, except above, where it is rapidly compressed into the hinge-line, its posterior border being truncate with bluntly rounded angles; generally gaping. A broad, obtuse gibbosity passes from the umbones diagonally across the shell, in the direction of the inferior-posterior angle, with a slight oblique sulcus anterior to it, reaching the inferior margin about its centre. Cartilage external. Shell small.

Interior nacreous; pallial sinus entire, with lamellar markings; above and over the oblique gibbosity some fine, radiating lines. Anterior-adductor muscle-scar situated just within the anterior border, at the anterior-superior angle: large, rounded accessory scar above, and nearer the umbo. Posterior-adductor scar situated just below the posterior end of the hinge-line, large and rounded.

Exterior.—Surface covered with fine concentric lines, which become parallel to the inferior border as they pass across the shell. Shell very thin.

Size.—Antero-posterior measurement, 35 mm. ($1\frac{3}{8}$ inch); dorso-ventral, near posterior end, 17 mm. ($\frac{11}{16}$ inch); greatest lateral measurement at the centre of the shell, 5 mm. ($\frac{1}{5}$ inch).

Remarks.—This pretty little shell is very variable, scarcely two specimens being exactly alike. Its chief variations are in the position of the umbones, length of the anterior end, comparative length of the shell, and shape of the posterior end, which may be bluntly rounded and much compressed. I find in Brown's 'Fossil Conchology' a figure which agrees closely with mine, to which that author has given the name of *Modiola Williamsoni*, at the same time referring it to *M. elongata*, MSS. Williamson. I adopted the latter specific name as having the right of priority, and with the greater pleasure because it does away with a meaningless, purely complimentary, barbarous term.

Locality.—Hard Mine roof, North Staffordshire Coalfield (where it is fairly common). Most museums in the country possess these shells from this bed.

Anthracomya lanceolata, sp. nov., Wheelton Hind. (Pl. X. figs. 13, 13 *a*.)

Modiola lithodomoides. R. Etheridge, Jun., & J. Ward, Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x. (1890) p. 130, pl. i. fig. 11.

Specific Characters.—Shell slightly inequivalve, much elongated transversely, with rounded ends. Hinge-line straight, about $\frac{4}{5}$ length of the shell, not raised posteriorly. Umbones small, only just raised above the hinge-line, obtuse, not contiguous, situated $\frac{1}{6}$ length of the shell from the anterior end. Lunule narrow and elongated. Anterior end much lower than the umbones, short, almost straight above, rounded below, convex. The posterior end is elongated, flattened, lanceolate, only slightly expanded below. There is a slight oblique sulcus which indents the inferior border, at the junction of the anterior with the middle third of the shell. The shell is moderately convex in its anterior two-thirds, being gradually flattened above, below, and posteriorly in the hinder third. Inferior border straight for $\frac{1}{3}$ its length, then slightly sinuated, and then produced downward in a straight line at a slight angle, till it curves bluntly upward to meet the posterior border.

Interior smooth; anterior-adductor muscle large, just within the anterior-superior angle of the shell. Posterior unknown. Shell thin, ligament external.

Exterior.—Surface covered with fine lines and laminæ of growth.

Size.—Antero-posterior measurement, 32 mm. ($1\frac{1}{4}$ inch); greatest dorso-ventral, $\frac{1}{3}$ from posterior end, 10 mm. ($\frac{2}{5}$ inch); from side to side, centre of shell, 7 mm. ($\frac{5}{16}$ inch).

Remarks.—I know of only two examples of this species, which is separated from other species by the absence of a raised hinge-line posteriorly, and by the acute and generally flattened posterior end. It has no similarity to *Modiola lithodomoides*, R. Etheridge, Jun., Geol. Mag. for 1875, p. 241, a Mountain Limestone species much larger than our specimen. One was picked up at the Glebe Colliery, Fenton; exact horizon unknown.

Locality.—Bowling Alley Seam, Middle Coal Measures, Whitfield Colliery, North Staffordshire.

Anthracomya obtusa. (Pl. X. figs. 14, 14 *a*.)

Unio obtusus, Ludwig, 'Palæontographica,' vol. viii. pl. iv. figs. 13–15.
Pleurophorus subcostatus, Meek & Worthen, 'Geol. of Illinois,' Palæont., vol. ii. (1866) pl. xxvii. figs. 2, 2 *a*.

Specific Characters.—Shell very inequilateral, oblong. Anterior end very bluntly, obtusely rounded. Posterior end truncate; the superior and inferior angles rounded; the superior and inferior borders nearly parallel. Hinge-line curved anteriorly as far as the umbo, afterwards straight and slightly elevated, edentulous. Umbones almost anterior, otherwise separate, about as high as the hinge-line. Lunule well marked. Inferior border very slightly sinuated. Anterior end almost obsolete, moderately convex; posterior elongated, gently flattened, compressed above into the hinge-line. An almost obsolete diagonal swelling crosses the shell obliquely from the umbones.

Interior.—Smooth. Pallial line simple. Anterior-adductor scar at the superior-anterior angle; posterior large, hemispherical, at the upper part of the posterior end.

Exterior.—Surface marked with fine concentric lines, parallel for most part of the way to the inferior border.

Size.—Antero-posterior measurement, 25 mm. (1 inch); dorso-ventral, 12 mm. ($\frac{7}{16}$ inch); from side to side, 8 mm. ($\frac{11}{32}$ inch).

Remarks.—This shell is somewhat rare. It is differentiated from other species by its oblong rectangular form, and obsolete anterior end. I believe this shell is similar to that described and figured by Meek and Worthen in the 'Palæontology of Illinois.' They referred their shell to a Permian species (King) on account of a few radiating lines on the posterior surface, a kind of ornament which also obtains in *Anthracomya*; and describe the groove in casts, on each side at the posterior end of the hinge-line, as impressions of long lateral teeth, instead of as an expansion of the articulating plate. It is, however, impossible to speak positively without handling the American specimens.

Locality.—Hard Mine Seam, North Staffordshire.

ANTHRACOMYA ANGUSTA, sp. nov., Wheelton Hind. (Pl. X. fig. 15.)

Specific Characters.—Shell very transversely elongated, narrow. Hinge-line straight, nearly as long as the shell, not raised posteriorly. Umbones small, obtuse, very slightly raised above the hinge-line, situated about $\frac{1}{8}$ length of the shell from the anterior end. The inferior border is straight, being broadly grooved for the byssal sinus. Anterior end obsolete, tumid; posterior end elongated and flattened. An obtuse angular ridge extends from the umbones, becoming lost on the posterior part of the shell, and there is a broad sinus just anterior to it. Posterior border bluntly truncated.

Interior unknown.

Exterior.—Surface ornamented with fine concentric lines parallel to the lower border, which become strongly reflected upward over the posterior part of the shell towards the superior border. Periostracum very strongly wrinkled.

Size.—Antero-posterior measurement, 11 mm. (about $\frac{2}{5}$ inch); dorso-ventral, 6 mm. (about $\frac{1}{5}$ inch).

Remarks.—I know of only one specimen, which is in my own collection. It is distinguished from other species by its narrow, elongated form, and by its surface-markings.

Locality.—Hard Mine Seam, Bucknall, North Staffordshire.

ANTHRACOMYA SUBCENTRALIS. (Pl. X. figs. 30 and 30 *a*.)

Salter, Geol. Surv. Mem., 'Iron Ores of South Wales,' pl. ii. figs. 9 and 9 *a*, p. 231.

Specific Characters.—Transversely oblong, convex. Anterior end rounded, tumid, somewhat prominent. Posterior end bluntly rounded, with a blunt swelling which passes from the umbones to the posterior-inferior angle of the shell; the surface above this swelling is compressed into the hinge-line. There is a very slight, broad, oblique sinus anterior to the ridge. The hinge-line and ventral margin are nearly parallel, the latter being sinuate in its middle third. The umbones are prominent, raised above the hinge-line, and situated at $\frac{1}{3}$ length of the latter, which is not quite so long as the shell, from the anterior end. The beaks are apart. Lunule large and elongated. Cartilage external.

Interior unknown.

Exterior.—Surface almost smooth, with nearly obsolete striæ and lines of growth. Periostracum strongly wrinkled.

Size.—Antero-posterior measurement, 20 mm. ($\frac{4}{5}$ inch); dorso-ventral (at umbo), 7 mm. ($\frac{5}{16}$ inch); from side to side, 5 mm. ($\frac{1}{5}$ inch).

Remarks.—Salter observes that the more convex form and central beaks distinguish this species from *A. pumila*, to which it most nearly approaches. This appears to be a very rare form.

Localities.—South Wales: No. 6 pit, Victoria, over the Three-quarter Coal; Hard Mine, Longton, North Staffordshire.

Anthracomya pumila. (Pl. X. figs. 17, 18, 18 *a*, 19, 28, and 29.)

Salter, Geol. Surv. Mem. 'Iron Ores of South Wales,' pl. ii. fig. 10, p. 230.

Specific Characters.—Shell transversely oblong, slightly convex. Hinge-line and ventral margin nearly straight, almost parallel. Umbones small, apices depressed, situated about $\frac{1}{3}$ length of the hinge-line from the anterior end. Lunule narrow and elongated. Anterior end short and somewhat pointed, with or without a slight oblique depression. The posterior end, which is bluntly rounded and truncate, has an obtuse diagonal ridge arising at the umbones and passing to the posterior-inferior angle of the shell. Gently flattened and slightly expanded above the ridge.

Interior.—Anterior and posterior muscle-scars as in other species of this genus. Pallial line simple, ligament external.

Exterior.—Surface covered with fine striæ and lines of growth. Periostracum wrinkled.

Size.—Antero-posterior measurement, 19 mm. (about $\frac{4}{5}$ inch); dorso-ventral, 10 mm. ($\frac{2}{5}$ inch); from side to side, 7 mm. ($\frac{5}{16}$ inch).

Remarks.—I feel very uncertain as to this form, as I have been unable to see the type-specimen. I think it very probable that the form here described may eventually be recognized as the young of the commonest species in the Hard Mine Beds of North Staffordshire, to which I have given the name of *A. elongata* (see p. 266). If this prove to be the case, the name of *pumila* will have to be removed. Salter's figure shows the posterior end to be less in the dorso-ventral dimensions than is the case with the family generally.

ANTHRACOMYA SENEX. (Pl. X. figs. 20, 20 *a*, and 21.)

Salter, Geol. Surv. Mem., 'Iron Ores of South Wales,' pl. ii. fig. 12, p. 231.

Specific Characters.—They are thus described by Salter:— "One inch wide (antero-post.), very unequal-sided (modioliform), the beaks close to the anterior end, which is divided by a well-marked byssal furrow and notch from the posterior side; the latter is convex along the blunt siphonal ridge. Anterior side very short, its edge falling vertically under the rather prominent beak. The posterior side (or slope) is expanded and very convex; the hinge-line raised; the ventral margin sinuate and concave.

"Epidermis deeply wrinkled V-fashion over the posterior slope."

Remarks.—The type-specimen is in the Museum of Practical Geology, Jermyn Street. I have obtained and I figure here specimens of this form from the Hard Mine Seam, Longton, North Staffordshire.

ANTHRACOMYA OBOVATA, sp. nov., Wheelton Hind. (Pl. X. figs. 22 and 22 *a*.)

Specific Characters.—Shell obovate, inequivalve, the left valve being more convex. Anterior end almost obsolete, tumid, bluntly pointed. Posterior end expanded, flattened backward and downward and into the hinge-line, which is much raised. The hinge-line is straight, about $\frac{3}{4}$ length of the shell. Umbones prominent, blunt, separate, situated $\frac{1}{7}$ distance of the hinge-line from the anterior end. The inferior border is curved rapidly downward from the anterior end, then becomes bluntly and gently rounded into the posterior border, which extends in the form of a regular semicircular curve from the inferior to the superior angle. A blunt swelling, rapidly flattened on its posterior side, extends from the umbo to a point in the inferior border, anterior to its posterior limit. There is no appreciable byssal sulcus, but there appears to have been a byssal notch at the junction of the anterior and middle thirds of the inferior border.

Interior smooth, with folds of growth; anterior- and posterior-adductor scars as in other species. Ligament external. Lunule distinct.

Size.—Antero-posterior measurement, 30 mm. ($1\frac{1}{5}$ inch); greatest dorso-ventral (at posterior end), 17 mm. ($\frac{7}{10}$ inch); from side to side, 7 mm. ($\frac{5}{16}$ inch).

Remarks.—I have found only one specimen of this very distinct and characteristic form. It looks much like some forms of *Anthracoptera*, from which it can be distinguished by its umbones and hinge-line. It has occurred to me that this may well be an example of mimicry, the more so because the new form *Anthracoptera elongata* resembles very closely certain forms of *Anthracomya* (see p. 256); in fact, it is only on very close examination of the umbones and hinge-lines that these forms can be correctly referred to their proper genera. This shell closely resembles *Naiadites* (*Anthracomya*) *carbonaria*, Dawson, 'Acadian Geology,' 2nd ed. p. 204, fig. 42; but I have not been able at present to compare the two forms.

Locality.—Hard Mine Seam, Dividy Lane, North Staffordshire.

ANTHRACOMYA, sp. nov. (?), Wheelton Hind. (Pl. X. fig. 23.)

Specific Characters.—Shell oblong, ovate, tumid. Anterior end $\frac{1}{4}$ of the shell, has its superior border much below the umbones, and is bluntly rounded. Inferior border almost straight, joining the anterior and posterior borders with rounded angles. Hinge-line straight, about $\frac{2}{3}$ length of the shell. If it and the inferior border were produced anteriorly, they would meet at a very acute angle. Umbones obtusely broad, more conspicuous, more elevated and separated than usual with this genus, at $\frac{1}{4}$ distance of the hinge-line from the anterior end. Posterior border oblique, truncate from above downwards, rounded below. The shell has a very slight oblique constriction anteriorly, more marked in the left valve. There is no oblique ridge, but the shell becomes generally swollen, being only slightly compressed towards the anterior end.

Interior normal.

Exterior (?).

Size.—Antero-posterior measurement, 38 mm. ($1\frac{1}{2}$ inch); dorso-ventral, 20 mm. ($\frac{4}{5}$ inch); lateral, 15 mm. ($\frac{3}{5}$ inch).

Remarks.—This shell may possibly prove to be a local variety of *A. modiolaris*, but is distinguished from the typical form by the comparative measurements, by the absence of an oblique ridge, and by the short hinge-line and much truncated posterior border.

Locality.—Durham Coalfield.

ANTHRACOMYA WARDI, Salter MSS. (Pl. IX. figs. 9 & 10.)

Ward, Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x. (1890) p. 126, with description by R. Etheridge, F.R.S.

Specific Characters.—Shell small, oblong, margins sub-parallel, moderately convex. Hinge-line straight, nearly as long as the shell, not elevated posteriorly. Anterior end about $\frac{1}{4}$ of the shell; its border forms a right angle with the hinge-line above, bluntly rounded below. Posterior end obliquely truncate above, bluntly rounded at the lower angle, flattened above along the hinge-line and backward into the margin. Umbones situated in the anterior third of the shell. A blunt, oblique tumidity extends from the umbonal area towards the lower part of the posterior end, where it becomes lost.

Exterior.—Surface smooth, with fine, close, concentric striæ and lines of growth, rapidly curving up to the posterior hinge-line. Periostracum thin.

Size.—Antero-posterior measurement, 40 mm. ($1\frac{3}{5}$ inch); dorso-ventral, 16 mm. (about $\frac{7}{10}$ inch). These measurements are, in a specimen belonging to Mr. Geo. Wild, of Oldham, respectively 33 mm. ($1\frac{1}{32}$ inch) and 10 mm. ($\frac{2}{5}$ inch).

Remarks.—I know of only one specimen from North Staffordshire, a right valve, from the cabinet of Mr. J. Ward, F.G.S. It was evidently described by Mr. Etheridge with the preconceived idea that the shell belonged to the Anatinidæ. The specimen is much broken along the anterior half of the hinge-line, and on a cursory examination a fractured fold might be taken for a central umbo. On a closer inspection it will be seen that more anteriorly the shell has disappeared, and left the cast of a small umbo in the normal position of the genus, at the junction of the anterior and middle thirds. I figure another specimen from the cabinet of Sir U. K. Shuttleworth, with the kind permission of that gentleman. This fossil is in a better-preserved condition than the type-specimen, and shows both valves lying open, displaying the characteristic posterior border and shape of the shell; it has a more pronounced ridge than the crushed type, and the umbones are seen to be at $\frac{1}{4}$ length of the hinge-line from the anterior end.

In the Geol. Surv. Mem. of the Country round Bolton, p. 35, Salter notes the occurrence of *Anthracomya sanguinolaris*, MSS., in the Ganister series of Burrs, half-a-mile north of Bury. He had seen Mr. Wild's specimen, and named it *Orthonota* (?) or *Sanguinolites* (?); I am unable to find any specimen bearing the name *A. sanguinolaris*, and hazard the conjecture that it may have been a specimen similar to that described.

Localities.—Holly Lane Coal, roof, Adderley Green, North Staffordshire; Low Baton Bed, Fulledge, Burnley, Lancashire.

[ANTHRACOMYA MINIMA, sp. nov., Wheelton Hind. (Pl. IX. figs. 11 and 12.)

Anthracomya, undescribed forms, Salter, Geol. Surv. Mem., 'Iron Ores of South Wales,' pl. ii. figs. 1, 2, 3.

Specific Characters.—Shell triangular, very small. The hinge-line, if produced, would meet the inferior border at an acute angle. Anterior end short, tumid, border rounded. Posterior expanded and flattened into the borders, behind an oblique obtuse swelling, which passes from the umbones towards the posterior-inferior angle. The posterior border is obtusely rounded below, sloping rapidly upwards into the hinge-line. The hinge-line is a little more than half the length of the shell; the umbones are small, situated about $\frac{1}{5}$ length of the hinge-line from the anterior end. The inferior border is nearly straight, very slightly sinuated about the centre.

The shell is constricted by an oblique groove anterior to the oblique swelling, and is marked by fine lines of growth.

Interior casts show the arrangement of muscle-scars as in other species of the genus.

When young, the shell is more elongate, and not so triangular; it appears to grow in an oblique direction towards the posterior border.

Size.—Antero-posterior measurement, 9 mm. (about $\frac{3}{8}$ inch); dorso-ventral, 4 mm. (about $\frac{1}{6}$ inch); lateral, 3 mm. (about $\frac{1}{8}$ inch).

Remarks.—Blocks of clay-ironstone crammed with shells of this species were sent me for description by Mr. C. Roeder of Manchester, from the Middle Coal Measures of Prestolee. They agree in form with those figured by Salter (*op. supra cit.*), and I have come to the conclusion that the more transverse forms are only the young of these, more expanded posteriorly and triangular. The specimens I have described were obtained by calcining the blocks of stone.

Localities.—Middle Coal Measures, Prestolee, Manchester; Blackband, Blaina, South Wales.

Anthracomya carinata, sp. nov., Wheelton Hind. (Pl. X. figs. 16 and 16 *a*.)

Specific Characters.—Shell transversely elongate, anterior end almost obsolete, moderately tumid, pointed bluntly above the border, sloping quickly into the inferior edge, which is slightly convex in its outline. Posterior part of shell produced. Nearly $\frac{7}{8}$ of the shell with a strong oblique swelling passing downward from the umbones to the inferior border, at the junction of its third and posterior fourth. The extremity is flattened, and gradually compressed into the border, which is bluntly rounded. The hinge-line is straight, about $\frac{3}{4}$ length of the shell. Umbones very anterior, tumid, obtuse.

Interior unknown.

Exterior.—Surface covered with fine striæ and lines of growth, which, starting from the anterior end, become curved upwards, as they reach the oblique swelling, and are reflected to the superior border. The greatest dorso-ventral measurement is at the posterior end of the hinge-line. Periostracum wrinkled.

Size.—Antero-posterior measurement, 22 mm. ($\frac{9}{10}$ inch); dorso-ventral, 8 mm. ($\frac{11}{32}$ inch); lateral, 8 mm. ($\frac{11}{32}$ inch).

Remarks.—I know of only two specimens of this form, one from the Strickland Collection of the University of Cambridge, and one from the Middle Coal Measures of Prestolee, Manchester, kindly lent me by Mr. C. Roeder. Its distinctive characteristics are the strong oblique swelling, transverse form, short anterior end, and rounded posterior extremity. It most closely resembles *Anthracomya lanceolata* (see p. 267), which has a similar posterior border, but does not possess so stout an anterior end, nor so strong an oblique tumidity.

Localities.—Middle Coal Measures, Manchester; South Wales Coalfield, Merthyr Tydvil.—March 15th, 1893.]

[*Note.*—I find that Eichwald, in 'Lethæa Rossica' (Partie ancienne), pp. 976–978, and pls. xxxviii.–xxxix., describes and figures under *Modiolopsis* several species from the Coal Measures of Russia which are evidently *Anthracomya*: they are *Mod. conspicua*, *M. tenera*, *M. tenuissima* (fig. in 'Urwelt Russlands,' Heft i. p. 100, pl. iv. fig. 1), and *M. Pallasii*. For the last-named, and for *M. Teplofi*, he quotes De Verneuil, 'Paléont. de la Russie,' pp. 316, 318, pl. xix. figs. 16, 17.—April 19th, 1893.]

EXPLANATION OF PLATES VII., VIII., IX., & X.

Plate VII.

Figs. 1, 1 *a*, 1 *b*. *Anthracoptera modiolaris*, showing striated hinge-plate and pit-like muscle-scars. Ten-foot Seam, roof. Bucknall, North Staffs.

2, 2 *a*. *Anthracoptera carinata*, showing the striated hinge-plate and muscle-scars.

3. Cast of interior of *Anthracoptera modiolaris*, showing the muscle-scars and pallial line. Hard Mine, Adderley Green, North Staffordshire.

4. *Anthracoptera modiolaris*, with short form of hinge-line. Hard Mine, Adderley Green.

5, 6. *Anthracoptera modiolaris*. Hard Mine, Adderley Green.

7. —— *triangularis*. Hard Mine, Adderley Green.

8. —— ——, intermediate form between *A. triangularis* and *A. carinata*. Hard Mine, Adderley Green.

9, 9 *a*. *Anthracoptera triangularis*, in profile. Hard Mine, Adderley Green.

10, 10 *a*. *Anthracoptera carinata*. Hard Mine, Adderley Green.

11. —— ——, form approaching *A. quadrata*. Hard Mine, Adderley Green.

12, 12 *a*. *Anthracoptera carinata*. Hard Mine, Adderley Green.

13, 13 *a*. —— *tumida*. Hard Mine, Adderley Green.

14. —— ——, mimicking *Anthracomya dolabrata*. Collection of Mr. J. Ward, F.G.S.

15, 15 *a*. *Anthracoptera elongata*. Knowles Ironstone, Fenton Park, North Staffordshire.

16. *Anthracoptera elongata*, young of. Knowles Ironstone, Fenton Park.

17. *Anthracoptera elongata*, form approaching *A. carinata*. Knowles Ironstone, Fenton Park.

Plate VIII.

Fig. 1. *Anthracoptera quadrata*. Hard Mine, Adderley Green, North Staffs.

2. —— ——, flattened form. Hard Mine, Adderley Green.

3. —— ——. Hard Mine, Adderley Green.

4. —— ——, compressed specimen. 'Stinking coal-shale,' Froghall.

5. *Anthracomya Adamsii*. Little Mine Ironstone, Great Fenton, North Staffordshire.

5 *a*. *Anthracomya Adamsii*, view of hinge and umbones. Little Mine Ironstone, Great Fenton.

6. *Anthracomya Adamsii*, showing straight, edentulous hinge-line. Great Fenton.

7. *Anthracomya Adamsii*, specimen showing colour-bands. Great Fenton.

8. —— ——, more transverse form. Great Fenton.

9, 9 *a*. —— *dolabrata*, approaching *Adamsii*. Little Mine, Great Fenton.

10, 10 *a*. —— ——. The second figure shows the tumidity. Little Mine, Great Fenton.

Plate IX.

Figs. 1, 1 *a*. *Anthracomya dolabrata*. Type-specimen from the cabinet of Prof. Prestwich, F.R.S. See Sowerby's figure in 'Geology of Coalbrookdale.'

2. *Anthracomya Adamsii*, var. *expansa*. Great Fenton, North Staffs.

3. —— ——. Pitts Hill. In the collection of Mr. F. Barke.

4, 5. —— *dolabrata*. Collection of Mr. J. Ward, F.G.S. Longton, North Staffordshire.

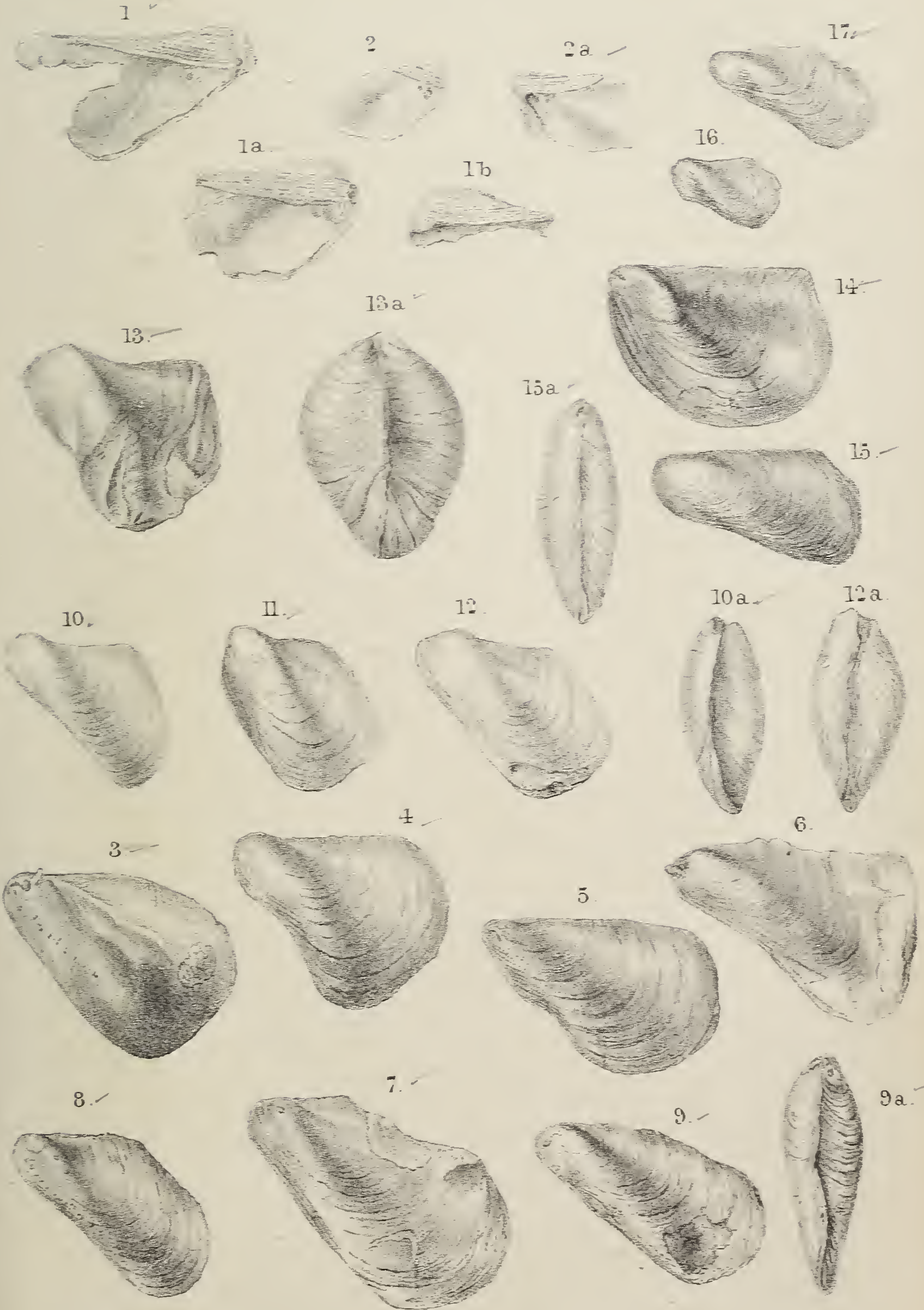
6, 6 *a*. —— *Phillipsii*. Knowles Ironstone, Fenton, North Staffordshire.

7. —— ——, specimen differing slightly in form.

8. —— ——, crushed specimen from the Blackband Ironstone.

9. —— *Wardi*. Mr. J. Ward's specimen.

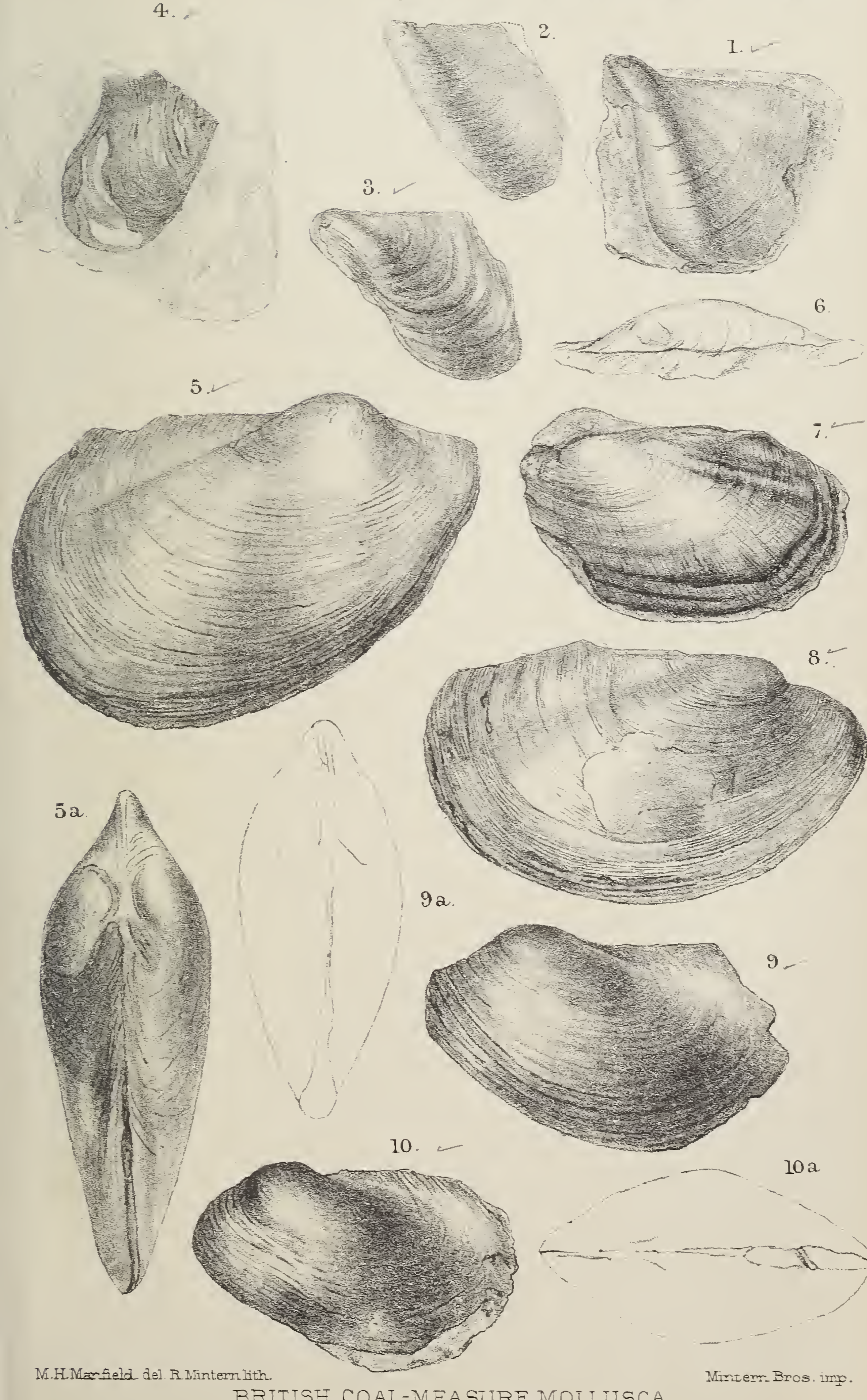
10. —— ——. From the collection of Sir U. K. Shuttleworth, from Burnley.



M. H. Manfield del. R. Mintern lith.

Mintern Bros. imp.

BRITISH COAL-MEASURE MOLLUSCA.



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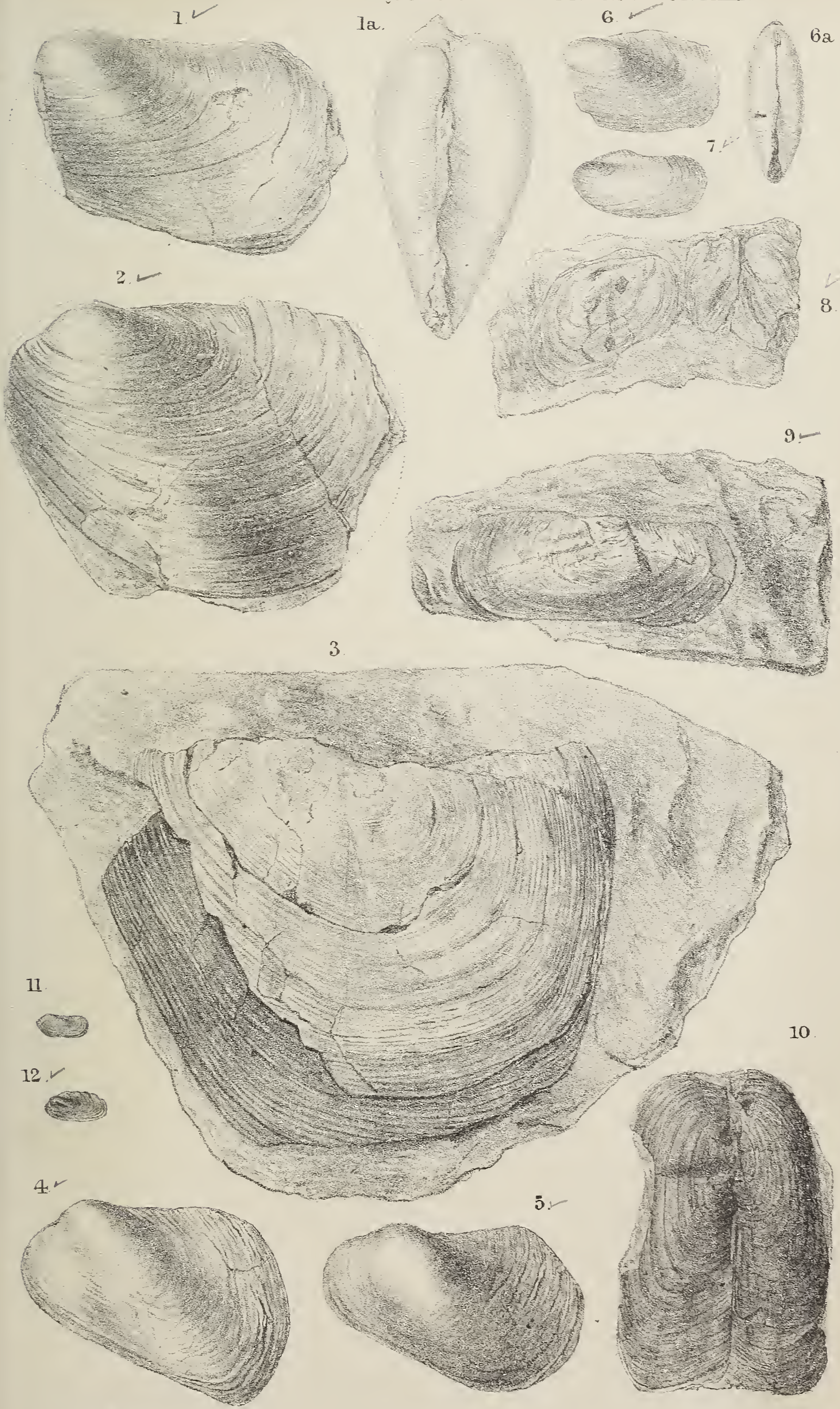

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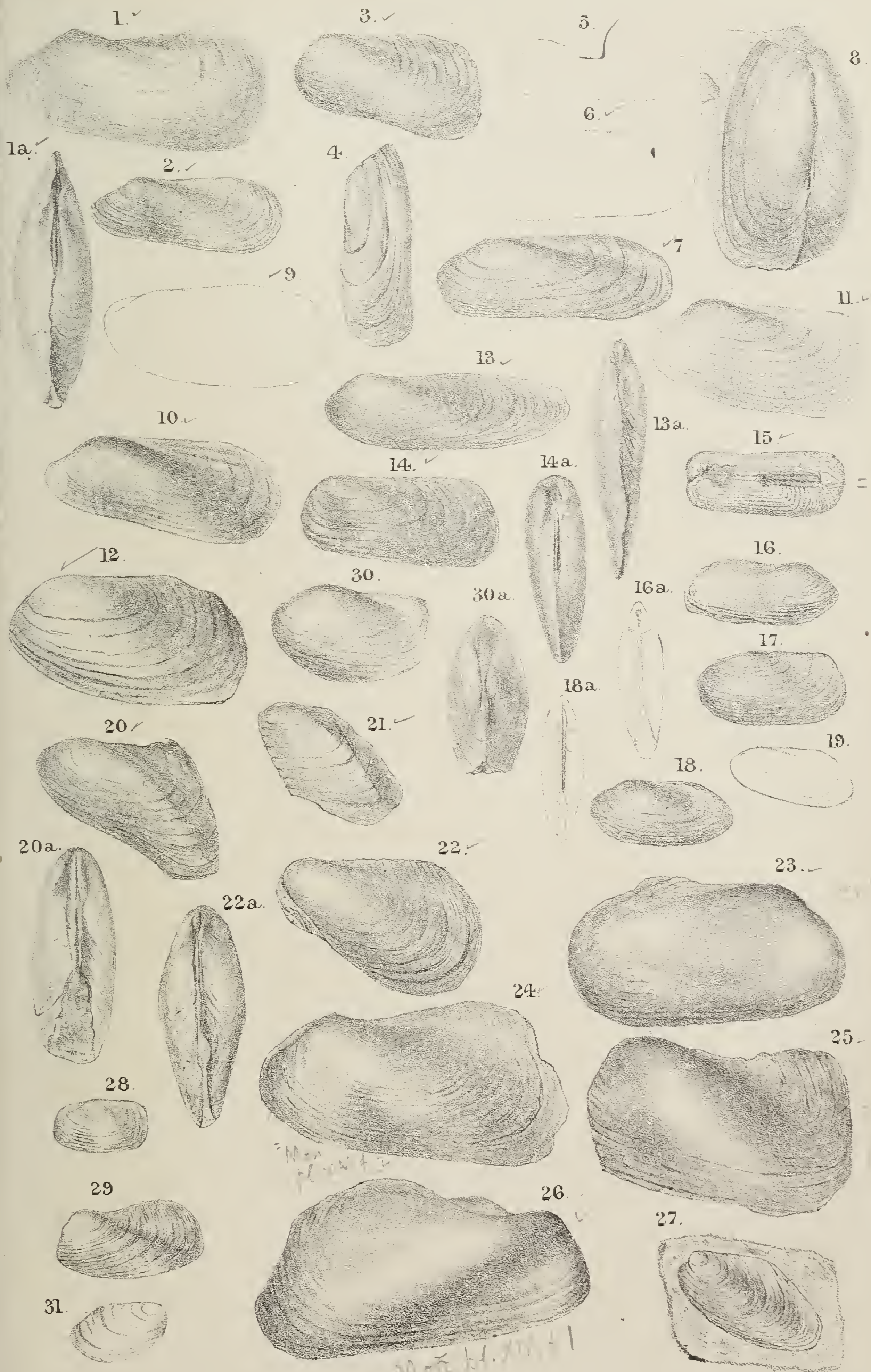

M. H. Manfield del. R. Mintern lith.

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BRITISH COAL-MEASURE MOLLUSCA.

PLATE X.

Fig. 1. *Anthracomya elongata.* Longton, North Staffordshire.
1 *a.* —— ——, profile.
2–5, 9–12. *Anthracomya elongata,* showing variations in form. No. 12 from the collection of Mr. J. Ward, F.G.S.
6. *Anthracomya elongata,* showing muscle-scars.
7, 8. —— ——, testiferous specimens.
13, 13 *a.* *Anthracomya lanceolata.* Fenton, North Staffordshire.
14, 14 *a.* —— *obtusa.* Longton, North Staffordshire.
15. —— *angusta.* Bucknall, North Staffordshire.
16, 16 *a.* —— *carinata,* wrinkled specimen from Merthyr Tydvil. From the Strickland Collection, Woodwardian Museum, Cambridge.
17–19. *Anthracomya pumila* ?, probably young of *A. elongata.*
28, 29. —— ——. Pitts Hill.
20, 20 *a*, 21. *Anthracomya senex.* Longton, North Staffordshire.
22, 22 *a.* *Anthracomya obovata.* Same locality.
23. —— sp. ? *modiolaris.* Durham.
24–26. —— *modiolaris.* Bucknall, North Staffordshire.
27. —— *Phillipsii.* Type-specimen from Owens College, Manchester.
30, 30 *a.* —— *subcentralis.* Specimen at Owens College, Manchester.
31. —— ? *scotica.* Ardwick Limestone.

DISCUSSION.

The PRESIDENT had no doubt that this was a useful piece of palæontological work. The forms of life described by the Author had not received the attention which they deserved. An alternation of salt and freshwater beds in the Coal Measures, as in other formations, was easy to understand. He thought that the Author was probably correct in referring these fossils to the Unionidæ, and spoke of the analogies between *Anthracomya* and *Anodon.*

Mr. B. B. WOODWARD congratulated the Author on the results of his labours in a hitherto much neglected corner of palæontology. He pointed out that Fischer had placed both the genera in question under *Myalina*, but had included that group in the Mytilidæ. The Author's proposal to separate these forms from the Mytilidæ, and to place them nearer to the Unionidæ, would receive support from the fact that *Dreissenia*, which, like *Anthracoptera*, closely resembled the Mytilidæ in external form, had lately been shown by its anatomy to be a near ally of the Unios. He hoped Dr. Wheelton Hind would extend his researches to *Anthracosia* with the view of confirming or correcting Amalizky's recent researches.

Prof. J. F. BLAKE also spoke, and the AUTHOR replied.

21. *On a* Sauropodous Dinosaurian Vertebra *from the* Wealden *of* Hastings. By R. Lydekker, Esq., B.A., F.G.S. (Read December 21st, 1892.)

In an earlier volume of this Journal Mr. Hulke figured and described certain vertebræ of a large Sauropodous Dinosaur from the Wealden of the Isle of Wight, under the name of *Ornithopsis*,[1] that name having been substituted for *Eucamerotus*,[2] which the author had previously intended to use on account of its being the earlier. I have subsequently had reason to indicate that the name *Ornithopsis* itself must, for the same reason, yield to *Hoplosaurus*,[3] which was proposed by Gervais on the evidence of a tooth of the same animal.

In addition to *Hoplosaurus armatus* and the still larger *Pelorosaurus Conybeari*, there is evidence of another large Sauropodous Dinosaur in the Wealden, now known as *Morosaurus brevis* (Owen).[4] Up to the present time it has, however, been impossible to compare adequately *Hoplosaurus armatus* with *Morosaurus brevis*, owing to the circumstance that while the former is known by teeth, cervical and dorsal vertebræ, and the pelvis, the latter is mainly represented by the bones of a forelimb and some caudal vertebræ; an imperfect centrum of a late dorsal vertebra having been also tentatively assigned to it.

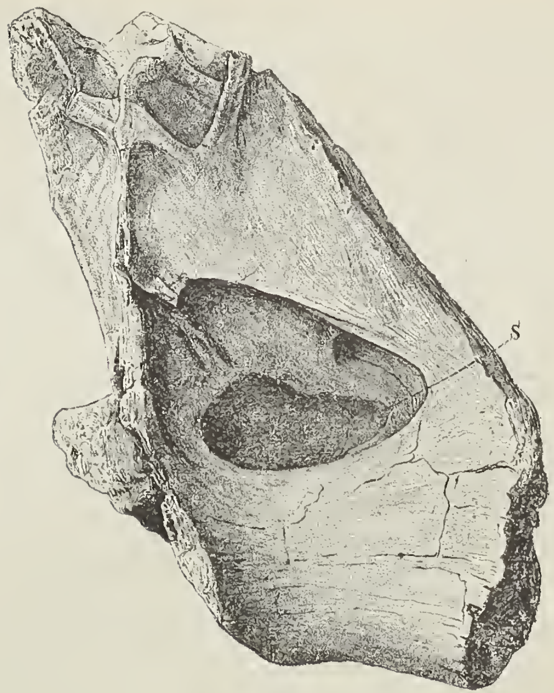
Recently Mr. P. Rufford, of Hastings, has sent to the British Museum (Nat. Hist.) for identification an imperfect dorsal vertebra of a large Sauropodous Dinosaur from the Wealden of Hastings, which has enabled the desired comparison to be made.

I would observe in the first place that the specimens which must be regarded as the types of *Cetiosaurus brevis* are four associated caudal vertebræ from the Wealden of Cuckfield, bearing the numbers 2544–2550 in the British Museum Register.[5] Subsequently Prof. Marsh [6] applied the name *Morosaurus Becklesi* to a Dinosaur represented by the bones of a forelimb formerly in the collection of the late Mr. Beckles, which have now been acquired by the British Museum. Still later I pointed out that there was every probability that these limb-bones belonged to *Cetiosaurus brevis*, for which the name *Morosaurus brevis* was accordingly substituted.[7]

Now, all these bones are characterized by their ochreous colour, and are thereby very different from those of *Hoplosaurus* from the Isle of Wight, which are blackish. Mr. Rufford's specimen is likewise of the same ochreous tint, and comes probably, therefore, from the same bed as the limb-bones obtained by Mr. Beckles. This

[1] Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 31, pls. iii. and iv.
[2] *Ibid.* vol. xxviii. (1872) p. 36.
[3] Cat. Foss. Rept. Brit. Mus. pt. iv. (1890) p. 243.
[4] *Ibid.* p. 237.
[5] *Ibid.* pt. i. (1888) p. 140.
[6] Am. Journ. Sci. ser. 3, vol. xxxvii. (1889) p. 325.
[7] Nicholson & Lydekker, 'Manual of Palæontology,' vol. ii. (1889) p. 1179; and Cat. Foss. Rept. Brit. Mus. pt. iv. (1890) p. 236.

Fig. 1.



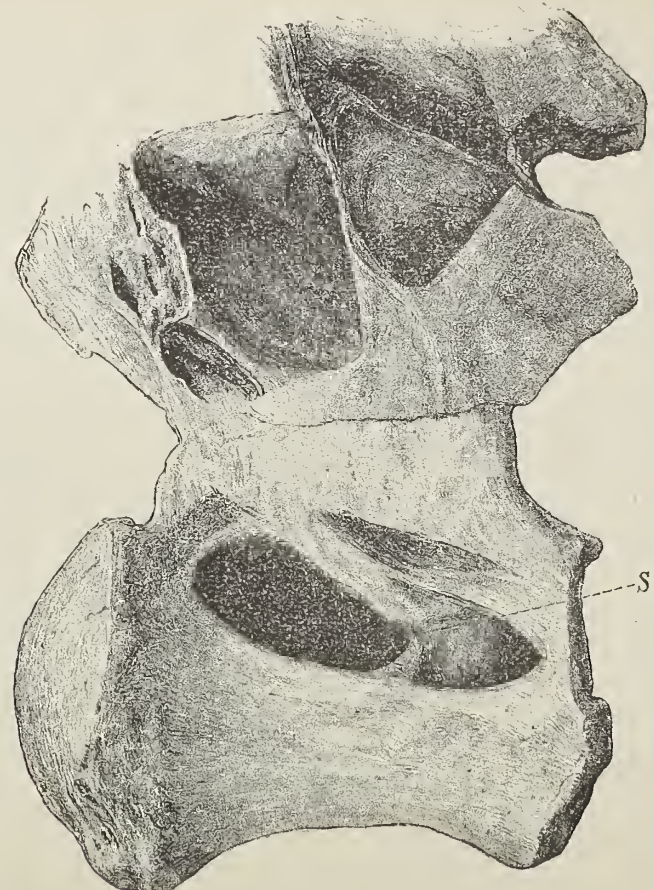


Fig. 2.

Fig. 1. Left lateral view of an imperfect dorsal vertebra of *Morosaurus brevis*, from the Wealden of Hastings.

Fig. 2. The corresponding view of a dorsal vertebra of *Hoplosaurus armatus*, from the Wealden of the Isle of Wight.

s = septum in lateral cavity. Both figures are $\frac{1}{3}$ natural size.

accordingly affords a strong presumption that all the three sets belong to one and the same species, which is conclusively shown by the present specimen to be quite different from *Hoplosaurus armatus*.

The vertebra in question, which probably belongs to the middle portion of the dorsal series, has lost the anterior ball of the centrum, and the upper part of the neural arch, the base of the transverse process being absent. It is figured from the left side in fig. 1 (p. 277), and for comparison I have added a reversed reproduction of a portion of Mr. Hulke's figure of the dorsal vertebræ of *Hoplosaurus armatus*, from pl. iv. vol. xxxvi. of this Journal. So far as I can determine, both vertebræ occupied nearly the same position in the series. There is no very great dissimilarity in the two specimens, but the present vertebra is, on the whole, smaller and apparently relatively shorter than the other, with a stouter centrum. In the present specimen the width of the hinder face of the centrum is about 7 inches, and its height 6 inches; the corresponding dimensions of the other specimen being approximately 7 and $5\frac{1}{2}$ inches.

The most obvious point of distinction between the two vertebræ is to be found in the form and position of the lateral cavity. In the vertebra of *Hoplosaurus* this cavity is of a very elongated egg-shape, tapering to a point posteriorly, and it is divided into two moieties by a vertical partition placed some distance below the general level of the centrum. These two moieties are of nearly equal length, and the hinder opens directly outwards. The total length of the cavity is $5\frac{1}{4}$, and its height $2\frac{1}{4}$ inches; and the lower border of the hinder moiety reaches to within 2 inches of the nearest part of the lower border of the centrum.

On the other hand, in Mr. Rufford's specimen the lateral cavity (of which the innermost recesses are choked up with ironstone) is more ear-shaped, being much shorter and higher than in *Hoplosaurus*. Moreover, the septum between the two moieties is placed close to the posterior end, and is very deeply sunk. In consequence of this the posterior compartment has scarcely any lateral extent, and its aperture looks nearly directly forwards, so that the portion seen from the outside forms a vertical ellipse. Then, again, above the deeper portion of the anterior end of the cavity, there is a shallow depressed area which is totally wanting in the other vertebra; while the cavity is bounded anteriorly by a vertical wall of bone which does not exist in *Hoplosaurus*. The length of the lateral cavity is $4\frac{1}{4}$, and its height about 3 inches; while its lower border does not come within 3 inches of the level of the lower border of the centrum.

Above the lateral cavity is a large, triangular, flat surface bounded by ridges, which is directed more upward and less forward than in *Hoplosaurus*. Moreover, the *V* bounding the first triangular hollow on the side of the arch is placed much more forward than in the latter. There are also differences in the form of the 'fore-and-aft' surfaces of the two bones, into which I need not enter, as the imperfect condition of the present specimen renders them difficult to describe satisfactorily.

It might be urged that the difference in the form and structure of the lateral cavity in the two specimens is due to difference in serial position. I find, however, that all the numerous series of dorsals of *Hoplosaurus* in the British Museum have the same general characters, some of them being identical with the one here figured. In others, however, which occupied a different position in the series, the cavity is shorter and higher, but it still retains the same egg-like shape with the vertical septum near the middle.

It seems, therefore, certain that the present specimen cannot belong to *Hoplosaurus*, and the presumption, accordingly, is that it should be referred to the so-called *Morosaurus Becklesi*, which, as I have said, cannot apparently be separated from *Cetiosaurus brevis*. As I have been unable to compare Mr. Rufford's specimen with the dorsals of the American *Morosaurus*, I have not this aid in coming to a conclusion whether the English Dinosaur is correctly assigned to that genus. If, however, I am right in my conclusions, we are now in a fair way to be able to define tolerably well two species of English Wealden Sauropods.

I may add that the centrum of a vertebra from Cuckfield in the British Museum (No. 2239),[1] figured long ago by Mantell, is probably a late dorsal or lumbar of *Morosaurus*.

Discussion.

The Chairman (Prof. Judd), in opening the discussion, insisted on the importance, where such a course is possible, of getting rid of palæontological names which had been given to different parts of the same organism.

Mr. Hulke endorsed the remarks of the Chairman respecting the great utility of re-assembling under a smaller number of genera and species the many genera, etc., often founded on scattered bones belonging frequently to different skeletal segments; where such reduction of unnecessary genera and species can be done with certainty, the worker is a benefactor to palæontology. Mr. Hulke would not follow the Author through all the details he had placed before the Society, but he would say that vertebræ, of the type of the large specimen exhibited formerly from the Fox Collection, occurred at widely different horizons—and in Isle of Wight horizons so far apart and representing such long periods of Wealden time—that he was prepared to find the family represented by these vertebræ a very large one, comprising several distinct genera and species.

Prof. Seeley said that, without further study of the specimen described than was possible at the table of the Society, he was not prepared to express a final opinion on its interpretation. On the general question of the classification of the genera which had been reviewed, he urged that the first need of science was accuracy in the evidence on which its truths were to be based. He was not aware of any evidence on which it could be predicated that the humerus known as *Pelorosaurus* belonged to an animal which possessed the

[1] Cat. Foss. Rept. Brit. Mus. pt. i. (1888) p. 142.

caudal vertebræ known as those of *Cetiosaurus brevis*. There was no principle of correlation which could infer a generic type of humerus from the tail. In the same way, there is no evidence at present from association of specimens which would justify reference of the tooth named *Hoplosaurus* to any of the other Wealden remains: it is a type of tooth which shows but little modification in allied animals. And therefore it seemed to him safer not to assume knowledge, when the evidence did not prove the nature of the rest of the skeleton. With regard to the vertebræ named *Ornithopsis*, he had long been prepared to find that the Wealden vertebræ, originally described from Tilgate, might belong to a different species from the Isle of Wight type; because he believed that few, if any, of the species of fossil reptiles are common to these two Wealden areas. He had not yet seen evidence of generic difference; and he thought that weight was to be attached to the Author's suggestion that the new vertebra from Tilgate came from a vertebral region not previously known. There was no means of showing that these vertebræ could be associated with the remains referred to the other genera discussed. It therefore seemed to him that the future progress of science required that these genera should be kept separate. Future discoveries may enable some of them to be put together; but if that was to be done hereafter, great caution was required so as not to attempt formulating conclusions beyond the limits of knowledge.

Mr. E. T. Newton acknowledged the desirability of uniting under one name parts of skeletons which had been differently named, when there was reasonable evidence of their belonging to one form; but he pointed out the necessity of caution in this matter, lest the troubles of nomenclature should be increased rather than diminished.

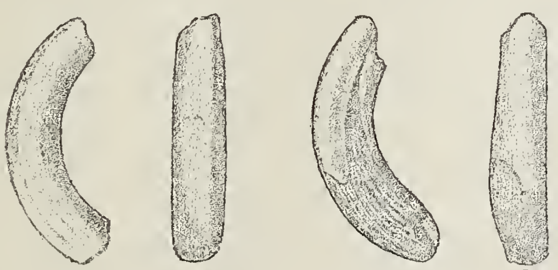
The Author replied, maintaining his conclusions.

22. *On a* Mammalian Incisor *from the* Wealden *of* Hastings. By R. Lydekker, Esq., B.A., F.G.S. (Read March 22nd, 1893.)

Hitherto the only evidence of the existence of mammals in the English Wealden is afforded by a cheek-tooth from the Wadhurst Clay of Hastings, described recently by Mr. A. Smith Woodward,[1] and referred to the Purbeckian genus *Plagiaulax*. I am now, thanks to Sir John Evans, K.C.B., in a position to affirm the presence of a second mammal in the same formation, which likewise seems to be referable to a genus originally described from the Purbeck.

The specimen on which this determination rests is an apparently entire, small incisor tooth embedded in a fragment of Tilgate Grit. Sir John Evans tells me that he found the specimen in a block of stone at Hastings, in or about the year 1854, and that he presented it to Prof. Prestwich, by whose permission it is to be now transferred to the collection at the Natural History Museum, South Kensington. The rock in which the tooth is embedded shows some signs of having formed part of a bone-bed, although there are in it no other distinctly recognizable organic remains.

The tooth, of which figures are given in the accompanying cut (figs. 1, 1 *a*), is so embedded in the matrix as to exhibit only the



1. 1a. 2. 2a.

Figs. 1, 1 *a*. Side and front views of a mammalian incisor from the Tilgate Grit. $\frac{3}{1}$ nat. size.

Figs. 2, 2 *a*. Similar views of an incisor of *Allodon*, from the Jurassic of North America.

front edge and one lateral surface, with part of the opposite side. In size and form it so closely resembles an incisor tooth of a rat, that at first sight it might be taken to indicate the existence of a member of the Rodentia in the Wealden. The tooth has the usual curved form of a Rodent incisor, and exhibits on its anterior face a thick coating of enamel, which stops abruptly at the edge of the exposed lateral surface, and at the free extremity of the specimen is likewise seen to be wanting on the opposite surface. The exposed lateral surface is flattened, while the opposite one is somewhat convex and bevelled away; and it is thus evident that the former is the

[1] Proc. Zool. Soc. 1891, p. 585.

inner aspect of the tooth. The summit of the tooth appears to have the oblique wear characterizing the incisors of Rodents, while the lower and larger extremity seems to have been open. We have here, in fact, an incisor which evidently grew from a persistent pulp, and which can in no way be distinguished from that of a Rodent. That the tooth is mammalian there cannot be the slightest doubt, as no reptile exhibits any approximation to this type of dental structure; and, so far as I can see, there is no possibility of distinguishing it from a Rodent incisor. In this opinion, I am permitted to state, I have the support of my friends, Dr. Forsyth Major and Mr. Oldfield Thomas.

As it would, however, be in the highest degree improbable to meet with Rodents in the Wealden, we naturally turn to the Mesozoic Multituberculata as being the group to which the specimen is most likely to belong, seeing that these mammals were furnished with more or less scalpriform incisors.

Now, in *Plagiaulax* and the allied or identical *Ctenacodon* of North America, the lower incisors (which are the only ones at present known) are quite unlike the specimen under consideration, and it may be inferred that the corresponding upper teeth would likewise have been of a different type. I find, however, that from the Upper Jurassic of North America Prof. Marsh [1] has described and figured a Rodent-like incisor tooth, which he refers with the greatest probability of correctness to the genus *Allodon*,—a genus, by the way, which I fail to distinguish from *Bolodon* of the English Purbeck. In his description of the specimen in question, which is here represented in figs. 2, 2 *a*, p. 281, Prof. Marsh writes that it "is faced with enamel in front, and grew from a persistent pulp, like the incisor of a Rodent. The summit is incomplete, and hence the shape of the worn surface cannot be determined." In the figures of the American tooth the enamel is represented as stopping short of the lower extremity; but this is doubtless due to the imperfection of the particular specimen. Otherwise, the two specimens accord both in form and in size; and there can be no doubt that they belong to closely allied animals. In the upper jaw of the so-called *Allodon* there are three pairs of incisors, of which the middle one is larger than either of the others. It is against this large middle upper incisor that the lower tooth of the type under consideration is presumed to have bitten. As there is no other known genus of mammal to which this type of tooth could have belonged, I am disposed to endorse Prof. Marsh's reference of the American specimen to *Allodon*; and I accordingly assign the English example to *Bolodon*. Unfortunately, we cannot compare the Wealden *Bolodon* with *B. crassidens* of the Purbeck, which is described on the evidence of upper jaws; and it is consequently impossible to say whether the two are specifically different. If, however, this should eventually prove to be the case, I would suggest that the Wealden form should be named after the finder of the present specimen.

[1] Am. Journ. Sci. ser. 3, vol. xxxiii. (1887) p. 331, pl. vii. figs. 14, 15.

Discussion.

The President said that it was natural to expect the occurrence of mammalian remains in the Wealden, seeing that they were known to occur in the underlying Purbeck.

Sir John Evans gave some details as to the discovery of the specimen and its subsequent history. He found it at Hastings, in a block of Tilgate Grit which formed part of a heap by the side of the sea-shore, and almost immediately afterwards gave it to Prof. Prestwich, in whose collection it was mislaid for a period of over thirty years. On again coming across it, Prof. Prestwich placed it at the disposal of the speaker, who now presented it to the National collection. The finder had all along regarded the tooth as an incisor, not improbably of a Rodent, and was glad to find his attribution now confirmed.

Mr. C. Dawson remarked that it was unfortunate that the specimen had been taken from a loose block, because at Hastings stones foreign to the district and miscellaneous drifted stones from the shore were frequently broken up for road-metal. From the limited view permitted him of the specimen that evening he was unable to identify the matrix as from the Hastings district; and he did not recognize the fragmentary specimen before them as portion of a mammalian tooth. Seven years' careful study of the Bone-beds at Hastings had yielded him only one minute mammalian tooth (*Plagiaulax*), and it was fortunate indeed if after forty years a fragment in the possession of Sir John Evans should prove to contain one. The speaker thought that if the Author and those gentlemen who supported his theory were to study the bone-breccias of the Hastings Beds, a long list of mammals might be forthcoming.

Mr. Oldfield Thomas expressed his entire concurrence with the Author's reference of this Wealden tooth to a mammal, and commented on its close resemblance to a Rodent incisor. He considered that, in view of its great antiquity, the Author's reference of it to *Bolodon* was probably the best determination that could be made at present.

Dr. Forsyth Major and Dr. Henry Woodward also spoke, and the Author replied.

23. *On the* Jaw *of a* New Carnivorous Dinosaur *from the* Oxford Clay *of* Peterborough. By R. Lydekker, Esq., B.A., F.G.S. (Read March 22nd, 1893.)

[Plate XI.]

I am indebted to my friend Mr. A. N. Leeds, of Eyebury, near Peterborough, for the opportunity of bringing under the notice of the Society a very interesting, although unfortunately imperfect, Dinosaurian jaw, recently obtained from the brick-pits in the Oxford Clay near the town named.

The specimen comprises the anterior and posterior extremities of the left ramus of the mandible, showing the alveoli of the teeth and the cavity for the articulation of the quadrate. The fractured surfaces are fresh, and it is thus evident that the present imperfect condition of the specimen is due to a blow from the pick of the workman by whom it was disinterred. When entire, its total length was probably about 1 foot. The anterior fragment (Pl. XI. figs. 1, 1 *a*) comprises the greater portion of the dentary bone, with the symphysis entire; while the hinder moiety (*ibid.* figs. 2, 2 *a*) includes the articular, and portions of the angular and surangular elements.

The dentary bone is somewhat roughened and pitted on its external surface, with a broad symphysial channel; while the symphysis itself is oblique, and in life was evidently united by ligament. Superiorly the outer surface is concave from above downwards, while below the concavity it is traversed by a prominent longitudinal ridge, dividing the proper lateral from the inferior aspect. The alveolar margin is characterized by its abrupt deflection near the middle of its length: the deflected portion falling away continuously to the extremity of the shallow symphysis. The whole of the margin in question is penetrated by a series of complete dental alveoli, which extend to the extremity of the symphysis, and thus indicate the absence of any predentary element. The teeth in use at the time of the death of the animal to which the jaw belonged have entirely disappeared from these alveoli, which appear to be 19 in number. Fortunately, however, a replacing tooth is apparent in the first alveolus; while the points of two other replacing teeth may be observed piercing the jaw on the inner side of the alveolar margin of its hinder portion. Indeed, in this part of the jaw a row of small cavities running parallel to the main line of alveoli indicates the presence of a whole series of these replacing teeth. This mode of dental succession—that is to say, the new teeth perforating the jaw internally to those they are to replace, and subsequently breaking into the main alveoli—serves at once to distinguish the specimen from the jaw of a Crocodile, where the replacing teeth come up immediately beneath those in use. The tooth-germ in the first alveolus (Pl. XI. fig. 1 *b*) shows that the crown was laterally compressed, with trenchant, serrated 'fore-and aft' edges, and a sharp point. The whole crown is somewhat recurved, and its outer surface shows a prominent vertical ridge continuing to the summit. The marginal serrations are relatively large, and set obliquely to the long axis of the tooth. From the deflection of the symphysial region it may be inferred that the premaxillary portion of the cranium was likewise bent downwards. The total number of teeth was probably about 22.

The hinder fragment (Pl. XI. figs. 2, 2 *a*) calls for only brief notice. It is of the usual Crocodilian and Dinosaurian type, with the surangular forming only the outer wall of the upper portion; while a short distance in advance of the line of fracture there was doubtless a vacuity. The quadratic cavity is narrower than in existing Crocodiles, while the production of the articular element behind that cavity is also less: both these features being characteristic of the Theropodous Dinosaurs. Moreover, the upper margin of the surangular rises considerably above the plane of the quadratic cavity, which is likewise a feature distinguishing the jaws of the latter group from those of Crocodiles. The outer surface of the angular and surangular elements is pitted in a manner somewhat similar to Crocodilian jaws.

That the specimen is Archosaurian there can be no question; while the features just indicated, together with the declination of the alveolar margin, and the form of the teeth and their mode of succession, serve to differentiate it from the Crocodilians. The absence of a predentary element, together with the form of the teeth, distinguish the specimen from the Ornithopodous Dinosaurs; while the teeth alone are sufficient to distinguish it from the Sauropodous section of the same order. We have, therefore, only the Theropodous group of Dinosaurs to which to refer the specimen; and as its characters are essentially those of that group, the jaw may be regarded as having pertained to an Oxfordian representative of those reptiles.

From the large size of the jaw and its solid structure, we may safely put on one side *Cœlurus*, *Calamosaurus*, and their allies; and its dimensions alone will probably also serve to distinguish the specimen from *Compsognathus*. On the other hand, the jaw under consideration differs from the mandibles of *Megalosaurus* and its allies, not only by its inferior dimensions, but likewise by the greater number of the teeth,[1] as also by the serrations on the latter being set obliquely, instead of at right angles to the long axis of the crown. The latter feature will also serve to distinguish the specimen from *Zanclodon* (*Plateosaurus*) of the Trias and Lias, in which most of the species are also of considerably larger dimensions. Compared, however, with *Thecodontosaurus*, a much closer resemblance will be found to exist. Thus in *Th. antiquus* the number of lower teeth is 21: each of these teeth being characterized by the oblique serrations, and the prominent, vertical, recurving outer ridge, which

[1] Marsh gives 15 lower teeth in *Ceratosaurus*, which is identified by Cope with *Megalosaurus*.

have been already referred to as distinguishing those of the specimen under consideration. It is true that *Th. antiquus* is of much smaller size than the Dinosaur before us; but this difference does not apply to the tooth originally described by Riley and Stutchbury as *Palæosaurus platyodon*, and subsequently referred by Prof. Huxley to *Thecodontosaurus*. I find, however, that in a lower jaw of *Th. antiquus* figured by the last-mentioned writer[1] there is not the deflection of the symphysial extremity which forms so characteristic a feature of the present specimen, and which must assuredly be regarded as of generic value. The same feature is also wanting in the lower jaw of the nearly allied American genus *Anchisaurus*, in which Prof. Marsh[2] gives the number of lower teeth as 18. From the small Indian *Epicampodon*[3] the present specimen is sharply distinguished by the existence of serrations on the front, as well as on the hinder margins of the teeth.

I take it, therefore, that while the Oxfordian Dinosaur cannot be assigned to the Megalosauridæ, it appears to be more nearly allied to the Anchisauridæ, or—as the family ought properly to be called—Thecodontosauridæ. It seems, however, to differ from all described genera of that family by the marked deflection of the mandibular symphysis; and on this ground I propose to refer it to a new genus under the designation of *Sarcolestes*. The species may be appropriately named after the discoverer of its type, *S. Leedsi*.

Postscript.

[During the discussion on the above my attention was called to the maxilla described by Prof. Seeley as *Priodontognathus Phillipsi*,[4] of which the age is not definitely known, although it is probably either Wealden or Jurassic. By the courtesy of Prof. Hughes I have had an opportunity of comparing that specimen with the mandible under consideration, and find that there is a probability of the two belonging to allied forms, although they are certainly specifically distinct. In both, the successional teeth pierce the bone on one side of those in use: the new alveoli in the upper jaw being situated externally to those of the teeth in use, while in the mandible they are internal,—such a reversal being exactly what we might expect in the opposite jaws of one and the same animal. Both have teeth of a very similar general type, but those of *Priodontognathus* (Pl. XI. fig. 3) have larger marginal cusps, and are altogether more Scelidosaurian in appearance. Moreover, there is no decisive evidence that the maxilla of the latter was deflected in a manner to correspond with the lower jaw from Peterborough. Whether, however, the two specimens may not belong to two species of a single genus I am not prepared to say; and therefore the generic name which I have suggested above may, for the present at least, stand. The teeth of *Priodontognathus* are somewhat suggestive

[1] Quart. Journ. Geol. Soc. vol. xxvi. (1870) pl. iii. fig. 1.
[2] Am. Journ. Sci. ser. 3, vol. xliii. (1892) pl. xv. fig. 1.
[3] See Lydekker, Cat. Foss. Rept. Brit. Mus. pt. i. (1888) p. 174.
[4] Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 439.

1b

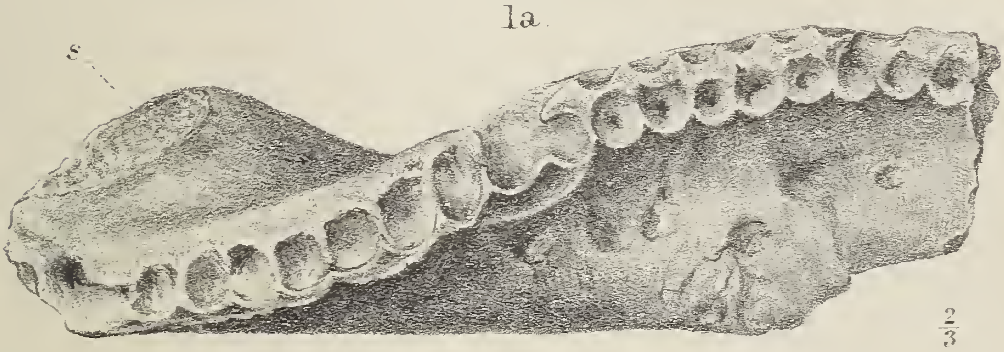
3/1

1.

2/3

1a.

s



2/3

3.

3/1

2a

2/3

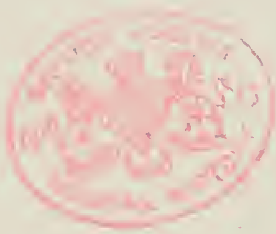
2.

2/3

J. Green del. et lith.

Mintern Bros. imp.

SARCOLESTES LEEDSI.



of Scelidosaurian affinities, but the absence of a premandibular element in the lower jaw forming the subject of this paper differentiates that specimen from all the Iguanodonts, Scelidosaurians, and Stegosaurians in which the complete mandible is known; and, after all, the structure of the teeth is so little removed from the Megalosaurian type as not to forbid the reference of both specimens to the carnivorous group of Dinosaurs.—May 5th, 1893.]

EXPLANATION OF PLATE XI.

Figs. 1, 1 *a*. Outer and oral aspects of the imperfect left dentary bone of *Sarcolestes Leedsi*, from the Oxford Clay of Peterborough. $\frac{2}{3}$ nat. size. *s*=symphysis.

Fig. 1 *b*. A single tooth of the former. $\frac{3}{1}$ nat. size.

Figs. 2, 2 *a*. Outer aspect and quadratic cavity of the hinder region of the same jaw. $\frac{2}{3}$ nat. size.

Fig. 3. A single tooth of *Priodontognathus Phillipsi*, $\frac{3}{1}$ nat. size, shown for purposes of comparison. Specimen in the Woodwardian Museum, Cambridge.

Discussion.

The President was glad to see that the Author had been again able to make use of the Leeds Collection, which was invaluable.

Prof. Seeley said that he had only seen the specimen for a minute or two since entering the room, and was not prepared to express a final opinion upon its relations. The mode of succession of the teeth, and, so far as he had seen, the forms of the teeth, reminded him of *Priodontognathus*, which the Society had figured in 1875. He had founded that genus on a maxillary bone, which therefore could not be closely compared with this mandible. The form of the dentary bone recalled Cretaceous types, and among others a bone from Gosau, which might belong to *Cratæomus*, figured in the Society's Journal for 1881. He did not recognize characters which would approximate it to *Megalosaurus*, *Anchisaurus*, or *Thecodontosaurus*; and he should not expect a Triassic type to occur in the Oxford Clay. The specimen might possibly prove to be a jaw of one of the Oxford Clay saurians already known from near Peterborough; and, rather than place it in a new genus, he would have preferred to group it provisionally with the remains which have been affiliated to *Omosaurus*. Some time ago, Mr. Leeds had submitted to him some long, terminal caudal vertebræ, which might be a part of the same animal as the jaw. It was to be hoped that other remains between these extremities may be found.

The Author briefly replied.

24. *On some* Palæozoic Ostracoda *from* Westmoreland. By Prof. T. Rupert Jones, F.R.S., F.G.S. (Read April 12th, 1893.)

[Plate XII.[1]]

Contents.

§ 1. Introduction.

In 1865 the Author determined for Prof. Harkness some fossil Ostracoda which he had obtained from the Lower-Silurian rocks of S.E. Cumberland and N.E. Westmoreland, and subsequently other specimens mentioned by Harkness and Nicholson in 1872. In 1891 Prof. Nicholson and Mr. Marr submitted a series of similar microzoa from the same district; and the Author now endeavours to determine their specific alliances, and revises the list of those previously collected. He has to notice about eleven forms of *Primitia*, *Beyrichia*, *Ulrichia*, *Æchmina*, and *Cytherella*—several of them being closely allied as varieties, but all worthy of study as biological groups, such as have been illustrated from other regions by writers on the Ostracoda, with a view to the exact determination, if possible, of species and genera, of their local and more distant or regional distribution, and of their range in time.

§ 2. References to Figures and Descriptions of Groups of mutually-related Ostracoda of Palæozoic Age.

1. J. Barrande. Syst. Sil. Bohême, vol. i. Supplem. 1872. Various.
2. Fr. Schmidt. Mém. Acad. Imp. Sc. St.-Pétersbourg, sér. 7, vol. xxi. 1873, *Leperditiæ*; *ibid.* vol. xxxi. 1883, *Leperditiæ.*
3. G. Reuter. Zeitschr. Deutsch. geol. Gesellsch. vol. xxxvii. 1885, pp. 621–679, pls. xxv., xxvi.
4. M. Verworn. *Ibid.* vol. xxxix. 1887, pp. 27–31, pl. iii.
5. J. Kiesow. *Ibid.* vol. xl. 1888, pp. 1–16, pls. i., ii.; Jahrb. Geol. Landesanst. u. Bergakad. Preuss. 1889, pp. 80–103, pls. xxiii., xxiv.

[1] The drawing on stone for this Plate was presented by Messrs. Nicholson and Marr.

6. A. Krause. Zeitschr. Deutsch. geol. Gesellsch. vol. xli. 1889, pp. 1–26, pls. i., ii.; *ibid.* vol. xliii. 1891, pp. 488–521, pls. xxix.–xxxiii.; *ibid.* vol. xliv. 1892, pp. 383–399, pls. xxi., xxii.
7. T. R. Jones. Ann. Mag. Nat. Hist. ser. 6, vol. i. 1888, pp. 395–411, pls. xxi., xxii.; *ibid.* vol. iii. 1889, pp. 373–387, pls. xvi., xvii. Besides other memoirs, several of them written in conjunction with Dr. Holl and Mr. Kirkby, in which numerous Palæozoic Ostracodous forms, more or less closely allied, are figured and described, either as biological or local groups.
8. E. O. Ulrich. Journ. Cincinnati Soc. Nat. Hist. vol. xiii. pt. i. 1890, pp. 104–137, and pt. ii. 1891, pp. 173–211, pls. vii.–xvii.; 'American Geologist,' vol. x. 1892, pp. 263–270, pl. ix.

§ 3. References to former Notes on the Lower-Palæozoic Ostracoda of the Lake District.

1. "On the Lower-Silurian Rocks of the South-east of Cumberland and the North-east of Westmoreland." By Prof. R. Harkness, F.R.S. Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 235 *et seqq.*

At p. 243 the "dark-coloured fossiliferous flaggy rocks" of the Dufton Syke (similar to those of Pusgill) are stated to have yielded *Beyrichia* (now *Primitia*) *strangulata*, Salter, among other fossils. This fossil is also alluded to, in a footnote, as having been found by Dr. Henry Nicholson in the higher part of Pusgill.

The limestone near Keisley is mentioned at the same page as containing "*Cythere phaseolus*," M'Coy (not Hisinger). This was referred to *Primitia Maccoyii* (Salter) in the Ann. Mag. Nat. Hist. July 1868, p. 55, and is now regarded as *Aparchites*.

2. "On the Strata and their Fossil Contents between the Borrowdale Series of the North of England and the Coniston Flags." By Profs. Harkness and Nicholson. Quart. Journ. Geol. Soc. vol. xxxiii. (1877) pp. 461 *et seqq.*

From the "Dufton Shales" are noted, at p. 463:—

"*Beyrichia Wilckensiana*, Jones. Abundant in Pusgill in the *Discina-corona* bed, and also in the ashy beds in Swindale." This is probably one knob or tubercle of *Ulrichia*, or of *Æchmina obtusa*, mistaken for the central lobe of the above-mentioned *Beyrichia* in a partly embedded condition.

"*Primitia semicircularis*, Jones & Holl. In ashy beds, Swindale." Probably either a short form of *Primitia minuta* or of *Aparchites subovatus*.

From the "Coniston Limestone" ("Limestone of Keisley, near Dufton"), p. 468:—

Beyrichia impendens, Jones, and *Primitia protenta*, Jones. Appletreeworth Beck. These specimens have been lost sight of.

From the "Graptolitic Mudstones," p. 473:—

Discinocaris, near *D. Browniana*, H. Woodward. "Not uncommon in the Mudstones at Skelgill and Poolwyke."

3. "*Beyrichia Wilckensiana*" and "*Primitia semicircularis*" are noted by Nicholson and Marr (Quart. Journ. Geol. Soc. vol. xlvii. 1891) in their memoir on the Cross-Fell Inlier, at pp. 505, 510, from the *Corona*-beds; the *Beyrichia* at "Pusgill; Roman Fell"; and the *Primitia* at "Pusgill." See further on for a note on these specimens.

Nicholson and Marr, *op. cit.* p. 507, quote "*Primitia Maccoyii*, Jones," and "*Cytheropsis phaseolus*, His.," from the Keisley Limestone. *P. Maccoyii* (Salter) is now placed with *Aparchites*; and *Cythere phaseolus*, M'Coy (not Hisinger), is a synonym for the same (Ann. Mag. Nat. Hist. July, 1868, p. 56).

4. J. E. Marr. "The Coniston Limestone Series." Geol. Mag. dec. 3, vol. ix. 1892, pp. 97 *et seqq.*

In the Sleddale Group:—

P. 109. *Primitia strangulata*, Salter. Applethwaite; Stile End.
P. 108. *Beyrichia complicata*, Salter. Applethwaite; Coniston.

The specimens labelled "Pusgill" and "Dufton" respectively, and containing the Ostracoda hereinafter described, consist of a dark-grey or nearly black limestone, weathering rusty, and composed of small and fragmentary organisms. Two pieces collected by Prof. H. A. Nicholson in 1877 were from the "Dufton Shales" (=Bala Beds), and three pieces of similar limestone, labelled "Ordovician (*Trematis-corona* Beds), Pusgill, Dufton, Westmoreland," were confided to me by Messrs. Nicholson and Marr in 1892. Although "Pusgill" may more particularly refer to the "*Corona*-beds" and "Dufton" to the "Dufton Shales," yet Pusgill is near Dufton, and, as both of these formations occur in it, there may be some forms from the "Dufton Shale" among those marked "Pusgill."

[§ 4. The appended Table, made from Mr. J. E. Marr's notes, shows the Place and Order of Succession of the Formations referred to in this Paper.

	In the Lake District.	*Equivalent Groups.*
	Coniston Grits	Lower Ludlow.
	Coniston Flags	Lower Ludlow and Wenlock.
	Stockdale Shales	Llandovery.
Coniston Limestone Series.	Ashgill Shales	Upper Bala (*Sedgwick*).
	Staurocephalus-limestone	
	Keisley Limestone	Caradoc (or Middle Bala, *Sedgwick*).
	Dufton Shales	
	Corona-beds	
	Rhyolitic Group	Llandeilo.
	Eycott Group	
	Skiddaw Slates	Arenig.

T. R. J., April 27th, 1893.]

§ 5. Description of the Species and Varieties.

I. Genus Primitia, Jones & Holl, 1865.

1. Primitia centralis, Ulrich. (Pl. XII. figs. 1 *a*, *b*, *c*.)

Size.—Length ·64 millim., height ·36 millim., thickness ·2 millim.

This neat little ovate-oblong *Primitia*, from Pusgill, is gently and evenly convex, with a faint central pit and a punctate surface. It resembles the narrow variety of Ulrich's *P. centralis* (Journ. Cincinn. Soc. Nat. Hist. vol. xiii. pt. i. 1890, p. 130, pl. x. fig. 2) more nearly than any other published form. The American specimens are from the Utica Shales in the Ohio River, near Cincinnati.

Locality.—" Pusgill."

2. Primitia mundula,[1] Jones. (Pl. XII. figs. 2 & 3.)

[See Ann. Mag. Nat. Hist. ser. 6, vol. iii. 1889, pp. 373–383, pl. xvi., for synonyms and varieties.]

Size.—Fig. 2: Length ·72 millim., height ·48 millim.
Fig. 3: Length ·64 millim., height ·52 millim.

These subquadrate casts, one of which (fig. 3) is obliquely distorted, have resemblances to some published forms, especially fig. 5 of pl. xvi. referred to above, but have a rather stronger sulcus. They are proportionally shorter than *Primitia Barrandiana*,[2] Jones, and they have too straight a hinge-line for *P. pusilla*,[3] Jones and Holl. They are somewhat like *P.* (*Halliella*) *seminulum*,[4] Jones, especially in the strong furrow, but they want the ornament and border. The most approximate form is shown by Krause's illustration of *P. mundula*.[5]

This species has a long range in time and a wide distribution.

Localities.—Fig. 2: " Pusgill." Fig. 3: In a greenish-grey schistose mudstone, from the *Staurocephalus*-limestone at Billy Beck.

3. Primitia mundula, Jones, var. longa, nov. (Pl. XII. figs. 4 *a*, *b*.)

Size.—Length 1 millim., height ·52 millim., thickness ·32 millim.

This differs from the foregoing (fig. 3) only by its greater length and sub-oblong outline.

Locality.—" Pusgill."

4. Primitia mundula, Jones, var. producta, nov. (Pl. XII. figs. 5 *a*, *b*, & 6 *a*, *b*.)

Size.—Fig. 5: Length 1·68 millim., height ·64 millim., thickness ·48 millim.
Fig. 6: Length 1·16 millim., height ·52 millim., thickness ·4 millim.

[1] There are some curious imitations of suboval *Primitiæ*, with the dorsal notch varying in size and position, among Barrande's figures of *Discina dubia* in his 'Syst. Silur. Bohême,' vol. v. pl. xcviii. divn. iii. figs. 3, 5, 6.

[2] 'Monogr. Girvan Fossils,' vol. i. 1880, p. 220, pl. xv. figs. 11 *b* & 11 *f*.

[3] Ann. Mag. Nat. Hist. ser. 3, vol. xvi. 1865, p. 424, pl. xiii. fig. 11.

[4] *Ibid.* ser. 2, vol. xvi. 1855, p. 173, pl. vi. fig. 24, *et postea*. Referred provisionally to *Halliella* by Ulrich, 1891.

[5] Zeitschr. Deutsch. geol. Gesellsch. vol. xliii. 1891, p. 495, pl. xxx. fig. 5.

These are much longer and more scaphoid forms than fig. 4, being narrower and produced anteriorly, with a long elliptically-curved antero-ventral border. Fig. 6 shows a faint continuation of the sulcus downwards.

Localities.—Fig. 5: In dark-grey schistose mudstone; from the *Staurocephalus*-limestone Series at Billy Beck. Fig. 6: In a crushed limestone of the *Staurocephalus*-limestone Series from Swindale.

II. Genus Aparchites, Jones, 1889.

1. Aparchites subovatus, sp. nov. et var. (Pl. XII. figs. 7 & 8 *a*, *b*, *c*.)

Size.—Fig. 7: Length 1·4 millim.
Fig. 8: Length ·76 millim., height ·4 millim., thickness ·28 millim.

In form like *Primitia minuta*, treated of in Quart. Journ. Geol. Soc. vol. xlvi. 1890, pp. 7–9, pl. iii. figs. 18, 19, 21–23; but, not showing any signs of a dorsal furrow, nor associated with similar forms having that sulcus, they stand as *Aparchites*.

Specimens of nearly the same outline and features occur in the Lower-Silurian strata of the Girvan district, and are termed *A. subovatus* in the descriptive notes on those Ostracoda, hereafter following (p. 297).

Figs. 7, 8 appear to be varieties of one form; although possibly, if we had better material to study, they might be found to be quite distinct. Fig. 7 (a left-hand valve) is narrowed and subacuminate anteriorly (having approximately the outline of fig. 5 *a*). Fig. 8 (left valve) is much shorter than fig. 7, fuller in the ventral curve of its anterior moiety, and has preserved a punctate surface; the others are more or less decayed on the surface.

Localities.—Fig. 7: In greenish-grey schistose mudstone; from the *Staurocephalus*-limestone Series at Billy Beck. Fig. 8: "Dufton."

2. Aparchites subtruncatus, sp. nov. (Pl. XII. figs. 9 *a*, *b*, *c*.)

Size.—Length 1·04 millim., height ·46 millim., thickness ·28 millim.

Fig. 9 (right valve) is blunter in front than fig. 7, and more evenly curved below than figs. 7 and 8, and it has a postero-dorsal slope.

Locality.—"Pusgill."

3. Aparchites leperditioides, sp. nov. (Pl. XII. figs. 10 *a*, *b*, *c*.)

Size.—Length ·8 millim., height ·44 millim., thickness ·24 millim.

This has a decidedly *Leperditia*-like outline, such as gives cause also to the name *A. leperditioides* among the Girvan specimens (see p. 296). It has here a punctate surface.

Locality.—"Pusgill."

III. Genus Cytherella, Jones & Bosquet, 1848–52.

[For a synopsis of the *Cytherellæ*, see Monogr. Carbonif. Cypridin. Pal. Soc. 1884, pp. 58–69; also Ann. Mag. Nat. Hist. ser. 5, vol. xix. 1887, p. 192, for a Silurian species.]

1. CYTHERELLA SUBPARALLELA, sp. nov. (Pl. XII. figs. 11 *a*, *b*, *c*, 12, 13 *a*, *b*, 14 *a*, *b*.)

Size.—	Length.	Height.	Thickness.
Fig. 11..	·76 millim.	·4 millim.	·24 millim.
Fig. 12..	·76 „	·4 „	
Fig. 13..	·88 „	·44 „	·4 „
Fig. 14..	·76 „	·36 „	·24 „

These have the usual characteristics of *Cytherella*: nearly oblong shape, posterior convexity, valves thick and unequal, the right valve larger than the other, surface sometimes sculptured or pitted.

Cytherellæ are common in the existing seas, and not rare in some Tertiary and Secondary formations. In some of the Carboniferous strata they abound, and one or more Silurian forms have been recorded.

Of all the published figures of *Cytherellæ*, none come so close to these from Dufton and Pusgill as some of the illustrations given of the Cretaceous *Cytherella parallela*[1] (Reuss), with its nearly oblong outline and rounded ends. It is not punctate, however, and its posterior moiety is not relatively so large.

Localities.—Figs. 11 & 12: "Dufton." Figs. 13 & 14: "Pusgill."

IV. Genus ULRICHIA, Jones, 1890.

The chief character of this genus, indicated in Quart. Journ. Geol. Soc. vol. xlvi. 1890, p. 543, was essentially the pair of tubercles supplanting the Primitian sulcus. *Ulrichia Conradi* was there defined, and the following species were referred to it and removed from *Primitia*:—*Ulrichia bicornis*, Jones, *Ul. æqualis*, Jones and Holl, *Ul. diversa*, J. & H., *Ul. cornuta*, J. & H., and *Ul. Morgani*, Jones. Mr. E. O. Ulrich had independently noticed the necessity for such a new genus, and he has recorded *Ul. nodosa*, *Ul. emarginata*, and *Ul.*? *confluens* in the Journ. Cincinn. Soc. Nat. Hist. vol. xiii. p. 203, etc. In his two species, *Ul. nodosa* (Silurian) and *Ul. emarginata* (Carboniferous), there are, besides the two normal tubercles, some others distributed irregularly on the valves. The Carboniferous *Beyrichia tuberculo-spinosa*, J. & H.,[2] may also belong to *Ulrichia* (see Mr. Ulrich's paper, *loc. cit.*). *Primitia perforata*,[3] Barrande, also evidently belongs to *Ulrichia*; and so does *P. bipunctata*,[4] J. & H., from the Llandeilo flagstone near Builth.

A. Krause records "*Beyrichia* (*Ulrichia*?) *bidens*,"[5] with two tubercles *low down* on the valve and a broad radiate margin. In his "*Primitia* (*Ulrichia*?) *umbonata*"[6] there is one nearly central tubercle, and he is inclined either to refer this non-sulcate form to *Ulrichia*, or to regard it as having been subject to some deformity or disease.

[1] Haidinger's 'Abhandlungen,' etc., vol. iv. 1851, p. 47, pl. vi. fig. 1.
[2] Ann. Mag. Nat. Hist. ser. 5, vol. xviii. 1886, p. 258, pl. viii. figs. 7 & 8.
[3] 'Syst. Sil. Bohême,' vol. i. Suppl. 1872, p. 550, pl. xxvii. fig. 12.
[4] Ann. Mag. Nat. Hist. ser. 4, vol. iii. 1869, p. 220, woodcut, fig. 5.
[5] Zeitschr. d. Deutsch. geol. Gesellsch. 1892, p. 396, pl. xxii. fig. 12.
[6] *Ibid.* p. 389, pl. xxi. figs. 10 & 11.

1. Ulrichia Nicholsoni, sp. nov. (Pl. XII. fig. 15.)

Size.—Length ·68 millim., height ·56 millim.

The two knobs on this subquadrate valve seem to be an almost extravagant outcome of the Ulrichian form, the pair of monticules occupying all the dorsal region with their broad, short elevations, divided by a wide triangular opening.

This species is named after Prof. H. A. Nicholson, D.Sc., F.G.S., who has long been one of the most enthusiastic workers in the Lake District.

Locality.—"Pusgill."

2. Ulrichia Marrii, sp. nov. (Pl. XII. fig. 16.)

Size.—Length ·56 millim., height ·44 millim.

The outgrowths on this valve form two oblique, subcylindrical, horn-like processes, rising from the anterior (?) moiety, and, if this be the antero-dorsal region, they point backwards, with a narrow space between them.

Named after Mr. J. E. Marr, F.R.S., Sec.G.S., who has greatly aided in the elucidation of the geology and palæontology of the Lake District.

Locality.—"Dufton."

V. Genus Æchmina, Jones & Holl, 1869.

1. Æchmina obtusa, sp. nov. (Pl. XII. figs. 17 *a*, *b*, *c*, & 18.)

Size.—Fig. 17: Length ·44 millim., height ·36 millim.
Fig. 18: Length ·76 millim., height ·6 millim., thickness ·4 millim.

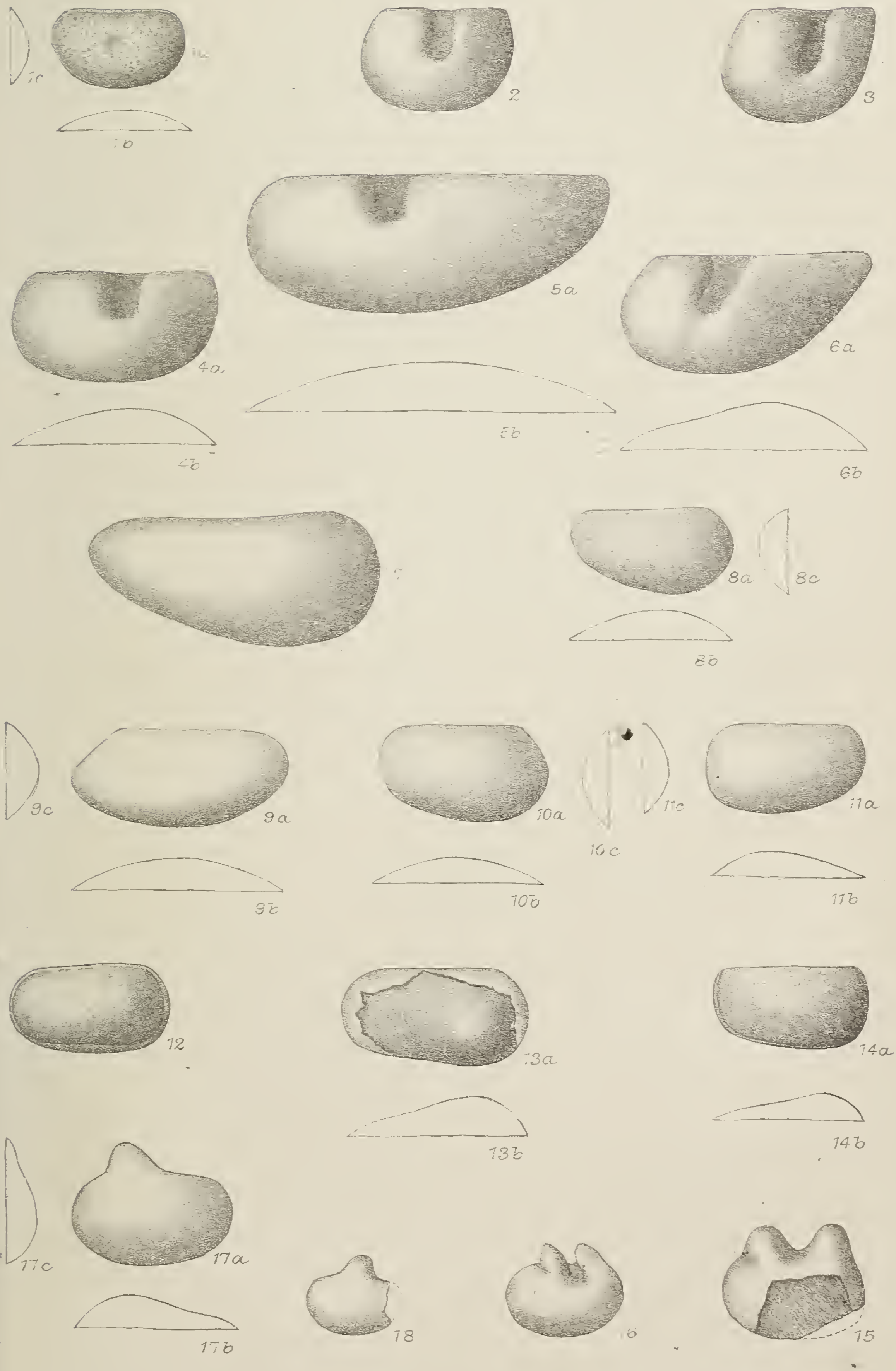
Nearly semicircular on its ventral border; the valves protrude dorsally in a thick, blunt process, which probably bears a close relationship to the neat, short, triangular, horn-like process in *Æchmina brevicornis*,[1] Jones, but the dorsal projection differs from the former in its lumpy, almost inelegant shape, in involving so much more of the hinge-line, and in giving a subtriangular outline to the valve.

In the habit and make of the valves there is some likeness in figs. 15–18; but how far they indicate an alliance between *Ulrichia* and *Æchmina* is not at all clear.

That *Ulrichia*-like forms may vary in the number of their tubercles is possible. *Primitia timida*,[2] Barrande, looks like a one-tubercled *Ulrichia* (if such might be), and is associated with *Ulrichia perforata* (Barrande), mentioned above, in the black shales of the Band *d* 3, near Trubin.

Locality.—"Pusgill."

[1] Ann. Mag. Nat. Hist. ser. 5, vol. xix. 1887, p. 413, pl. xiii. fig. 8.
[2] 'Syst. Sil. Bohême,' vol. i. Suppl. 1872, p. 553, pl. xxvii. fig. 11.



E. C. Knight del. et lith.

West, Newman imp.

OSTRACODA FROM WESTMORELAND.

§ 6. List of Species of Lower-Palæozoic Ostracoda from the Lake District.

Including the forms mentioned in the preceding pages, the following Lower-Palæozoic Ostracoda have been described and figured as having occurred in North-eastern Westmoreland :—

1. *Aparchites Maccoyii* (Salter). Keisley Limestone.
2. —— *subovatus*, sp. nov. et var. Dufton and *Staurocephalus*-limestone, Billy Beck.
3. —— *subtruncatus*, sp. nov. Pusgill.
4. —— *leperditioides*, sp. nov. Pusgill.
5. *Primitia strangulata* (Salter). Dufton Syke; Applethwaite; Stile End.
6. —— *protenta* (?), Jones. Appletreeworth Beck (Sleddale Group).
7. —— *centralis*, Ulrich. Pusgill.
8. —— *mundula*, Jones. Pusgill; *Staurocephalus*-limestone, Billy Beck.
9. —— ——, Jones, var. *longa*, nov. Pusgill.
10. —— ——, Jones, var. *producta*, nov. *Staurocephalus*-limestone, Billy Beck and Swindale.
11. *Beyrichia complicata*, Salter. Applethwaite; Coniston.
12. —— *impendens* (?), Jones. Appletreeworth Beck (Sleddale Group).
13. *Ulrichia Nicholsoni*, sp. nov. Pusgill.
14. —— *Marrii*, sp. nov. Dufton.
15. *Æchmina obtusa*, sp. nov. Pusgill; Dufton Shales (?).

EXPLANATION OF PLATE XII.

[All the figures are magnified 25 diameters.]

Fig. 1. *Primitia centralis*, Ulrich. *a*, left valve; *b*, edge view; *c*, end view.
Figs. 2 & 3. *Primitia mundula*, Jones. Right valves; 3 distorted.
Fig. 4. *Primitia mundula*, Jones, var. *longa*, nov. *a*, right valve; *b*, edge view.
Figs. 5 & 6. *Primitia mundula*, Jones, var. *producta*, nov. *aa*, right valve; *bb*, edge view.
Fig. 7. *Aparchites subovatus*, sp. nov. Left valve.
Fig. 8. *Aparchites subovatus*, sp. nov., var. *a*, left valve; *b*, edge view; *c*, end view.
Fig. 9. *Aparchites subtruncatus*, sp. nov. *a*, right valve; *b*, edge view; *c*, end view.
Fig. 10. *Aparchites leperditioides*, sp. nov. *a*, left valve; *b*, edge view; *c*, end view.
Figs. 11–14. *Cytherella subparallela*, sp. nov. 11. *a*, right valve; *b*, edge view; *c*, end view. 12. Carapace, showing the left valve. 13. *a*, left valve; *b*, edge view. 14. *a*, carapace, showing the left valve; *b*, edge view.
Fig. 15. *Ulrichia Nicholsoni*, sp. nov. Right valve.
Fig. 16. *Ulrichia Marrii*, sp. nov. Right valve.
Figs. 17 & 18. *Æchmina obtusa*, sp. nov. 17. *a*, right valve; *b*, edge view; *c*, end view. 18. Left valve.

25. *On some* Palæozoic Ostracoda *from the* District *of* Girvan, Ayrshire. By Prof. T. Rupert Jones, F.R.S., F.G.S. (Read April 12th, 1893.)

[Plates XIII. & XIV.]

Contents.

§ 1. Introduction.

This paper aims at the completion of the palæontological account of the Girvan district, so far as the Ostracoda are concerned; and follows up the researches indicated in the 'Monograph of the Silurian Fossils of the Girvan District in Ayrshire,' by Nicholson and Etheridge, Jun., vol. i. 1880.

In about a dozen pieces of the fossiliferous shales, submitted for examination some few years ago, the writer finds nearly thirty specimens (chiefly casts) of *Primitia*, *Beyrichia*, *Ulrichia*, *Sulcuna*, and *Cypridina*, which show interesting gradations of form, not always easy to be defined as specific or even varietal, but valuable as illustrating modifications during the life-history of individuals, thus often leading to permanent characteristics of species and genera. Like those formerly described in Nicholson and Etheridge's 'Monograph,' the specimens have all been collected by Mrs. Elizabeth Gray of Edinburgh.

Excepting a small cast of a *Beyrichia Klœdeni*, M'Coy, *B. Klœdeni*, var. *scotica*, Jones & Holl, and *Ulrichia Grayæ*, Jones, which are of Llandovery age, from the Burn leading to Bargany Pond, all the specimens here described are from the dark-grey Lower-Silurian (Middle-Bala) shales of Whitehouse Bay. See Dr. C. Lapworth's Memoir on 'The Girvan Succession,' Quart. Journ. Geol. Soc. vol. xxxviii. 1882, pl. xxv. fig. 3 (map); fig. 16 at p. 595; and pp. 597, 603, 606, 612, 621, and 661.

The numbers attached to Mrs. Gray's little hand-specimens are here inserted, together with the character of the shale in which the Ostracoda occur, for each species.

§ 2. Description of the Species and Varieties.

I. Genus Aparchites,[1] Jones.

1. Aparchites leperditioides, Jones. See the preceding paper, p. 292, Pl. xii. fig. 10. (Pl. XIII. figs. 1, 2, & 3.)

[1] Ann. Mag. Nat. Hist. ser. 6, vol. iii. 1889, p. 384.

Size.—Fig. 1: Length ·56, height ·44 millim.
Fig. 2: Length ·76, height ·48 millim.
Fig. 3: Length 1·16, height ·76 millim.

These small Ostracods, having the outline of a *Leperditia* without any of its other features, come within the group of *Aparchites.*

A. Maccoyii (Salter),[1] from the Lower-Silurian limestone of the Chair of Kildare, Ireland, and known also from Aldens, on the Stinchar River, in Ayrshire,[2] approximates to fig. 1 in shape, but is much larger and more oval.

The smaller *Aparchites mutus*,[3] J. & H., with rounded and nearly equal ends, from the Upper Silurian of Beechey Island, is also a close ally. Two little '*Primitiæ*' from the *Olenus*-shales of Shineton[4] are also *Aparchites*, nearly allied to fig. 1; but one of them is too attenuate, and the other too oblong.

Our Girvan specimen, fig. 1, is more ovate than *A. matutinus*, Jones & Holl,[5] from the Bala-Caradoc formation at the River Onny, near Cheney-Longville, Shropshire; and more oblong than *A. semicircularis*, J. & H.,[6] from the Scandinavian limestone of the North-German Drift.

Fig. 2 is larger and more oblong than fig. 1, having its antero-ventral region developed with a bolder curve; thus almost, but not quite, identifying itself with *A. matutinus*, J. & H.

Fig. 3 is almost oblong, except that its ventral region is curved and not straight. Its extremities are nearly equally rounded; and its long, straight, dorsal edge ends with pronounced angles.

These three specimens are evidently gradations of one form, and the other figures above mentioned supply some intermediate shapes.

In a grey shale,[7] nos. 116 (fig. 1), 123 (fig. 2), 115 (fig. 3).

2. Aparchites subovatus, Jones. See the preceding paper, p. 292, Pl. xii. figs. 7–9. (Pl. XIII. figs. 4 & 5.)

Size.—Fig. 4: Length 1·0, height ·52 millim.
Fig. 5: Length 1·48, height ·68, thickness ·4 millim.

In the Quart. Journ. Geol. Soc. vol. xlvi. 1890, pp. 7–9, pl. iii. figs. 18, 19, 21–23, some long-ovate, variable forms, having Primitian features to some extent, but in many instances destitute of the characteristic sulcus, were described and figured, and some synonyms were mentioned and discussed. *Primitia concinna*, Jones, with its prior name *P. minuta* (Eichwald), was accepted, because

[1] Ann. Mag. Nat. Hist. ser. 4, vol. ii. 1868, p. 55, pl. vii. figs. 1–3 (*Primitia*).
[2] *Ibid.* p. 56. It also occurs in the Lower-Silurian Beyrichien-Kalk of the North-German Drift. Krause, Zeitschr. Deutsch. geol. Gesellsch. vol. xliii. 1891, p. 494, pl. xxx. fig. 3.
[3] Ann. Mag. Nat. Hist. ser. 3, vol. i. 1858, p. 254, pl. ix. fig. 3 *a* (× 4), 3 *b* (× 24), then termed '*Cytheropsis concinna*?;' and *ibid.* ser. 3, vol. xvi. 1865, p. 425 (*Primitia muta*).
[4] *Ibid.* ser. 4, vol. iii. 1869, p. 221, (woodcuts) figs. 6 and 7.
[5] *Ibid.* ser. 3, vol. xvi. 1865, p. 418, pl. xiii. fig. 7, then regarded as a *Primitia.*
[6] *Ibid.* p. 424, pl. xiii. fig. 10 (*Primitia*).
[7] This dark-grey shale from Whitehouse Bay is very full of Ostracodous valves and other small fossils.

occasionally among local groups individuals bore evidence of the sulcus or of a slight dorsal depression.

Among the Girvan collection similar, but quite non-sulcate, forms exist, and there appears to be no valid reason for placing them with *Primitia*; they should therefore be systematically grouped under *Aparchites*, together with figs. 1, 2, & 3. Fig. 4, indeed, may be said to be an elongated modification of fig. 1, so far as the outline is concerned; and fig. 5 is a larger and more symmetrical subovate form, like some examples of *Primitia minuta* abovementioned. Neither here nor in the Westmoreland district, where similar specimens are found (see above, p. 292), are there evidences of the Primitian sulcus or pit, which is required for the division of that genus from *Aparchites*.

Fig. 4 in no. 115, grey shale; fig. 5 in no. 117, hard greenish shale. Thin films of decayed shell remain.

II. Genus Primitia, Jones & Holl, 1865.

1. Primitia elongata, Krause, var. nuda, nov. (Pl. XIII. fig. 6.) Zeitschr. Deutsch. geol. Gesellsch. 1891, p. 494, pl. xxx. fig. 4.

Size.—Length ·88, height ·4 millim.

Except in having a smaller sulcus and no punctation, fig. 6 agrees with Dr. Krause's *P. elongata* referred to above, from the Lower-Silurian Beyrichien-Kalk of Scandinavia. Its outline has just the same elongate dorsal, and very slightly curved, parallel ventral border, and nearly equal truncate ends, curved below, but meeting the dorsal edge with strong angles. At most the difference in sulcus and pitting can make it a variety, *nuda*.

This neat sub-oblong form of *Primitia* is not common; but it has allies among the varieties of *P. valida*, J. & H., and of *P. humilis*, J. & H.

In no. 116, grey shale.

2. Primitia Krausei, sp. nov. (Pl. XIV. fig. 7.)

Size.—Length ·52, height ·36 millim.

Sub-oblong, elongate, compressed anteriorly. Front end subtruncate; posterior elliptically rounded. Sulcus short, but distinct. Surface punctate (?). Differs from fig. 10, Pl. XIII., in its narrower and more oblong form, and in its compressed anterior moiety. A thin film of shell shows faint pitting.

This new species, *P. Krausei*, is named after Aurel Krause, of Berlin, an enthusiastic worker among the Scandinavian Ostracoda found in the Drift of North Germany.

Is in no. 116, grey shale.

3. Primitia girvanensis, sp. nov. (Pl. XIII. figs. 7, 8, & 9.)

Size.—Fig. 7: Length ·84, height ·6 millim.
Fig. 8: Length ·96, height ·68 millim.
Fig. 9: Length 1·16, height ·76 millim.

The dorsal edge is straight, the ventral elliptical; the hinder end is more fully curved than the other (fig. 9). The free margin has a flattened rim. The sulcus is wide at the top, and bordered anteriorly by an incipient lobe. The surface is punctate. Fig. 9 retains some shell.

Primitia bursa, Krause (Zeitschr. Deutsch. geol. Gesellsch. 1889, p. 9, pl. i. figs. 7–10), is a simple form with a thickening of the edge of the sulcus, especially in front, and is a near relative to the above. In the Girvan form here noticed there is the difference of a flattening along the border, a wider sulcus, and the rounded thickening at its front edge. The imperfect lobe and its sulci are not so far advanced as, although evidently prototypical of, *Beyrichia arcuata*[1] (Bean).

Not knowing, we may regard it as a new species, *girvanensis*.

Figs. 7 & 8 in no. 114, and fig. 9 in 115, both grey shale.

4. Primitia Grayæ, sp. nov. (Pl. XIII. fig. 10.)

Size.—Length ·6, height ·4 millim.

This small semi-oval or bean-shaped *Primitia*, with the front margin of its sulcus much thickened, and the surface pitted, appears to be different from any at present published; and it may well be distinguished by naming it in honour of Mrs. Gray, the discoverer of this and many other fossils in the Girvan district, to which she has devoted careful attention for several years.

With a film of shell. In no. 120, grey shale.

5. Primitia mundula, Jones, var. fimbriata, nov. (Pl. XIII. fig. 11.)

Size.—Length (without the border) 1·52, height 1·0 millim.

Among the series of Lower-Devonian varieties of *P. mundula* described and figured in the Ann. Mag. Nat. Hist. ser. 6, vol. iii. 1889, pp. 375–377, pl. xvi., there are two in particular (figs. 6 & 9), which approximate closely to our fig. 11 in the form and sulcus, and would probably have quite the same shape, but the latter is slightly imperfect at the antero-dorsal border. There is, however, a distinctive feature in the broad border and prickly posterior margin of fig. 11; but these need not separate it specifically, and we may regard it as var. *fimbriata*.

P. mundula has a long and wide range as a species with many variations. Dr. Krause figures and describes some good Upper-Silurian forms in the Zeitschr. Deutsch. geol. Gesellsch. vol. xliii. 1891, p. 495, pl. xxx. figs. 5–7.

In no. 118, grey shale.

6. Primitia mundula, Jones, var. Klœdeniana, nov. (Pl. XIII. figs. 12, 13, 14, & 15.)

Size.—Fig. 12: Length 1·0 , height ·48 millim.
Fig. 13: Length 1·04, height ·48 millim.
Fig. 14: Length 1·04, height ·52 millim.
Fig. 15: Length 1·2 , height ·56 millim.

[1] Ann. Mag. Nat. Hist. ser. 6, vol. iii. 1889, p. 381, pl. xvii. fig. 7.

These may be said to be varieties of an elongate *P. mundula*, with a thickened lip of the sulcus being developed into a lobe, as (among others) in *P. bursa*,[1] Krause, and *P. Schmidtii*,[2] K., *P. cincinnatiensis*[3] (S. A. Miller), and others.

We see this feature in varying conditions among specimens of *P. mundula*[4] passing into some forms of *Beyrichia Klœdeni*.[5] A similar observation has been made by Mr. E. O. Ulrich, *op. cit.* p. 136, and particularly at p. 132, where he describes an adult specimen of *Primitia cincinnatiensis* (pl. x. fig. 5), as having acquired, by a modification of the anterior edge of the sulcus, a nearly isolated median lobe, like that of *Klœdenia* and *Beyrichia*; while in the more common and average forms of the species (fig. 6) the two sides of the sulcus are merely thickened to an equal or nearly equal extent, as in Ulrich's *Primitia parallela*,[6] *P. lativia*,[7] and *P. impressa*,[8] Barrande's *Primitia prunella*,[9] and others.

In Pl. XIII. figs. 12, 13, 14 (left-hand valves), and 15 (a right-hand valve) the thickening of the front edge of the sulcus becomes gradually almost circumscribed by a sloping furrow, first curving under, and then round in front of the lobule; so that, except in size and proportional length, these specimens very nearly approach figs. 4 and 8 of pl. xvii. (1889) referred to above (*Beyrichia Klœdeni*, var. *acadica*); but they do not entirely put on the features of *Beyrichia* with its definite median lobe. They may be looked upon as *Primitia mundula*, var. *Klœdeniana*, narrow sub-oblong, with the ends almost equally rounded, though often modified by pressure. Fig. 14 is much like Ulrich's fig. 5 of *P. cincinnatiensis* (adult); but the lobe is not sufficiently pronounced, and the valve is proportionally long and narrow.

The specimen referred to *Beyrichia impendens*, Jones, Monogr. Girvan Foss. 1880, p. 219, pl. xv. fig. 10 *c*, is evidently to be associated with the figs. 12–15 of Pl. XIII.; figs. 10 *a* and *b* are distinct.

Fig. 12 is in no. 117, hard greenish-grey shale; fig. 13 in no. 122; fig. 14 in no. 120; and fig. 15 in no. 116, all three being grey shale.

7. Primitia Ulrichiana, sp. nov. (Pl. XIV. fig. 1.)

Size.—Length ·84, height ·64 millim.

This extreme form of *Primitia* has a wide and deep sulcus curving obliquely, from the middle third of the dorsal region, downward and

[1] Zeitschr. Deutsch. geol. Gesellsch. vol. xli. 1889, p. 9, pl. i. figs. 7–10.
[2] *Ibid.* p. 10, pl. i. figs. 14, 15.
[3] As given by E. O. Ulrich, Journ. Cincinn. Soc. Nat. Hist. vol. xiii. pt. i. 1890, p. 132, pl. x. figs. 5, 6.
[4] Ann. Mag. Nat. Hist. ser. 6, vol. iii. 1889, p. 375, etc., pl. xvi.
[5] *Ibid.* pl. xvii.
[6] Geol. Surv. Canada, 'Contributions etc.,' part ii. 1889, p. 51, pl. ix. fig. 7 (referred with doubt to *Primitia* or *Beyrichia*).
[7] *Ibid.* p. 50, pl. ix. fig. 8 (differing from *P. parallela* in its proportions).
[8] Journ. Cincinn. Soc. Nat. Hist. vol. xiii. pt. i. 1890, p. 131, pl. x. figs. 3 & 4.
[9] 'Syst. Sil. Bohême,' vol. i. suppl. 1872, p. 550, pl. xxvi. fig. 6.

forward, beneath an antero-dorsal swelling or pseudo-lobe, which dies away anteriorly, leaving a narrow, triangular, flattened area at the front angle. The valve is straight above, boldly curved below, and nearly semicircular, with a full postero-ventral curvature and general ventral convexity.

Mr. E. O. Ulrich has a somewhat allied form (*P. rudis*),[1] from the Lower-Silurian (Cincinnati) group in Kentucky; but its nearly oblong shape, parallel-sided sulcus, and minute anterior tubercle separate it from our fig. 1. Another close ally is *P. mundula*, var. *incisa*, Jones,[2] from the Trenton Limestone.

The boldly curved and expanded sulcus of fig. 1 particularly distinguishes it; and I propose to name it *Ulrichiana* after Mr. E. O. Ulrich, one of our colleagues in the study of Palæozoic Ostracoda.

In no. 116, grey shale.

Beyrichia comma, Jones, Monogr. Girvan Foss. 1880, p. 219, pl. xv. fig. 9, may have been a *Primitia* with a strong curved sulcus (and in so far agreeing with fig. 1), but with the convexity of the valve represented by a narrow, comma-shaped swelling bordering the under side of the sulcus.

III. Genus Beyrichia, M'Coy, 1846.

1. Beyrichia Klœdeni, M'Coy, Monogr. Girvan Foss. Nicholson & Etheridge, Jun. vol. i. 1880, p. 218, pl. xv. figs. 8 *a*, 8 *b*.

Casts of smooth individuals from Thrave Glen (Mrs. Gray's collection), and from Hillside, near Blair Farm, and Knockgardner (Coll. Geol. Survey Scotland), are here referred to. A cast of *B. Klœdeni*, very similar to that from Thrave Glen, but with evidence of a *tuberculate* valve, is among the fossils from Whitehouse Bay.

In no. 116, grey shale.

2. Beyrichia Klœdeni, M'Coy, var. infecta, nov. (Pl. XIV. fig. 2.)

Size.—Length 1·24, height ·68 millim.

Pl. XIV. fig. 2 is removed from Pl. XIII. fig. 13, the lobe being made more distinct by the development of its front curve, emphasized by an anterior notch, which indicates a real Beyrichian character. These features are seen in a sharper and stricter form in *B. arcuata*, fig. 7 *a*, pl. xvii. 1889, Ann. Mag. Nat. Hist., and a much weaker stage in *Primitia girvanensis*, *supra*, p. 298.

Fig 2 is sufficiently distinguishable, with its high-placed forward lobe and scaphoid outline, to be regarded as a noticeable variety, *infecta*,[3] of *B. Klœdeni*.

There are close links between *Primitiæ* with thickened sulcus-walls and those that, having one of those edges swollen into a distinct tubercle, pass into a weak form of *Beyrichia*. This is traceable

[1] Journ. Cincinn. Soc. Nat. Hist. vol. xiii. pt. i. 1890, p. 136, pl. x. fig. 8.

[2] Geol. Surv. Canada, 'Contributions, etc.,' pt. iii. 1891, p. 64, pl. x. fig. 9.

[3] 'Unfinished': in allusion to this form being an imperfect evolution of the genus.

when a series of individuals show more or less clearly both conditions, as, for instance, among these Girvan specimens, and in *Primitia granimarginata*,[1] Ulrich (Carboniferous), and in the *P. cincinnatiensis*, above mentioned. For convenience, however, if not on biological grounds, the generic division may be made at the limit of the isolation of the tubercle by the side of the sulcus; and, indeed, we know not the possible physiological value of the change of structure in the soft parts of the animal, thus indicated by modifications of the outside.

In no. 116, grey shale.

Beyrichia parasitica, Hall (Quart. Journ. Geol. Soc. vol. xlvi. 1890, p. 17, fig. 1), presents an advanced stage in Beyrichian outcome beyond *B. Klœdeni-infecta*; and, were the two furrows more equal and symmetrical, it would be near to *Klœdenia*.

3. Beyrichia Klœdeni, M'Coy, var. scotica, Jones & Holl, Ann. Mag. Nat. Hist. ser. 5, vol. xvii. 1886, p. 356, pl. xii. fig. 10.

Size.—Length ·8, height ·6 millim.

"This is relatively shorter than *B. Klœdeni*, subvar. *clausa*, J. & H., being more nearly semicircular; the middle lobe is rather more definitely egg-shaped, and there is a thick, raised, marginal rim in all. A smooth sub-variety was described and figured as *B. Klœdeni* by one of us in the 'Monograph of the Silurian Fossils of the Girvan District,' by Nicholson and Etheridge Jun., 1880, p. 218, pl. xv. figs. 8–8 *b*; and of the present strongly granulate form (fig. 10) we have seen four imperfect specimens (in Mrs. Gray's collection) from Bargany-Pond Burn. Of these, one small hollow cast, preserving the best proportion of characters, is here figured; but the mid-lobe is higher up than in older individuals. Excepting this lobe, the surface bears large scattered granules, sometimes concentrically arranged, and the raised margin has a distinct row of them also. The specimens occur in a hard limestone, and have not been got out free of matrix." The rock is of Llandovery age.

4. Beyrichia Klœdeni, M'Coy. Other varieties. (Pl. XIV. figs. 3, 4.)

Size.—Fig. 3: Length ·68, height ·44 millim.
Fig. 4: Length 1·04, height ·68 millim.

In Pl. XIV. fig. 3 we see definite indications of the three lobes of *B. Klœdeni* in their normal relation to each other, except that the anterior (smallest) looks as if it were modified in its growth; or it may have been affected by accident of fossilization.

Fig. 4 may be a wide-margined symmetrical variety of *B. Klœdeni*, with indications of three unequal and not clearly defined lobes.

When the margin is present in *Beyrichia* it is usually ornamented, and rarely so broad as in fig. 4. *B. Klœdeni*, however, figured in the 'Monogr. Girvan. Fossils,' 1880, pl. xv. figs. 8 *a*, *b*, has a correspondingly broad margin.

[1] Journ. Cincinn. Soc. N. H. vol. xiii. pt. ii. 1891, p. 201, pl. xii. fig. 8.

Figs. 3 and 4 are in nos. 118 and 119, both of them hard greenish-grey shale.

5. Beyrichia impar, sp. nov. (Pl. XIV. fig. 5.)

Size.—Length 1·0, height ·72 millim.

This, at first sight, somewhat obscure fossil may be seen to resolve itself into a Beyrichian form with a narrow, curved, median lobe, separated on one side by a widely-ovate sulcus from a curved lobe-like swelling, and on the other side by a shallow furrow from a conspicuous round tubercle on the other convex moiety of the valve (not quite perfect). This latter might be the anterior part, for the larger or stronger furrow is usually behind the middle; but in the outline of this valve the boldest curve indicates that it is the posterior moiety. There is a distant resemblance to be traced in the furrows, lobes, and tubercle to those of fig. 12, pl. xiii. Ann. Mag. Nat. Hist. ser. 5, vol. xix. 1887, p. 406, there referred with doubt to *Octonaria? paradoxa*.

In no. 113, a hard greenish-grey shale.

IV. Genus Ulrichia, Jones, 1890.

Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 543.

1. Ulrichia, sp. (?). (Pl. XIV. fig. 6.)

Size.—Length 1·12, height ·76 millim.

Fig. 6, Pl. XIV. in its sub-oblong shape, straight back, nearly parallel and slightly curved ventral border, and somewhat equal, rounded ends, represents a valve resembling those of several Primitian and Beyrichian groups; but it exhibits three isolated tubercles, in a nearly straight row (the middle one rather lower down than the others) along the dorsal moiety of the valve, and above the median line. The surface is partially pitted.

Three such tubercles occur also in *Kirkbya tricollina*, Jones and Kirkby (Carboniferous), with some difference as to relative position; and in *Beyrichia tricollina*, Ulrich (Devonian), with a great difference in arrangement. Doubtless they have an analogy to those in fig. 3.

It may be that the three-tubercled Primitian forms should be definitely included in *Ulrichia* (for some remarks on this point, see the preceding paper, p. 293), and some such forms have been provisionally referred to this genus. If we regard these tubercles as either survivals or forerunners of the three lobes of *Beyrichia*, rather than the modified sulcus of *Primitia*, this form should be assigned to a genus closely allied to *Beyrichia*; and indeed this latter sometimes has, in the young state, an Ulrichian aspect with two medio-dorsal knobs, namely, in *B. nova-scotica*, J. & K.,[1] in which, when adult, the three normal lobes are sufficiently distinct. At all events the genera are closely allied.

Fig. 6 is in no. 123, a grey shale.

[1] Geol. Mag. dec. 3, vol. i. 1884, p. 358, pl. xii. fig. 7; and Quart. Journ. Geol. Soc. vol. xlvi. 1890, p. 544.

2. ULRICHIA GIRVANENSIS, sp. nov. (Pl. XIV. fig. 8.)

Size.—Length ·72, height ·48 millim.

Fig. 8 seems to be decidedly a bituberculate valve, without the normal Beyrichian features, although the posterior moiety of the valve bears a slight eminence. It is neatly sub-oblong, straight on the upper, elliptically curved on the lower edge, and almost symmetrically rounded at the ends. The pair of tubercles are high up in the medio-dorsal region, and the smaller of the two is rather in front of the other.

This species may be known conveniently as *girvanensis*. Fig. 8 is in no. 123, grey shale.

"*Primitia perforata*," Barrande, 'Syst. Sil. Bohême,' vol. i. Suppl. 1872, p. 550, pl. xxvii. fig. 12, is a somewhat similar *Ulrichia*, but more oval and with a small, deep, pit-like sulcus between two round unequal tubercles.

3. ULRICHIA GRAYÆ, sp. nov. (Pl. XIV. fig. 9.)

Size.—Length 2·08, height 1·36 millim.

This is evidently a large, well-pronounced *Ulrichia*, with a bean-shaped and somewhat reniform outline, larger behind than in front, with well-defined dorsal angles, a deep, straight sulcus, and two strong tubercles, both broken, one (anterior) leaving a broader fracture than the other. The specimen, being an internal cast, fails to show the surface of the valve.

The definite features and large size make it worthy of a specific distinction under the name *Ulrichia Grayæ*, by which we can recognize the assiduous and intelligent care exercised by the energetic collector of these and numerous other fossils at Girvan.

The specimen occurs with the cast of a small *Beyrichia Klœdeni* (?) in greenish-grey, finely micaceous shale, from Bargany-Pond Burn, and is regarded as belonging to the Llandovery formation.

V. Genus SULCUNA, Jones & Kirkby, 1874.

1. SULCUNA PRÆCURRENS, sp. nov. (Pl. XIV. figs. 10, 11.)

Size.—Fig. 10 : .... Length ·8, height ·6 millim.

Fig. 11 { without the margin, length 1·16, height ·8 millim.
{ with the margin, length 1·32, height ·92 millim.

Pl. XIV. fig. 10, has a striking resemblance to some Carboniferous forms of *Sulcuna* figured and described in the Monogr. Carbonif. Cypridin., Pal. Soc. Part I. 1874, pp. 36, 37 ; and at the same time there is an apparent relationship to Pl. XIV. fig. 1 (Girvan, see above, p. 300), except that in figs. 10 and 11 the Primitian sulcus is empty, leaving the dorsal margin bare and deeply notched. In these poorly preserved casts we have not sufficiently clear evidence to be certain on all points, either of detail or generalization.

Fig. 11, although of relatively large size, and apparently characterized by sulcus and border, is only a hollow cast, not quite satisfactory enough for safe definition. It may, however, be a broadly-margined *Sulcuna*; and fig. 10 may once have been margined.

Fig. 10 is in no. 116, and fig. 11 in no. 115, both grey shale.

These occurrences of an Upper-Palæozoic genus in Lower-Palæozoic strata are of sufficient interest to lead us to make the most we can of the evidences before us.

There seems to be some approach to the characteristic notch of *Sulcuna* in *Primitia Ulrichiana*, Pl. XIV. fig. 1.

VI. Genus Cypridina,[1] Milne Edwards, 1837.

1. Cypridina Grayæ, sp. nov. (Pl. XIV. fig. 12.)

Size.—Length 1·08, height ·76 millim.

The specimen here shown is a rough cast, evidently of such a *Cypridina* as is often found fossil and known under this general term, for want of knowledge of the differential soft parts of the animals. The shape of the valve is nearly that of *C. Youngiana*, Jones & Kirkby,[2] though boldly rounded in the front moiety.

This affords another example (besides the *Sulcunæ*) of the precurrence of Carboniferous forms in the Lower-Silurian strata; and we may well name it after its discoverer, Mrs. Gray.

It occurs in no. 118, grey shale.

Another Silurian *Cypridina* (*C. Raisiniæ*) has of late been discovered by Miss Raisin in North Wales (see Quart. Journ. Geol. Soc. vol. xlix. 1893, p. 164); and another Lower-Palæozoic *Cypridina* had been figured and described in the Geol. Mag. dec. 2, vol. viii. 1881, pp. 337, 347, pl. ix. fig. 7.

§ 3. List of the Fossil Entomostraca from the Girvan District.

(*a*) Species mentioned in the 'Monograph of the Silurian Fossils of the Girvan District in Ayrshire,' vol. i. 1878–80.

P. 227. Penkill. Referred to the lower part of the Upper Silurian, or the Upper-Llandovery Beds, or Mayhill Sandstone.

1. "*Peltocaris?*" (p. 212); this is a *Dipterocaris*, a genus rare in Britain, but well known from the Devonian of New-York State (J. M. Clarke).

P. 227. Balcletchie. Referred to the Caradoc Beds with doubt.

2. *Pinnocaris Lapworthi*, Etheridge Jun. (p. 210). A similar form occurs in the Upper Silurian of Kendal.

Note.—The *Solenocaris* referred to this locality (Monogr. Girvan, p. 207) has proved to belong to a Chitonous family (Geol. Mag., August 1885, p. 356, *Helminthochiton*).

P. 232. Thrave Glen. Referred to the Llandovery Beds with doubt.

3. *Beyrichia* [*Primitia* ?] *comma*, Jones (p. 219).

[1] Among the figures of *Silurina* in Barrande's 'Syst. Silur. Bohême,' vol. vi. pl. xlvi. etc., some have nearly the outline of *Cypridina*, but the superficial lines of growth and of ornament sufficiently distinguish them; thus the outline of *Silurina complanata* closely resembles that of a subglobose *Cypridina*.

[2] Monogr. Carbonif. Cypridin., Pal. Soc., pt. i. 1874, p. 17, pl. ii. fig. 11.

4. *Beyrichia Klœdeni*, M'Coy (p. 218).
5. *Cythere* [*Pontocypris*?] *aldensis*, M'Coy (p. 216).

P. 232. Aldens. Referred to the Bala beds.

(5). *Cythere* [*Pontocypris*?] *aldensis* (M'Coy, p. 216).
6. —— [——] ——, var. *major*, Jones (p. 216).
7. —— [——] *Grayana*, Jones (p. 217).
8. —— [——] *Wrightiana*, Jones & Holl (p. 217).
9. *Primitia Barrandiana*, Jones (p. 220).
10. *Aparchites Maccoyii* (Salter). See Ann. Mag. Nat. Hist., July 1868, p. 56; and *ibid.* May 1889, for *Aparchites*, gen. nov.

P. 232. Hillside, near Blair Farm. Referred to the Upper Silurian.

11. *Entomis globulosa*, Jones (p. 223).
12. *Beyrichia impendens*, Jones (p. 219).
(4). —— *Klœdeni*, M'Coy (p. 218).

(*b*) Species of Ostracoda from the Whitehouse-Bay Shales.[1]
Of Lower-Silurian age.

1. *Aparchites leperditioides*, Jones. Pl. XIII. figs. 1–3.
2. —— *subovatus*, Jones. Pl. XIII. figs. 4 and 5.
3. *Primitia elongata*, Krause, var. *nuda*, nov. Pl. XIII. fig. 6.
4. —— *Krausei*, sp. nov. Pl. XIV. fig. 7.
5. —— *girvanensis*, sp. nov. Pl. XIII. figs. 7–9.
6. —— *Grayæ*, sp. nov. Pl. XIII. fig. 10.
7. —— *mundula*, Jones, var. *fimbriata*, nov. Pl. XIII. fig. 11.
8. —— ——, var. *Klœdeniana*, nov. Pl. XIII. figs. 12–15.
9. —— *Ulrichiana*, sp. nov. Pl. XIV. fig. 1.
10. *Beyrichia Klœdeni*, M'Coy; cast of a tuberculate valve.
11. —— ——, var. *infecta*, nov. Pl. XIV. fig. 2.
12. —— ——, varieties. Pl. XIV. figs. 3 and 4.
13. —— *impar*, sp. nov. Pl. XIV. fig. 5.
14. *Ulrichia*, sp.? Pl. XIV. fig. 6.
15. —— *girvanensis*, sp. nov. Pl. XIV. fig. 8.
16. *Sulcuna præcurrens*, sp. nov. Pl. XIV. figs. 10 and 11.
17. *Cypridina Grayæ*, sp. nov. Pl. XIV. fig. 12.

(*c*) Species from Bargany-Pond Burn. *Of Llandovery age.*

1. *Beyrichia Klœdeni* (?), M'Coy, small cast.
2. —— ——, M'Coy, var. *scotica*, Jones & Holl.
3. *Ulrichia Grayæ*, sp. nov. Pl. XIV. fig. 9.

EXPLANATION OF PLATES XIII. & XIV.

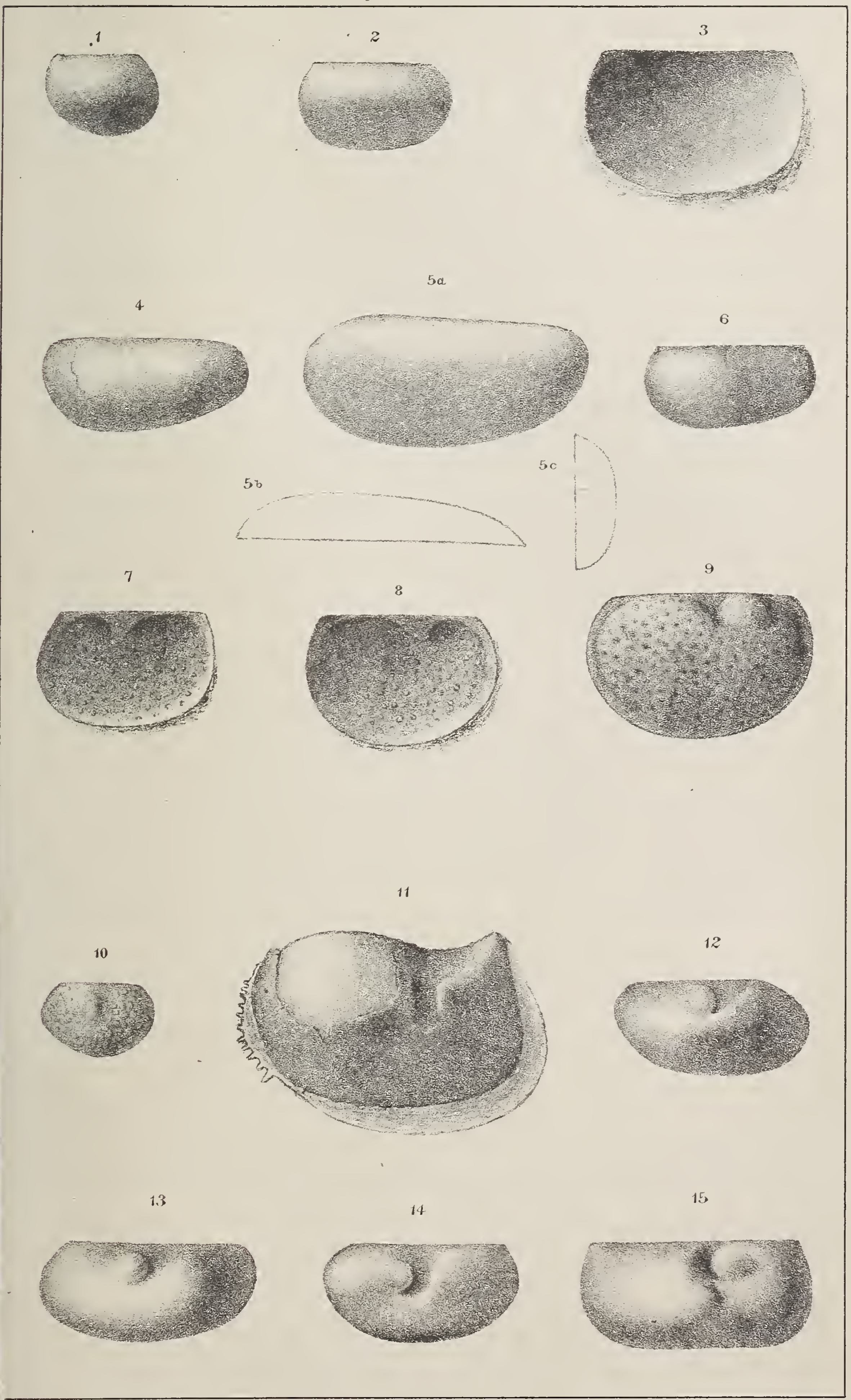
(All the figures are magnified about 25 diameters.)

Plate XIII.

Figs. 1–3. *Aparchites leperditioides*, Jones Three different individuals.—Fig. 1. Left valve; Fig. 2. Right valve; Fig. 3. Right valve.

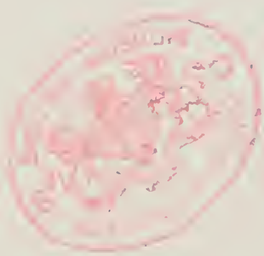
Figs. 4 & 5. *Aparchites subovatus*, Jones. Right valve.

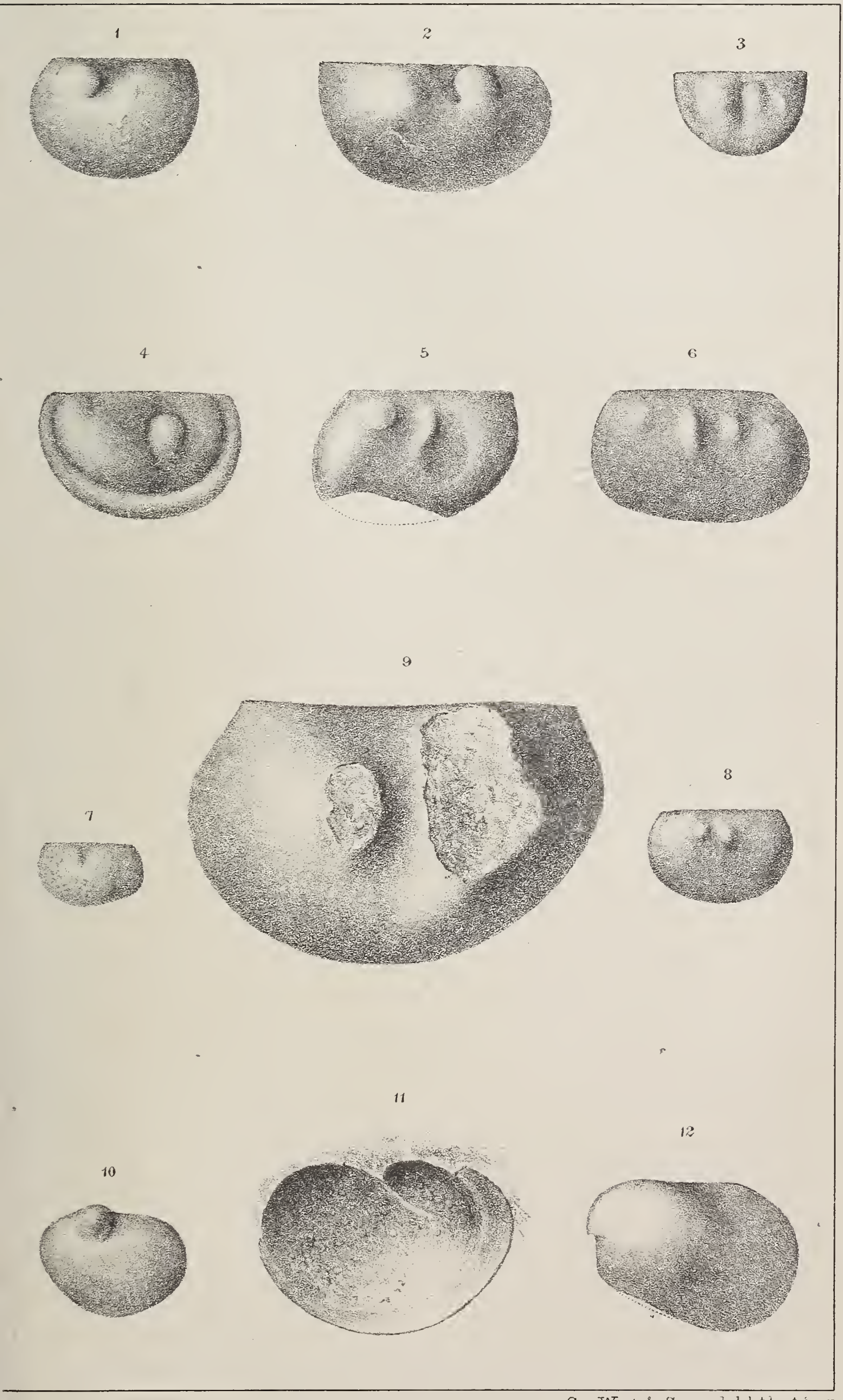
[1] Not mentioned in the first fasciculus of the 'Monograph Sil. Foss. Girvan,' because the fossils had not then been discovered.



Geo. West & Sons del. lith et imp.

PALÆOZOIC ENTOMOSTRACA FROM GIRVAN.





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PALÆOZOIC ENTOMOSTRACA FROM GIRVAN.

Fig. 6. *Primitia elongata*, Krause, var. *nuda*, nov. Right valve.
Figs. 7–9. *Primitia girvanensis*, sp. nov. Fig. 7, hollow cast of right valve; 8, hollow cast of left valve; 9, right valve.
Fig. 10. *Primitia Grayæ*, sp. nov. Left valve.
Fig. 11. *Primitia mundula*, Jones, var. *fimbriata*, nov. Right valve.
Figs. 12–15. *Primitia mundula*, Jones, var. *Klœdeniana*, nov. Figs. 13 & 14. Left valves; Fig. 15. Right valve.

Plate XIV.

Fig. 1. *Primitia Ulrichiana*, sp. nov. Left valve.
Fig. 2. *Beyrichia Klœdeni*, M'Coy, var. *infecta*, nov. Right valve.
Figs. 3 & 4. *Beyrichia Klœdeni*, M'Coy. Varieties. Fig. 3. Right valve, with the front lobe modified; Fig. 4. Right valve, broadly margined.
Fig. 5. *Beyrichia impar*, sp. nov. Right valve.
Fig. 6. *Ulrichia*, sp.? Right? valve.
Fig. 7. *Primitia Krausei*, sp. nov. Right valve.
Fig. 8. *Ulrichia girvanensis*, sp. nov. Left valve.
Fig. 9. *Ulrichia Grayæ*, sp. nov. Right valve.
Figs. 10 & 11. *Sulcuna præcurrens*, sp. nov. Fig. 10. Left valve; Fig. 11. Right valve.
Fig. 12. *Cypridina Grayæ*, sp. nov. Left valve.

Discussion (on the two preceding papers).

The President said that it was a great advantage to have descriptions of these small organisms from such an expert as Prof. Jones. *In tenui labor, at tenuis non gloria.* The Author, like specialists in other groups, was finding that the forms ran into each other and that difficulties in nomenclature arose in consequence.

Mr. Marr stated that Prof. Nicholson and he were greatly indebted to the Author for the trouble he had taken in studying these obscure fossils from the rocks of the Cross Fell Inlier. He asked whether any assurance could be given of the restriction of some of these fossils to definite zones.

The Author, in reply to the previous speaker's inquiry as to the zonal occurrences of these Palæozoic Ostracoda, could refer to his Table of the Range of the Genera in the Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 3–5, to which *Sulcuna* and *Cypridina* would now have to be added, both reaching to the Carboniferous. Speaking as to the stratigraphical value of the species, he said that some are very characteristic of certain stratal groups—as, for instance, *Primitia strangulata*, *Beyrichia complicata*, etc., of some Lower-Silurian beds; *Leperditia balthica*, etc., of the Upper; *Entomis striato-striata* of Devonian; and *Carbonia fabulina* of the Coal-measures. He would not trouble them with definitions of character,—many forms were distinguished with difficulty, and we had to rely on small differences in the carapace-valves, indicating probably considerable differences in the limbs and soft parts within the test.

26. *On the* Occurrence *of* Boulders *and* Pebbles *from the* Glacial Drift *in* Gravels south *of the* Thames. By Horace W. Monckton, Esq., F.L.S., F.G.S. (Read March 8th, 1893.)

I. Introduction.

In Hertfordshire, Middlesex, and Buckinghamshire the Glacial Drift consists of Boulder Clay and also of extensive sheets of gravel. The reasons for classing this gravel as Glacial Drift are given by Mr. Whitaker in his 'Geology of London,' 1889, vol. i. pp. 299–300. In this gravel we frequently find numerous pebbles or boulders of red quartzites and sandstones, black cherty pebbles, blocks of white quartz; and occasionally we meet with boulders of igneous rock. Now all these materials are characteristic of the Glacial Gravel or Northern Drift, but are practically absent from the Southern Drift, as has been pointed out by Prof. Prestwich. Not only are materials of this sort wanting or very rare in the Southern Drift, but also in the valley-gravels of what I may call the 'Southern Drift country,' in which I include large parts of Kent, Surrey, North Hampshire, and Berkshire. It is true that very rarely boulders of white quartz occur in these gravels, and pebbles of various old rocks may occasionally be found; these last are, however, quite unlike the red quartzite and sandstone-pebbles so common in the Glacial Drift, and probably are derived from Tertiary pebble-beds.

The southern limit of distribution of the Northern Drift materials in hill- and valley-gravels very nearly coincides with the River Thames, at least in the country east of Pangbourne, but not absolutely so, and the object of the present paper is to show where and to what extent the Glacial Gravels or their débris are now to be found south of that river.[1] In my search for sections and in the collection of facts I have been greatly assisted by several gentlemen, and I am more particularly indebted to Messrs. J. H. Blake (of the Geological Survey) and R. S. Herries. Prof. Bonney has also very kindly assisted me in the examination and description of my specimens and microscope-slides.

II. Tilehurst.

I have already pointed out[2] that the Glacial Gravel crosses the Thames above Reading, and forms the plateau above which the

[1] [I am unable to agree with the opinion expressed in the discussion on this paper that the narrow valley of the Thames is of later origin than the broad valley of the Kennet (see fig. 1, p. 311). I believe that the difference in width and shape of the valleys is due to the nature of the strata in which they are cut out, just as is the case with the cuttings on the Great Western Railway: the Sonning cutting being wide, the Pangbourne cutting narrow.—May 18th, 1893.]

[2] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 40.

village of Tilehurst stands. The highest part of that plateau is 343 feet O.D.,[1] but the best section is in a gravel-pit near Norcot Kiln at 290 feet O.D.[2] The gravel is roughly stratified, and is composed of the following classes of material:—

(a) *Derived from the Chalk and Tertiary beds, mostly local.*

1. Flints internally black and often very little rolled or waterworn.
2. Flint-pebbles abundant, some probably from older gravels, but mostly from Tertiary pebble-beds.
3. Sarsens, many rolled blocks.

(b) *Derived from older gravels.*

4. Brown, subangular flints.
5. Pebbles of quartz.

(c) *Origin doubtful, probably erratics of Glacial Drift.*

6. Black grit-pebbles, possibly from Bunter pebble-beds.

(d) *Erratics of Glacial Drift.*

7. Quartzites. Reddish quartzite-boulders, more than 3 inches long, are common; white quartzite-pebbles, reddish vitreous quartzite, etc.
8. Large blocks of quartz.
9. Igneous-rock boulders.
10. Ironstone—small pebbles abundant, very characteristic of the Glacial Gravel on the north side of the Thames in this neighbourhood.

I submitted a section cut from a block of igneous rock found here and given to me by Mr. O. A. Shrubsole, F.G.S., to Prof. Bonney, and he pronounced it to be a true igneous rock, probably once a glass, now devitrified, with indications of fluidal structure, and a few micro-porphyritic crystals of felspar, two or three of which show Carlsbad twinning, probably sanidine. He considered that the rock had been a glassy rhyolite, now devitrified, and perhaps also a little silicified, as in the case of the Arvonian at St. David's.

The diagrammatic section (fig. 1, p. 311) shows the relation of the gravel at Tilehurst to the other gravels of this part of the country. At the northern end are Chalk hills, having an altitude of over 500 feet. The patches of gravel at Greenmoor Hill and Checkendon (Woodcote Common), described as Westleton Shingle by Prof. Prestwich,[3] being a little west of the line of section, are indicated in outline. Between them and the Thames at Tilehurst are extensive patches of Glacial Gravel, and on the south of the river is the Tilehurst Plateau. Between this plateau and the Thames there is a patch of gravel about 275 feet O.D., shown in the figure. It is a reddish gravel, with many pebbles of red and brown quartzite, and very like the Glacial Gravel in composition, but its position and level lead me to believe that it is really a high-level river-gravel newer than, and mainly derived from, Glacial Gravel. South of the valley

[1] The altitudes in this paper are taken from the Ordnance Survey maps as far as possible, and given in figures above the Ordnance datum, written shortly O.D.

[2] See J. H. Blake, Proc. Geol. Assoc. vol. x. (1888) p. 495.

[3] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 140, & pl. vii. fig. 1.

of the Kennet is the extensive plateau of Mortimer and Burghfield Commons (the Silchester Plateau), which is $1\frac{3}{4}$ mile west of the line of section of fig. 1. It is capped by Southern Drift.[1]

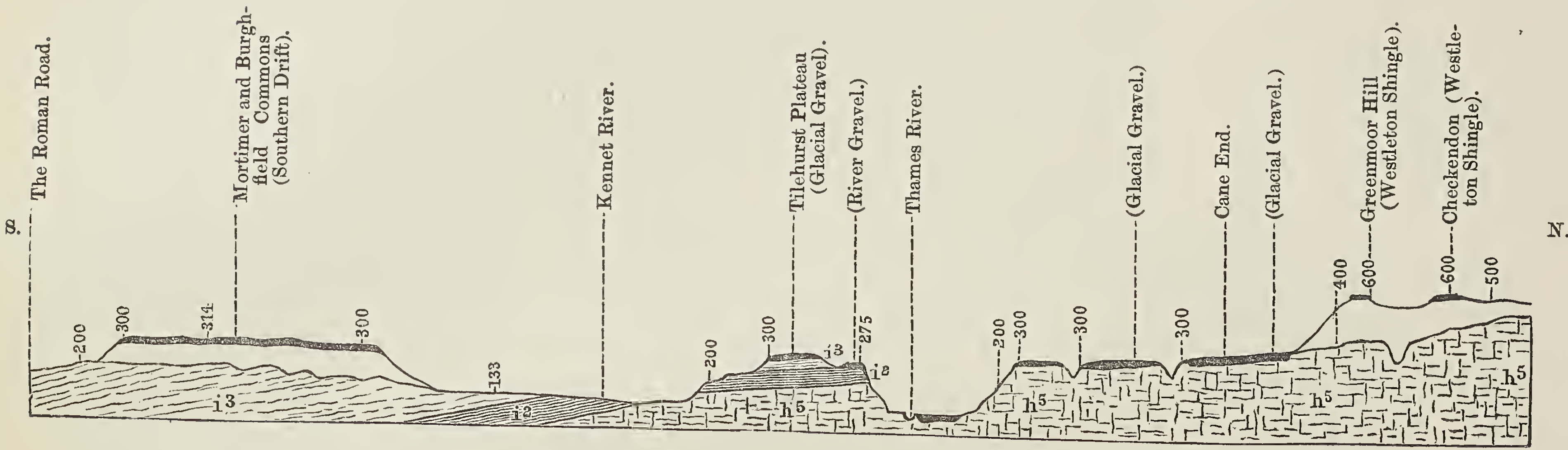
III. Reading.

Around Reading are several terraces of gravel, all of which gravel strongly resembles that of Tilehurst and contains pebbles of red quartzite, etc. These terraces are therefore obviously of newer age than the Glacial Gravel, and give evidence of the gradual erosion of the valley by the Rivers Thames and Kennet[2] after that gravel was spread out in this area.

South of Reading we find the gravel-capped plateau which extends from that town to Shinfield, and the highest part of which is 265 feet O.D. Sections are scarce, but there is sufficient evidence to show that the gravel is that of a river flowing into the Thames from the south. Thus, at the southern or Shinfield end, the fields are covered with stones, among which Lower Greensand fragments are common, while Northern Drift pebbles are apparently absent; whereas at the northern end (Southern Hill, Reading), Northern Drift pebbles abound and Lower Greensand fragments become scarce. As the valleys were cut down to lower levels similar conditions prevailed, and the gravel of the terrace on the southern side of the plateau up to Earley, 205 feet O.D., contains Lower Greensand fragments, but, so far as I can discover, no débris from the Glacial Gravel. I therefore believe that Southern Hill (Reading) is on the boundary of the area over which débris from the Glacial Gravel are distributed. On that hill there is a gravel-pit above Waterloo Kiln, locally called 'Bob's Mount,' I believe, at a level of 210 feet O.D. I found there an abundance of red quartzite-pebbles, and also some black pebbles, which appear to have come from the Glacial Drift. Being anxious to ascertain the origin of these black pebbles, I had a section cut from one, a very hard, close-grained, subangular fragment, nearly $2\frac{1}{2}$ inches long; a quartz-vein runs through it. It turns out to be a quartz-grit, the grains of quartz being in places surrounded by a minute greenish-blue material which Prof. Bonney believes to be, in part or wholly, tourmaline. He states that there are in his collection two sections from a somewhat similar rock—the one of a black pebble from the Bunter Beds of Cannock Chase, the other of a pebble from the Neocomian Beds, near the 'coprolite'-bed horizon between Sandy and Potton. The Reading pebble is quite unlike any tourmaline-grit known to Prof. Bonney from Cornwall. The evidence seems, therefore, to favour the derivation of these black pebbles from the north. I have no doubt this is an old river-gravel, and, as it is south of both the Thames and Kennet, and 94 feet above the level of the present junction of those rivers, it shows to how small an extent the valleys were excavated at the time of its deposition.

[1] See my former paper in this Journal, vol. xlviii. (1892) p. 39.
[2] See Shrubsole, Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 585.

Fig. 1.—Section from the Roman Road, near Silchester, to the hills near Stoke Row.



Horizontal scale: 2 miles=1 inch. Vertical scale: 900 feet=1 inch.

Note.—The letters used in this and in the following sections to indicate the solid geology are the same as those used in the Geological Survey Map: h^5=Chalk, i^1=Thanet Sand, i^2=Woolwich and Reading Beds, i^3=London Clay, i^4=Lower Bagshot Sand, i^5=Middle Bagshot or Bracklesham Beds, i^7=Upper Bagshot Sand.

IV. Sonning.

East of Reading we come to the gravel-capped plateau between Earley and Sonning which overlooks the Thames Valley on the north and west, and that of the Loddon on the south and east. This plateau is at a higher level than the tract of country through which the Great Western Railway runs till it crosses the Thames at Maidenhead. There is a pit, about 205 feet O.D., close to the bridge where the London and Reading road crosses the Sonning cutting on that railway. The gravel is 9 feet or more thick, roughly and indistinctly stratified. It is very ferruginous in places, and is composed of the following materials :—

(*a*) Flints forming the main part of the gravel; all waterworn, but some of irregular shapes. I noted one flint, 11 inches long and not much rolled or waterworn, near the top of the gravel. It must have been derived from the Chalk of the neighbourhood, *i. e.* from the north or west, and not from the older gravels of the south.
(*b*) Flint-pebbles.
(*c*) Quartz.
(*d*) Red and brown quartzites and brown sandstone abundant, no doubt from the Glacial Gravel. I noted one red quartzite (which measured $4\times2\frac{1}{2}\times2$ inches) 3 feet below the surface of the ground.
(*e*) Small pebbles of ironstone, like those in the Glacial Gravel at Tilehurst.
(*f*) Lower Greensand fragments, from the Southern Drift, small but numerous.

Clearly there is here a mingling of Thames and Loddon gravels, the Loddon draining a Southern Drift-gravel country. On this plateau, near Bulmershe, I found one or two pebbles of a Glacial Gravel character, and I believe that is the southern limit of their distribution at this point.

North-east of this plateau there is a pit by the high road, $3\frac{3}{4}$ miles from Reading, about 170 feet O.D. It is, as one would expect, in a Thames gravel. Northern Drift pebbles abound, and I could find in it no Lower Greensand fragments. On the Loddon side of the plateau we find, as we should expect, if my view be the right one, gravel composed of materials from the south—débris of Southern Drift or Tertiary pebble-beds—in other words, Loddon gravels.

There are pits at Hurst, 126 feet O.D.; half a mile west of Bill Hill, 128 feet O.D.; near Berrygrove Farm, 150 feet O.D.; and at Wokingham, 227 feet O.D., in none of which have I found Northern Drift pebbles.

V. Bisham and Cookham.

Within the great bend of the Thames between Wargrave and Maidenhead are several gravel-capped hills, and on one of them above Bisham there is a patch of Glacial Gravels at 351 feet O.D., which is shown at the right end of the diagram, fig. 2. It is mapped 'Pebble Gravel' on sheet 7 of the Geological Survey Map.

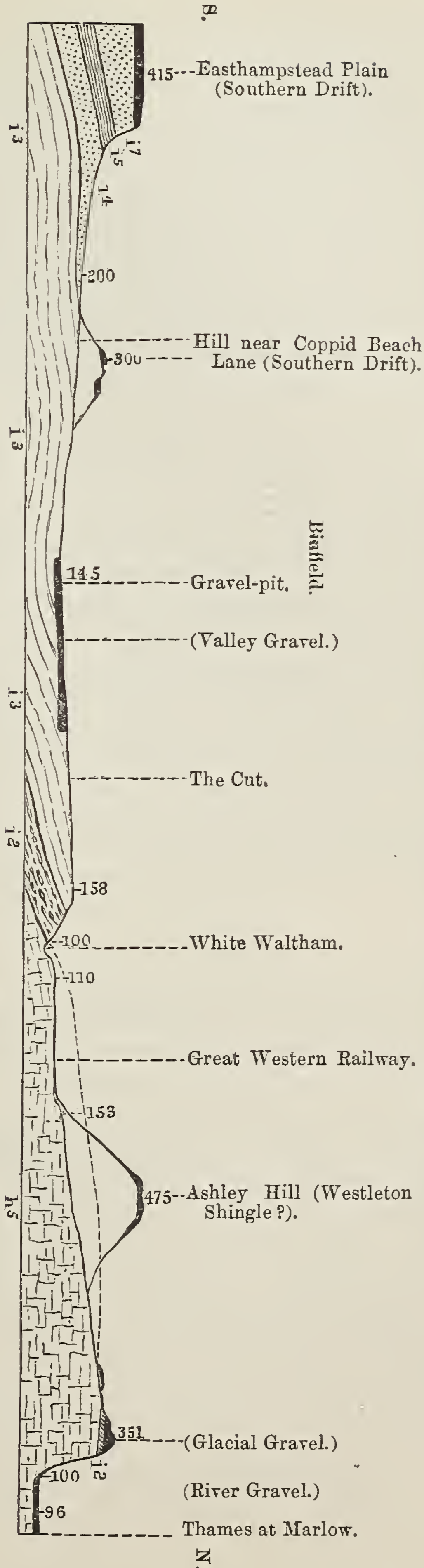
There is the following section in a gravel-pit, close to the eastern fence of the wood by the Hockett:—

	feet.	in.
1. Surface-bed full of stones up to	1	6
2. Brown, rather earthy sand, with scattered stones, and in one place a patch of mottled clay, variable up to	3	0
3. Gravel	3	6
4. Yellow sand.		

There is a south-westerly dip which may be due to a landslip. The gravel is composed of the following materials:—

(*a*) Flints, black internally; large broken flints, and large flints very slightly rolled or worn (from the Chalk of the neighbourhood).
(*b*) Flint-pebbles abundant.
(*c*) Sarsens from Tertiary Beds or older gravels.
(*d*) Brown subangular flints from older gravels.
(*e*) White quartz, with some pink pebbles and some large brown pebbles—too abundant for Southern Drift. Both (*a*) and (*e*) are too abundant for Westleton Shingle.
(*f*) Black pebbles, with quartz-veins.
(*g*) Quartzites and sandstones, Glacial Erratics. Red and brown quartzites abundant; specimens of red pebbles measured $4{\cdot}3 \times 2{\cdot}8 \times 2$ inches and $8{\cdot}5 \times 5{\cdot}75 \times 4$ inches.
White and brown sandstone-pebbles.
(*h*) Blocks of white quartz; specimens measured $9 \times 6 \times 3\frac{1}{2}$ inches and $5\frac{1}{2} \times 4\frac{1}{2} \times 3\frac{1}{2}$ inches = Glacial Erratics.
(*i*) A pebble of quartz-grit = Glacial Erratic.
(*k*) Igneous-rock boulders = Glacial Erratics.

I could find no fragments of which it could be safely affirmed that they were from the Lower Greensand. The gravel bears the strongest resemblance to the Glacial Gravel mapped on the opposite side of the Thames (at Littleworth Common, for instance), and the level is about the same.



Horizontal scale: 2 miles = 1 inch. Vertical scale: 900 feet = 1 inch.

Fig. 2.—*Section from Easthampstead Plain to the Thames at Marlow.*

The igneous-rock boulders are very much decayed. One of them, from which I brought some fragments, measured $12\frac{1}{2} \times 6 \times 4$ inches. It is a greenish-grey rock, not unlike that already described from the Tilehurst Plateau; under the microscope, too, the rocks bear a considerable resemblance to one another. In both are porphyritic crystals of orthoclase; but while in the Tilehurst rock they are fairly free from enclosures, in that from Bisham, as Prof. Bonney has pointed out to me, the felspars contain enclosures rather conspicuously. There is also an absence of the fluidal structure in this latter rock, while it is very conspicuous in that from Tilehurst. On the whole, Prof. Bonney is of opinion that the two rocks, though not from the same rock-mass, may well have come from the same district. Where that district may be is a question upon which it would not be wise to express an opinion, until a considerably larger series of the igneous rocks found in the Glacial Drift near London have been examined.

Patches of gravel with red quartzites occur at Cookham Dean at 300 feet O.D.;[1] and at 250 feet O.D. there is a patch of gravel capping Winter Hill, mapped as 'River Gravel.' Red quartzite-pebbles abound in it, and I saw one of white quartz measuring $3\frac{3}{4} \times 2$ inches. Clearly this is a very early Thames Gravel, mainly derived from Glacial Gravel.

Near Cookham Station are patches of gravel 100 to 146 feet above O.D., mainly composed of black and white flints from the Chalk; but red quartzites are fairly common. The level of the Thames here is about 80 feet O.D. These gravel-patches thus afford good evidence of the gradual excavation of this part of the Thames Valley after the Glacial Gravel had been laid down, for all contain fragments or pebbles which may be reasonably supposed to be derived from it.

VI. Ashley and Bowsey Hills.

On Ashley Hill and Bowsey Hill are patches of gravel which have been assigned to the Westleton Shingle by Prof. Prestwich;[2] and the great abundance of white quartz-pebbles, together with the scarcity of subangular flints and Lower Greensand fragments, tells in favour of the view that this gravel is, at least very largely, composed of débris from the Westleton Shingle. The presence of other material, which may most probably have come from the north, leads one to suspect that this gravel has been rearranged in more recent times, and has received a mixture of material from the Glacial Gravel. A large collection of pebbles from these hills has been made by Mr. H. J. Osborne White,[3] and he has kindly lent me a series of specimens which I have compared with those collected by Mr. R. S. Herries and myself. There are amongst them a number of black pebbles, with veins of white quartz, up to $1\frac{1}{2}$ inch long. I have had a microscope-section cut from one of

[1] See Whitaker, 'Geology of London,' vol. i. p. 301, 1889.
[2] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 141.
[3] See his paper, Proc. Geol. Assoc. vol. xii. (1892) p. 379.

these, and it proves to be a chert with indistinct signs of organic remains, some of which Dr. G. J. Hinde pronounces to be sponge-spicules. Mr. White also found a pebble of grey chert with casts of detached joints of crinoids at Bowsey Hill, and another of a similar character at Ashley Hill. Both the black and grey cherts may well be derived from the Carboniferous Series of the north.

Besides these cherts, Mr. White found at Ashley Hill occasional red quartzite-pebbles, unlike any which I have found in undoubted Westleton Shingle, and they may very probably be derived from the Glacial Gravel. I should therefore draw the line of the southern boundary for Glacial Drift materials from Ruscomb, south of Bowsey Hill, Ashley Hill, and Cookham Dean, to the highest terrace of Thames Gravel near Maidenhead.[1]

VII. Maidenhead.

South of Ashley Hill, Bowsey Hill, and the Cookham hills, there is a stretch of low-lying country reaching from the Thames at Wargrave to the Thames at Maidenhead (see fig. 2, p. 313), and it has been suggested that the river may once have flowed along this line, but the gravels afford no evidence in favour of such a contention.[2]

I have already described the Sonning Plateau, which is capped by Thames Gravel and overlooks this low ground from the west. On the east there is a similar plateau—a portion of the highest terrace of Mr. Whitaker's account.[3] This plateau, owing to denudation since its deposition, has come to project into the valley south of Maidenhead, and overlooks on one side the Thames, and on the other the low-lying ground towards Reading. Its level is about 150 feet O.D., and a good section is usually open in a gravel-pit at Shoppenhanger's Farm. The gravel consists of:—

(a) *Local Material.*—Tertiary flint-pebbles, green-coated flints, black flints, sarsen-stone.
(b) *Southern Drift Material.*—Brown subangular flints, flint-pebbles, Lower Greensand fragments, small quartz.
(c) *Glacial Gravel Material.*—Pebbles of red and grey quartzite, and large quartz-pebbles.

In a gravel-pit close to the Great Western Railway, a little west of Maidenhead Station, on the same plateau, Mr. R. S. Herries found a block of quartz-conglomerate measuring about $6 \times 2\frac{1}{2}$ inches. This terrace is some 100 feet lower than the gravel already noted at Hillgrove Farm, above Cookham, and is the highest of the three terraces at Maidenhead. We have therefore a series of gravels showing the gradual excavation of this part of the Thames Valley, and, as all the gravels here (so far as I have seen) contain Northern

[1] Ashley Hill is shown in outline in fig. 2, p. 313, as it lies two miles west of the actual line of section.
[2] See Prestwich, Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 141, note.
[3] 'Geology of London,' vol. i. p. 391, & fig. 70, 1889, and Mem. Geol. Surv. (Sheet vii.) p. 82, fig. 12, 1864.

Drift pebbles and boulders, all are probably newer than that formation; and if the Thames ever flowed south of Bowsey Hill, I should expect to find Glacial Gravel material in the area between Maidenhead and Sonning.

I have already described the patches of Southern Drift shown on the left of fig. 2.[1] In the low ground between them and Ashley Hill there is a patch of gravel in which I have seen many small pits, and I once found a pebble of reddish-brown quartzite on a heap of gravel in one of them; but with that exception everything may well have come from the Southern Drift or Tertiary pebble-beds—in short, it is a gravel of the Binfield Brook. About Warfield and Winkfield there are patches of a gravel which is, so far as I have seen, of the same character as the last. Pits are, however, scarce, and pebbles of Glacial Gravel character are seen here and there on the surface of the ground. I think it nevertheless probable that Thames Gravel may have been brought from time to time for mending the roads about here; therefore such pebbles are of little value as evidence.

There is a small gravel-pit a little west of Warfield Church; there the gravel consists of Southern Drift materials and flint-pebbles. Lower Greensand fragments are very abundant, and this is also the case in the pits by the Binfield Brook. I have thus failed to find any evidence of the existence of Thames Gravel between Ashley Hill and Easthampstead Plain, and I therefore think it most probable that even before the Glacial Gravel was deposited the Thames flowed in its present direction by Wargrave, Bisham, and Cookham to Maidenhead.

VIII. Weybridge, Kingston, and Wimbledon.

Below Maidenhead the river flows in a southerly direction, and though material from the Northern Drift is found in the more recent gravels (these, on the south of the river, are generally less than 50 feet above Ordnance datum), I have not found any in the gravels at higher levels. Thus the hills above Egham, 260 feet O.D., are capped by gravel derived almost entirely from Tertiary pebble-beds, and the same may be said of St. Ann's Hill, near Chertsey, 220 feet O.D. Near Portnall Park (about 230 feet O.D.) there is an outlying patch of the Southern Drift in which Lower Greensand fragments are very abundant,[2] and the gravels at about 100 feet O.D. near Virginia Water Station are composed of materials from pebble-beds and Southern Drift. There are several pits, but I have never

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) pp. 33–36. The diagram now given will serve to illustrate the relation of the drift on Easthampstead Plain to that at Coppid Beach Lane, and will also elucidate the argument at p. 40 of the same paper as to unequal elevation having taken place since the deposition of the hill-gravels.

[2] This locality may be added to the list of gravels with abundance of Lower Greensand fragments, given at p. 36 of my paper in vol. xlviii. of this Journal; the gravel-pits were shown to me by Mr. R. De Salis, F.G.S.

seen either a red quartzite-pebble or a block of white quartz or of igneous rock in them. Between Staines and Chertsey there is a stretch of Thames Gravel, and in it are hard reddish-brown quartzites and vitreous greyish-brown quartzites of Glacial Gravel character. I have noted shallow workings at Thorpe Lee.

St. George's Hill, near Weybridge, is capped by Southern Drift, and the plateau, 100 feet O.D., between Walton and Weybridge, is capped by gravel seemingly derived from the Southern Drift. In this gravel I could not find any red quartzites, but Lower Greensand fragments are abundant.

I have not found any sections in the gravel between Walton and Molesey; and the next locality to which I wish to draw attention is Kingston Hill (178 feet O.D.). There are sections near Thatched House Lodge, in Richmond Park, and in the great gravel-pit south of Warren House, described in the Proc. Geol. Assoc. vol. vi. (1880) p. 371; and I also found a good section on the southern side of the hill at Coombe Warren, about 150 feet O.D. They all show roughly-stratified sandy gravel containing both red quartzites of the Glacial Gravel type and Lower Greensand fragments from the south.

On Wimbledon Common there is a very similar gravel, which attains a level of 180 feet O.D., and here I found red quartzite-pebbles in many places.[1]

The latitude of the Coombe Lodge pit is 51° 25′ N., and the most southerly patch of Glacial Gravel indicated on the map is near Iver, 51° 31′ north latitude. The level is about the same as that of the Kingston and Wimbledon patches; so perhaps we should look upon these latter as Glacial Gravel. In any case I believe them to be on the southern boundary of the area over which Glacial Gravel débris are distributed.

Note.—For doubts as to gravel classification, see Whitaker, 'Geology of London,' vol. i. pp. 296, 300.

IX. Dartford.

East of Wimbledon the high ground is much built over, or it is covered by gravel apparently almost wholly derived from the Blackheath Pebble Beds, or it is formed by those beds themselves. But at Dartford Heath there is a gravel in which pebbles of red quartzite and other material from the Glacial Drift are abundant. I have had the advantage of visiting that locality in company with Mr. F. C. J. Spurrell, F.G.S., who will, I hope, soon describe the sections at length. I merely therefore mention that in all the pits I found red quartzite-pebbles, and in most places Lower Greensand fragments from the south as well. At Wansant Farm the gravel is very thick, and in the bottom bed I found a pebble of basalt, rounded and much decayed externally, about 2 inches in

[1] See Prestwich, Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 159.

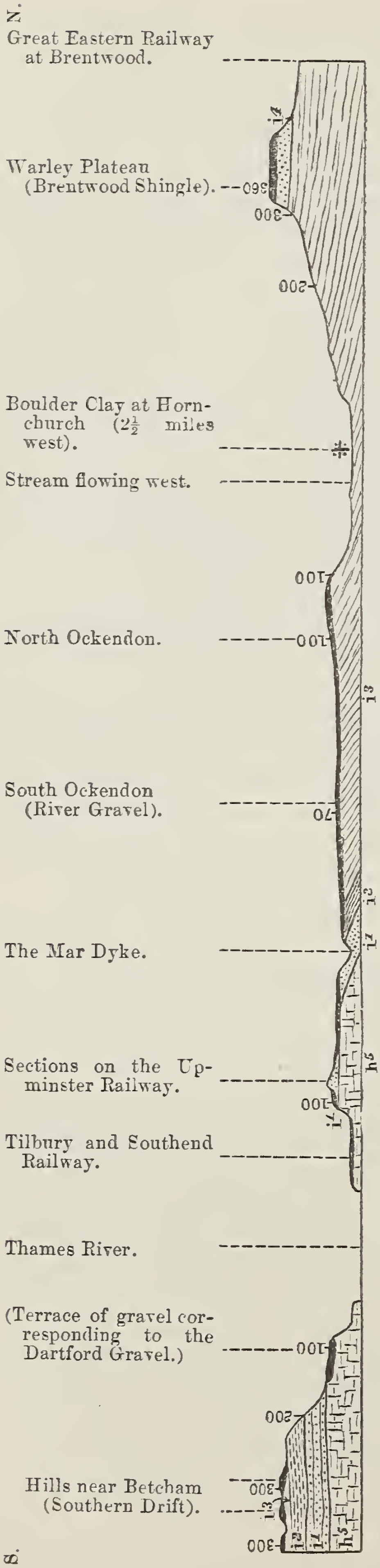


Fig. 3.—*Section from the Hills near Betcham to the Great Eastern Railway at Brentwood.*

Horizontal scale: 2 miles = 1 inch. Vertical scale: 900 feet = 1 inch.

longest diameter. I had a section cut from it, and it proves to be a fine-grained dolerite, composed of lath-shaped crystals of plagioclase felspar, with here and there one somewhat larger and broader than the rest. There are several crystals stained brown by limonite, which may represent a ferruginous olivine or a mineral of the enstatite group. There is nothing very characteristic about the rock.

The composition of the gravel shows that it is partly derived from the south, and partly from the north or from the débris of Northern Drift. Dartford Heath forms part of an old high terrace of gravel, 136 feet O.D.; and south of the gravel-patch the ground rises to above 200 feet O.D. in Joydens Wood. The patches of gravel on the opposite side of the Darent, at Dartford Brent (131 feet O.D.), at Horns Cross (115 feet O.D.) and above Greenhithe (100 feet O.D.), were, as Mr. F. C. J. Spurrell pointed out to me clearly, once part of the same terrace. The last of these patches is shown in fig. 3. I have drawn the line of that section 2½ miles west of Dartford Brent, in order to bring in the Brentwood Shingle of Warley (360 feet O.D.) and to show its relation to the Thames Gravels. The level and position of the patch of Boulder Clay described by Mr. T. V. Holmes, F.G.S.,[1] is shown by a star.

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 365.

The Thames Gravel near the Mar Dyke is shown, and in it I have found Northern Drift pebbles (100 feet O.D.). The Grays brickfield is 2 miles east of the point where the Tilbury and Southend Railway crosses the line of section. The hills near Betcham are capped by very pebbly gravel with Lower Greensand débris, probably Southern Drift.

South of Dartford Heath I have not, at present, found Northern Drift pebbles; indeed, such sections as I have seen in the long-shaped patches of gravel which run up the Longfield and Orpington valleys lead me to believe that the materials are almost entirely derived from beds of Red Clay-with-Flints or from the Chalk.

It seems to me that the facts enumerated in the present communication strongly support the conclusions expressed in the last communication on this subject which I laid before the Society; and also prove that, if (as I think probable) rivers flowing in the direction of the present Thames and Kennet existed at the time when the Glacial Gravel was spread out, the valleys in which those rivers now flow have to a large extent been excavated since.

27. *On the* Plateau-gravel South of Reading.

By O. A. Shrubsole, Esq., F.G.S. (Read March 8th, 1893.)

[Abridged.]

The gravel of the Easthampstead-Yateley plateau, to which this paper refers, has already been fully described in the Quarterly Journal of this Society and elsewhere.[1] It is therefore proposed now to submit only a few supplementary observations.

The gravel may be briefly described as consisting principally of rolled and subangular flints. With these is a small proportion of flint-pebbles, with fragments of chert, sandstone, etc., and a few very small quartz-pebbles.[2] The flint-material, excluding the pebbles of flint, has usually a worn and altered appearance (noted already by Dr. Irving), and consists chiefly of nodular flints of small size, the nodules frequently being entire. Internally the flint is usually of a bright brown or amber colour. It is generally understood that these ordinary materials of the gravel have had a local and southern origin. There is a small element, however, which cannot be so readily referred to the same source. The finding of boulders of quartz and a specimen of quartzite at various points on the plateau has been already referred to by Mr. H. W. Monckton.[3]

I have at different times found several fragments of white vein-quartz varying in longest diameter from 2 to 6 inches, the larger specimens being less rolled than the smaller. They were found chiefly in the gravel-pits near Cæsar's Camp (Easthampstead) and at Finchampstead Ridges, lying on the heaps of gravel, in the former case at about 400 feet, and in the latter case at about 330 feet above sea-level. I also found, under similar circumstances, in a gravel-pit at the summit of the northern continuation of Chobham Ridges,[4] at about 400 feet above sea-level, a large pebble of purplish, highly metamorphosed, veined quartzite.

Noticing its strong resemblance to the quartzites of the Glacial Gravel in the Thames Valley, I searched a gravel of the Tilehurst plateau, and had no difficulty in finding in the Norcot gravel-pit a pebble of an exactly similar character. Recognizing the desirability of obtaining more than a single specimen, I have since visited the Olddean pit on one or two occasions, but without success. Only two pebbles of quartzite, which might be of northern origin,

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 120 & 557, and vol. xlviii. (1892) p. 29. See also Proc. Geol. Assoc. vol. vi. (1880) p. 437, and vol. viii. (1883) p. 161.

[2] See Prof. Prestwich's description of 'Southern Drift' in Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 156.

[3] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 29.

[4] At the eastern end of Olddean Common, a little to the left of the road from Blackwater to Bagshot.

have been observed at other localities—one at Yateley Heath (at about 300 feet above sea-level), and the other at Wokingham in a pebbly gravel, marked as 'Valley Gravel' in the Geological Survey map, at about 227 feet above sea-level.

As regards the flint-material of the gravel, I have occasionally observed fragments which have a fresher appearance than the bulk of the gravel, and are more like the flint of the Thames-Valley gravels; and possibly these, with the boulders of quartz and quartzite, may represent an element of later introduction. In any case, they have to be accounted for.

It seemed desirable to ascertain whether the gravel would afford any indication of man in the shape of worked weapons or tools. Various sections have therefore been under observation with this view. The result may be briefly stated. At the highest level of the plateau, nothing has been found at all resembling the carefully-worked implements of the ordinary Palæolithic type. I found, however, in the gravel-pit on Finchampstead Ridges, at about 330 feet above sea-level, what appears to be a massive tool of a somewhat primitive kind. It has been regularly chipped at one side, and is apparently of flint similar to that of which the greater part of the gravel is composed. I have also obtained a number of fragments of flint, and one of chert, which have hollows worn in one of the edges in the manner of the hollowed 'scrapers' which are abundant in some of the valley-gravels. Several of them conform to a specific type. They are, as a whole, not so highly finished as some Palæolithic specimens.

I have not hitherto observed any of the large flint-flakes which are usually found in implement-bearing gravels; but while recently examining some of the smaller material in the pit on Finchampstead Ridges, I found a small flake of brown flint (showing the 'bulb of percussion'), the edges of which have been worn as if by scraping.

The localities from which the specimens have been obtained are chiefly Cæsar's Camp near Easthampstead, Chobham Ridges, Yateley Heath, and Finchampstead Ridges.

In the gravel at Wokingham, to which reference has been made (about 227 feet above sea-level), a large and highly-finished Palæolithic implement of the pointed type has lately been obtained by Mr. P. Sale. It is stained bright brown.

The gravel tract of the Easthampstead-Yateley plateau, in common with the Upper Bagshot on which it rests, has doubtless suffered much from denudation. In sections it is not unlike gravels which are generally regarded as fluviatile, but the usually small size of the constituent material seems to suggest a sorting action of some kind, although, of course, it would be hardly fair to take the coarse gravel of the Thames Valley as a type. On the other hand, if we consider the extent of the deposit, it appears to be due to something more than ordinary river-action. The boulders of quartz, etc., if of northern origin, seem to require marine agency to account for their presence; and in the spreading out of the gravel at lower levels there is much to suggest such agency. Its position indicates that it is an old deposit, and its inclusion of so small a proportion of the rock-material that now constitutes the surface of the Weald-country points to its having been originally formed during an early stage of the Wealden denudation. Possibly we have here, in great part, old fluviatile material which has been brought within the reach of marine agencies. The precise age of such old material can at best form the subject of a more or less approximate conjecture. The rude implements (the genuineness of which must be to some extent a matter of opinion) evidently belong to the older part of the gravel, and as, hitherto, none but specimens of a simple and primitive type have been found at high levels here, such an indication, so far as it goes, is well in accord with the evidence of age in the gravel itself.

The fragments of vein-quartz and the pebbles of quartzite, with a proportion of the flint-material, might be accounted for by a subsequent submergence up to a height of 400 feet above the present sea-level. Slight irregularities of bedding are observable, at various levels on the plateau up to the height named, which to some extent suggest the agency of ice; and the larger quartz-fragments do not show much abrasion. But any such invasion by the sea could hardly have taken place at the time of the general dispersion of the Triassic pebbles and other material of northern origin, or at any later date, or more substantial traces of it would have been found. The quartzite-pebbles, in particular, are extremely rare here, and none have been observed absolutely *in situ*. It is therefore desirable to await further evidence and the complete mapping of the gravels of the district, before venturing on a positive conclusion as to the significance of some of the facts adduced.

Discussion (on the two preceding papers).

The President said that the determination of the position of the line separating the gravels of northern from those of southern origin in the Thames basin was a matter of great importance and attended with considerable difficulty. The Authors had not brought forward any evidence tending to shake our faith in the distinctness of the two sets of gravels. In deciding as to the source of any particular gravel, he thought that the occurrence of rare pebbles should not be allowed to have too much weight.

Dr. Hicks said that the sections exhibited clearly showed that the valley, running more or less in a line from W. to E., in which the River Thames now flowed, was excavated before the so-called Middle Sands and Gravels and the Chalky Boulder Clay were deposited. If the river flowed at the level of the glacial deposits, after they had accumulated, it was difficult to understand how the deposits on the southern side are so different from those on the northern side of the valley.

Mr. J. Allen Brown said he feared his remarks would tend to still further complicate the subject, when he stated, as the result of his own observations in the Valley of the Thames, that the two kinds of gravel (the one mostly a shingly deposit, with fragments of sarsen and without quartzites, etc., and the other containing small boulders and pebbles of quartzite and other northern rocks) are found in separate deposits on hills overlooking the Valley, and in close proximity to the implementiferous Valley-drift, and sometimes nearly at the same levels; moreover, he had noticed that large masses of each of these supposed more ancient deposits had been carried bodily into the old channel of the river, the old bed being seen in the stratified gravels which are generally found beneath them. It is observable that these large masses of material transported by ice *en bloc* from the north often cause cross-bedding where they stranded, as seen in numerous sections—though a more even stratification is noticeable in other places at the same contour.

All this rendered it sometimes very difficult to determine whether the origin of a particular bed of gravel was glacial or fluviatile, and it was often hard to show where the one deposit ended and the other began. His own conviction was that the very high-level Valley-drifts were to no small extent due to glacial agency, and in part also to fluviatile action; the two causes of deposit appear to have been in operation at the same time, and this was the condition of the Thames Valley in glacial times.

The two papers read were of great interest, and he hoped that future observers would direct their attention to the evidence of the transport of very large masses of material bodily into the high-level Valley-drift to which he had referred.

Prof. J. F. Blake said that the Authors had given them the data without offering a definite solution of the problem. He (the speaker) did not find anything in these data to modify his previous ideas of the history of the Thames. The narrow valley in which that river was shown in the diagrams to run indicated rapid erosion, and consequently later origin for the main stream than for the Kennet, which latter was the original boundary between the Northern and Southern Drift. When the Goring gorge was opened, and the waters of the Upper Thames were admitted to the lower basin, the course of the main stream was altered, and then the Northern Drifts began to be cut through.

Mr. W. J. L. Abbott remarked, with reference to the eastern end of the plateau upon which he was now engaged, that he had found red quartzites similar to those exhibited up to over 600 feet, together with volcanic and metamorphic rocks about which he hoped to speak on a future occasion. He also pointed out the occurrence of northern fossils and boulders at Westcombe Park and elsewhere in the south. In the main there appeared a great similarity in the drift in the E. and W., but in the E. it was decidedly more ferruginous. With reference to the implements shown, he would have liked to see some better specimens, such as had been found in the E., but those exhibited were sufficient to demonstrate their existence. There were persons, whose number was rapidly decreasing, who had as yet been unable to accept these as man's work; but to his mind they showed signs of man's handiwork as unmistakable as those of generally accepted Palæolithic implements.

Mr. Herries reminded Mr. Monckton of Prof. Prestwich's theory of the gradual rising of the land towards the west after the deposition of the Westleton Shingle, which obviated the necessity of supposing that the Thames flowed at the present elevation of the Glacial Gravels, at the time when those gravels were deposited. He expressed surprise at Mr. Shrubsole's discovery of quartzites in the Southern Drift, but did not quite understand what, if any, inference the Author drew from their presence. He confessed himself very sceptical about the so-called 'implements' from the Southern Drift.

Mr. Monckton thought the facts detailed by Mr. Shrubsole were consistent with the views expressed in his own paper. The relative age of the various drifts shown in the diagrams was probably as follows, beginning with the most ancient:—(1) Southern Drift of Burghfield Common, Easthampstead Plain, and the hills above Betcham. (2) Brentwood Shingle. (3) Glacial Drift. (4) Various Valley Gravels, the highest Thames Gravels being probably contemporaneous with the Glacial Gravel.

In reply to the President, he said that he had not claimed as glacial any gravel described by Prof. Prestwich as Southern Drift.

Mr. Shrubsole stated, in reply to Mr. Herries, that most of the specimens of vein-quartz exhibited had been found by himself.

28. A fossiliferous Pleistocene Deposit *at* Stone, *on the* Hampshire Coast. By Clement Reid, Esq., F.L.S., F.G.S. (Read March 8th, 1893. Communicated by permission of the Director-General of the Geological Survey.)

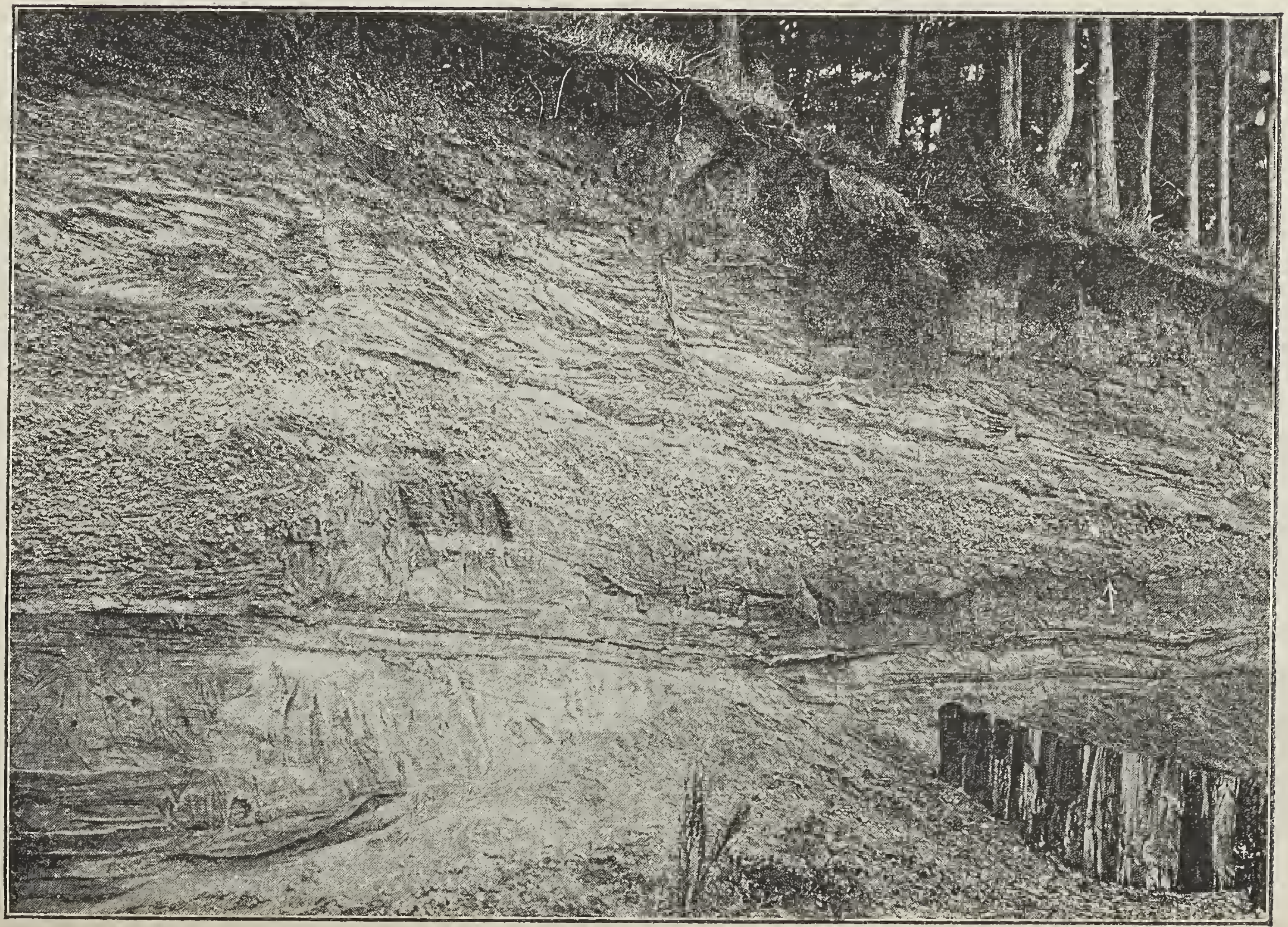
About a year ago I communicated to this Society a note on 'The Pleistocene Deposits of the Sussex Coast,'[1] in which were given some of the more important results brought out by the new geological survey of that district. It was suggested, among other things, that the fossils of the 'mud-deposit' of Selsey indicated an inter-glacial mild period, represented also by some abundantly-fossiliferous strata at West Wittering. The continuation of the survey westward now enables me to state that the same deposit is found also in Hampshire, where it yields similar fossils, and distinctly underlies the mass of the implement-bearing gravels of that coast.

The new locality for the 'mud-deposit' is the foreshore at Stone, three miles south of the village of Fawley, and the same distance from the entrance to Southampton Water; it is consequently about 20 miles west of the patches already known. The mass of tenaceous *Scrobicularia*-clay, now visible at Stone, may have been observed by other geologists, but I can find no record of it; in all probability, if observed at all, it was passed by as being merely an exposure of recent estuarine mud belonging to the Dark Water, a stream which now flows into the Solent a quarter of a mile farther west. Opposite the spot where the clay is seen, a low cliff marks the seaward edge of the great gravel-plateau of the New Forest; but this cliff is so low, that at first sight the gravel might be mistaken for a storm-beach thrown up by the sea in modern times. In the sheltered Solent no storm now throws beach-material to this height; yet from the stratigraphical evidence alone one could not feel absolutely confident as to the Pleistocene age of the gravel and of the underlying estuarine clay. After a short search, however, I found the broken end of an elephant's tusk projecting from the clay and covered with seaweed. This discovery showed that the clay was a genuine Pleistocene deposit, in no way connected with the modern river-channels, all of which, in that district, are more recent than the gravel-plateau. A box of the clay was therefore taken to London for examination, and the result showed that the deposit contains a fauna and flora identical, so far as it goes, with that of the upper 'mud-deposit' of Selsey.[2] The species obtained were the following:—

Elephas (portion of nearly straight tusk).
Helix pulchella, Müll.
Melampus myosotis, Drap.
Hydrobia similis, Drap.
—— *ulvæ*, Pen.
—— *ventrosa*, Mont.
Cardium edule, Linn.
Scrobicularia piperata, Belon.
Ranunculus sceleratus, Linn.
—— *repens*, Linn.
Rubus fruticosus, Linn.
Acer monspessulanum, Linn.
Quercus robur, Linn.
Atriplex patula, Linn.
Zannichellia palustris, Linn.
Carex riparia ?, Curtis.
Phragmites.

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 344.
[2] *Op. cit.* p. 355: No. 4 in fig. 2 there.

Fig. 1.—*Section in the sea-cliff, near Stone (Hampshire).* From a photograph.



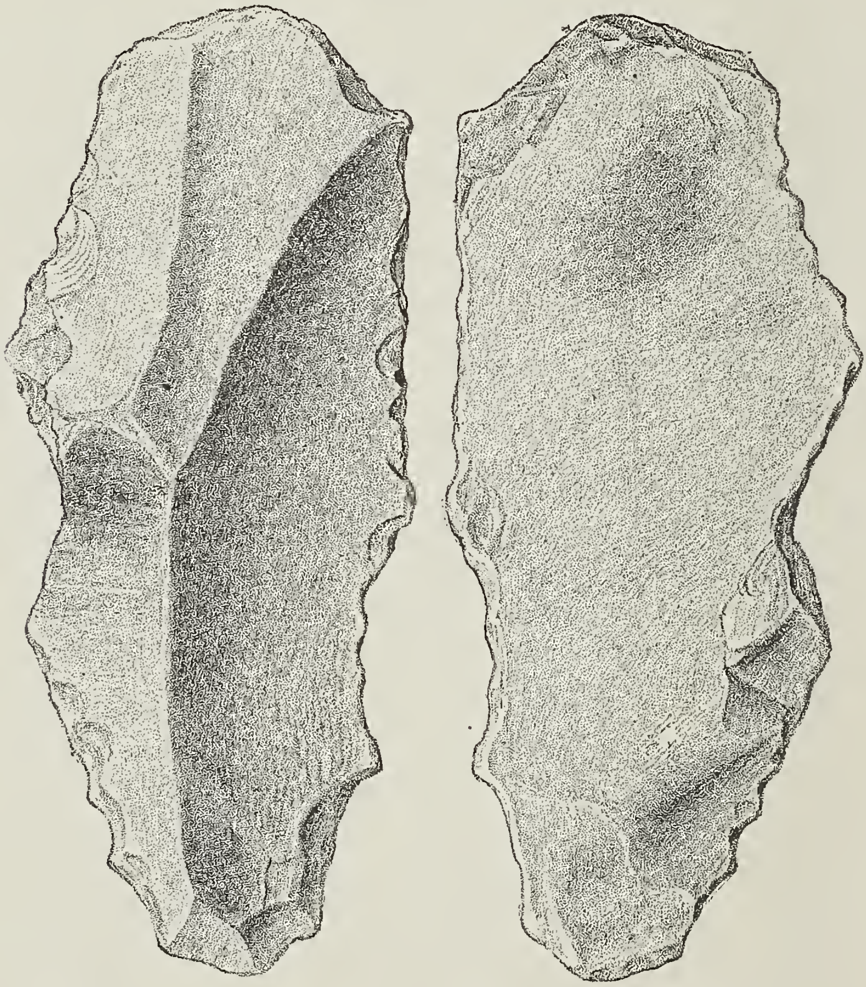
It will be observed that, besides the occurrence of Elephant-remains, there is the discovery of *Hydrobia similis*, now confined in Britain to the Thames, to connect this deposit with the one at Selsey, and to separate the fauna from that of the existing Hampshire estuaries. *Melampus myosotis* has not been found at West Wittering or at Selsey, but in this genus the species are so often local in their distribution that their occurrence or non-occurrence is of no importance.

The plants are all species found at Selsey or at West Wittering, but among them is one of great interest, for it distinctly points to a mild period. The fruit of the South European maple, *Acer monspessulanum*, occurs not uncommonly in the *Scrobicularia*-clay both at Selsey and at Stone; but, owing to the destruction of the wing, the Selsey specimens had not been recognized as belonging to a maple when my former note was published. Some examples recently obtained from Stone have part of the wing preserved, and it is clear that they are quite different from our only native maple, and different also from the introduced sycamore-maple. Comparison with the fruits of the European maples in the British Museum (Nat. Hist.) herbarium shows that our fossils agree with one only of the species—the South European *Acer monspessulanum*, which does not at the present day range nearer to Britain than Western Germany and Southern France. Both the maple and the oak point to a mild climate, very unlike that of the cold periods which seem to have preceded and succeeded the deposition of the *Scrobicularia*-clays.

Overlying the fossiliferous clays just described is a mass of subangular flint-gravel like that of Selsey, but less worn, for Stone is a more sheltered locality. At the base of this gravel I found two or three waste flint-flakes, lying immediately above the mass of clay; but no good implements were seen at this spot. About a mile and a half to the north-east, however, a Palæolithic flake-knife was dug out of the undisturbed gravel about 18 inches from the base, the gravel being about 15 feet thick. An oyster-shell placed in the small hole from which the implement was removed forms the white dot in the photograph from which Fig. 1 is taken: the arrow pointing to the exact spot was cut in the underlying Barton (or Upper Bagshot) Sands. Though so many implements have been found on the Hampshire coast, few have been observed actually in place, and it seems advisable to show the exact conditions under which they occur—at the base of a mass of gravel, apparently of estuarine or marine origin.

It will probably be asked what is the exact relation between these implement-bearing gravels and the wide plateau which rises inland till it reaches a height of 300 feet above sea-level. This question I am unprepared at present to answer; for, though the sheet is undoubtedly continuous and must be mapped as one mass, yet slight indications make one suspect that in reality its formation extends over a period of considerable length, and that it will be possible ultimately to distinguish successive stages. Until the rest of the plateau in South Hampshire has been examined in detail, it will be safest to leave untouched all theoretical questions, merely

Fig. 2.—*Front and back views of the Palæolithic flake-knife.* Nat. size.



observing that the wide sheet in Hampshire is distinctly older than the Coombe Rock, which thus far has yielded only a single, much-rolled Palæolithic implement.

Discussion.

The President congratulated the Author on his good fortune in finding so many plants, especially the South European maple, in this interesting Pleistocene deposit.

Dr. Hicks asked the Author how he accounted for the presence of the South European maple in a deposit which seemed to indicate a pluvial period, unless the seeds had been transported from some distance or derived from an earlier deposit. The interesting find of a flint-implement in the stratified gravel shows that man lived in the area before the changes indicated by the deposits set in.

Mr. W. J. L. Abbott said that the implements found in the neighbouring sections were of a diversity of types; their waterworn condition is in all stages, from perfectly fresh and sharp to many where the traces of work are almost obliterated. When subjected to the effects of surface-waters, in common with the accompanying gravels, they became whitened and slightly decomposed; otherwise they were of a warm brown, and fairly patinated. Most of the implements he had dug out were from within a few feet of the bottom of the gravel. He had found numerous flakes from less than 1 inch up to 6 inches in length, sometimes simple, at others secondarily worked.

The Author replied.

29. *On an* Intrusion *of* Muscovite-biotite Gneiss *in the* South-eastern Highlands *of* Scotland, *and its* accompanying Metamorphism. By George Barrow, Esq., F.G.S. (Communicated by permission of the Director-General of the Geological Survey. Read March 22nd, 1893.)

[Plates XV. & XVI.]

Contents.

I. Introduction.

The area to which attention is directed in the following pages lies in the north-eastern corner of Forfarshire, and forms part of the singularly flat table-land of the South-eastern Highlands. It is essentially a moorland district, much covered with peat and heather, and is drained by two rivers, the North Esk and the South Esk. The rocks of which the area is composed consist principally of gneisses and schists; these are clearly seen in the craggy sides of the valleys through which the two Esks and their tributaries flow. Boulders of these rocks may be noticed in the rough walls by the roadside as one drives up the glens, and their intensely crystalline aspect is a most striking feature. A brief visit to the crags and the flat-topped moorland speedily convinces the observer that this crystalline aspect is one of the chief characteristics of the district. It is proposed to show in the present communication that this area contains several masses of intrusive rock which are probably connected underground, and that the highly crystalline character of the surrounding schists is mainly the result of thermometamorphism.

II. Distribution and Mode of Occurrence of the Igneous Rocks.

The normal condition of the intrusive rock is that of a slightly foliated granite, with two micas; but there are considerable variations from this type, both as regards structure and composition, as will be seen from the detailed descriptions that follow. It is met with in masses which vary greatly in size, and the larger of these are more or less fringed with pegmatite, veins of which cut the schists in every direction. In one part of the area the gneiss occurs as thin bands, permeating the other rocks, and any crag- or scar-face will show clearly its intrusive nature. The foliation of the larger masses is rudely parallel to that of the surrounding schists, and their intrusive nature is not so obvious; but it is proved by detailed mapping, for these masses traverse different bands of the schists, the latter ending off against the igneous rock much in the same manner as in any ordinary case of intrusion.

The great crags at the head of Glen Clova are seen to be more or less permeated by small tongues or thin bands of a grey gneiss. In some cases this intrusive rock nearly equals in total bulk the surrounding metamorphic rocks, and to the district in which this is the case we have applied the term 'permeation-area.' This area commences at the north-western end of Glen Clova and stretches in a north-easterly direction for about 6 miles, No. 1 in the Map, Pl. XV. No strict boundary can be drawn to such an area, for, especially at its north-eastern end, it tails away by a continual decrease in the number of small intrusions, and consequently in the proportion of igneous material to the surrounding rocks.

Some distance to the south-east of this area the intrusion is met with again as a distinctly foliated granite. It is no longer minutely subdivided, but forms rather a continuous mass with many inclusions. The two types of igneous rock are connected by a narrow band, in which the decreasing proportion of the surrounding schists and the thickening of the separate intrusions may be fairly well made out, in spite of the covering of peat.

The mass (No. 2 in the Map, Pl. XV.) which is thus connected with the permeating gneiss is, on the whole, much less foliated and weathers more like a granite, especially towards its edges. Inclusions are more numerous on the western than on the eastern side, the latter edge being often fringed with pegmatite.

The next mass (No. 3 in the Map) is very irregular in shape. The appearance of the rock of which it is composed is that of a slightly foliated granite; but the most marked feature of the mass is the enormous fringe of pegmatite on its southern and eastern edges. There is also a slight fringe on the other edges.

Another outcrop (No. 4 in the Map) forms part of the high ground drained by the eastern branch of Rottal Burn. The foliation is always slight, and the rock passes insensibly on its south-eastern margin into a mass of aplite. Of the two masses shown in the Map on the western side of Glen Clova, No. 5 is identical with No. 3; while No. 6 is an inextricably-confused mass of foliated granite, pegmatite, and inclusions.

There are in the North Esk area, that is, north and east of these larger masses, many smaller patches of gneiss, granite, and pegmatite. The gneissose structure, never so well seen as in the permeation-area, is developed only when the outcrops have a breadth of 100 yards or more, and in all the more easterly patches the foliation is not easily seen in a hand-specimen. These small patches are, however, invariably accompanied by a fringe of pegmatite, which occurs in large masses. In the neighbourhood of Millden the intrusion is represented solely by large masses of pegmatite.

Thus it appears that the intrusive rock is most gneissose in the north-western portion of the area, and that, as we proceed towards the south-east, the gneissose character is gradually lost, while the amount of pegmatite is seen to increase until at last it occurs as isolated masses, and thus becomes the sole representative of the intrusion in that area. It must not be supposed that these isolated pegmatites are restricted to this district. Starting from the South Esk, they may be met with at intervals at least as far west as Pitlochry; and they are well known also on the east coast, a few miles north of Stonehaven.

III. Petrological Characters of the Igneous Rocks.

The gneiss of the permeation-area, when unweathered, has a grey colour. On a surface cut at right angles to the foliation, the felspars are seen to be somewhat rounded or pointed-elliptical in shape. A section made from a specimen taken from the head of the Lee Water shows the following features (4557 A)[1] :—It is composed of quartz, felspar, muscovite, and biotite. The lenticular crystals of felspar are mostly plagioclase (usually oligoclase); there is no microcline, and it is doubtful whether there is any orthoclase. A feature in the plagioclase is the very irregular way in which the polysynthetic twinning is rendered visible under crossed nicols. Part of a lenticle may show none, while in another portion of the same individual it is well marked; moreover, part of a crystal may be water-clear, while the rest is more or less clouded. The micas do not show any definite form, and the brown mica is not much less in amount than the white. The former contains numerous inclusions of small zircons, with marked pleochroic halos, and irregular patches of garnet, with a very fissured appearance. Apatite-inclusions appear to be totally absent. The areas of quartz, of which there is a considerable amount, break up under crossed nicols into small, irregularly-shaped patches with a tendency to undulose extinction. Small allotriomorphic garnets are scattered throughout the slide.

The aspect of the different minerals of the gneiss under the microscope suggests that the crystals of earlier consolidation underwent an appreciable amount of comminution; for, on the whole, they distinctly differ in size and shape from those seen where the intrusions are more or less massive. But there is no evidence of crushing after consolidation.

Thus it appears that in this area plagioclase is the dominant felspar; microcline is absent; and the white mica is about equal in quantity to the brown.

In the second area, where the intrusions are thicker, a slide

[1] The numbers of slides, referred to throughout this paper, are those of the slides preserved in the Museum of Practical Geology, Jermyn Street.

(4557) from a specimen taken near the western side of the mass shows the following characters:—The rock is a fine-grained, granitoid gneiss, composed of quartz, plagioclase, a little orthoclase (?), and two micas. There is no microcline. Its structure is more like that of a normal granite than the last. The plagioclase does not show the lenticular form, but is rather rounded in outline. The micas are in distinctly thicker flakes, especially the muscovite, which shows a tendency to idiomorphism. The dark-bordered inclusions in the biotite are hardly so numerous and are extremely small, still some can be clearly made out to be zircon. Irregular grains of garnet are also met with. There are no apatite-inclusions. The quartz fits into the rest of the rock as in a granite. A point of special importance is the occurrence of micropegmatite. The rock is essentially a foliated granite, and the foliation is even less marked under the microscope than in the hand-specimen. Several slides have been cut from this mass and they are mostly similar to the above. On approaching the eastern edge the rock has rather a pink tinge, and after one has crushed up a number of fragments it becomes clear that this part of the foliated granite contains a considerable amount of microcline, a mineral hitherto absent. It has already been stated that pegmatite, in which the bulk of the felspar is microcline, is often largely developed here.

The points in which this area differs from the former may therefore be summarized as follows:—White mica is more abundant than brown; micropegmatite occurs throughout; the structure is more granitic, and microcline begins to appear near the edges of the mass.

The third mass varies considerably in character. Small portions of the central and west-central parts, where the outcrop is broad, closely resemble the area last described; but the main mass has a different character, well represented by a specimen (4234) from the eastern side of Ben Tirran. It is composed of quartz, oligoclase, orthoclase (?), microcline, muscovite, and biotite. The quartz contains 'hairs,' and inclusions with bubbles. The 'hairs' may occasionally be seen crossing the junction of two quartz-grains without interruption or distortion. Zircon occurs as an accessory. Some of the oligoclase shows fairly well-marked zonal banding. This felspar and microcline are roughly equal in amount. The white micas are usually much larger than the brown. Inclusions of zircon and garnet occur only in a few crystals of biotite; the smaller individuals, which much predominate, usually contain none. Towards the edge of the intrusion a further increase of potash-felspar takes place. Thus a specimen from a point about a mile south-east of Loch Brandy (4232) is composed of microcline, oligoclase, quartz, muscovite, and biotite. This is distinctly less foliated than the two preceding, and the microcline exceeds the oligoclase in amount. Still closer to the edge a specimen (4236) taken from Rough Craig, about a mile east of Clova Hotel, shows under the microscope orthoclase, microcline, oligoclase (rare), quartz, and muscovite. The quartz contains 'hairs' and inclusions with bubbles. Magnetite occurs as an accessory. Thus the brown mica is almost absent, and oligoclase is quite subordinate in amount, white mica and potash-felspar being dominant. Finally the borders of the mass are fringed with pegmatite, of which there is a vast quantity on the south-eastern side, and of this rock microcline is the chief component. The pegmatite here often assumes the 'graphic' structure, and where this is the case the amount of muscovite is always small. A section (4233) shows microcline and albite in microperthitic intergrowths, with some quartz. The 'graphic' structure is seen in portions only of the slide.

The special points to be noticed in this area are as follows:—The centres of the broader portions contain oligoclase to the exclusion of microcline, and are more foliated than the rest of the mass (which is essentially a slightly foliated granite, and contains the two felspars in nearly equal parts); white mica is here much in excess; while close to the edges microcline is the dominant felspar, and muscovite the dominant mica.

A typical specimen (4241) of the fourth mass, taken from the head of Kennel Burn, may be described as a fairly coarse granitic rock, composed of quartz, microcline, plagioclase, and two micas. Microcline is the dominant felspar. A tendency on the part of the micas to flow round the plagioclase is well marked in a few places, otherwise the structure approximates very closely to that of a normal granite. On the south-east of the mass all trace of foliation disappears, and the rock is an aplite. This last, from its composition, probably represents the pegmatite, which now forms a fringe on the northern and western edges. The feature, then, of this fourth mass is that microcline much exceeds plagioclase, and brown mica occurs only in very small quantity.

The facts enumerated above conclusively prove that this great intrusion becomes steadily more and more acid as we follow it from the north-west to the south-east; and further, that the acid character of each outcrop is more pronounced on its southern and eastern edges than in the rest of the mass; except perhaps in the case of the fourth mass, which is very acid throughout. This conclusion may be tabulated as follows:—

North-western Area	1. Maximum plagioclase, minimum microcline. 2. Maximum biotite, smallest white micas.
South-eastern Area	1. Minimum plagioclase, maximum microcline. 2. Minimum biotite, largest white micas.

The meaning of this distribution of the component minerals is made intelligible by examining one of the larger apophyses of any of the post-metamorphic Highland granites shown in Sir Archibald Geikie's Geological Map of Scotland (2nd ed. 1892). At the junction with the granite the dyke is very coarse in texture, but farther from the parent mass it gradually becomes less and less coarse, till eventually it consists of porphyritic crystals set in a fine-grained matrix. These crystals, which belong to the earlier phase of consolidation, consist of bipyramidal quartz, oligoclase, and brown mica, while the bulk of the finer material consists of potash-felspar and quartz, the minerals of later consolidation.[1] By applying these facts to the distribution of the minerals in the area under consideration, we see that those which are most abundant in the north-west belong to the first phase of consolidation, while those which are most abundant in the south-east belong to the second phase. Thus the earlier-formed minerals appear to have been retained or strained off, while the still liquid potash-bearing material travelled on in a south-easterly direction. Hence it may be inferred that the source of origin lies to the north-west, and that the intrusion ends with the formation of the masses of pegmatite, which are the acid or potash-bearing residuum. Further, the fact that in one area the intrusion is minutely subdivided while in the south-east it hangs together, finally consolidating as aplite, suggests that the rocks to the north-west must have had a higher initial temperature than those farther south-east. It will be found that this view is strongly corroborated by the evidence adduced later on. The high temperature was probably due to the intrusion of slightly older gneisses, of the same type as the muscovite-biotite gneiss, in which white mica is rare or absent. It was intended to give a brief account of the intrusion, but the idea has been abandoned on account of the writer's reluctance to lengthen what is already a long paper.

The igneous origin of these pegmatites having been placed beyond reasonable doubt, a few additional details may be given here as to their chief petrographical characters. They are most commonly composed of quartz, microcline, and muscovite, and the smaller veins are nearly all of this type. An important feature is that there are always at least two faces of the prism developed in the last-named mineral, often more; but we know of no case in which all six sides are shown in a large crystal. Moreover, the white mica is not often in immediate contact with the microcline. It is usually separated from the latter by a very variable amount of quartz. The other types of pegmatite are a rude kind of graphic granite, quartz-microcline rock common in the larger veins and masses, and a quartz-muscovite rock which occurs only in small patches. In addition to these normal constituents, garnet and schorl are associated with the pegmatites. The former is locally abundant, though absent over considerable areas; the latter also is abundant locally, and is the black variety, brown in thin section.

We may conclude the petrographical description of this intrusion with a short account of some of the special features of the minerals which enter into the composition of the rocks. The brown mica has been isolated and analysed. The iron occurs as $FeO = 20{\cdot}87$ and $Fe_2O_3 = 2{\cdot}56$ per cent. The magnesia averages only 4·32 per cent. As the mineral is approximately uniaxial, the mica may be fairly classed as haughtonite. The inclusions in it are grains of garnet and zircon, and the latter has always a black 'skin' in addition

[1] See a paper by the present writer on the 'Origin of certain Gneisses,' Geol. Mag. for 1892, pp. 64–65.

to a pleochroic halo. Apatite has not been observed, and its absence distinguishes this brown mica from that of the newer (pre-Old Red Sandstone) granites, in which apatite occurs abundantly.

The white mica contains 8·47 per cent. of potash, and only 0·91 per cent. of soda. As it is widely biaxial, it may be fairly claimed as typical muscovite. The large micas of the pegmatites have the same composition as the small individuals of the 'permeation-area.'

The plagioclase has in the majority of cases been proved to be oligoclase, but it is often impossible to determine accurately its true nature. Traces of zonal banding are common in the plagioclase of the larger masses of the intrusion. This plagioclase-banding is often very puzzling. A part of a crystal is well-twinned oligoclase; the rest may show no twinning at all and be water-clear. The twinned portion merges insensibly into the untwinned. A common phenomenon is a binary twin, with little patches of plagioclase-banding in one half only, and from this we pass to the simple binary twin, identical as regards state of decomposition with the undoubted oligoclase. The passage strongly suggests that the binary twin is not orthoclase, and for that reason a note of interrogation is often put after 'orthoclase' in describing the specimens.

The analyses of the microcline are not satisfactory. The variation in the proportion of potash to soda is such as to suggest that some albite is invariably intergrown with the microcline proper. The individual crystals in the pegmatite fringing the third igneous mass are often of enormous size.

The highly crystalline condition of the rocks into which the above-described igneous masses have been intruded has been already referred to. Their grain is coarser than in most other areas, and the micas are especially large. The general aspect of the north-western portion of the district is distinctly gneissose. Proceeding in a south-easterly direction, this gneissose character is gradually lost, the rocks become finer in grain and more like the ordinary schists of the Southern Highlands. Eventually they assume the phase of phyllites in the case of the originally fine-grained sediments, and of more or less crystalline arkose grits in the case of the coarser deposits. This decrease in crystalline aspect is most rapid when measured in a south-easterly direction from the pegmatites, which have been proved to form the outer edge of the intrusion. Further, the variation in crystalline aspect has been found to be accompanied over a large area by a change in the minerals of which the rocks are composed. This is especially well-marked in the case of the aluminous silicates (sillimanite, cyanite, and staurolite), minerals which have been clearly recognized as the products of thermo-metamorphism (so-called contact-metamorphism). In the area in question the three minerals mentioned above characterize three more or less distinct zones, the boundaries of which are sensibly parallel with a line joining the most southerly or south-easterly exposures of the igneous intrusion at the surface. Thus the distribution of the minerals, as well as the crystalline phase of the rocks, is seen to be dependent on nearness to or remoteness from the igneous masses; and in presence of such evidence it seems only reasonable to attribute both the minerals and the crystallization to the thermometamorphism of the intrusion.

IV. Minerals of the Metamorphic Rocks.

In the following petrological descriptions, the minerals that are especially suggestive of this mode of origin will first be dealt with, and a brief account will then be given of the rocks in which they occur.

(1) *Sillimanite* or *Fibrolite.*—This mineral occurs so abundantly in the region of greatest metamorphism as to justify the application of the term 'sillimanite-zone' to the area in which it occurs. Over at least 50 square miles fully one half of the rocks contain this silicate of alumina, and usually in considerable quantity. Its distribution in the north-west is probably limited by a huge fault shown in the Map (Pl. XV.), but to the south-east sillimanite does not occur far from the acid edge (pegmatite) of the great intrusion. As the mineral has hitherto been so little known to most British geologists, it may not be out of place to give a brief summary of the previously published accounts of it. Of the earlier writers,[1] Dr. E. Kalkowsky, in a paper on the 'Gneissformation des Eulengebirges,' Leipzig, 1878, notes the presence of sillimanite-needles in quartz (*faserkiesel*). Several communications by different authors appeared soon after, but it seems that Michel-Lévy was the first to recognize its mode of production. In a paper of two pages in the Bull. Soc. Franç. Minéral. (1880) he gives an account of its optical properties and chemical composition. Its origin is then traced to 'contact'-action; and he concludes by stating that Sainte-Claire Deville had succeeded in producing it artificially by heating to redness a mixture of aluminium fluoride and silica. The contact-origin of this mineral has been further proved by Dr. Barrois's papers on the Guémené and Rostrenen Granites, published in the Annales Soc. Géol. du Nord.[2] In these cases the sillimanite occurs in sandstones of Lower Silurian age. In the Hautes Pyrénées Lacroix found sillimanite in the andalusite of the maclites (massive andalusite-rocks), and he also ascribed it to contact-action.[3] In this country Prof. Heddle recorded sillimanite from Pressendye Hill in Aberdeenshire, and also from Glen Clova. Soon afterwards Prof. Bonney published an account of its occurrence in the Rock of the Black Dog, again in Aberdeenshire; but neither of these writers made any suggestion as to its mode of origin. In 1890 Miss Gardiner communicated to this Society the results of her work on the contact-

[1] A list of the German memoirs is given in Rosenbusch's 'Mikroskopische Physiographie' (art. Sillimanite, 3rd ed. 1892, vol. i. p. 440).

[2] 1884, vol. xi. pp. 134 *et seqq.*, and vol. xii. pp. 1 *et seqq.*

[3] 'Roches métamorphiques et éruptives de l'Ariège,' Bull. Serv. Carte Géol. France, No. 11, vol. ii. (1890); see also 'Note sur une association de sillimanite et d'andalousite,' Bull. Soc. Franç. Minéral. vol. xi. (1888) p. 150.

metamorphism due to the Galloway Granite.[1] Her investigations have an important bearing on the origin of the crystallization of the Highland schists. Sillimanite is shown to occur close to the granite both in altered grits and shales, and is associated with quartz and two micas.[2]

In the area under consideration sillimanite occurs in two phases. First and by far the most abundant mode of occurrence is that known as *quartz sillimanitisé* or *faserkiesel*. This substance consists of minute glassy needles of sillimanite embedded in quartz. The centre of a patch is seen, under the microscope, to be made up of a great number of massed needles. Where the needles are fresh, they produce the effect of ice-needles in snow; that is, the centre of a patch is opaque snow-white. Away from the centre the needles decrease in number, and at the edges isolated needles are seen. Under crossed nicols the mineral gives high polarization-tints, and the usual linear arrangement is well brought out in the centre of the mass, giving the whole a more intense *flaser*-appearance. The patches of *faserkiesel* weather out on the surface of the rocks. They appear as quartz with a silky, pearly, or nacreous lustre, the tint varying from pure white to yellowish or greenish. The aspect of a fresh hand-specimen is perfectly characteristic, and quite unmistakable after it has once been clearly recognized. The second mode of occurrence of the mineral is that in which it is more or less independent of quartz. The needles in this case are arranged in wavy threads and films, and somewhat resemble spun silk. They are massed in the film except at the ends, where the needles diverge, and are fewer in number, thus producing the impression of a frayed edge. This frayed edge interlocks with a similar edge of some other mineral, usually brown mica. Sillimanite in this form occurs chiefly in small patches, and is not often recognizable on a hand-specimen.

(2) *Cyanite* or *Disthene*.—Like the last-described mineral, this is also a silicate of alumina, and is met with abundantly on weathered faces of the rocks in which it occurs. The detailed mapping has shown that a more or less interrupted belt of cyanite-bearing rocks follows the south-eastern edge of the 'sillimanite-zone' in such a way as to form an outer zone of metamorphism. The interruptions of the belt are due to its being crossed by rocks that are not likely to contain free silicate of alumina in any great quantity, such as siliceous rocks; for these zones are not rigidly coincident with the strike of the rocks of the district. The general trend of this zone is shown in the Map (Pl. XV.), and specially good places for collecting are indicated by the letter *c*. Cyanite occurs macroscopically in two forms: first, as single crystals scattered fairly evenly through the mass of the rock, and secondly, as more or less segregated or aggregated crystals. The single crystals show very little variation in form. They may be briefly described as follows:—Take a piece of common lead-pencil half an

[1] Quart. Journ. Geol. Soc. vol. xlvi. p. 569.

[2] Since I wrote the above, Mr. W. M. Hutchings has kindly lent me some slides of highly-altered ash, taken a few feet from the edge of the Shap Granite. In these sillimanite-needles are seen, embedded in quartz.

inch long; cut off two slips along the length of the pencil, so that the flat faces are parallel and the distance between them is roughly half that of the diameter of the pencil; then round the ends a little, and a fair model is produced of all the isolated crystals of cyanite in the district. This rounding of their angles and ends is a never-failing character. As the crystals become smaller, the tendency to roundness in outline becomes more marked; but while the brachypinacoid (0 1 0) is often obliterated in this manner, the macropinacoid (1 0 0) never is quite lost. All crystals of cyanite cleave with extreme facility parallel to the latter face, and fairly well parallel to the former. They break easily, but at irregular intervals, nearly at right angles to the macropinacoid, across the length of the prism. These planes of fracture are the well-known 'gliding-planes' parallel to the basal pinacoid. Further, these evenly-distributed crystals are never twinned, so far as has been observed in this district. An interesting feature in the larger isolated crystals is that, instead of showing the typical blue colour to which the mineral owes its name, they seem to be coated with a black dust, having the appearance of graphite or 'black lead.' As such crystals are extremely abundant over large areas, they may be conveniently designated 'black-leaded,' to distinguish them from the normally blue-coloured specimens. The graphitic aspect of the black dust is, however, deceptive; for, on examining a cleavage-flake under the microscope, it is seen that these crystals have a vast number of grains (sometimes crystals ?) of iron ore scattered through them in a fairly even manner. It is impossible not to feel that the structure thus produced is of the same character as those described by Dr. Salomon, as occurring in the inclusions in the tonalite of Adamello; and these 'black-leaded' cyanite-crystals exhibit 'typical contact-structure.' Sections of this mineral under the microscope are easily recognized. In the first place, they have a clear glassy appearance, very rarely showing the blue colour of the large crystals. Then their high refractive index, which makes their borders and characteristic cross-jointing or cleavages stand out in bold relief, assists largely in the determination. A section parallel to the length of the crystals extinguishes almost straight, if it be also parallel to the face 0 1 0, and at about 30° if parallel to the face of easiest cleavage (1 0 0). Under crossed nicols they give moderately high polarization-tints. It may be here added that the isolated crystals tend to lie with their broadest face (1 0 0) parallel to the dominant foliation of the rock; but it is doubtful how far this holds good in the case of very small crystals. Cyanite also occurs as segregations or aggregations. In both cases the blue colour is well shown; but by far the most beautiful crystals occur in quartz-segregations, from which, unfortunately, it is impossible to extract them, as they break so much more easily than quartz.

My colleague, Mr. J. J. H. Teall, F.R.S., in addition to kindly helping me with the petrological descriptions of the slides, has further drawn my attention to some very remarkable literature bearing on the points here discussed, and has shown me the following passage in Dana's 'System of Mineralogy,' 6th ed. 1892, p. 499:—"Vernadsky shows that cyanite is transformed at 1320°–1380° into sillimanite" (Bull. Soc. Franç. Minéral. vol. xii. p. 447, 1889, and vol. xiii. p. 256, 1890). Thus the experience of the laboratory furnishes an explanation of the fact that sillimanite characterizes the inner, and cyanite the outer, zone in an area of thermometamorphism. Further, we obtain a general idea of the high temperature to which great masses of the Central Highland rocks have been raised. This temperature was probably greater than that suggested by Vernadsky's experiments; for as the specific gravity of sillimanite (3·23) is less than that of cyanite (3·56–3·60), the temperature required to effect the change would almost certainly be increased by pressure.

(3) *Staurolite.*—In addition to the zones already described, there is a third still farther removed from the igneous rocks, characterized by the presence of staurolite. This is the best marked of all; for, with the exception of an interval of a few hundred yards, the zone is nowhere interrupted by siliceous rocks throughout a distance of nearly 10 miles. This is probably due to the fact that the zone very nearly corresponds with the actual outcrop of a particular bed. Moreover, if a line be drawn joining up all the most southerly outcrops of the intrusion, then this zone is roughly parallel with that line. In hand-specimens staurolite usually weathers out as yellow-tinged crystals. In the more crystalline areas these are of large size, and twinning is the rule, the exception being to find untwinned crystals, in which respect staurolite is the reverse of cyanite. For some undiscovered reason, twinning takes place so that the crystals cut one another at an angle of 60°. In other districts in the Central Highlands the twins frequently assume the form (roughly) of a Maltese cross; but here they rarely do so. The crystals may be seen, from the part projecting from the rock, to be mostly eight-sided or six-sided. Under the microscope they vary in colour from pale yellowish-brown to red, and are distinctly pleochroic. Their refractive index is a little higher than that of quartz, and they are much cracked, the cracks standing out in strong relief. The mineral is composed of silica, alumina, and iron, thus differing from sillimanite and cyanite in composition, and approaching the garnets. It is essentially an unstable mineral, in marked contrast with its ally, the garnet, which is unusually stable. It is rare to find a crystal of staurolite which has not decomposed more or less to a 'shimmer'-aggregate; and if a weathered-out crystal be pounded up, scarcely a single grain will be found to possess the optical properties of the original mineral.

(4) '*Shimmer'-aggregates.*—Sillimanite, cyanite, and staurolite all tend to pass over to a fine-grained material giving a 'shimmer' of high polarization-tints under cross nicols. Dr. Barrois, *op. jam cit.*, says they have been altered (*épigénisé*) into white mica. But though the shimmer of colour may be due to very minute scales of this mineral, they must be cemented by some hard substance, possibly quartz; otherwise the replacing material would not project, but

would fall out and leave hollows. Moreover, in many cases the pseudomorphs after staurolite are often harder than white mica. In staurolite and cyanite the replacement starts from the outside, and then frequently proceeds into the interior along cracks so as to leave cores of the unaltered mineral, thus reminding one of the well-known mode of alteration of olivine into serpentine. In the case of sillimanite in quartz the reverse happens. The sillimanite, where massed, practically reaches the outside of the quartz-lenticle and decomposes ; but the projecting needles round the edges of a felted mass are buried in quartz, and so protected. In consequence, a ‘shimmer’-aggregate may be proved to be sillimanite by carefully examining its edges for the ends of the needles under a high power. The fine *flaser*-aspect of the sillimanite may often be recognized under crossed nicols, even when complete alteration has taken place.

(5) *Micas.*—Brown and white micas occur more or less abundantly in nearly every rock in the district. In the most altered areas the crystals are usually large, and arranged parallel to the foliation-planes. They are rarely, if ever, idiomorphic. The brown mica has been isolated and analyzed. It is rich in ferrous oxide, and low in ferric oxide and magnesia. As it is also approximately uniaxial, it may be classed as haughtonite. Seen in sections at right angles to the basal plane, it is always strongly pleochroic. There are two well-marked tints observed in such crystals : the first is pale brown, changing to blackish brown on rotating the nicol 90° ; and the second is very pale red-brown, changing to a deep red-brown. This mineral has a curious mode of occurrence in the less highly-altered schists. Oval grains of brown mica are seen in the angles of the puckers of fine schists, so that the basal cleavage of the mineral is at right angles to the foliation-planes. The puckering may be frequently traced through the grains by means of minute inclusions of iron ores. A special point of importance is the occurrence in many cases of numerous pleochroic spots in the red-tinted micas (rare in the brown). In sections parallel to the vertical axis these spots are almost invisible when the short axis of the polarizer lies at right angles to the trace of the cleavage, and the crystal is very pale in colour. When the short axis is parallel to the cleavage, the spots are deep black and the mica is deep red-brown. These spots are seen to have tiny grains in their centre : in some cases these are iron ores ; in others they have been extracted and proved to be epidote. In a thin section the epidote-grains can be distinguished from grains of zircon by the fact that the latter (in igneous rock at least) always have a black ‘skin’ round them, independently of the pleochroic halo ; but this black ‘skin’ does not appear to ever surround the inclusions of epidote. This type of mica, with its pleochroic spots, has been so often recorded in contact-rocks, such as those of Shap and New Galloway in this country, and those of the Britanny granites in France, that it may be fairly claimed as a ‘typical mineral’ produced by thermometamorphism. In the most highly-altered rocks white mica often occurs in considerably larger flakes than brown ; but in the finer sericite-schists it is always the smaller of the two minerals.

Oval grains, similar to those of brown mica, are rare; but when they do occur the rocks containing them are always intensely crystalline. The only inclusions of importance in this mineral are minute flecks of brown mica lying parallel to the basal cleavage of the enclosing mica. Chemical analysis shows that potash and soda occur in the proportion of 7·56 : 3·2 per cent., so that the soda is considerably higher than in the muscovite of the igneous rocks. The white mica of these highly-altered rocks is frequently more or less embedded in the brown, in such a way that the basal plane of the latter makes an angle of about 60° with the former. When the muscovite appears in section as a number of tiny laths, these laths bear the same relation to the brown mica as the felspars do to the augite in an ophitic dolerite.

(6) *Garnets.*—The garnets in this area do not differ from those so abundant all over the Highlands, until we approach one of the igneous masses, or are well within the area of intense thermometamorphism. In this case they are of a weak port-wine colour, and remarkable for their transparency; such garnets do not habitually show the usual crystalline form (dodecahedron) when large, but are often like drops of transparent red gum. Both under the microscope and in the hand-specimen, they exactly resemble the garnets which Miss Gardiner has shown to be produced by the intrusion of the Galloway granite in the surrounding rocks.

(7) *Tourmaline* or *Schorl.*—This mineral has not been largely developed; but there seems good ground for stating that when it occurs in the pegmatites it is also developed in the adjacent schists. The number of instances is too small to enable one to speak confidently. The schorl of the igneous rock is brown in thin sections; it is dark olive-green in the schists (slide 4865). The blue schorl of the limestone is not specially connected with the pegmatites.

(8) *Quartz.*—Over an area of at least 60 square miles the larger grains of quartz possess a curious character. Under crossed nicols they do not extinguish as a whole; but neither can the extinction be fairly called undulose. There is a difference of several degrees in the extinction-positions of different parts of a large grain. Thus a grain will break up sometimes into five or six parts; while half are dark, the remainder are very nearly so; but there is no definite boundary to the patches, which fade into one another. This phenomenon is so constant in the area surrounding the intrusions, and so uncommon elsewhere, that it seems unreasonable to doubt that this curious optical property has been produced by intense heating. As is well known, the optical properties of many minerals are liable to be entirely changed by being kept at a high temperature for a considerable time.

(9) *Lime-silicates.*—A distinct group of minerals has been developed in the calcareous rocks of this district. The chief members of this group are malacolite, a green pyroxene, zoisite, epidote, idocrase, and sphene. A variety of pale-brown mica also occurs, but not in sufficient quantity to enable us to determine its composition; it has a somewhat different appearance from, and is less

pleochroic than, the ordinary form of that mineral. Most of these minerals are well known to occur in *cipolino* and in varieties of *kalksilicat-hornfels.*

(10) *Felspar.*—Microcline occurs in the principal band of the group of calcareous rocks mentioned above. With this exception, almost the whole of the felspar developed in the metamorphosed rocks is plagioclase; and, where the identity of the species can be established, it is mostly oligoclase. This fact is of extreme importance, because the bulk of the felspar-pebbles in the grits of the less-altered areas are also oligoclase; and these grits can be clearly seen to pass into gneisses as they approach the great intrusion. Fresh specimens of the oligoclase are seen under the microscope to be water-clear,[1] a feature which appears to be characteristic of these rocks. The larger grains are not only twinned, but the twinning-planes usually pass right across the crystal. In the oligoclase of the igneous rocks the twinning-planes frequently stop short of the edge of the crystal, *i. e.* the edge is more or less completely untwinned. No trace of zonal banding has been met with in the felspars of the metamorphosed rocks.

V. Rocks of the Metamorphic Area.

A brief description may now be given of the principal types of rock in which the minerals above described occur. They may be divided into four groups: firstly, those of the sillimanite-zone; secondly, those of the cyanite-zone; thirdly, those of the staurolite-zone: and lastly, those lying between the third zone and the Great Highland Fault, as seen on the banks of the North Esk.

(a) *The Sillimanite-zone.*

Quite in the north-western corner of the area here described the dominant rock is a coarse felspathic gneiss, of which the felspar is almost exclusively oligoclase. The felspar occurs in lenticles of variable size, more or less associated with quartz. These lenticles are separated one from another by felted masses of mica, both brown and white. As the lenticles get more and more elongated, and of greater thickness (they are at times 2 feet thick), a rudely parallel-banded, coarse gneiss is produced. Into this the tongues of igneous gneiss are intruded, and so inextricably are the two rocks interwoven that it frequently becomes impossible to say how much of the mass is igneous and how much of metamorphic origin. In such rocks sillimanite is rare. By an increase of the silica or alumina, these coarse gneisses pass insensibly into fine-grained, grey, siliceous rocks on the one hand, or into still gneissose, though less coarse, sillimanite-bearing rocks on the other. The former siliceous type occurs abundantly on the Driesh, the highest mountain

[1] Messrs. Harker and Marr have drawn attention to the clearness of the minerals in the metamorphic rocks surrounding the Shap Granite, Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 266.

in the district. A microscopic section (4881) shows this rock to be composed of quartz, felspar, biotite, and muscovite. Structurally it is a fine gneiss or schist; but the amount of free silica in the dominant rock of this mountain places the sedimentary origin of the schist beyond reasonable doubt.

The most gneissose phase of the sillimanite-bearing rocks is seen close to the outcrop of the limestone, in the crags south of the stables on the Lee Water. A microscopic section (4531) shows it to be composed of plagioclase (mostly oligoclase), quartz, and white and brown mica. The micas occur in films, and are associated with a considerable amount of sillimanite, which interlocks with the frayed edge of the brown mica. A few garnets are also present.

These three types, the coarse felspathic, the siliceous, and the coarse sillimanite-bearing gneiss, are very abundant in the western part of the sillimanite-zone. A less coarsely gneissose phase occurs in the great pass of the Unich, above Loch Lee, and extends almost down to the Loch. A specimen (4544) taken from Craig Maskeldie is a puckered, grey, gneissose rock in which segregation of felspar-lenticles is still fairly well-marked, and the surface is coated with *quartz sillimanitisé*. It is composed of quartz, felspar, sillimanite, muscovite, biotite, garnets, and iron ores (sillimanite-gneiss). Farther down the glen, and farther from an outcrop of the igneous gneiss, the same band shows still less segregation of the felspars, and a smaller quantity of sillimanite; indeed, Mr. Teall describes one specimen (4541) as a schist containing sillimanite rather than a gneiss.

Some garnetiferous varieties of the sillimanite-bearing rocks are seen on the top of the crags above Loch Brandy, and stretching thence down a narrow ridge to the Unich. The first of these is a very coarse garnet-schist (? gneiss) with minute patches of *quartz sillimanitisé*. Proceeding towards the igneous gneiss which crops out close to the Unich, a segregation of the components takes place. Siliceous patches with a silky lustre are interlaminated with more garnetiferous portions of the rock. A microscopic section of the former (4540) shows sillimanite-needles embedded in quartz. This is a perfectly typical specimen of *faserkiesel* or *quartz sillimanitisé*. Close to the Unich, where it is joined by the Longshank Burn, is a considerable mass of extremely garnetiferous coarse-grained rock, somewhat gneissose in aspect, and associated with much sillimanite. Seen in section (4543) it is composed of quartz with a little felspar, white and brown mica, and large, irregularly shaped wine-clear garnets. Iron ores and sillimanite also occur. Some of the sillimanite is enclosed in garnet, but most of it is of the filamentous type, fraying out on the edges and interlocking with brown mica. The garnets in this case form nearly one half of the rock, which is obviously so rich in silicate of alumina and iron as to place its sedimentary origin beyond dispute.

Some sillimanite-bearing rocks, with a peculiar mode of weathering, occur on the hill about $\frac{1}{2}$ mile E.N.E. of the church of Loch Lee. In these the *quartz sillimanitisé* projects from the weathered micaceous surfaces almost in the form of little cones from which the apex has been broken with a jagged fracture. These conical projections vary in colour from green to yellow. They give the rocks a very jagged or roughened surface, which can be easily noticed several yards off. A cross-fracture of such a specimen is generally compact, and, if fresh, not a trace is seen of the structure brought to light by weathering. About Tarfside, a rock very similar to the last in weathering, but with a still more compact fracture, keeps close to the outcrop of the limestone which was at one time extensively quarried. There is every reason to believe that a large proportion of the rocks to the eastward contain sillimanite in the 'film' phase, associated with frayed brown mica.

In the neighbourhood of Millden, on the North Esk, the little projections of *quartz sillimanitisé* are frequently met with on the weathered surfaces of the rocks. Fine examples of rather highly crystalline sillimanite-bearing rocks rise almost like dykes out of the ground, close to the Meallie Burn. This is on the northern side of the main river. On the southern side, somewhat similar rocks are seen above the large farmhouse of Dalhastnie, while in the little Dalscampie Burn, farther south-east, the least crystalline variety of sillimanite-bearing rocks is seen. It is a fine crystalline schist in which segregated quartz occurs in very thin films. A specimen (5107) is seen to be composed of quartz, chlorite, and white mica, with larger patches of quartz fairly free from the other components of the rock. Lying parallel with the schistosity are certain faintly-yellow lenticular patches, closely resembling 'shimmer'-aggregates. Their centres are invariably very finely fibrous, and a comparison with other slides leaves little doubt that these patches are *faserkiesel* or *quartz sillimanitisé*. No other sillimanite-bearing rocks are known to occur south-east of this locality.

There is in this zone a sill of basic igneous rock, which always occurs close to the limestone (see below, p. 350). In the most altered areas, *i. e.* the most gneissose, this sill is a more or less coarse, hornblendic gneiss, while in the areas where the felspar-segregations are of a less coarse type, it becomes a more ordinary hornblende-schist.

In addition to the rocks described above, a band of impure crystalline limestone is frequently met with. Its colour and appearance vary little if unweathered, but there is a good deal of difference in the decomposed rock, depending on the presence in greater or less quantity of iron-bearing silicates. Along the Lee Water it is bright bluish-grey, and a microscopic section shows it to be composed of calcite, green hornblende, zoisite, felspar, quartz, sphene, and pyrites. Blue tourmaline is rare.

The zoisite is well marked by the weak indigo tint under crossed nicols. The mica, or some of it, does not look like the ordinary brown mica of the district, but it is not easy to isolate a sufficient quantity for analysis. Much of the sphene is in roundish grains. A very interesting type of the limestone is seen in an old quarry at Stylemount, halfway between Loch Lee and Tarfside, going by the old road.

Since the quarry was opened, the rock has decomposed to a depth of several inches to a soft, brown, ferruginous mass; the unweathered rock is a bluish-grey limestone. A specimen of this (4869) shows calcite, green hornblende, malacolite, zoisite, sphene, felspar (including microcline), and iron ores. The microcline is very remarkable, because we have never yet found it in any of the metamorphosed rocks of the Central Highlands, except where it was part of an original crystal of an igneous rock, as the Ben Vuroch granite. There is no white mica in the limestone, and further there is very little in the rocks next to the limestone, though they contain much brown mica. White mica increases rapidly in amount as we leave the limestone: it is, indeed, doubtful whether this mineral is ever absent from the altered sediments of this area, except close to the calcareous rocks. Microcline continues to be abundant in the limestone over all the Tarfside area. The malacolite has no idiomorphic boundaries, but it occurs in much larger individual crystals than the other constituents.

At the base of this little calcareous series are one or more bands of siliceous rocks, which weather like very massive quartzites. They are exclusively confined to the north-eastern side of the North Esk, where they cover a great area and are the lowest rocks yet known to occur in the Southern Highlands. From a nearly pure quartzite they vary to a felspathic phase, in which both white and brown mica are present. Such a rock is seen under the microscope to be markedly foliated. The felspar occurs in little patches shaped rather like a double wedge: these are joined together by their taper ends and so give a well-marked foliated aspect to the rock, quite independently of the micas. It can only be fairly called a muscovite-biotite gneiss, but its extremely high percentage of free silica puts its sedimentary origin beyond doubt.

(b) *The Cyanite-zone.*

Though highly crystalline, the rocks of this zone are not so coarse in texture as those of the sillimanite-zone in the same neighbourhood. This is shown both by the size of the micas and also by that of the individual grains composing the felspar-segregations. To begin with the rocks in which the characteristic mineral is met with: cyanite is shown in a slide made from the schist close to the old limestone-quarry in Glen Clova; it is not visible in a hand-specimen. This schist is fairly soft and finely puckered, being practically a sericite-schist, and is dotted over with specks of brown mica. Under the microscope it is seen to consist of quartz and two micas, the flakes of white mica frequently meeting so as to form a number of small angles; and in these angles the brown micas, seen on the surface of the rock, mostly lie. They are the typical red-brown contact-mica, and are full of intensely pleochroic spots. In addition to these micas, a few crystals of garnet, and crystals (or more often aggregates) of cyanite occur. Farther up the glen larger crystals of cyanite are seen in the fallen blocks of gneiss, above the farm-steading of Alton. The gneiss consists of large flakes of brown and white mica lying in layers in a fine gneissose matrix, mostly of quartz and felspar. In Bonhard Corrie, a short distance north-west of the Clova Hotel, the weathered surfaces of some of the finer-grained rocks are coated with a vast number of tiny crystals of blue cyanite. The same is true of the fine gneisses at the head of Saughs Burn. About Loch Lee rather coarsely-micaceous rocks (fine gneisses) frequently show cyanite-crystals on their weathered surfaces. A specimen (4547) is composed of quartz, muscovite, and chlorite, with a little garnet and iron ores. In this as a matrix are set glassy crystals of cyanite, the high refraction and cross-cleavage cracks being well shown.

A section was also made of a rock-specimen (4539), occurring close to the last, in which the cyanite is not so well preserved. The matrix is composed of quartz, chlorite, muscovite, and a little felspar, with iron ores, garnet, and tourmaline as accessories. In this are set a number of vividly-polarizing aggregates, in the centre of which small patches of cyanite may still be recognized. Comparing slide No. 4539, containing cyanite, with No. 4541, containing sillimanite, in what can be clearly proved to have been originally the same rock, the transverse section shows that in the latter a further segregation of felspar has taken place, and the rock is on the whole more crystalline and gneissose. That is, the development of sillimanite in place of cyanite in the same band is accompanied by a higher phase of crystallization in the whole rock.

Some of the finest and most interesting specimens of cyanite are seen on the weathered rock-surfaces on the northern flank of Glen Effock, about halfway up the hill. Almost every crystal, and they are both numerous and large, shows in perfection the regular dissemination through it of iron ore-grains (ilmenite). They probably form about one fourth of the whole, as seen under the microscope. The structure is best marked in thin cleavage-flakes, which can be taken off with a blunt knife. At the head of Glen Effock (a little north of the word 'Cruys' on the one-inch Ordnance map, Sheet 66) there are some rather coarse quartz-segregations, in which are embedded the most perfect specimens of bright blue cyanite-crystals to be met with in the whole district. On Bulg, a mountain close to the main stream of the North Esk, some way below Keeny or Millden, a finely-marked horizon of cyanite-schist is met with, striking E.N.E. across the river. The cyanite here occurs principally as 'blackleaded' crystals in a fine-grained schist composed of felted mica cemented by little grains of quartz and felspar. The amount of this rock is very large, and specimens of it occur abundantly as drifted boulders in the fields between the Wood of the Burn (on the North Esk) and Fasque. A section of such a rock shows crystals of cyanite full of black inclusions, set in a matrix of quartz and brown and white mica. The cyanite is surrounded by the typical 'shimmer'-aggregate. In addition to these evenly-distributed crystals, cyanite is also to be found on Bulg in aggregated masses, sometimes as large as a man's head. A microscopic section (5105) was made from the edge of one of these aggregates. The cyanite is clear and glassy, and only one little spot shows the blue colour.[1] It is set in a matrix of chlorite (after biotite), white mica and iron ores, associated with a curious dusty material, probably quartz full of minute inclusions. Some of these are large enough to be made out as garnets, but most of the dust is black and probably consists of iron ores.

Now, comparing the rocks of this neighbourhood with those seen about Loch Lee and the watershed of Glen Clova, there is a very great difference between the matrix in which the cyanite is set in the southern and northern areas. In the latter the micas are frequently large, and each individual may be easily seen by the unaided eye; so that it is not correct to say that *any* cyanite-bearing rock is less crystalline than *any* sillimanite-bearing rock. But it is absolutely true that a specimen of the former is *invariably* less crystalline than a specimen of the latter lying between that cyanite-rock and the nearest outcrop of igneous gneiss.

In addition to the cyanite-bearing rocks described above as occurring in this zone, there are some gneisses, quartzites, and grits. The former are felspathic in the northern area; but though lenticles of felspar, or quartz and felspar, are often met with, the individual grains are much smaller than those composing similar lenticles in the sillimanite-zone close by. The quartzites are thin bands occurring near the Clova Hotel and in Glen Effock. They have a very bedded look, due to the presence of thin layers of white and brown mica. But these layers have nothing to do with original bedding, for they are entirely parallel to the planes of strain-cleavage. The grits are especially interesting. On the eastern side of Loch Brandy, as well as in Ben Reid on the west, there are some rather gneissose felspathic rocks, which from their weathering appear to be intensely altered felspathic grits, traces of the incompletely-absorbed felspar-pebbles being still visible. Moreover, at the former locality these pass gradually into more siliceous rocks, in which much-deformed quartz-pebbles can be recognized in a highly siliceous matrix of quartz-schist. The high percentage of silica was not favourable to the development of new minerals, and the original clastic character of the rock can still be made out. Again, starting from the southern side of Glen Effock and proceeding along the low ridge between the head of Keeny Burn and the main stream of the North Esk, this phenomenon is repeated far more slowly. The rocks gradually become less gneissose, and traces of pebbles are seen here and there, every little infolded patch with an originally siliceous matrix being an unquestionable pebbly grit. Gradually even the felspathic grits show clearly their original clastic character, till, as we approach Bulg, the whole mass of the group of pebbly grits is clearly recognizable.

On Cairn Caidloch, a mountain due south-east of Loch Lee, is a mass of pure white quartzite. On breaking the loose blocks, they

[1] The blue colour is hardly ever seen in microscopic slides; when it is, the colour occurs only in isolated spots, like the yellow specks in cordierite, etc.

are found to contain little crystals of an emerald-green mica. The extreme purity of this quartzite, coupled with the presence of this very rare mica, enables us to recognize the rock instantly. It is here quite close to the rock containing the largest isolated crystals of cyanite, with ilmenite-inclusions, that occur in the whole district.

(c) *The Staurolite-zone.*

The first staurolite-bearing rock was met with on the south-western side of Glen Clova, just where the pack-road to Glen Prosen reaches the crest of the hill. The staurolite weathers out of the rock in six-sided crystals, which are frequently twinned. The crystals are embedded in a matrix of fine sericite-schist, spotted over with specks of brown mica similar to those seen in the schist close to the limestone. This outcrop is separated from the main mass of staurolite-bearing schist by a great development of the pebbly grits of the Southern Highlands. The pebbles in the grits can still be clearly recognized, in spite of the profound alteration which the rocks have undergone.

The main mass of staurolite-schist commences on the ridge that forms the watershed between Glen Effock and the West Water (Burn of Saughs in its upper part). A specimen taken from the Cruys (4862) is a silvery mica-schist, with conspicuous staurolite-crystals on the weathered surface. Under the microscope only a few small patches of staurolite are left as kernels to 'shimmer'-aggregates, which are set in a schist-matrix composed of quartz, white mica, and chlorite (? after biotite). Small garnets and iron ores are scattered through the slide, while blue tourmaline is occasionally seen.

Following the outcrop of this staurolite-schist along the ridge, the crystals that weather out are seen to diminish in size. They show also a tendency to aggregate together, so that several smaller crystals are twinned obliquely with a larger one.

Staurolite-bearing rocks are abundant in the north-western face of Bulg; these are mostly compact schists with little crystals of staurolite weathering out as small yellow projections. Under the microscope the matrix is seen to be composed of brown and white mica and quartz. The latter occurs as evenly-distributed grains with the micas, and also as clear patches in the small segregations. These, under crossed nicols, show the signs of optical strain common to nearly all the larger grains in the contact-rocks. In the schist-matrix are set a great number of what were once staurolite-crystals. For the most part they are replaced by 'shimmer'-aggregates, in some of which cores of staurolite are still visible; the boundaries of the aggregates are those proper to the mineral replaced. A specimen from the south-east of Bulg, close to the 949' bench-mark, shows the typical yellow projections on the surface. The matrix (5100) is composed of white and brown mica and a little quartz. In this are embedded a considerable number of quite fresh garnets, and still more numerous grains and crystals of staurolite. The latter mineral is a good deal altered in the usual manner.

The most southerly outcrop of staurolite-bearing rock is seen on a narrow ridge north-west of Cornescorn Farm, rather less than half-a-mile from the house. Comparing this rock with a specimen (4862) from the Cruys, it is seen that while the latter contains large crystals of staurolite and the matrix is coarsely crystalline, in the former the crystals are quite small and set in a fine schist-matrix.

These staurolite-bearing rocks are frequently seen on the ridge to be close to a mass of pebbly grits, just as in Glen Clova. At the north-western end of the ridge the grits cannot be recognized as such ; they are here represented by distinctly coarse schists or fine gneisses, often garnetiferous. As we recede from the area of intrusion little patches occur, in which the pebbles begin to be recognizable, and at the great gap in the ridge where it is crossed by the old road to the West Water, the bulk of the rocks are unmistakably of clastic origin. They are, of course, much altered, and the matrix in which the pebbles are set is thoroughly schistose. The pebbles are also granulitized.

In addition to these grits there is in this zone a little band of very pure quartzite, containing bright emerald-green crystals of mica. This rock is unmistakable wherever seen, and it follows the staurolite-schist continuously for some miles, after which it is frequently met with as small infolds, fixing accurately the horizon of the surrounding rocks. It is no exaggeration to say that this quartzite gives the clue both to the structure of the country and to the succession of the rocks, for it is the same rock as that described on Cairn Caidloch (see pp. 348–349) ; and it follows that this long outcrop of staurolite-schist is the *same bed* as the far more highly-crystalline cyanite-gneiss in Glen Effock. The latter rock is *much nearer* the igneous gneiss than the former.

The area close to the North Esk between the staurolite-zone and the Great Fault that bounds the Southern Highlands is chiefly composed of the massive pebbly grits and slates (or phyllites) so well known along the Highland border. In addition there are two rocks occurring close to the Great Fault, not known west of this district. These are the red-and-yellow jaspers, and a sill of basic igneous rock. The sill, when uncrushed, is a massive ophitic dolerite or fine gabbro, in which the augite is singularly fresh. The jaspers are essentially limestone and chert, altered by the contact-action of the sill.

We may ask, what further evidence is there of the effects of the great intrusion on these rocks? In the case of the grits the metamorphism is considerably greater in the north-western portion of their outcrop than in the south-eastern ; but the effect of contact-alteration on coarse grits has not yet been sufficiently worked out to justify our ascribing the increased metamorphism to that cause. However, a band of fine grey phyllite, folded in with the grits at the Mooran Burn, contains little rounded grains of brown mica closely resembling the brown contact-mica described above. The only other rock which affords clear evidence of increasing metamorphism to the north is the old basic sill. Near the Great Fault, where sharply folded, this is a dark green, fine-grained, schistose rock, mainly composed of chlorite, epidote, and carbonates. Half-a-mile north of the Great Fault it has gradually passed into a distinctly crystalline chlorite-schist.[1]

VI. Sedimentary Origin of the Metamorphic Rocks.

The sedimentary origin of the group of rocks last described will probably be admitted without question, but in the case of the more highly-altered rocks it is not so clear, and we have to depend rather on the broader structural features due to original stratification and on the chemical composition of the rocks for information as to their original characters. Thus the lowest rocks, the quartzites of the North Esk valley, are highly siliceous. Like the quartzites of Ben-y-Ghlo (North-eastern Perthshire), they contain a certain amount of felspar, and differ from the latter chiefly in the greater reconstruction that they have undergone. These highly siliceous rocks form nearly one-fifth of the whole area described. The quartzite is succeeded by the limestone—a perfectly normal sequence—while the character of, and the minerals contained in, this calcareous rock are such as the researches of Prof. Brögger and others would lead us to expect. Next to the limestone in the Tarfside area is a bluish-grey *hornfels*-like rock which contains sillimanite, and its cross-fracture is suggestive of its being an altered shale or clay; but it has not yet been analysed. There is, however, a mass of sillimanite-bearing rocks extending along the southern side of the North Esk for a considerable distance, as to the origin of which it is impossible to speak with certainty. But it may be fairly said that the evidence of the area as a whole points to their sedimentary origin, and there is nothing to suggest that they have been formed of crushed igneous material. The great mass of pebbly grits that can be traced to fairly coarse gneisses has already been mentioned; it may, however, be here added that the felspar, both in the grits and the gneisses, is almost exclusively oligoclase.

There are only two other bands of importance in the highly altered area. One of these forms the long outcrop of staurolite-schist already referred to. This rock contains no less than 36·4 per cent. of alumina;[2] consequently it could only have been shale or clay originally. The other is the green-mica quartzite, which often consists almost entirely of silica. Thus it will be seen that the greater part of the series was probably of sedimentary origin.

[1] [It has been suggested that the alteration of these jaspers and green chloritic phyllites (they are not truly crystalline schists) is no greater than that known to be produced by earth-movement alone, unaccompanied by igneous intrusions. It is doubtful whether such may not be the case, but the extreme clearness of the minerals in fresh specimens of the chloritic rocks suggests incipient thermometamorphism, as well as mechanical deformation.—May 29th, 1893.]

[2] See Table of Analyses, p. 355.

Moreover, it appears that the entire area is formed of some seven, or at most eight bands of rock, not one of which need originally have been of any great thickness. The detailed evidence for these statements is too long and complicated to be given here, and must be reserved for the official Survey memoir on the district.

VII. Evidence of Progressive Metamorphism.

The green-mica quartzite, which has been so often referred to, is seen on the eastern flank of Bulg. Ascending this hill and keeping along the ridge overlooking Keeny Burn, one meets with the quartzite at intervals infolded in staurolite-schist. On the same ridge farther north it can be followed continuously for some miles, while the metamorphism in the surrounding rocks is seen to be steadily increasing. Quartzite traverses the zone of cyanite-schists, and finally at East Craig, near the head of Inchgrundle Burn, it enters the sillimanite-zone, where it is penetrated by the third mass of the great igneous intrusion. Thus this quartzite, which is easily recognized and is not liable to undergo important alteration in consequence of its composition, may be followed through the various metamorphic zones. The band of rock adjacent to the quartzite, at the point farthest from the igneous mass, is a staurolite-schist. As we approach the intrusion, it becomes first of all a cyanite-gneiss, and finally, close to the contact, a coarse-grained sillimanite-gneiss. A more conclusive proof of progressive metamorphism in one and the same bed is not easily conceivable.

VIII. General Conclusions, and Summary of Results.

In concluding this account of the thermometamorphism of the South-eastern Highlands, there are two features that call for special explanation. These are, firstly, the great extent of the area affected, and secondly, the intensity of the alterations produced.

Much light is thrown on the first of these by the wide distribution of the pegmatites. The connexion between these pegmatites and the muscovite-biotite gneiss has been established in the first part of this paper. They have been shown to represent that part of the magma which consolidated last, and penetrated farthest into the overlying rocks. Their occurrence in any area may therefore be reasonably supposed to indicate the presence of an underlying mass of muscovite-biotite gneiss; as they increase or decrease in quantity, it becomes obvious that this gneiss is nearer to or deeper below the surface. But the area over which they occur is so great that, viewed on a large scale, the upper surface of this igneous mass must be roughly horizontal. And so we are led to the conclusion that these gneisses occur in huge sills or laccolites having approximately horizontal upper surfaces. That this is the true explanation of their mode of occurrence is rendered almost certain by the fact that we have already mapped a sill of muscovite-biotite gneiss, closely resembling the gneiss of the permeation-area in its mode of intrusion, in which both the top and the base keep at a fairly uniform horizon. This permeating sill is so inextricably interwoven with the cyanite-schists and other rocks with which it is associated that it was not until Mr. Teall showed how the minute structures of the thin intrusions were largely those of original igneous rocks that it became possible to believe that the whole complex mass was not of one age and of one mode of origin. If this mode of intrusion as sills or laccolites be admitted, it follows that one of the chief factors in increasing or decreasing metamorphism of the rocks affected must be the variation in depth of the sills below the surface. In the case of ordinary granite-intrusions it is customary to measure the metamorphism by the distance from the edge of the granite at the surface; but in the special case under consideration it must rather be measured by the height above the top of the intrusion.

The intensity of the metamorphism is doubtless largely due to the great depth below the surface of the rocks affected by the intrusion. The importance of this factor is conclusively shown by Dr. Barrois in his papers on the granites of Britanny. The same mass is there proved to have affected Cambrian, Silurian, and Devonian rocks; but the metamorphism in the Cambrian strata is more pronounced than in the Silurian and still more than in the Devonian. In other words, the lowest rocks are most affected.

In estimating the difference in depth at which the change took place in the rocks of the different periods, account must be taken not only of the thickness of the deposits, but also of the folding to which they had been subjected before the intrusion of the granite. If the folds were of great depth, the older rocks would be buried under a cover of newer strata, the original thickness of which would be enormously increased. Now, in the area to which this paper refers, it can be shown that the rocks affected are the lowest in the series and that they have been enormously folded, the depth of the major folds being apparently never less than 2000 feet. Thus the occurrence of sillimanite and coarsely crystalline gneisses over large areas may be easily explained by the great depth at which the metamorphism took place.

Rocks of the kind described in this communication are usually of great antiquity, and their especial features are regarded by some geologists as evidence of the existence in early geological times of physical conditions distinctly different from those which now prevail. The considerations which have been advanced above suggest that these special features may after all be due to the depth in the earth's crust at which the metamorphism took place, rather than to any physical conditions peculiar to early geological time. A comparison of the rocks of Shap and New Galloway with those of the district under consideration shows that the difference between them is one of *degree*, not one of *kind*, and strengthens Dr. Barrois's conclusion that "regional metamorphism and contact-metamorphism are much the same thing." The great geological age of most, if not of all, of the areas where phenomena similar to those we have referred to may be observed receives a simple explanation in the fact that an enormous amount of time is required to remove the overlying material by denudation.

Summary of Results.

1. In the area drained by the higher branches of the Forfarshire North Esk and South Esk, there are a number of outcrops of an igneous rock varying both in structure and composition.

2. The variations in structure are due to the presence or absence of foliation; while those of composition are due to changes in the relative proportions of the potash-bearing constituents (microcline and white mica) and those constituents in which the characteristic bases are soda and iron (oligoclase and biotite).

3. As the various intrusive masses are followed towards the south-east the amount of potash-bearing constituents increases, and the soda-felspar (oligoclase) diminishes.

4. The masses are frequently fringed with pegmatite (in which the potash-bearing constituents attain a maximum), especially on their southern and eastern borders.

5. The fact that these pegmatites occur over a very large area in the South-eastern Highlands suggests that a great portion of the district must be underlain by the intrusion of which they form a part.

6. The rocks that surround the areas in which the intrusive masses are exposed at the surface, are in a coarsely-crystalline condition.

7. This coarsely-crystalline character decreases as the rocks are followed towards the south-east.

8. Three zones characterized by the abundance of the three minerals, sillimanite, cyanite, and staurolite, may be roughly mapped out in the North-west Forfarshire area.

9. The sedimentary character of the metamorphic rocks as a whole is established by their chemical composition. Limestones, shales, quartzites, and coarse grits may all be recognized in the metamorphic zones.

10. A special feature in the altered rocks is the abundance of oligoclase. This is explained by the frequent occurrence of this mineral in the grits of the Highland border, and by the presence of a high percentage of alkalis in the phyllites. The potash which was present in the original rocks is entirely absorbed in the formation of the micas.

IX. Analyses of the Rocks.

The appended table of analyses [1] shows the composition of

A. The brown mica of the igneous rock.
B. The white mica of the igneous rock.
C. The brown mica of contact-metamorphism.
D. The white mica of contact-metamorphism.
E. The grey slate or phyllite, north of the Great Highland Fault.
F. The staurolite-schist north of Bulg.

[1] Analyses E and F were made by Mr. A. Dick, Jun., who moreover kindly helped me with the others.

The brown micas are both rich in ferrous oxide and low in magnesia. They belong to the haughtonite group. The white mica of the altered rocks contains appreciably more soda than that of the igneous rock; but the water of crystallization in the igneous mica is more than twice as great as in the contact-mica. This is true of both brown and white mica, but it is more noticeable in the latter case.

The grey slate or phyllite shows the high percentage of alkalis (6·41) which the finer sediments of the Central Highland Series contain. This rarely falls below 5, and often reaches 7 per cent.

The staurolite-schist affords a perfect example of a rock that can be proved to be a sediment by analysis. The percentage of alumina shows that it must have been a clay or a shale. No known igneous rock could have even approximately such a composition. The iron is about the same as that given in Prof. Renard's analyses of the Ardennes phyllite, and was originally in the form of pyrites.

	A.	B.	C.	D.	E.	F.
SiO_2	34·90	43·08	35·00	45·80	58·00	39·70
Al_2O_3	23·27	32·85	25·06	31·84	20·16	36·40
FeO	20·87	2·76	15·30	......	......	......
Fe_2O_3	2·56	·73	3·94	5·86	7·64	9·60
CaO	1·20	1·07	1·50	Trace	·73	1·20
MgO	4 32	·33	6·48	1·15	2·49	3 20
K_2O	6·94	8·78	9·31	7·56	3·91	3·60
Na_2O	2·01	1·00	1·84	3·19	3·41	2·58
Loss	3·60	9·12	1·72	4·90	3·03	4·50
Total	99·67	99·72	100·15	100·30	99·37	100·78

EXPLANATION OF THE PLATES.

(Map) Plate XV.

For many miles to the S.W. the Central Highland rocks have been found to be pierced by a number of coarse pegmatite-veins, the origin of which was uncertain. They have now been clearly traced to the parent mass, a muscovite-biotite gneiss, from which they proceed. The Map shows the only known outcrops of this parent mass in the South-eastern Highlands. To the N.W. the gneiss is let down by an enormous fault, but in all other directions it is sinking very slowly beneath the crystalline schists, the *upper limit*, however, being extremely uneven.

The small patches in the sillimanite are upward prolongations of the type of No. 2 or the centre of No. 3. No other outcrop of No. 4, the southerly termination of the intrusion, is known. The zones of staurolite- and cyanite-gneiss or schist really represent the variation in *height above* the upper limit of the underlying gneiss.

The great fault, shown to the N.W., crushes and greatly alters these metamorphic rocks, while the newer granite and diorite are more recent than this fault, as the Map clearly shows in the case of the diorite. Further, these newer intrusions largely destroy the older crystallization, as may be seen in Glen Clova. (Shown in the scars a little above 'G' of 'Glen' on the Map.)

Specially good places for observing the minerals sillimanite, cyanite, and staurolite are shown by the letters S, C, and St., and good outcrops of limestone by the letter L.

Plate XVI.

Fig. 1 (Slide No. 4540). Sillimanite-needles in quartz. × 40 diameters.

Fig. 2 (Slide No. 4531). Sillimanite associated with mica. Close to the Lee Water, North Esk. × 40 diameters.

Fig. 3 (Slide No. 4547). Cyanite-schist or gneiss. In the centre of the field is a crystal of cyanite enclosing a small garnet. The cyanite shows the planes of easiest cleavage, and the gliding-planes parallel to the base. The garnets are very similar to those shown in pl. xxiii. vol. xlvi. of this Journal, which have been developed by the contact-metamorphism of the Galloway Granite. × 20 diameters.

Fig. 4. Iron-ore inclusions in cyanite. 'Contact-structure.' Bulg, North Esk. × 20 diameters.

Fig 5 (Slide No. 5101). Staurolite surrounded by 'shimmer'-aggregate. × 20 diameters.

Fig. 6. Brown contact-mica, in the position of maximum and minimum absorption of light. One half shows the pleochroic spots in the most marked manner, in the other half the spots are almost invisible. Some cyanite (glassy-white mineral) is also present, showing the typical high refractive index by its strongly-marked borders.

Discussion.

The President said that it was of great advantage to the Society to have communications from the Officers of the Geological Survey now engaged in the work of mapping the Highlands of Scotland. In this paper the Author suggested solutions of some geological puzzles. He (the speaker) asked for fuller information as to the relations between the oligoclase- and microcline-bearing portions of the intrusive masses; as to the effects of the later granite; and as to the nature of the original rocks. Why was sillimanite found in one area, cyanite in a second, and staurolite in a third?

Prof. Judd called attention to the circumstance that the district described by the Author of the paper is near Kinnordy, the birthplace and home of the late Sir Charles Lyell. A year or two before Lyell's death, the speaker had spent some days in Glen Clova, in company with the veteran geologist, examining the geological structure of the district, and they had been greatly impressed by the intricacy as well as the suggestiveness of that structure. He complimented the Author of the paper on the thoroughness and excellence of his work in the district, and was pleased to find that the Officers of the Geological Survey, in carrying on their important studies of the Highland rocks, were ready to accept and weigh all evidence, without any reference to preconceived opinions. He remarked, in conclusion, that the paper constituted a splendid vindication of the principles so long ago enunciated by Lyell concerning the mode of formation of the 'hypogene rocks.'

Mr. Rutley fully endorsed the statements of the last speaker with reference to the value of the paper. He considered that some of the rocks exhibited bore a resemblance to those met with in the Malvern range, and that the latter had probably been altered under conditions similar to those which the Author had indicated. He thought it likely that both sillimanite and cyanite might be developed in the same rock, but that staurolite would be formed in a

MAP OF A PORTION OF
NORTH-EAST FORFARSHIRE
Embracing the Area of Outcrop of the Muscovite-Biotite-Gneiss, and showing the Zones of Occurrence of the Silicates of Alumina which are connected with the Intrusion.
BY GEORGE BARROW, F.G.S.
EXPLANATION
Newer Granite & Newer Diorite.
Permeation area and Intrusive masses.
Cyanite Zone.
Staurolite Zone.
S = Sillimanite
C = Cyanite
St = Staurolite
ABERDEENSHIRE
NEWER GRANITE
NEWER DIORITE
SILLIMANITE AREA
FAULT
WATERSHED
HIGHLAND FAULT
Craig Doune
Glen Mark
The Mark
Lee Water
Unich Water
Church
Tarfside
Millden
Ben Tirran
Cruys
Bulg
Glen Clova
Loch Brandy
Clova
Burn of Saughs
Hunthill
West Water
Wirren
Burn of Mooran
North Esk
South Esk
Rottal
Edzell
Pegmatite
Approximate Scale of Miles
0 1 2 4 6
Typo. Etching Co. Sc.

F. H. Michael del. et lith.

Mintern Bros. imp.

MINERALS DEVELOPED BY THERMOMETAMORPHISM
OF MUSCOVITE BIOTITE-GNEISS.

rock differing in composition from that in which the sillimanite and cyanite were developed.

General McMahon congratulated the Author on the interest and importance of his results. Of late years the geological mind had been so fascinated with the doctrine of dynamo-metamorphism that thermo-metamorphism and the foliation of igneous rocks prior to their complete consolidation had not received adequate consideration. It was encouraging to find that the tide had now turned. In the Himalayas, where the eruptive gneissose granite was of a strongly porphyritic type, he had observed in some places that the porphyritic structure was well maintained in veins sent off from the main mass into the adjoining sedimentary rocks. When an eruptive rock had been moved into position after the partial crystallization of the magma, such a result might be expected; and when a mass full of crystals was forced through the jaws of a fissure, parallelism of structure and the crushing and crumpling of crystals would inevitably result.

General McMahon also alluded to observations at the Lizard made by Prof. Bonney and himself, where the very coarse-grained gabbro was not in the main mass but in small dykes—a state of things analogous to the Author's observations regarding his 'giant granite'; and it pointed to a similar cause, namely, to the moving up at a later stage in an eruption of deeper-seated portions of a magma, the crystallization of which had considerably advanced.

Dr. Hicks said it was clear the results referred to by the Author could not have originated from one cause, but during a period when a combination of circumstances tended to favour such changes. Mechanical movements were necessary, if only to produce the fractures through which the magma and the heated waters and vapours permeated the rocks. The recent intrusions could have had little or no influence in producing the main results, as the evidence clearly pointed to their having taken place at a much earlier period. Similar pegmatite-veins were found traversing not only the rocks in the Central Highlands, but also those of the North-western Highlands, and fragments which must have been derived from such veins occurred frequently in the Torridon Sandstone. He was satisfied that the metamorphism of these rocks dated back to pre-Cambrian time; but there was no reason, of course, why such changes should not have taken place since that time. What he maintained was that for hundreds of square miles rocks of similar composition, and showing a similar state of change, were to be found, and that, under the circumstances, it was legitimate to attempt here a correlation by petrological characters. The differences observed were in the main due to the original character of the sediments, and to the readiness of the materials to undergo change. He congratulated the Author on the broad and liberal manner in which he had dealt with the several questions involved.

Mr. Marr said that, in their joint paper on the Shap Granite, he and Mr. Harker had expressed the hope that their work would be found to have a bearing on the general question of metamorphism.

The present communication showed that this was the case. He mentioned a letter from Mr. Greenly, who stated his belief that great masses of gneiss behave as igneous rocks, chiefly as sills, and that their foliation was acquired at the time of their intrusion. He (Mr. Greenly) had observed junctions and inclusions of schists in gneiss similar to those figured by Lawson, and had noticed the development of sillimanite and cyanite in such of the sedimentary schists as could have furnished material for the growth of these minerals.

Dr. Du Riche Preller wished to ask the Author whether and how far the more recent eruptive rock shown in the diagram, and marked 'newer diorite,' had affected the contiguous older igneous (granitic) mass. He congratulated the Author on his paper, and on the ingenious and conclusive way in which he had worked out the process of the potash-bearing part of the magma being forced out, and of the potash being subsequently consolidated and crystallized into microcline and muscovite. In this connexion, Dr. Preller asked what, according to the analysis made, was the relative proportion of silica and potash in the rock in which the latter formed so large a constituent. He also wished to express his entire concurrence in Dr. Hicks's view that the metamorphic phenomena described in the paper were due not only to thermal but also to dynamic agency. Indeed, it could not be otherwise, for, physically speaking, one agency involved the other.

Mr. Teall said he had watched the growth of this paper, and could testify to the great amount of important detail contained in it. It was almost impossible to give an idea of such a paper in the short time available for reading. Vernadsky had shown that cyanite could be converted into sillimanite by heating to about 1300° centigrade, and the latter mineral had been proved by Mr. Barrow to occur in the most highly altered area. It appeared probable, therefore, that the line separating the sillimanite-zone from the cyanite-zone was an isothermal.

The Author only claimed credit for holding fast to Lyell's principles of uniformitarianism. In answer to the President, he said that the metamorphism of the newer granites could be easily separated from that which he had described. Its effect was to destroy many of the characters due to the earlier action.

In reply to Dr. Preller, he remarked that the microcline of the pegmatites was perfectly normal in its composition, but that owing to the coarseness of the grain he had not determined the relative proportions of felspar and quartz.

30. Supplementary Notes *on the* Metamorphic Rocks *around the* Shap Granite. By Alfred Harker, Esq., M.A., F.G.S., and J. E. Marr, Esq., M.A., F.R.S., Sec. G.S., Fellows of St. John's College, Cambridge. (Read April 26th, 1893.)

[Plate XVII.]

Contents.

I. Introduction.

In a paper presented to this Society two years ago we described at some length the phenomena of metamorphism exhibited by the various volcanic and sedimentary rocks around the Shap Granite.[1] Since that time re-examination of some of the rocks, in the light of what we have seen in other parts of the Lake District, has enabled us to make certain corrections and additions to our work; and we now offer these with the intention of rendering the description of the metamorphism in some measure more complete.

The chief correction we have to make relates to the volcanic rocks on the northern side of the granite, which we formerly classed with the intermediate rocks (andesitic lavas and ashes) seen to the west of the granite. We now find that they constitute a distinct group of more basic composition. To such a conclusion, indeed, we should have been led by the low silica-percentages of some metamorphosed specimens from Low Fell,[2] a fact which we contented ourselves with recording as inexplicable on the supposition that the rocks had been originally similar to the Stockdale andesites. We have since learnt that basic lavas are very widely distributed over the Lake District, and that the rocks on the northern side of the Shap Granite must be placed in this division. They may with propriety be named basalts, although, on account of the absence of olivine, some petrographers would prefer to call them basic andesites. Since our description of the metamorphosed intermediate rocks was founded on a traverse along a definite line of strike through Sleddale Pike, it is not materially affected by this correction of the mapping; but two or three features which we noted incidentally as of exceptional occurrence in the metamorphosed andesites were really observed in the rocks to the north. These will be pointed out in the brief description which we now proceed to give of the metamorphism of the basic rocks.

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 266.
[2] Namely, 50·75 and 50·90, *ibid.* p. 300.

II. Metamorphism of the Basic Rocks.

In their non-metamorphosed state the basic lavas of this district differ from the intermediate lavas chiefly by being richer in porphyritic felspar, and that of a basic variety. As other characteristic features, we may note in some examples the somewhat greater abundance of iron ores and the presence of a rhombic as well as a monoclinic pyroxene. The rocks have undergone to a considerable extent the ordinary changes included under the term 'weathering.' Of the resulting secondary products some (bastite, kaolin, etc.) have remained as pseudomorphs of the minerals which generated them, while others, more soluble, have become disseminated through the mass of the rock, and especially collected in small fissures and in the vesicles with which the lavas abound. It is essential to bear in mind that these changes were effected prior to the metamorphism. We hope in a future paper to describe, from another part of the Lake District, the thermal metamorphism of comparatively fresh basic lavas and ashes. In the ashes accompanying the basic lavas of Shap Fell the weathering-products are more uniformly distributed, and metamorphism has developed fewer peculiarities; indeed, these rocks do not differ so much from the andesitic ashes as to demand special attention. (See Pl. XVII. fig. 5.)

Another change which the rocks under consideration have undergone, though not universally, is that resulting in cleavage. This is, as might be expected, most marked in the ashes, and seems to have often determined the direction of the foliation which these show when highly metamorphosed. Locally the lavas have also been crushed, though in less degree. The cleavage clearly preceded the metamorphism, and it is equally clear that it was itself preceded by the processes which filled the vesicles of the lavas with weathering-products. It is interesting to note how, in one and the same specimen, those vesicles which were occupied only by soft materials were completely flattened, while those filled with quartz successfully resisted deformation [760].[1] This feature is to be seen in many parts of the Lake District, and has been remarked by Sir Archibald Geikie.[2]

The first clear signs of metamorphism are seen on Low Fell at a distance of 1150 or 1200 yards from the granite, and, as usual, in the decomposition-products of the rock. One slide shows little streaks of minute flakes of brown mica, with an occasional small crystal of sphene [1279]; in others from the same neighbourhood green hornblende, also accompanied by sphene, occurs almost to the exclusion of the mica [759, 760]. Nearer to the granite the changes increase progressively, those in the contents of the vesicles and small fissures being in advance of those in the body of the rock. The most altered examples always consist entirely of minerals produced in the metamorphism, and present the clear, fresh appearance which seems to be so characteristic.

[1] The numbers in square brackets are those affixed to the slides in the collections of the Woodwardian Museum, Cambridge.

[2] Pres. Addr., Quart. Journ. Geol. Soc. vol. xlvii. (1891) *Proc.* p. 140.

In describing the metamorphism of the andesites, we have remarked that, of the coloured silicates, the one most usually produced is brown mica, hornblende being mostly confined to particular streaks and veins and to the interior of the vesicles, where some accumulation of calcite would favour the formation of a lime-bearing mineral. The basic lavas, as appears from Mr. Garwood's figures,

	Andesite, *West of Wasdale Pike.*	Basic Lava, *Low Fell.*	Basic Ash, *Low Fell.*
SiO_2	59·95 per cent.	50·75 per cent.	50·90 per cent.
CaO	3·95 per cent.	10·50 per cent.	3·80 per cent.

are much richer in lime, and accordingly we find green hornblende more common than mica, in the body of the rock as well as in the contents of the vesicles. The ashes associated with the basic lavas, however, have brown mica far more abundantly than hornblende, and the reason for this is seen in the low percentage of lime which they contain.

The mode of distribution of both hornblende and mica in the metamorphosed basic lavas points to these minerals having been formed largely by reactions among the weathering-products, such as the chloritoid substances, calcite, and kaolin; but some of the knots and patches doubtless represent remnants of pyroxene not destroyed by weathering.

In place of, or in addition to, the hornblende, we not infrequently find a colourless pyroxene with good prismatic cleavage and the optical properties of an augite. The occurrences mentioned as exceptional in our account of the andesites belong properly to the basic group. The mineral seems to be identical with the dominant pyroxene of the metamorphosed Coniston Limestones. It is usually found in narrow veins, associated with epidote [759], and within the larger vesicles [1614, etc.].

Epidote occurs abundantly, in more or less perfect crystals and in granular aggregates. The small grains show a pale yellow tint with feeble pleochroism, but in the larger crystals the pleochroism, changing from yellowish green to colourless, is quite vivid. Zonary growth is often indicated by the interior of the crystal showing stronger absorption than the margin. The two leading cleavages are usually evident, and when the crystals are well-bounded the habit is normal [1614, etc.]. We formerly noted epidote in the andesites of Little Saddle Crag, some 1350 yards from the granite-boundary, but, as the mineral was not found nearer the granite, we doubted its connexion with the metamorphism. In the basic lavas there is no room for doubt on this point, and the mineral is found as an accompaniment of very considerable metamorphism, though not close to the granite-junction. It is characteristically found among the contents of the larger vesicles, but occurs also in certain veins and in the general mass of the rock, where it appears to replace felspar [900, from Howe Gill]. The metamorphic origin of the epidote is evident from its mode of association with the pyroxene, garnet, etc., and the way in which epidote-crystals enclose bundles of actinolite-needles [1750, 1747]. (See Pl. XVII. figs. 2 and 4.)

Sphene, in small quantity, is widely distributed, usually building small crystals of the usual habit, but imperfectly developed. It has a pale brown tint in slices, with feeble pleochroism, never showing, so far as our observations go, the purplish colour and strong pleochroism of the sphene in the metamorphosed andesites. (See Pl. XVII. fig. 4.)

The iron ores of these rocks are magnetite and probably ilmenite, besides pyrites. It is not in every case easy to judge how far the first two can be regarded as metamorphic minerals, but we may fairly assume that, in the most highly altered rocks at least, the original iron ores have undergone complete reconstruction.

In all the most metamorphosed of the basic lavas a large part of the mass consists of a very finely granular mosaic, perfectly clear and colourless, which must represent in a general way the felspathic constituent of the original rock, in so far as that was not decomposed, and its elements worked up into silicates of different type. In the porphyritic felspars we can trace the progress of a recrystallization, which begins with the original turbid crystals and ends with clear granular aggregates retaining nothing of the original except its outline. The clear mosaic in the matrix is probably in a great measure similar to this. There is little indication of crystal form, and usually no twinning. It is quite possible that quartz may form part of this mosaic. At least, that mineral is easily recognized in separate patches, which probably represent the silica liberated by weathering and recrystallized during the metamorphism. The similar quartz which, in larger patches, figures constantly inside the vesicles has clearly been recrystallized in the processes of metamorphism, as appears from its relations to the associated minerals.

The metamorphism of the amygdules or infilled vesicles, which occur more or less plentifully in most hand-specimens of the lavas, requires special notice. The contents of the smaller vesicles, from 1 inch in diameter down to much less dimensions, have usually given rise to a mixture of green hornblende and quartz. In the smallest quartz predominates, in those which are a little larger hornblende, the quartz often surrounding it as a border, although these relations are not constant [1613, etc.]. The phenomena differ little from those of the similar vesicles in the andesites, except in the occasional presence of other minerals, such as granular sphene [760], epidote, or scattered irregular granules of a light brown garnet [900, from Howe Gill].

In some localities, however, as upon the northern bank of Longfell Gill, these basic lavas enclose amygdules of exceptional size, up to 2 inches or more in length. In some cases the elongated form due to a flowing movement of the lava has been further accentuated by deformation, the rocks giving evidence of cleavage [1614]. As seen on a surface of the rock freshly broken these larger vesicles often present one or more shells of compact appearance and pale colour, while the interior is occupied by a confused crystalline aggregate of dark hornblende with an occasional patch of pyrites. In slices the paler portions are found to consist chiefly of quartz and epidote, with a little actinolite or hornblende, most of the hornblende occurring in the dense patches of imperfect crystals which are so conspicuous to the naked eye. The augite already mentioned also occurs. But the most interesting feature is the preservation in the centre of these large vesicles of some remnants of calcite, a mineral never left undestroyed in the smaller ones or in the body of the rock. The calcite is in crystalline patches moulding or enclosing the other minerals mentioned, and, in particular, it is often penetrated by fringes and brushes of slender needles of actinolite [1614]. From this it is evident that the carbonate, though not decomposed, has been recrystallized at the time of the metamorphism.

The most interesting specimens come from a large block which was not found in place, but must belong to a locality very near the last mentioned. This rock, besides smaller vesicles, has others of unusually large size, often 2 inches in diameter, and the metamorphism of their contents has given rise to some curious features. Hand-specimens show the usual quartz, epidote, and green hornblende, the last less abundant than is ordinarily the case, with occasional specks of pyrites and some residual calcite; but the most prominent mineral in all the largest vesicles is a deep-brown garnet in crowded groups of small crystals, or in larger crystals sometimes $\frac{1}{4}$ inch in diameter. The colour and lustre are those proper to the lime-iron-alumina garnets. The faces of the rhombic dodecahedron are often well developed, especially when the mineral is moulded by calcite, and the broken crystals show the concentric shell-structure which is so frequent a character in garnets produced in thermometamorphism.

In thin slices [1747-1752] the garnets vary in colour from a rather light brown to a very pale tint. Zones of growth are often indicated, either by differences of colour in successive layers or by the accumulation of impurities along the surfaces which divide them, and in this way the dodecahedral form may be seen even when the crystals are so closely clustered as to prevent the development of bounding-faces (see Plate XVII. fig. 3). The recognizable inclusions are calcite, epidote, quartz, hornblende, augite, and sphene, but these are only wedged in between garnet-crystals, not really enclosed. Most of the garnets examined are strictly isotropic, or give but very indistinct glimpses of illumination when rotated between crossed nicols. Some, however, show marked double refraction [1749], the phenomena being very similar to those described in the idocrase-garnet rock of Wasdale Head (*op. jam cit.* p. 312). The polysynthetic twinning on the 'rhombic-dodecahedron type' of Klein,[1] and the numerous concentric zones differing in birefringence, are well exhibited. Here, however, the doubly-refracting crystals are found in juxtaposition with others of closely

[1] 'Optische Studien am Granat,' Neues Jahrb. 1883, vol. i. pp. 87 *et seqq.*

similar appearance, which have no action on polarized light, or the interior of a crystal is seen to be birefringent, the marginal portion isotropic. The converse relation, described by Wichmann[1] as occurring in the rocks of Berggiesshübel and Schwarzenberg in Saxony, we have not observed, but a shell of doubly-refracting sometimes occurs within a shell of singly-refracting garnet, and encloses a kernel which is very nearly isotropic. The absorption-colour, presumably connected with the relative proportions of lime and ferrous oxide in the mineral, does not seem to stand in any very evident relation with the optical anomalies, but it may be noted that we have not found birefringence in the more deeply coloured, and so more ferriferous, variety.

As a curious illustration of the facility with which lime-garnets are produced in connexion with thermal metamorphism, we may be permitted to cite a literally far-fetched example. It occurs among the rocks collected by Mr. J. J. Lister from the Tonga Islands. The island of Mango[2] consists, above sea-level, entirely of volcanic tuffs and breccias, but these are presumed to rest upon an old coral-reef, and fragments of coral, some 6 inches in diameter, are found mingled with blocks of lava, etc., among the volcanic ejectamenta. Although these corals preserve perfectly their characteristic structures, the interstices are completely occupied, in the specimens examined, by crystalline garnet, doubtless grossularite. The mineral is colourless in thin slices, and though, from the nature of the case, there are no external crystal-faces, the birefringence, the polysynthetic structure, and the concentric zones are beautifully exhibited [1274, 1331].

In addition to the minerals already named, these metamorphosed vesicles show under the microscope a colourless augite, granules of felspar (?), patches of magnetite, and occasional crystals of sphene. An examination of the manner in which the several minerals mould or enclose one another proves that they have generally followed a definite order of crystallization, which is not often departed from. The order is—iron ores, garnet, sphene, augite, green hornblende and actinolite, epidote, quartz, calcite. So far as it goes, this bears a close resemblance to the normal order of consolidation of minerals from igneous fusion, as expressed in Rosenbusch's 'law of decreasing basicity.' The iron ore in the centre of the vesicles is often pyrites, that near the edge magnetite or some other black ore. The little patches of green hornblende are most plentiful near the margin, where they are associated with a finely granular mass which seems to be felspar. The epidote is most abundant, as a rule, in the marginal portion of the large vesicles, while the calcite and the best-developed garnets are found in the central portion. Many of the minerals, however, show a rather intricate commingling. The augite forms either crowds of little imperfect crystals or larger crystal-plates, in the latter case after enclosing a quantity of green actinolite or actinolitic hornblende in needles or shreds, intergrown with the

[1] Zeitschr. Deutsch. geol. Gesellsch. vol. xxvii. (1875) pp. 749–751.
[2] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 596.

augite with the usual crystallographic relation. The appearances are very similar to those in a common kind of 'uralitization,' but it is almost certain that we are dealing here with an original parallel intergrowth. The amphibole-mineral often projects in a fringe into a contiguous crystal of epidote or calcite, and apparently isolated needles, with the same orientation, lie embedded in the latter mineral. (See Pl. XVII. figs. 2 and 4.)

III. The Silurian Beds of Wasdale Beck.

Leaving the basic lavas, we pass on to some other points. In our former paper we stated that the oldest members of the Silurian were not visible in the Shap district. Since that statement was written we received from Prof. H. A. Nicholson a specimen which induced us to re-examine the Wasdale Beck section.

Prof. Nicholson's specimen is a black mudstone, somewhat hardened, and generally resembling the flags of Wasdale Beck, but blacker and less splintery than those above the junction of that beck with Blea Beck, whence its finder believes it was derived, though, as it has been in his possession for some years, he is not certain that it was obtained *in situ*. It shows every sign of having been altered to the same extent as the supposed Coniston Flags of that locality, and indicates the existence of the *convolutus*-zone of the Skelgill Beds in the Shap district, for it contains *Monograptus communis*, Lapw., *M. convolutus*, His., *M. gregarius*, Lapw., *M. Hisingeri*, Carr., and *Rastrites hybridus*, Lapw. Our re-examination led us to believe that the flaggy beds near the junction of the streams have been correctly referred to the Coniston Flags, but that Stockdale Shales may occur higher up the beck. The matter is not one of importance as affecting our studies of the metamorphic rocks, for the shales of the Stockdale series could no doubt be altered in much the same way as those of the Coniston Flags, but it is of interest to note the probable occurrence of Stockdale Shales in Wasdale Beck, where Prof. Nicholson long ago recorded their existence.

Our re-examination of the section in Wasdale Beck led to the discovery of discontinuous calcareous bands in highly argillaceous rocks, cropping out of rushy ground $\frac{1}{2}$ mile S.W. of Shap Wells. The calcareous bands yielded an obscure brachiopod, and from the general appearance of the rock we believe that we have here either an exposure of the *glaber*-zone of the Skelgill Beds or else of a portion of the Ashgill Shales, but more probably the former. These calcareous bands will be referred to again.

Some features in the metamorphism of the Silurians of Wasdale Beck, which had escaped our notice, have been pointed out by Mr. Hutchings.[1] He describes garnets as occurring in great numbers in some of the slates, at about the same stage as the development of decided 'spots.' As the crystals do not exceed $\frac{1}{200}$ inch in diameter, the precise variety would not be easy to determine, but we

[1] Geol. Mag. for 1891, p. 459.

may probably regard them as common garnet. The hornblende-mineral noticed near the same place is perhaps the same as that which we referred to tremolite in the Upper Coldwell Beds at Packhouse Hill.

Another mineral of considerable interest discovered by Mr. Hutchings is sillimanite,[1] which he finds in highly metamorphosed ashes belonging to the rhyolitic group at a distance of 3 feet from the granite-junction. It is associated with andalusite. The sillimanite does not occur in matted patches as at Knocknairling Hill,[2] but in isolated prisms.

IV. Conditions attending the Formation of Secondary Felspar-crystals.

In our former paper (*op. jam cit.* p. 297, pl. xi. fig. 6) we recorded an instance of felspar-crystals occurring, in association with brown mica, inside the vesicles of one of the metamorphosed andesites. This we regarded as an exceptional effect of the metamorphism, and were obliged to leave unexplained. We have since learnt that clear crystals of felspar, both monoclinic and triclinic, occur within the vesicles of lavas which have never been subjected to such metamorphosing influences as those due to the Shap Granite. Mr. Hutchings [3] has observed numerous cases in the Lake District, and the same thing occurs in the Cross Fell Inlier.[4] These instances certainly seem to prove that, with proper conditions, felspars may be formed inside vesicles without the co-operation of either high temperature or exceptional pressure. The case near the Shap Granite may well fall under the same head. The purity of the crystals, and the manner in which they are moulded by the brown mica accord with the supposition that the felspar was crystallized in the vesicle prior to the metamorphism. The apparent rarity of the phenomenon is another confirmation of the idea, for while a striking regularity is observable in the undoubted effects of thermal metamorphism around the granite, the formation of felspar under ordinary conditions of temperature seems to be quite capricious. The remarkable freshness of the Shap metamorphic rocks precludes the third alternative, that the felspar was formed subsequently to the metamorphism. It may be pointed out that, the available lime within these vesicles being used to make felspar, the coloured silicate produced in the metamorphism was a brown mica instead of the usual hornblende.

The formation of felspar in rocks quite independently of the special conditions usually connoted by the term 'metamorphism' is a subject which deserves further investigation. Veins largely composed of clear crystalline felspar fill cracks in some of the Dartmoor diabases,[5] and among acid rocks we have noticed a similar

[1] See also Mr. Barrow's paper in this number of the Quarterly Journal, especially pp. 337–338.

[2] Miss Gardiner, Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 575 *et seqq.*

[3] Geol. Mag. for 1892, p. 224.

[4] Harker, Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 514, 515.

[5] *Id.* Geol. Mag. for 1892, p. 346.

occurrence in some old rhyolites and ashes from Malvern, collected by Mr. J. F. Bryant. If such processes are possible within the mass of a rock, as well as in vesicles and fissures, some peculiarities which have been ascribed to dynamic metamorphism may be found to admit of a different explanation. The rock described by one of us from Wythwaite Top in the Cross Fell Inlier is a case in point.[1]

V. The Metamorphosed Coniston Limestone Beds of Wasdale Head.

In describing the highly metamorphosed members of the Coniston Limestone group at Wasdale Head we showed that, although pure lime-silicates, such as wollastonite, are not wanting, the more common minerals are augite, tremolite, etc., and an analysis yielded a noteworthy amount of magnesia. Since the supposition that this or any other constituent was introduced during the metamorphism was opposed to all our results, we suggested that the rocks had been partially dolomitized before the intrusion of the granite (*op. jam cit.* p. 315). To put this to the test, we have re-examined the non-metamorphosed rocks of Blea Beck. In the case of the more ashy beds it is not easy to form any conclusion, but the purer strata exposed in the beck give clear evidence of partial conversion to dolomite. One bed in the Upper Coniston Limestone, for example, consists of a pale brown, finely granular matrix enclosing pure white crystalline patches up to $\frac{1}{4}$ inch in diameter. The specific gravity 2·796 indicates the presence of both calcite and dolomite in the rock, and (allowing for the few quartz-grains which are the chief impurity) the two carbonate minerals must be present in roughly equal quantities. The white patches are unaffected by dilute acid, and consist of clustered rhombohedra of unusually pure dolomite [1616]. The greyish-brown, finely granular portion of the rock effervesces with dilute acid, and must be chiefly calcite: but, as it makes up quite $\frac{3}{4}$ of the total bulk, it would appear that there is some admixture of dolomite in it.

The various types of lime-silicate rocks which we have described at Wasdale Head all belonged to the more impure portions of the Coniston Limestone group, representing the metamorphism of calcareous ashes and shales rather than of true limestones or dolomites. Further search, however, shows that the latter are not entirely wanting at that locality, and that they present an instructive contrast with the less purely calcareous members of the group. They illustrate what seems to be a general law, that the carbonates are not decomposed in thermal metamorphism unless silica in some available form be at hand to replace the carbonic acid. A bed forming part of the Lower Coniston Limestone, and evidently representing one of the purer layers in that formation, is converted into what is essentially a grey saccharoidal marble, the calcite having apparently, for the most part, recrystallized without further change. This is within 100 yards of the granite-junction and close to the rocks formerly described, which have been converted into aggregates of idocrase, garnet, wollastonite, etc., with total elimination of their carbonic acid. Further,

[1] Harker, Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 515, 516.

in the relatively pure limestone now noted, the formation of lime-silicates, etc., has gone on wherever impurities were collected. While the greater part of the rock consists of rather finely crystalline calcite (perhaps with dolomite), the hand-specimens show little streaky patches which are harder than the rest and give no effervescence with acid. Of these little patches some are of a greenish tinge and are probably augite, others have the characteristic lustre and brown colour of idocrase, while others again are white and apparently felspathic. We also remark, scattered through the mass, little granules of a black iron ore and of a yellow pyrites.

Another feature of this rock, doubtless connected with the nodular structures so prevalent in the purer portions of the Coniston Limestone group, is the occurrence of distinct ovoid nests of lime-bearing silicates with a definite arrangement of nucleus and outer shell. The nucleus consists of brown crystals of idocrase [1427, 1428], often 1 inch in length, disposed in stellate groups; the outer part of the nest, forming a shell $\frac{1}{2}$ to 1 inch in thickness, is of a white crystalline mineral which proves to be chiefly a plagioclase-felspar [1746]. The mineral forms striated crystal-plates considerably larger than any yet observed in these limestone-rocks. Associated with it are specks of a brightly-polarizing pyroxene and grains of iron ore, the former becoming more abundant where the felspathic nodule meets the matrix of calcite. (See Pl. XVII. fig. 6.)

VI. Some Concluding Considerations.

In conclusion we would venture on one or two remarks which, following out ideas suggested in the foregoing notes, may be found to have a more general bearing. All that we have seen in the Shap district confirms the belief that thermometamorphism is not in general accompanied by any change in the chemical composition of the rocks affected. The exceptions we have already noted: namely, the (partial) loss of water and the expulsion (under proper conditions only) of carbonic acid.[1] These do not seriously modify the law in question. We have, however, gone farther in applying this law not only to the metamorphosed rocks as a whole, but also to any small portion of any of these rocks. In the course of our descriptions we have seen innumerable facts which point to the conclusion that no transference of material has taken place within the mass of the rocks except between closely adjacent points. If this be, as we believe, a general law, it follows that the mineral produced by complete thermal metamorphism at any point of a rock depends upon the chemical composition of the rock-mass within a certain small distance around that point.[2] The question naturally arises, what is the radius of this sphere of influence? Can we form any estimate of the maximum range at which interchange of material takes place between points in the interior of a rock undergoing thermal metamorphism?

The distance in question will presumably not be the same for

[1] In some districts we should have to allow other exceptions for rocks in the neighbourhood of an acid intrusion: namely, the introduction of boric and hydrofluoric acids.

[2] Comp. Harker, Bull. Geol. Soc. Amer. vol. iii. (1891) p. 20.

different chemical substances, and we must also expect to find it greater at higher temperatures; but we may at least arrive at some idea of its order of magnitude by considering some one case. The case which is most easily discussed is the production of lime-silicates at the expense of calcite. The carbonate is decomposed, as we have remarked, only in presence of silica or of some silicate from which silica can be disengaged, and, given this condition, the process is one that can be effected at a comparatively low temperature. Now, in the amygdaloidal basic lavas we have pointed out that the calcite in the centre of the largest vesicles is never destroyed, although it has recrystallized during the metamorphism, and free quartz has recrystallized in the surrounding rock and in the marginal parts of the same vesicles. Between the residual calcite and the quartz various lime-bearing silicates are interposed. The calcite is preserved only in the centre of the largest vesicles, smaller ones in the same rock being occupied by silicate minerals, quartz, etc. In the examples we have more particularly studied calcite is never preserved within less than $\frac{1}{4}$ inch of the boundary of the vesicle, and this gives a first approximation to the distance we are seeking. It is, however, a maximum estimate, and is doubtless too great, for the vesicles before metamorphism were not always occupied by calcite alone. If we measure the distance between calcite and quartz which have recrystallized within the same vesicle, we shall reduce our estimate considerably: perhaps $\frac{1}{20}$ inch would be nearer the mark for the distance to which the interchange of lime and silica has demonstrably taken place in the production of lime-silicates. Similar evidence is furnished by certain flat calcareous nodules noted above in the metamorphosed Silurians of Wasdale Beck, belonging probably to a faulted lenticle of Stockdale Shales (*Phacops glaber*-zone). Here the calcite often remains in the centre of a nodule, the marginal part being always converted into an aggregate of pyroxene and other silicates. This border is often $\frac{1}{8}$ inch thick; but if, to allow for impurities in the nodules, we take the least thickness, we obtain as before about $\frac{1}{20}$ or $\frac{1}{25}$ inch. The distance from the granite—and so presumably the temperature of metamorphism—is not very different from that for the former locality.

The same question might be approached from another side, by examining the size of the individual crystals or groups of metamorphic minerals where their production has been dependent on the heterogeneous nature of the rocks metamorphosed. The clusters of brown mica produced in some of the ashes around grains of original magnetite are an example. Here, however, we have to exclude such minerals as contain numerous inclusions, either of other metamorphic products or of unchanged material. It is not easy to arrive at any quantitative results, but the impression gained by a study of specimens is in general accord with the foregoing conclusions.

We may add that the dependence of the range of transference of material upon the temperature attained during the metamorphism is well illustrated in the calcareous ashes of the Shap district. On the outer edge of the metamorphic aureole only the most finely divided calcite has been decomposed.

The spotted slates and ashes which we have described, where the spots are spaces relatively free from brown mica (*op. passim cit.* pp. 307, 319), may be taken as positive evidence of the transference of ferrous oxide from point to point in the rocks. The radius of the spots is not more than about $\frac{1}{20}$ inch, a distance similar to that found for the interchange of lime and silica.

VII. List of Metamorphic Minerals of the Shap District.

We append a revised list of the metamorphic minerals noticed in the Shap district, but such a list cannot of course claim to be exhaustive. It has been shown that basic, intermediate, and acid lavas and ashes, as well as pure and impure limestones, slates, and grits, all come within the metamorphic aureole, and further that the results were often modified by the effects of meteoric agencies prior to the intrusion of the granite. In the great variety of phenomena resulting from such conditions, it is probable that many points of interest remain still untouched.

	Basic Lavas and Ashes.	Intermediate Lavas and Ashes.	Acid Lavas and Ashes.	Calcareous Rocks.	Argillaceous Rocks.
Quartz	*	*	*	*	*
Orthoclase	......	*	*	*	*
Plagioclase (various)	*	*	*	*	*
White Micas	......	......	*	......	*
Brown Micas	*	*	*	*	*
Chlorites	*	......	......	......	*
Tremolite	......	......	......	*	*
Actinolite	*	*	......	......	......
Green Hornblende	*	*	(*)	......	......
Wollastonite	......	......	......	*	......
Lime-augite	*	......	......	*	......
Epidote	*	*	......	......	......
Idocrase	......	......	......	*	......
Lime-garnet (isotropic)	*	......	......	*	......
Lime-garnet (birefringent)	*	......	......	*	......
Common Garnet	......	......	......	......	*
Tourmaline	......	......	(*)	......	(*)
Sphene	*	*	......	*	......
Rutile	......	......	*	......	*
Anatase	......	......	......	......	*
Ilmenite	*	......	*	......	*
Magnetite	*	*	*	(*)	*
Pyrite and Pyrrhotite	*	*	*	*	*
Apatite	......	(*)	*	......	......
Andalusite	......	......	*	......	* ?
Disthene or Cyanite	......	......	*	......	......
Sillimanite	......	......	*	......	......
Calcite and Dolomite	(*)	......	......	*	......
Graphite	......	......	......	......	* ?

1.

2.

3.

4.

5.

6.

A. Harker del. F. H. Michael lith. Mintern Bros, imp.

SECTIONS OF METAMORPHIC ROCKS, SHAP.

EXPLANATION OF PLATE XVII.

(*The figures are all drawn in natural light and magnified* 20 *diameters. The numbers in brackets* [ ] *refer to the slides.*)

Fig. 1. [1748] Portion of a large amygdule in a loose block of metamorphosed basic lava, north of the granite mass. In the upper part of the figure is a large crystal of epidote, bounded on the right by clear quartz, on the left by calcite. The latter is penetrated in the lower part of the figure by needles of amphibole, and to the right of this is a plate of augite enclosing grains of epidote.

Fig. 2. [1750] Another amygdule in the same. In the lower left-hand quarter is a plate of augite with intergrown needles of amphibole. Similar needles, in parallel position, penetrate the calcite which occupies the central part of the figure. Above to the right is garnet, to the left quartz.

Fig. 3. [1749] Another amygdule in the same. A cluster of garnet-crystals, some showing zonary growth: patches of calcite occur interstitially.

Fig. 4. [1747] Another amygdule in the same. An intricate admixture of garnet and calcite, the garnet bounded on the right by a large epidote-plate enclosing two imperfect crystals of sphene. Above these is a crystal of augite with parallel intergrowth of amphibole-needles, some of which extend as a fringe into the epidote. Pyrites and quartz are also seen.

Fig. 5. [896] Highly metamorphosed ash associated with basic lavas, Poorhag Gill; very near the granite. Flakes of brown mica with partial parallel disposition are scattered thickly through a clear, very fine-grained mosaic, essentially of felspar. The relatively clear space marks the position of a felspar-crystal recrystallized into an aggregate of rather less fine texture than the matrix.

Fig. 6. [1746] Portion of highly metamorphosed Lower Coniston Limestone at Wasdale Head; about 100 yards from the granite. The slide shows part of the light-coloured border of one of the idocrase-nodules in the marble described on p. 368. Striated felspar occurs in relatively large plates, as well as in small grains; with it, in subordinate quantity, is a monoclinic pyroxene; the opaque mineral is apparently pyrites.

DISCUSSION.

The PRESIDENT congratulated the Authors on this important addition to their previous communication. In some respects this paper was the antithesis of the one which had just been read (Dr. Callaway's), for the Authors limited the area in which metasomatic change took place to a fraction of an inch.

Mr. RUTLEY considered that the statements made by the Authors regarding the development of certain minerals in the altered rocks were of great value. Concerning the absence of reaction between the calcite in the amygdaloids and the silicates which occurred in close proximity, he cited a case in which the molecular rearrangement brought about by the conversion of a piece of flashed glass into a crystalline mass had caused scarcely any disturbance of the coloured film. The statements relating to the development of epidote were important, since, so far as he was aware, that mineral had not yet been artificially reproduced.

Mr. TEALL was especially interested in that portion of the communication which dealt with the change brought about in the calcareous portions of the rocks. The silicates there produced were allied to those found in crystalline limestones associated with gneisses and schists, and the work of the Authors might therefore throw light on the conditions under which these rocks were produced.

Mr. HARKER, in reply to Mr. Rutley, said that the epidote described as occurring in the metamorphosed basic lavas was found chiefly in the outer parts of the large amygdules and in the rock bordering the amygdules. It was undoubtedly a product of thermal metamorphism.

Mr. MARR also spoke.

31. *On the* Dwindling *and* Disappearance *of* Limestones.

By Frank Rutley, Esq., F.G.S., Lecturer on Mineralogy in the Royal College of Science, London. (Read April 12th, 1893.)

[Abridged.]

[Plate XVIII.]

There are probably few instances in nature in which limestone-beds are so protected that water cannot gain access to them. A limestone-bed to which water charged with carbonic acid gains access becomes gradually dissolved, and, furthermore, the solvent action of humus acids must also, in some cases, be taken into account.[1] The question whether such a bed will completely vanish is one which involves merely the magnitude of the bed, the duration and energy of the solvent action, and the freedom of the limestone from foreign matter of a more or less insoluble nature. If unlimited time be conceded, there seems no reason why very thick beds of limestone should not wholly disappear; at all events thin ones may easily do so.

The formation of caves, chasms, and pinnacles, the general sculpturing of limestones, and the thick deposits of calcareous tufa which occur in many localities sufficiently attest the activity with which the erosion of limestones has been carried on in recent times,[2] and there appears to be no reason to doubt that similar work has been constantly in progress during bygone ages, under like conditions. Given like conditions, the greater the age of any limestone-deposit, the more will it have been wasted away. Granted sufficient time, its disappearance is inevitable.

Any argument adduced in support of the probable disappearance of very ancient beds of limestone may be applied with additional force in the cases of rock-salt and gypsum.[3]

Where limestones occur at the surface, their erosion is due not only to chemical, but also to mechanical natural agencies, the latter being likewise important factors.

In the case of a limestone-bed occurring between rocks of a different character the erosion of the limestone is quite, or almost wholly, dependent upon the infiltration of water charged with carbonic acid, or other solvent. The partial or entire removal of interbedded limestones must, probably, in many cases have taken place in this manner during the lapse of ages.

[1] Alexis A. Julien, 'On the Geological Action of the Humus Acids,' Proc. Amer. Assoc. vol. xxviii. (1879, Saratoga Meeting); sep. cop. Salem, 1880.

[2] Credner cites an instance in which, in one locality alone, the limestone-rocks yield, in one year, sufficient calcareous tufa to form a cube measuring over 33 metres ($35\frac{3}{4}$ yards) on the side, 'Elemente der Geologie,' 3rd ed. (1876) p. 188.

[3] Gypsum is soluble in 460 times its weight of water, and limestone in about 1000 of water charged with carbonic acid.

If the beds were horizontal or inclined at a low angle and the removal more or less complete, 'creeps' would occur, and finally the bed which originally rested upon the limestone would come in contact with the upper surface of the bed upon which the limestone rested.

[In the discussion which followed the reading of this paper, the question of 'creeps' was raised, the absence of disturbance in the beds which might once have rested upon or have supported a bed or a series of beds of limestone being adduced as evidence that the removal of such beds by the action of solvents did not occur either commonly or on a large scale. To this it may be answered that 'creeps' would certainly occur, but that they would be comparatively inappreciable when contrasted with those brought about by mining operations. Furthermore, the removal of a limestone by water charged with carbonic acid is a slow and gradual process compared with the dissolving of beds of rock-salt or the operations of the miner, and, although the principle involved is the same in both cases, yet the action in the one instance differs in degree from that in the other. The sand-grains gently trickling in an hourglass and the sliding and tumbling masses in a landslip afford examples of two very different phenomena dependent upon the same principle, namely the gravitation of matter upon smooth and sufficiently inclined surfaces. In the earlier stages of the dwindling of a bed of jointed limestone, the widening of the joints is comparatively slight. It is when a limestone-bed has been reduced to about half its original thickness that we have a condition which, on a diminutive scale, resembles the 'pillar-and-stall' work in a coal-mine, and it is at this stage that 'creeps' and 'sits' will become most marked. As the removal of the limestone continues the nodules will become thinner and more lenticular, and the flexures of the superincumbent and subjacent beds will diminish. As the nodules become smaller and thinner, these flexures (or 'creeps and sits') will become more and more flattened by pressure of overlying rock until, when the nodules have wholly disappeared, the once overlying and underlying beds come into unbroken contact, the flexures are smoothed out, and any comminuted rock-matter, which may have resulted from cracking consequent upon flexure, will become reconsolidated, by pressure, into the general planes of stratification.

Under such circumstances, no evidence would remain of the former existence of the limestone-bed, save perhaps in the more calcareous nature of the adjacent strata, through which water, holding calcium bicarbonate in solution, may have filtered, in the presence of chert which the limestone might have contained, or in the presence of silica or other comparatively insoluble substance by which the limestone might be replaced.—April 29th, 1893.]

In the case of a limestone interstratified with highly-inclined or vertical beds, the fissure, caused by the removal of the limestone, would either become closed by earth-movements bringing the walls together or be filled by rubble, sand, etc.,[1] or by matter deposited from infiltered solutions, or, under certain conditions, by sedimentary matter.

When a limestone-bed is dissolved, any calcareous fossils which it contains will share the same fate, and thus a page in the life-history of the locality, as well as in the stratigraphical record, would vanish for ever. How many such pages are lost to us it is impossible to tell, but if, in reviewing the stratigraphical record from Carboniferous to Archæan times, as we find it in England and Wales, we note the gradually decreasing thickness of the limestone-beds, it is not hard to believe that all of them have lost either in actual thickness, or have parted with more or less calcareous matter which has been subsequently replaced by material of a different nature. The latter hypothesis seems to be strengthened by the very impure character of some of the older limestones.

On the erosion of a cherty limestone, the bands of chert would remain after the limestone had been removed. In such a case the life-history of that particular zone would not be wholly lost.

Considering how commonly chert is associated with limestone, the independent occurrence of chert-bands or nodules in the older formations would, if found, afford a possible clue to the horizons at which long-vanished limestone-beds formerly occurred. In such an enquiry the chert would be to the limestone what a moraine-stone is to a departed glacier, a witness whose testimony cannot be controverted, unless it could be shown that the chert was originally developed in some rock other than a limestone. A chertless limestone leaves no record, and it can, therefore, only be by a diligent search for cherty seams in the older formations that we can hope for any information regarding such stratigraphical losses. Here, however, we come to a rather difficult question for the field-geologist, namely the ready recognition of a chert in formations where felstones and compact indurated grits are prevalent. So close is the outward resemblance of these rocks one to another that the name 'hornstone' was indifferently used in bygone years both for cherts and felstones, although the former are infusible and the latter fusible before the blowpipe. It should, however, be remarked that Macculloch, when speaking of chert, pointed out the difference, stating that "the hornstone of many authors is compact felspar."[2] The 'phthanite' of Continental petrologists is also an elastic term, embracing not only cherts and the siliceous limestones into which they graduate, but also siliceous slate (*kieselschiefer*), jasper, and chalcedony.[3] Chert is essentially cryptocrystalline, and occasionally it presents a banded structure. Like characters are also met with in some felstones, and very similar ones in certain porcellanites and

[1] A curious example of the infilling of fissures is afforded by the sandstone-dykes described by Prof. J. S. Diller, Bull. Geol. Soc. Amer. vol. i. (1890) pp. 411-442.

[2] 'Geological Classification of Rocks,' London, 1821, p. 171.

[3] A. Renard, 'Recherches lithologiques sur les Phthanites du Calcaire Carbonifère de Belgique,' Bull. Acad. Roy. de Belgique, 2ème sér. vol. xlvi. (1878) p. 471.

altered slates. It would therefore be an easy matter, in a district where such rocks abound, to overlook a narrow chert-band, and this, even if found, might fail to contain any organic remains which would afford satisfactory proof of its origin.

If the dwindling and disappearance of limestones, as suggested in this paper, be a fact, another circumstance connected with it would have to be taken into account. Let A and E be two beds of shale or other rock, between which a series of limestone-beds occurs, which may be lettered in ascending order B, C, D respectively. Assume also that B, C, and D represent more or less distinctly different fossiliferous zones. When erosion has so far advanced that only the middle member (C) of the series remains, we should then have two organic breaks to consider: the one between A and C, and the other between C and E; and if, in time, the whole of the limestone disappeared, there would be a still more marked organic break between A and E.

It may be contended that the thinness and scarcity of limestone-beds in the pre-Cambrian formations of Britain indicate that the waters of those early times contained less calcium bicarbonate than those of later date. Against this contention I would urge (without entering into the question of whether there were any pre-existing sedimentary rocks from which calcareous matter could have been derived) that in the disintegration of an eruptive rock the first stage necessarily consists in the partial decomposition of the more easily attacked constituents and the removal of matter *in solution*. Until this is effected, the second stage cannot begin. The second stage consists in the mechanical disintegration or crumbling of the rock and the removal of solid matter *in suspension*.

Disintegration once started, the two processes continue in regular sequence, the one being the consequence of the other. The solid detritus, however, which results from this action, may undergo further decomposition, since in its more or less finely divided state it offers a larger surface to any solvent.

Assuming that merely eruptive rocks were acted upon, we may, I think, infer from this that the waters of the early periods of the earth's history received mineral matter in solution quite as soon as they received any solid detrital matter.

Of the substances brought to them in solution calcium bicarbonate must assuredly have been one, and that not the least plentiful, and we can, therefore, readily believe that fairly thick beds of limestone were formed long before the deposition of the oldest fossiliferous beds with which we are acquainted. So far as the early life-history of the globe is concerned, we should probably have been more largely indebted to such limestones than to any other rocks.

The view that there has been a constant increase of limestone-making material is advocated by Sir Charles Lyell in the following words:—"The constant transfer, therefore, of carbonate of lime from the lower or older portions of the earth's crust to the surface, must cause at all periods, and throughout an indefinite succession of geological epochs, a preponderance of calcareous matter in the newer as contrasted with the older formations."[1]

That such action has given rise to a constant supply of calcareous matter in solution no one can doubt, but it seems probable that, unless the operations of nature have very materially varied, the supply has, throughout all ages, been tolerably uniform in amount. In other words, during equal periods of time, equal amounts of soluble matter have been abstracted from rocks of one kind or another. The transfer of matter, so derived, from one formation to another is, however, a different question, since it implies no difference in output, but merely a shifting of material already supplied. The output question is one which concerns the delivery of so many gallons of lime-bearing solution in a minute, or of so many tons of limestone in a thousand years.[2]

It has already been argued by some writers that the paucity of limestone in the older formations may have been due to the comparatively small number of lime-secreting organisms which tenanted the early seas. Bischof has stated that the sea contains five times as much carbonic acid as would be necessary to hold all the calcium carbonate which it contains in a state of solution, and if, therefore, chemical precipitation be out of the question and organic agency be admitted, as it now very generally is, to be the medium through which limestones have been formed, we can only look to a plentiful fauna as the indirect source of limestone-beds. Admitting this, how are the thick unfossiliferous Laurentian limestones to be accounted for? Were the pre-Cambrian seas more populous than we imagine them to have been? and, if so, has some process of metamorphism, as in the case of the Carrara marble, of Oolitic age, obliterated all traces of the fossils which those old limestones once contained? Sir Charles Lyell seems to have entertained this opinion.[3]

Moreover, the less stable character of fossils, when composed of aragonite, should not be lost sight of,[4] and this, in conjunction with the obliterating effects of superinduced crystallization, indicates, as Sir Archibald Geikie remarks, that "the absence of all trace of organic structure in a limestone need not invalidate an inference

[1] 'Principles of Geology,' 9th ed. (1853) p. 797.

[2] 'Taking the case of water delivered by springs in the Chalk, and which has but a moderate degree of hardness, it is found by analysis to contain about seventeen grains of carbonate of lime to the gallon. Now, out of a rainfall of say twenty-six inches annually, it has been found by experiment that in a Chalk district about nine inches would, in average seasons, find their way down to the springs; and it may be readily calculated that, at the rate of seventeen grains to the gallon, the amount of dry chalk or carbonate of lime dissolved by this quantity of water, and delivered by the springs, and thus carried away, is, in each square mile of such a district, upwards of one hundred and forty tons in each year, or about a ton to every four and a half acres.'—Sir John Evans, 'Ancient Stone Implements of Great Britain,' p. 429.

[3] 'The Student's Elements of Geology,' 1st ed. (1871) p. 584.

[4] H. C. Sorby, Pres. Address, Quart. Journ. Geol. Soc. vol. xxxv. (1879) *Proc.* pp. 71–72, where the possibly chemical origin of portions of some limestones is also alluded to.

from other evidence that the rock has been formed from the remains of organisms."[1]

The nodular character of limestones appears to be a matter deserving especial attention, since this condition may frequently denote the later stages of the process of dissolution of a limestone-bed. Such nodules, which I propose to term *residual*, should be carefully distinguished from concretionary calcareous nodules.

The conversion of a bed of jointed limestone into a band of residual nodules is a destructive process, while the formation of a band of concretionary calcareous nodules is a constructive one.

Nodular conditions may be most commonly met with at the top and at the base of a series of limestone-beds: that is, if the limestone-beds form an unbroken series; but if they alternate with beds of shale, sandstone, etc., they then result in a series of calcareous nodular bands with partings of shale, etc.

In considering the conversion of a rectangular block of limestone into a nodule it seemed desirable to show by experiment that, if the block were tolerably homogeneous, a solvent process would produce, from a cube, a sphere; from a long square prism, a fusiform body; and from a prism bounded by three dissimilar pairs of rectangular faces, a lenticular nodule.

This was most readily effected, on a very small scale, by submitting little prisms of ordinary white drawing-chalk of the forms respectively shown in Pl. XVIII., figs. *A*, *B*, and *C*, to the action of dilute hydrochloric acid. These were carefully watched while dissolving. The stream of ascending gas-bubbles, when viewed against the light, appeared as darker and denser columns where they arose from the solid angles of the chalk-blocks. This phenomenon was most marked in the earlier stages of dissolution, and became less perceptible as the process advanced.

A considerable time was found to elapse before the edges and solid angles of the block *B*, which was a roughly-broken cube, became appreciably rounded, and even when more than three-fourths of the mass had been dissolved, some of the edges remained tolerably sharp. At this stage the process was stopped, and the result is shown in Pl. XVIII. fig. *b*, of which fig. *b′* is an enlarged representation. Had the process been continued, the penultimate result would have been an approximately spherical body.

Another chalk-block, of the size and form shown in Pl. XVIII. fig. *A*, was also immersed for some hours in dilute hydrochloric acid. This finally became reduced to a very small, sharply-pointed, fusiform body, of which fig. *a* is a representation of the actual size and fig. *a′* an enlarged version. Owing to its extreme delicacy, it broke when being removed from the acid.

Fig. *C*, Pl. XVIII., represents yet another small block of chalk which was treated in a similar manner. When reduced to less than half its original bulk, it assumed the form shown in Pl. XVIII. fig. *d* (magnified 8 diameters). Finally, this was reduced to the

[1] 'Text-book of Geology,' 2nd ed. 1885, p. 113.

minute lenticular body shown in Pl. XVIII. fig. *c*, of which fig. *c′* is an enlarged representation.

On comparing figs. *d* and *c*, it will be seen that the lenticular form becomes more marked in the later stages of dissolution. It may, therefore, be inferred that the residual nodules of lenticular form, with sharp, thin edges, denote the stage which precedes the total disappearance of a limestone-bed. If this be the case, it may, I think, be assumed that a band of lenticular nodules at the base of a series of limestone-beds may have been preceded, or at the top of a series may have been succeeded, by one, by several, or even by many beds of limestone which have wholly disappeared. Different stages in the dissolution of such a series of beds are represented diagrammatically in Pl. XVIII. figs. *g*, *h*, *i*, and *k*.

Although the blocks of chalk figured in that Plate, figs. *A*, *B*, and *C*, were so small, yet one may conclude that the action of a solvent upon equally homogeneous limestone-blocks of vastly greater dimensions would probably give approximately similar results.

In connexion with these simple experiments, it is interesting to note that the directions in which the blocks are most rapidly dissolved correspond with those in which O. Lehmann has shown that the most rapid growth of a crystallite takes place.[1] The reasoning upon which Lehmann's theory is based has, it would appear, simply to be reversed. Instead of considering relative areas in which fresh material is supplied to the growing body, we have to deal with those in which matter is being removed from a body constantly diminishing in size. In Pl. XVIII. fig. *e* this is diagrammatically represented. The areas of solution are bounded by lines drawn at right angles to the surfaces of the successively decreasing solids and at equal distances from one another, and it will be seen that the greatest solution-areas occur along the edges and at the solid angles. The rate of solution is indicated by shading, which is darkest where the solid becomes most rapidly dissolved, *i.e.* where it is acted upon by the largest amount of the solvent. It will be noted that the dark bands in the shading correspond in direction with main ribs of chiasmolitic crystallites ('furculites' and 'arculites'). There can, of course, only be a perfect correspondence of solubility with form in homogeneous solids in which no differences of cohesion exist. In dissolving a crystal, the solubility would be more or less influenced by differences of cohesion in different directions. In the case of a limestone-block when acted upon by a solvent, it is the external form of the mass which determines the directions in which it is most rapidly dissolved, directions which vary with the gradually changing form of the solid. The solution of a limestone-block cannot, therefore, bear a strict comparison with that of a crystal, since in the one case the aggregate molecular grouping is indefinite, while in the other it is definite.

On referring to Pl. XVIII. fig. *e*, it will be noted that the

[1] 'Ueber das Wachsthum der Krystalle,' Zeitschr. für Kryst. u. Min., 1877, pt. i. pp. 453–496; see also Rosenbusch's 'Mikroskopische Physiographie,' 3rd ed. (1892) vol. i. p. 29.

rounding of edges and solid angles is less apparent in the early than in the later stages of solution, when the solution-areas of greatest magnitude, which began at 90°, eventually fall little short of 180°, the limiting angle of the solution-area.

Although, in this paper, the belief is expressed that many calcareous nodular bands represent, as residual nodules, what were once beds of limestone, it must by no means be inferred that all calcareous nodular bands have had a similar origin. Some are distinctly concretionary. Both residual and concretionary nodules may contain fossils. In the former the fossils are contemporaneous with the nodules which enclose them. Concretionary nodules sometimes exhibit a radiating or divergent crystalline structure. Such structure in a residual nodule would be quite exceptional. Both kinds of nodules may be traversed by planes of lamination; but, before saying more about their points of resemblance or dissimilarity, it is desirable to examine a large series of typical examples, so that some accurate means of discrimination may be arrived at.

If the views advocated in this paper be correct, the unqualified expression 'nodular limestone' is insufficient, and its use should, at least, be restricted to observations in the field.

In support of the foregoing statements it may be mentioned that Mr. Beeby Thompson, F.G.S. (in a paper on 'The Upper Lias of Northamptonshire,' part ii.), describes nodular conditions of the argillaceous limestone (Fish Bed) and gives reasons for regarding these nodules as portions of once continuous beds, which were subsequently traversed by transverse shrinkage-cracks, the dissolving of the limestone and subsequent widening of the cracks resulting in the formation of bands of distinct, flattened nodules, and these nodules are stated not to be concretionary.

The following extract from a paper on 'The Northern Slopes of Cader Idris,' by Prof. Grenville A. J. Cole and Mr. A. V. Jennings, Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 427, is worthy of note as also tending to confirm the belief that our older formations were once richer in limestones than they now are:—"If the iron ore of Cader Idris was at one time a fairly calcareous band among the more prevalent muds and shales, it owes its preservation to the pseudomorphic action that has gone on. The very marked proportion of carbonate of lime that occurs in the cavities of the permeable rocks from Llyn Gwernen to the summit of the mountain may have been in part derived from similar seams or shelly patches, the absence of which we have so frequently to deplore when examining Ordovician or Cambrian strata. It is unnecessary to dwell upon the increased effect of solvent action when occurring in a region subjected to pressure and earth-movement."

In some localities, where limestones are interbedded with shales, it has been noted that the latter weather away more rapidly, so that the limestones form projecting courses. Such conditions may, I think, be regarded as due either to dry situation, or to the crystalline limestone being more coherent than the shales and consequently less liable to disintegration by mechanical agency.

Nodular conditions are to be sought more among thin- than among thick-bedded limestones. In the latter, the residual nodules derived from one bed would become completely dissolved before the next bed became sufficiently thin to assume a nodular condition. This is indicated in the diagram, Pl. XVIII. fig. *f*. Where large fossils are present in a thick-bedded limestone, the latter is more likely to weather into irregularly eroded blocks, such as the 'rockery-stones' of the Carboniferous Limestone, than to pass into the condition of smooth nodules.

[When this paper was read, some details were given concerning the relative thicknesses of limestones in various formations and in different localities, but it was found so difficult to obtain satisfactory data, and the discrepancy of opinion appeared to be so great concerning the probable origin of certain nodular conditions, that the publication of all such notes has been abandoned, and this more especially since the conditions which occur in one district or country are not necessarily repeated in another. It has not been the purpose of this paper to enter into a discussion of the conditions which may have favoured or retarded the formation of limestones. No doubt the deposition of sediment within certain areas may, as Prof. Hull has pointed out, have acted as a check to the formation of limestones, but there are geographical, bathymetrical, climatic, and other conditions which cannot be overlooked in a question of this nature and the discussion of which could not have been attempted, even in outline, in the present paper.—April 29th, 1893.]

Conclusions.

1. That bands of limestone-nodules may in certain cases represent what were originally *beds* of limestone.

2. That the earlier stages of solution of a bed of jointed limestone result in a widening of the joints, or a wider spacing of the blocks which constitute the bed, and produce a certain degree of rounding of the edges and solid angles of each block.

3. That the later stages of solution result in nodules, the form of the nodule, if the limestone be tolerably homogeneous, being more or less closely related to the original form of the block from which it has been derived, one nodule being derived from one block.

4. That a limestone-block of irregular form, or which is not of uniform texture, may result in more than one nodule, and those, perhaps, of very irregular shape.

5. That nodular bands, occurring at the base of a series of limestone-beds, may have been preceded, occurring at the top of a series may have been succeeded, by other beds of limestone which have completely disappeared.

6. That bands or nodules of chert may represent all that remains of what were once beds of cherty limestone.

7. That the present thicknesses of limestones may in some cases

be very much less than their original thicknesses, and that the comparatively thin limestones in the older formations of this country were possibly once much thicker.

8. That the dwindling and disappearance of limestones through the action of solvents, especially of water charged with carbonic acid, gives rise to palæontological breaks, which, though often small, are numerous and consequently not unimportant.

9. That the absence of fossils, as pointed out by Sir Charles Lyell, is no proof that the limestones were not originally fossiliferous.

10. That if such non-fossiliferous, crystalline limestones are of organic origin and not chemical precipitates, the thickness of those of Laurentian age, found in Canada, militates against the assumption that the thinness of our older limestones in this country is due to the sparseness of life in those remote periods, as suggested by some authors.

11. That a distinction should be carefully made between nodules resulting from the partial dissolution of beds of limestone (residual nodules) and those concretions which result from the segregation of calcareous matter about detached nuclei (concretionary nodules).

12. That nodular conditions are to be looked for less among thick- than among thin-bedded limestones, since, by the time that one bed has passed into a nodular condition, the nodules resulting from the dissolution of the bed immediately above, or, if at the base of a series, immediately below it, will have been completely dissolved.

13. That the presence of large fossils in a limestone-block may materially influence the form of the resultant nodule or nodules.

14. That, although not dealt with in this paper, the mechanical agencies involved in marine and subaerial denudation must necessarily play a very important part in the removal of limestones, as well as of other rocks, and that they are more or less intimately, sometimes inseparably, connected with that chemical action of solvents upon which the foregoing conclusions are based.

EXPLANATION OF PLATE XVIII.

Nodular forms, procured by partially dissolving small blocks of chalk in dilute hydrochloric acid.

Fig. *a*. Fusiform body, derived from the block *A*.

a'. The same, magnified about 8 diameters.

b. Irregularly rounded body, derived from the block *B* (a roughly broken cube).

b'. The same, magnified about 8 diameters.

(Had *b* remained longer in the acid it would have been reduced to an approximately spherical form.)

c. Lenticular body, derived from the block *C*.

c'. The same, magnified about 8 diameters.

d. Form intermediate between *C* and *c*, observed when the block *C* was more than half dissolved. Magnified about 8 diameters.

(Figs. *A*, *a*, *B*, *b*, and *C*, *c* are shown of the natural size.)

e. Diagram representing successive stages in the reduction of a block of limestone to a lenticular nodule. The lines drawn at right angles to the surfaces successively formed represent solution-areas, which are largest at the solid angles and along the edges of the blocks. The shading indicates the directions of most rapid solution. These correspond with the initial directions of growth in a chiasmolitic crystallite

Fig. *f*. Diagram to illustrate the comparative poorness of the nodular condition at the top of a series of thick-bedded limestones. On the left, the nodules on the surface have been derived from Bed 7. On the right they have been derived from Bed 6. Before Bed 5 has passed into similar nodules, those derived from Bed 6 will have wholly disappeared. The signs × × denote the centres of the original blocks which supplied the nodules. On the right of the diagram, one bed (No. 7) has disappeared, Bed 6 is represented only by a few scattered nodules or eroded blocks, while Bed 5 has dwindled considerably in thickness, and its joints have been widened.

Figs. *g*, *h*, *i*, and *k* represent, diagrammatically, the successive stages in conversion of a series of thin-bedded limestones into the nodular condition.

s' and s'' denote underlying and overlying shale or sandstone, or overlying sandstone and underlying shale.

In fig. *g* there are seven beds of limestone.

In fig. *h* two of the beds have passed into nodular bands, two others have been greatly reduced in thickness and their joints have been widened, while two more have dwindled to a slight extent.

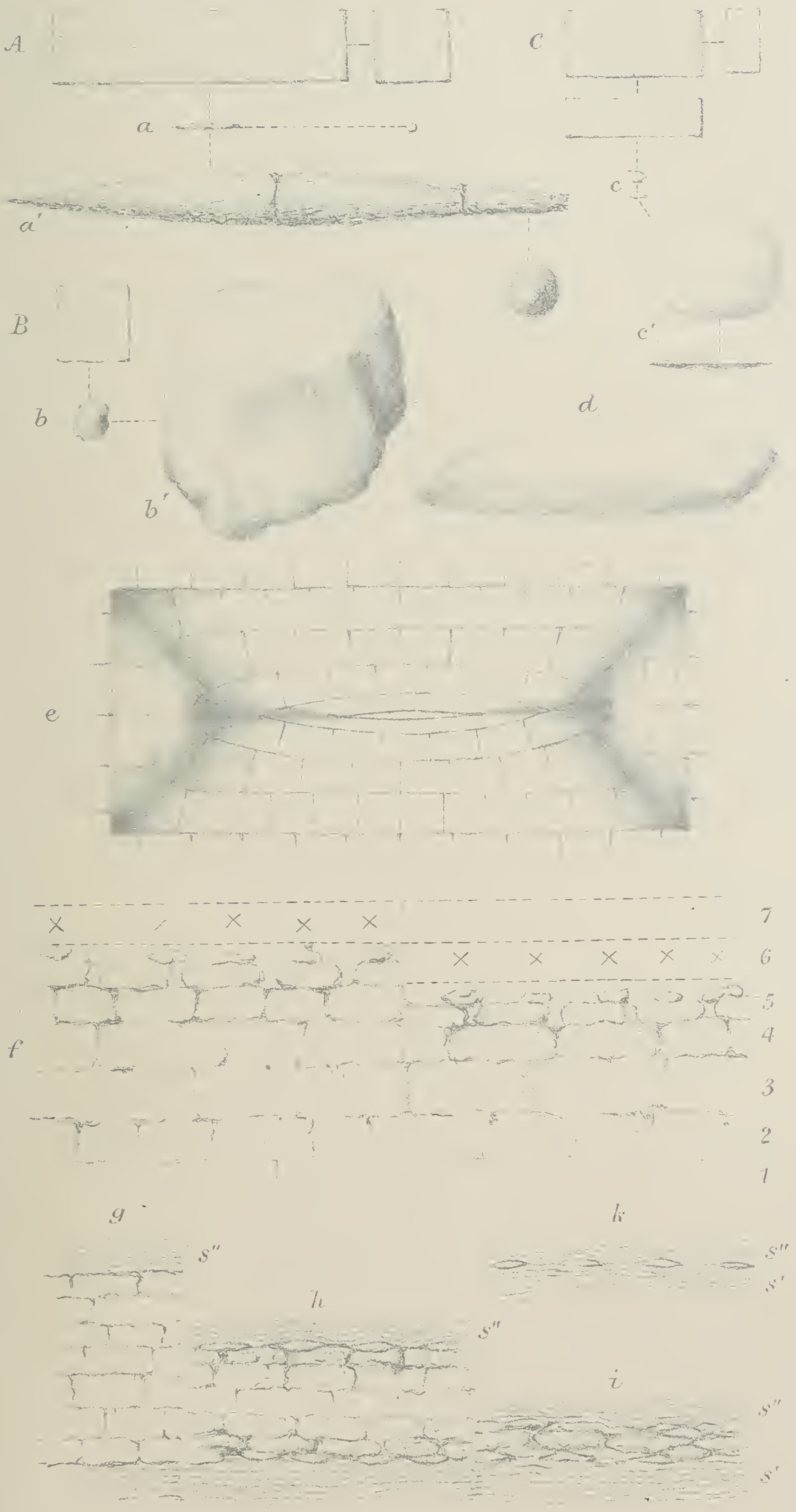
In fig. *i* only one bed (No. 4) remains, and that is greatly reduced; the other beds are represented only by nodules.

Fig. *k* represents the penultimate stage, wherein the central bed of the series (No. 4) is reduced to a band of nodules surrounded by shale or sandstone. These nodules are all that remains of the series of seven beds. When they disappear, the bed s'' will rest directly upon the bed s'.

Discussion.

The President said that the paper raised practical and theoretical questions of great importance. He thought that the Author's statements as to the thicknesses of the limestones in the several formations were open to doubt. The thickness depended on local conditions. His own experience in the Jurassic rocks did not bear out the Author's views. The 'doggers' were not due to the degradation of a pre-existing bed, but to concretionary action.

Prof. Hull was gratified that Mr. Rutley had endeavoured to account for the formation of calcareous nodules among beds of sand or shale, but could not accept his suggestion that the absence or sparseness of limestones among some of the older formations of the British Isles was to be accounted for on the grounds suggested by the Author. The presence or absence of limestones among marine formations was the result of the physical conditions of the ocean-bed at different periods; and, as such beds of limestone were formed mainly by vital agencies, where the conditions had been unfavourable to the development of marine forms, limestones were absent or only slightly represented. These views were illustrated by reference to the distribution of limestones among the Triassic strata of the Eastern Alps and the Nummulitic Limestone of the Middle Eocene period. Some years ago he (Prof. Hull) had read a paper before this Society (Quart. Journ. Geol. Soc. vol. xviii. 1862, p. 127) showing how the limestones on the one hand, and the sedimentary strata on the other, of British formations were developed in their maximum strength from opposite directions; the agencies by which they were respectively developed being mutually antagonistic (the one being vital, the other mechanical), it was shown that where the sediments predominated in the waters the



F. Rutley del.

Mintern Bros. lith.

FORMATION OF LIMESTONE-NODULES

limestones dwindled away or disappeared, and, on the other hand, where the waters were free from sediment the vital agencies flourished and built up the beds of limestone. He ventured to suggest to the Author the perusal of this paper before coming to a conclusion on the subject which he had treated.

Mr. Walford held that field-workers must know the truth of much that Mr. Rutley had dealt with. Speaking from knowledge of Jurassic deposits, he believed in the attenuation of limestones in clay-beds, and thought the nodules and the way in which they were studded with fossils often bore such evidence. Outflows of water frequently occurred along limestone-lines in a clay-series. Near faults he had noticed limestones considerably attenuated by such chemical solution. And in the same way the ferruginous limestones of the Middle Lias often lost all trace of their fossil contents, and fossiliferous and barren beds occurred close together. Calcareous beds could be broken up by both chemical and mechanical solution, but the greater work was done where the limestones and clays were in contact.

Prof. Judd agreed with the Author of the paper that, in some cases, limestones may be removed wholly or in part by solution, and he referred to the solution of the Chalk below the Thanet Sands about London as an example of this action. He was, however, unable to follow the Author in regarding the action as producing very widespread effects; the absence of disturbance in underlying and overlying strata (analogous to the 'creeps' produced in the removal of coal or salt) made it difficult to believe in such extensive disappearance of great thicknesses of limestone as was suggested.

General McMahon said that the Kankar Beds of Northern India showed that nodules were not always an indication of the waste of limestone-beds by aqueous agencies. The plains of Northern India were the creation of existing rivers in recent geological times, and they consisted of river-alluvium to a great but unknown depth. The lime set free by the decomposition of the finely triturated minerals in this alluvium was brought together by a process of segregation as carbonate, and formed extensive beds within a few feet of the surface. This earthy limestone was distinctly nodular.

Prof. T. Rupert Jones mentioned that in Kent the sandy limestone known as 'Kentish Rag' weathered at the surface into stony soil, and was disintegrated downwards into blocks, larger and more closely connected below, such as was shown by one of Mr. Rutley's diagrams. In another case, however, in Somerset, several distinct parts of the skeleton of a *Teleosaurus*, lying in the Lias clay, were seen to have been separately taken up by nodular concretions, not at all connected by limestone.

The Kankar, referred to by General McMahon, he had always understood was formed as separate nodules on and around the silted land- and river-shells and the scattered bones of drowned animals.

Prof. Hughes believed that the cases in which limestones had disappeared by subterranean erosion were very rare, except where they were replaced by silica. He thought that we should seek for evidence from the behaviour of the limestones, where they are last seen when thinning out. In the case of the Bala, Wenlock, and Aymestry Limestones, for instance, though the main mass was often uniformly nodular throughout, they died out into bands and streaks of less calcareous rock, not into rounded relics of similar limestones, and were frequently represented at last by lines and single specimens of the corals or *Rhynchonellæ* or other organisms, to the greater abundance of which in the adjoining area the limestone owed its existence. Moreover, when such limestones as these, or the Carboniferous limestones, were dissolved away in clays, they weathered into fretted forms, not into more or less flattened and irregular spheroids. Subsequent movements occasionally produced greater compression in the shale than in the hard concretions, and these showed evidence of such movement in their slickensided surface, but through them the lines of stratification could often be traced. On the other hand, where a single band of solid limestone passed into a series of rounded masses, as in the case of the limestones in the Kimeridge Clay of Littleport, for example, these rounded masses were obviously concretions (often determined by bones or shells) whose vertical diameter was the same as the thickness of the adjoining band of limestone, and whose shrinkage-cracks, radiating from the centre, had a distinct relation to the form of the septarian nodule and not to the joints of the adjoining band of limestone.

Mr. H. W. Monckton and Dr. G. J. Hinde also spoke.

The Author, in reply, stated that the thicknesses given were derived from various sources which he believed to be, on the whole, trustworthy. In many cases, however, the thickness of a limestone *series* was quoted, and it was then difficult to ascertain how much of that series consisted of rocks other than limestone. He did not attach much importance to the estimates given, and had indicated at the outset how different might be not only the relative thicknesses, but also the distribution of rocks in different areas. With regard to the diverse opinions expressed concerning the origin of certain nodular conditions, there were, as he had already pointed out, two distinct types of nodule—the one residual, the other concretionary; and he considered that the one type might, in most cases, be distinguished from the other by structural peculiarities. He thought that the type of weathering alluded to by Prof. Hughes was due to the presence of fossils. Had the limestone been perfectly homogeneous, it would probably have weathered into smooth-surfaced nodules.

Owing to the lateness of the hour, he could not adequately reply to the criticisms of each speaker. He admitted that in some of the remarks there was much justice, and he thanked the President and Fellows of the Society for the kindly manner in which the paper had been received. The discussion, which embodied many different shades of opinion, had been highly interesting.

32. NOTES on DARTMOOR. By Lieut.-General C. A. McMAHON, F.G.S. (Read May 24th, 1893.)

THE geology of Dartmoor has already furnished material for a somewhat extensive literature; but, as many points in connexion with this region are still in dispute, the discussion of the subject cannot be considered as finally closed. The view advocated by De la Beche was that the granite of Dartmoor was intrusive in the adjoining sedimentary rocks, and that the metamorphism exhibited by the Culm and Devonian beds for a certain distance round the margin of the granite was due to the contact-action of the heated eruptive rock. Quite recently, however, this view has been challenged by Mr. W. A. E. Ussher, F.G.S., of the Geological Survey,[1] and it is alleged by this observer that "the genesis of the Devon and Cornish granites . . . . resulted from the metamorphism *in situ* of pre-existing rocks of pre-Devonian age, which had in a rigid state exercised an obstructive influence on the N. and S. movements, and had thereby produced great mechanical effects on the surrounding strata prior to the alteration of the latter" (p. 219). The result of this dynamic action is spoken of as 'fusion' (pp. 207, 217); the "fusion and subsequent consolidation would appear to have been effected *in situ*" (p. 217), and "the consolidation of the granite in its present aspect may therefore be regarded as post-Carboniferous, or possibly coeval with the later stages of Carboniferous deposition" (p. 218).

If I understand Mr. Ussher aright, the north-and-south movement did not set up any material metamorphic change in the Culm and Devonian rocks, but it was sufficient to fuse the rigid pre-Devonian rocks on which they rested; and it was the heat of this fused mass that produced the "contact-metamorphism on the rocks bordering the Dartmoor Granite" (p. 209).

I had, prior to my visit to Edinburgh in 1892, arranged to spend a month at Lydford, on the western flank of Dartmoor; and having heard Mr. Ussher's paper read before the British Association,[2] in which the views more fully expressed in the paper above quoted were foreshadowed, I paid particular attention, during my residence at Lydford, to an examination in the field of points connected with the questions involved, and I have since studied under the microscope a good collection of thin slices made from specimens then collected. The object of the present paper is to place before the Society the results of my observations so far as they relate to the Dartmoor Granite. I am the more disposed to do so as the author has done me the honour to quote from a paper on the Culm Measures at Bude,[3] in which I suggested that the materials of which the Bude rocks are composed were derived from a granite. That paper, however, does not support the contention which it is at present my

[1] 'The British Culm Measures,' reprint from Proc. Somerset Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892).
[2] Geol. Mag. for 1892, p. 467.
[3] *Ibid.* 1890, p. 106.

desire to controvert. I did not point to the granite now exposed at Dartmoor as the parent of the Culm rocks; and it is obvious that granite which, even according to Mr. Ussher's view, consolidated at the close of the Carboniferous period, or in post-Carboniferous times, cannot have supplied by its subaerial waste material for the Culm Measures at Bude, which are indicated in Mr. Ussher's map as of Middle Culm age.

The first point to which I directed my attention last autumn was whether De la Beche was correct in asserting that the granite sent off intrusive veins from the main mass into the rocks adjoining it. This point is not so easily decided as might have been expected. As a general rule, along the western borders of Dartmoor the granite occupies higher ground than the sedimentary rocks, and the actual line of contact is obscured by a fringe of granite-*talus*,[1] or by vegetable growth. In its upper course, however, to the N.E. of the village of Lydford, at the place marked 'Mary Emma' on the one-inch Ordnance map, the Lyd is approximately the boundary of the granite and of the slates. The granite slopes down rapidly to the stream, and the slates rise abruptly on the other side. The actual boundary of the granite appears to be very close to the left margin of the narrow stream, and in some cases to pass over to the right bank. A careful examination of this locality revealed to me three intrusive veins of granite, a few inches thick, cutting through the Culm beds. They had all the appearance of coming from the main mass of the granite. About 100 feet in elevation above this spot, and distant, as the crow flies, about 150 yards from the stream, a railway for peat has been made round the flank of the hill, and I here found a granite-dyke about 1 foot wide cutting obliquely across the Culm Measures. The granite in this dyke is of medium-sized grain and contains porphyritic felspars 1 inch in length. It is streaked with dark lines along its lower margin. The Culm beds in which these four granite-veins occur are not contorted; they dip about 25° N.W., and the cleavage coincides with the dip.

A microscopical examination of four slices taken from three of these veins does not enable me to differentiate the granite in them from that of the main mass. These slices contain quartz, felspar (orthoclase and plagioclase), biotite, and silvery mica, much schorl, some garnet, and a little zircon. The veins must have been injected under considerable pressure and heat, for the quartz is full of liquid and gas cavities, and many of the former contain mineral deposits (a cube is a common form) as well as bubbles; and the mineral deposits and bubbles are of large size compared with the area of the cavities containing them, showing that the liquid had, at the time of injection, great solvent power.

These veins are undoubtedly intrusive veins, and although, owing to the intervention of loose boulders and vegetation, they cannot actually be traced back into the main mass of the granite, yet they are very close to its boundary; and from their agreement in mineral

[1] Now in the form of weathered boulders.

composition with the granite of the main mass, and other circumstances, I cannot doubt their being apophyses from it. The granite of the main mass is apparently, in this locality, porphyritic up to its contact with the slates, and these intrusive veins are also porphyritic. I saw no trace of elvans in the slates in this locality, or of granite-dykes in the granite, or of granite-veins in the Culm series at a distance from the main mass of the granite; and I am not aware of any fact to support the contention (which has not yet been made) that these intrusive veins are of later date than the granite of Dartmoor.

Mr. Ussher does not allude to the observations of De la Beche regarding eruptive apophyses emanating from the main mass of the granite.[1] It is possible, however, that he may admit the correctness of these observations, but explain them away in his own mind by supposing that, when his metamorphic mass was in a 'fused' condition, pressure acting on the liquid mass forced portions of it into the adjoining strata; but it is difficult to reconcile this suppositious theory with such statements as the following: "I think it may be admitted that the fusion and subsequent consolidation extended over a long period, so that at no one time was any of the masses in a general state of fluidity, for had this been the case, as we have no reason to infer that the N. and S. movements had ceased to act, the plastic masses would not have consolidated in the moulds of their original rigid outlines" (p. 218). The Dartmoor Granite did not, therefore, according to this passage, act as an eruptive rock.

I may mention in this connexion that, in the River Tavy, nearly a quarter of a mile above Hill Bridge, about 50 yards of indurated slates follow the granite in the bed of the stream, and then a reef of granite 8 or 10 yards wide cuts across the river-bed, followed by more slates. This second outcrop of granite is certainly *in situ*, and it appears to be an intrusive sheet. It is here a non-porphyritic rock containing many garnets, and is of a character exactly similar to the granite along the margin of the main mass, exposed higher up the stream, which will be alluded to farther on.

It is desirable also to refer here to a dyke of granite at Meldon, on the West Okements River, near the railway-viaduct over the stream. Two oval patches are marked on the Geological Survey map, but I could not find the second outcrop placed on the map under South Down. Much of the mapping in this part of Devonshire seems to have been filled in from surface-boulders and stray stones in walls, and it would not be safe, in many cases, to draw any inference from the outlines of igneous rocks shown on the map. For instance, the outcrop near the viaduct is not oval in shape, as represented on the map. On the contrary, it is a long, straight dyke, striking about W.S.W. 10° W. Its thickness I should estimate at about 40 feet. At the time of my visit this granite was being worked for road-material, and the lie of the dyke could be clearly seen. There is no doubt about the intrusive character of this rock. It not only

[1] 'Report on the Geology of Cornwall, Devon, and West Somerset,' 1839, p. 165.

cuts obliquely through the bedding of the slates, the dip of which is here northerly, but near its margin it sends numerous veins into the slates and infolds large slabs of them in its arms. The slates in contact with the dyke are highly altered. The intrusive character of this rock has also been recognized in recent years by Mr. Frank Rutley, F.G.S., who has kindly furnished me with an extract from an unpublished report on it.

A brief reference to the petrological characters of this rock will be found in Mr. Teall's 'British Petrography' (p. 316). I shall therefore content myself with mentioning an interesting characteristic of the rock that has not yet received notice. I have examined five thin slices of the Meldon granite, and find that a striking feature in them is that the leaves of mica and the prisms of felspar are sometimes *bent* and in some cases broken; and that the groundmass consists of a mosaic of quartz and felspar, which some writers seem to regard as proof of dynamo-metamorphism. This mosaic penetrates into the cracks in the felspar, and in some cases it divides the ruptured parts. Curiously enough, none of the quartz exhibits strain-shadows.

I see no reason to suppose that this rock gives evidence of dynamo-metamorphism. It is true that some of the epidiorites in this locality are foliated, but the strike of their foliation is discordant with the strike of this dyke. Moreover, the foliated epidiorites are quite close to, and this granite-dyke is in the vicinity of, the Meldon black Culm limestone, regarding which Mr. Ussher notes "the Culm limestones in Meldon quarry near Okehampton can scarcely be said to be altered at all, although within a mile of the Granite boundary [namely, the main granite-mass of Dartmoor] and in the vicinity of Greenstones and hard flinty Culm Measures" (p. 210).

The gneissose granite of the Himalayas at Dalhousie, where it is 8 miles thick, is full of this 'tesselated' mixture of quartz and felspar, but the rock contains undoubted inclusions which forbid the supposition that it was ground down after consolidation. A beautiful photograph of one of these (which speaks for itself) is published in the Records of the Geological Survey of India, vol. xvii. (1884) p. 174. Thin slices examined under the microscope show that the granite exhibits this tesselated structure up to the very margin of the included fragment of schist shown in the photograph. The mosaic structure is clearly not due, in this case, to shearing subsequent to the consolidation of the rock, for the included schist has not been sheared.

Some of the minerals of the Meldon granite show that they have suffered from abrasion and pressure; that is to say, some of the micas and felspars, as before stated, have been bent, cracked, and even broken; but these features, like the dark stripes along the lower side of the vein on the banks of the Lyd (see above, p. 386), are, I think, sufficiently accounted for by supposing that they were produced either when the granite was forced through the jaws of a fissure in the slates, or by strains while the dyke was solidifying.

Mr. Ussher holds that a long-continued north-and-south pressure was sufficient to 'fuse' the pre-Devonian rocks that occupied the sites of Dartmoor, Hingston Down, and Brown Willy. He considers that the "fusion" of the "obstructing masses" "commenced at, roughly speaking, the same period," but the "fusion and subsequent consolidation extended over a long period, so that at no one time was any of the masses in a general state of fluidity" (p. 218). It must have been a considerable squeeze if it were capable of fusing rocks occupying, in the case of Dartmoor, an area of "about 225 square miles," and in the case of Brown Willy of "65 square miles"; and I think one may fairly ask how such extraordinary dynamic force could have been exerted on the rocks of this region and have left the Culm beds unaltered.[1] Mr. Ussher does not, apparently, attribute the metamorphic changes set up in the slates that fringe the granite to dynamic action. He speaks of these changes as the "effects of contact-metamorphism" (p. 209), and from the general tenour of his remarks at pp. 209, 210, I understand him to use the terms 'contact-metamorphism' and 'contact-alteration' in their ordinary sense, and to imply the thermal and hydrothermal action of the 'fused' pre-Devonian rocks on the beds resting on them.

There certainly seems no escape from the conclusion that the metamorphism of the fringing-zone is due to the thermal contact-action of an uncooled, unconsolidated granite. The fringing-rocks exhibit in the mineral changes set up in them,[2] such as the production of chiastolite in beds rich in carbonaceous material, evidence of the contact-action of heated granite. We see these changes set up in other regions in rocks in contact with eruptive granite, and we note that they die out as we recede from the igneous rock, under conditions where dynamo-metamorphism is not in question. There are no grounds, that I am aware of, for attributing the metamorphism of the fringing-zone of Dartmoor to any other cause. A glance at the Geological Survey map of Devonshire will show that the metamorphism clings to the granite and follows all the remarkable sinuosities of its boundary. Now the material point is that directly we get beyond this fringing metamorphic zone—that is to say, when we get a mile, or a mile and a half, from the boundary of the Granite and the Culm Measures—we pass into unaltered rocks. Is it possible that a stupendous north-and-south squeeze exerted on the whole region, and capable of fusing a rigid rock covering an area of 225 square miles, would have left these beds untouched?

Mr. Ussher remarks at p. 192:—"The intervention of the Hingston Down and Kit Hill granites renders it extremely probable that a subterranean connection of the Dartmoor and Brown Willy granites exists at depths sufficient to protect the overlying Devonian from yielding to the compression to which a greater thickness of soft strata would be subjected by the north-and-south movements." But a stupendous squeeze capable of fusing the rocks of Dartmoor, Hingston Down, Kit Hill, and Brown Willy must inevitably have fused the "subterranean connection" of which Kit Hill and Hingston

[1] I think the condition of these beds is fairly comparable with those at Bude, as to which see my paper in Geol. Mag. for 1890, p. 106.

[2] These have already been described by previous writers.

Down formed a part, and then the squeeze would surely have come upon the soft rocks?

This subterranean connexion, however, which is supposed to have saved the zone of Devonian rocks to the east of Brown Willy, is not said by Mr. Ussher to have existed under the Launceston-Lydford zone of Lower Culm Measures. What saved them? The only answer to this question that I have come across is the following reference to Mr. Rutley's memoir on the 'Eruptive Rocks of Brent Tor:'—"Mr. Rutley, in commenting on the schistose[1] character of the volcanic ash-beds of Tavistock and round Brent Tor, observed that, so far as dips can be noted, the rocks have undergone but little pressure laterally. The abnormal extension of the Upper Devonian between the Dartmoor and Brown Willy granites would show that the beds have been kept at the surface, whilst at the same time exposed to a considerable strain, effecting contortions on so small a scale or under such conditions as to produce the effect of a general almost horizontal bedding" (p. 187).

The explanation of the difficulty which appears to be suggested in the remarks above quoted is that the Culm Measures were not metamorphosed by the squeeze that fused the rigid pre-Devonian rocks into granite because they were under *surface*-conditions—they were 'kept at the surface.' This explanation will not, I think, bear examination. From the fact that the Brown Willy, Kit Hill, Hingston Down, and Dartmoor masses consolidated as granite, we know that they must have consolidated under plutonic conditions at a considerable distance below the surface of the earth. It seems physically impossible, therefore, that beds only a mile or a mile and a half distant from these masses can have been 'at the surface.' Again, Mr. Ussher says that his granite consolidated '*in situ*'; namely, in the exact spot where the pre-Devonian rock was squeezed into a condition of fusion. Well, if that be so, at least 20,000 feet of strata must have been piled up on the top of the fused mass, and the pressure of the superposed strata would surely have forced so much of the granite as was in a fused condition through the Culm Beds lying 'at the surface' within a mile, or a mile and a half, of the granite.

If the north-and-south squeeze were capable of fusing the whole of a rigid rock covering an area of 225 square miles, even if the fusion were accomplished by sections—a supposition which my mind can hardly grasp—it ought to have exerted a tremendous effect on the rocks in actual contact with the granite. Contortion exists, but it is local; as a general rule the beds lie placidly against the granite with a very moderate dip. I have never seen anything at all like a passage between the Culm or Devonian rocks and the granite. Whenever the granite and sedimentaries are seen in contact, the line of division is sharp, both in hand-specimens and in the slices examined under the microscope.

[1] 'Fissile' would be a less misleading term. These rocks are not schists in a strictly technical sense.

In speaking of the Dartmoor Granite I have used the word 'fusion,' because that is the word employed by Mr. Ussher; but I may say that an examination of thin sections of this rock under the microscope leaves no doubt in my mind that this rock was once in as heated a condition as any typical granite. I am free to admit that the presence of liquid cavities containing bubbles, especially when the bubbles are small relatively to the area of the cavities, does not necessarily imply conditions of great heat; I also admit that liquid cavities are sometimes the products of secondary processes; but at the same time it is an undoubted fact that liquid and gas cavities are very characteristic of certain original minerals, found in granites under conditions that show them to be congenital. For instance, in a granite-dyke in the Himalayas that cuts across all the other rocks, I found large crystals of beryl embedded in all the other constituents of the granite. These minerals, on being sliced, proved to be extraordinarily full of liquid and gas inclusions. Now the quartz of the Dartmoor Granite is not only full of liquid and gas cavities, but the size of the bubbles, and the size of the mineral deposits contained in the cavities along with the bubbles, shows that the liquid must have possessed a high solvent power when it was shut up in the quartz, compared with what it possesses now. For instance, when you see a deposited mineral and a bubble taking up together about two-thirds of the area of the cavity (in some cases those found in the Dartmoor Granite take up even more room), the natural inference is that the liquid was in a superheated condition, and had more than ordinary capacity for holding mineral substances, or salts, in solution. The same inference seems inevitable when you see, as you may see in these granites, a small body of liquid and a large body of gas together in the same cavity. One cavity that I have before me as I write contains a large bubble of gas (it is not air), a mineral in the form of a cube, and a liquid with the appearance of water containing a small bubble which is certainly not filled with the gas which fills the large bubble. When the cavity was charged with its contents it is clear that the heat was intense enough to cause these solid, liquid, and gaseous substances to intimately blend together. These facts, and others might be cited, seem to point to the existence of great heat when the granite was in a plastic condition. In quoting the word 'fusion,' therefore, from Mr. Ussher's memoir, I am not catching at what some may consider an unguarded expression, but I do it because I think this word (used in a somewhat popular way) sufficiently indicates the original condition of the Dartmoor Granite.

I may note here another point which seems to me worthy of attention. I have not been able to discover any ground for supposing that the epidiorites of the Dartmoor area were erupted after the consolidation of the granite. These epidiorites are altered dolerites. That is the verdict of previous observers, and a microscopical examination of a good selection which I made in the field enables me to confirm this view. The alteration has been attributed—and, I think, rightly attributed—to contact-metamorphism. These epidiorites come up to the granite, as at White Tor,[1] and are apparently cut off by it. I looked for, but failed to find, any instance in which the diorite cuts the granite, and no previous observer has recorded a case of this kind. On the other hand, we have a recorded case (noted by De la Beche and admitted by Mr. Ussher, p. 200) in which an elvan cuts one of these 'greenstones.' A glance at Mr. Ussher's Map No. 2 shows how these elvans radiate from the granite-masses (*e. g.* the Camelford elvan from the Brown Willy), and this is so evident that Mr. Ussher admits the eruptive character of the elvans and suggests that they "were ejected through fissures in granite" (p. 199). Clearly, then, the igneous magma from which the elvans were shot out was situated at the base of the granite-masses from which they radiate.

The figure of which King Nebuchadnezzar dreamed had a head of gold, but feet partly of clay. Here the figure of Dartmoor brought before the eye of the imagination by Mr. Ussher is the converse of this conception, for it has a metamorphic top and an eruptive basis. For my own part, I think the evidence favours the old view: namely, that the granite of Dartmoor is as truly an eruptive rock as the elvans, though some of the latter may represent later phases of the eruption.

Another point alleged is that there has been a reciprocal metamorphic action between the granite and the slates (pp. 215, 217). I pass over the question of schorl and its abundance along the margin of the granite, as I do not think its discussion would elucidate any point at issue in the present enquiry. Schorl is present in every slice of Dartmoor Granite that I have examined, even in a slice cut off a specimen from Princetown. The normal type of the Dartmoor Granite is strongly porphyritic, the porphyritic crystals of felspar attaining, as at Princetown, a length of 4½ and a breadth of 3½ inches. Along the margin of the slates, on the other hand, the porphyritic type usually disappears and the granite becomes comparatively fine-grained and homogeneous as to the size of its grains. An examination of thin slices and a comparison between the porphyritic and the marginal non-porphyritic types have led me to believe that they are both parts of the same granite. Both contain quartz, felspar, mica, schorl, and garnet. The felspar is in part plagioclase, and some of the latter has the optical characteristics of oligoclase. The mica is principally a dark species, but there is more or less of a silvery variety.

The best locality for studying the two types of granite, that I have seen, is in the valley of the Tavy in the neighbourhood of Hill Bridge, between Hill Town and White Tor. The passage from the fine, even-grained type to the porphyritic normal type is rapid. In the bed of the river, owing to a long period of dry weather, I was fortunate enough to reach a mass of granite *in situ*, worn smooth on the surface by the water, that showed the actual blending of the two types. About 50 yards from where the slates first crop out (see *ante*) a mixture of the porphyritic and fine-grained varieties

[1] Ought not this to be 'Whit Tor'? It is so pronounced by the people of the neighbourhood.

may be seen. Masses of porphyritic rock containing rectangular crystals of felspar, from $2\frac{1}{2}$ to 3 inches in length, are included in the fine-grained variety. They have not the appearance of blocks of a coarse-grained granite included in another eruptive rock, but look like aggregations of porphyritic crystals in a fine-grained non-porphyritic base. The whole suggests the idea of an imperfectly-stirred plum-pudding, in which the plums have got together in a lump. We have here, I take it, evidence of the imperfect mixing of two portions of the granitic magma in different conditions of fluidity.

Students of quartz-porphyries, and similar rocks, are well aware that when a relief of pressure takes place, and a partially crystallized deep-seated rock is moved towards the surface, a partial remelting of the already-formed crystals takes place. The relief of pressure[1] in this case is believed to give increased potency to the solvent action of the heated liquid in which the crystals are suspended. It seems to me that a similar result would be produced if the pressure remained constant and the heat were locally increased. And the explanation I would suggest is that, as the partially crystallized granite was moved upwards, the traction and friction against the sides of the vent broke up the larger crystals and increased the heat, and consequent fluidity, of the marginal portions of the mass, so that we have a margin of fine-grained granite around the normal porphyritic rock, and an imperfect blending of the two along the line of junction.

The loss of heat during cooling would have been more rapid along the margin than in the central portions, and although it evidently was sufficiently slow to enable both portions to set up a holocrystalline structure, it was not slow enough to enable the marginal portion to develop porphyritic crystals.

The explanation offered above was formed in the field in sight of the rocks, and has been confirmed by an examination of my specimens under the microscope. It is evident that a strong solvent action has been set up by the acid magma on the crystals of first consolidation. The biotites have been eaten into internally and around their edges. They suggest the idea of slices of cheese that have been half nibbled away by mice. Similarly the felspars are eaten into, and riddled with granules of quartz. Some are dappled over with numerous microscopic crystals of a colourless mica, such as one often sees in quartz-porphyries and granites. There is nothing whatever to suggest that any of the above peculiarities have been

[1] By the operation of Thomson's Law, which is to the effect that in ordinary cases an increase of pressure raises, and a decrease of pressure lowers the melting-point. See Teall's 'Brit. Petrography,' pp. 407, 408, and Lagorio, Min. Mag. vol. vii. (1887) pp. 224, 225. Pressure increases the action of solvents in some cases by increasing the heat. It also, independently of a rise in temperature, facilitates melting and solution in cases in which substances on melting (as ice), or on solution (as sodium chloride), contract in volume ('Solutions,' by Ostwald). In cases in which melting, or solution, involves an increase of volume, pressure retards the change of state, or, in other words, raises the melting-point. The subject is a complex one, but the corrosion of porphyritic crystals formed under plutonic conditions, on the magma being moved towards the surface, seems sufficiently accounted for by the relief of pressure lowering the melting-point.

set up by dynamic agencies after the consolidation of the granite. There is not a trace of parallelism of structure or of strain-shadows, and lines of liquid inclusions in the quartz have no connexion with those in neighbouring grains. The neighbouring porphyritic granite gives evidence of similar conditions, and exhibits similar phenomena, but they are not so prominent as in the marginal fine-grained rock.

I now propose to consider briefly, in conclusion, the curious parallel jointing in the granite, which has been noted by almost all previous observers. This simulates bedding in a very curious way, and at once strikes the eye of the geologist. De la Beche regarded this as a "thick laminated structure pervading the masses on the large scale, probably agreeing in form with that of their original surfaces after protrusion" (Report, etc. p. 163). The explanation here suggested appears to have satisfied all subsequent writers on the granite of Dartmoor. To me it appears very unsatisfactory. I cannot suppose that the Dartmoor Granite did not rise beyond its present level; or, if it did, that the mammiform contour of its present surface, obviously due to subaerial agencies, represents the original contour of its surface. In all probability the granite was continued upwards, and the present contour of its rugged tors and rounded hills has no relation to the original outline of the intrusive mass. However this may be, it seems certain that subaerial agents have cut up the "original surfaces after protrusion" beyond recognition. Now, the first thing to strike me was that the pseudo-bedding of the granite conforms closely to the *present* slope of the surface of the hills, and this was confirmed by all my subsequent observations. When the outcrop occurs on the apex of a hill its pseudo-bedding is horizontal. When it occurs on the eastern side of the hill, it dips eastward at an angle that corresponds to the slope of the hill. On the northern side it dips northward; on the west, westward; and so on all round. Unless we are to suppose that the contour of the existing hills is an original structure, and that the very abundant rain that falls on Dartmoor has done nothing to carve out a new contour, it seems obvious that the pseudo-bedding must be a structure connected with subaerial agencies.

Some students of the Bible have been puzzled to understand what the Prophet meant when he said:—"Is not my word like as fire? saith the Lord; and like a hammer that breaketh the rock in pieces?"[1] To me it has always seemed that the Prophet had in his mind a simple, archaic form of mining that has survived to the present time in Southern India. A huge bonfire is kindled on a surface of rock, and after heat has been maintained for some time the fire is extinguished and the rock is allowed to cool down, the result being that a few feet below the surface a rupture takes place parallel to the external slope of the rock, and a slab is detached, which is broken up in the usual way, with hammers, into the size and shape required. At Dartmoor the sun, during the summer months, has acted like the fire of the Prophet, and the frosts of winter have completed the process. Cracks, small at first, have

[1] Jeremiah, xxiii. 29.

little by little grown into deep joints, and so the pseudo-bedding has been gradually produced.[1] With the dominant pseudo-bedding other joints, roughly speaking at right angles to the bedding, have also been formed by the constantly-recurring expansion and contraction. A similar phenomenon from a like cause may be commonly seen in surface-pits, in various parts of England, when solid strata are brought near the surface.

Discussion.

The President remarked that, as the paper alluded to was not in evidence nor its Author present, the discussion might be less effective, notwithstanding that the points actually criticized had been so well brought out by General McMahon.

Dartmoor had been the subject of many an hypothesis. A few years ago Ussher himself maintained that it was a laccolite; Worth saw in it the hypogene condition of a great Devonshire volcano; Hunt regarded it as an Archæan *massif*. There has always existed a school who have tried to prove that certain granites are due to some form of metamorphism. It had been reserved for Mr. Ussher to invent a modified metamorphic hypothesis. He is too ingenious to maintain, like the old metamorphists, that a potash granite is the result of the metamorphism of the encasing rocks: the impossibility of that has been too often demonstrated. Hence he has selected for the experiment a group of rocks—pre-Devonian—which no chemist can analyse in their unmetamorphosed condition.

In the paper now before the Society General McMahon had adduced some valuable additional evidence in favour of the eruptive origin of the Dartmoor Granite, and he had strikingly pointed out the almost insuperable difficulties presented by the unaltered condition of the Culm Measures. His explanation of the pseudo-bedding structure in the granite was well worthy of attention.

Mr. W. W. Watts observed that one of the main objects of Mr. Ussher's paper was to point out that the deflections in strike of the Culm and Devonian rocks would be explained, if there were a mass of rock in the position of the Dartmoor Granite in post-Carboniferous times; and that Mr. Ussher had only asserted the refusion of very small portions of the edge of the granite-mass to form the elvan and granite-dykes.

Mr. Teall wished to point out that the main object of Mr. Ussher's paper was to describe the Culm Measures and their stratigraphical relations to the granite. (The President here reminded Mr. Teall that the part of Mr. Ussher's paper dealing with the Culm Measures was more or less of the nature of an official memoir; whereas the theory criticized was the main point in that portion of the paper for which the Author was alone responsible.)

[1] [After the above was set up in type, a friend pointed out to me the following passage in Sterry Hunt's 'Mineral Physiology and Physiography,' p. 273: 'In this connexion I venture to recall the attention of geologists to a phenomenon already described both by Dr. Shaler and myself, apparently due to superficial alternations of temperature on certain crystalline rocks, which have resulted in establishing in them, to a considerable depth, a series of rifts or divisional planes parallel to the present surface, which are well known to quarrymen.'—July 11th, 1893.]

Mr. Teall, continuing, said he was sure the President would agree with him that Mr. Ussher's communication contained a record of many valuable facts. There was at present no really satisfactory explanation of the structural relations of the granite to the surrounding rocks. Realizing the difficulties which beset the current theories, Mr. Ussher had been led to propose the one under discussion, which, however, he (the speaker) could not accept. He considered that 'tesselated' structures arose in consequence of dynamo-metamorphism, but he agreed with General M^{c}Mahon that they might be formed in other ways.

Mr. Rutley expressed his inability to offer any unbiassed criticism upon this paper, because, in the first place, he entertained a profound regard for the opinions of Sir Henry De la Beche; in the next he was strongly impressed, from personal experience, by the extreme accuracy of Mr. Ussher's field-work, although with regard to his theory he felt somewhat less confidence. Last, but not least, he realized the importance of General M^{c}Mahon's observations. So far as his experience went, the contact of granite with other rocks usually showed a sharp line of demarcation. The small felspars in some of the lavas of the Brent Tor area were at times represented by pseudomorphs having a mosaic or tesselated structure. Some of the fragments in the Brent Tor tuffs which he had formerly spoken of as pumice he now regarded as vesicular basalt-glass, rendered black by separation of magnetite. He considered the Meldon dyke as an apophysis of the Dartmoor Granite. So far as the origin of the latter was concerned, he ventured to suggest that a cauldron of molten matter might have existed for a lengthened period beneath the Devonian and Cornish areas, and that it showed its existence first by eruptions of basic lavas; that towards, or after, the close of the Carboniferous period the granite of Dartmoor might have been the source from which trachytic lavas, long since removed by denudation, might have emanated, having reached the surface through a great thickness of overlying rock, now also removed by denudation; and that from the same reservoir the later basic lavas on the east of Dartmoor might also have been derived.

Prof. Bonney said that he felt some difficulty in accepting the Author's explanation of the bedded structure in the granite, for it appeared to be related to the present surface of the ground; this, however, only represented a phase in the denudation of the district, and it might be expected that the structure would be produced during an earlier one. In all other points he quite agreed with the Author. He had seen streaked structures, as described, in more than one dyke. Undoubtedly there had been a tendency among certain geologists to appeal to 'tesselated structure' as evidence of dynamo-metamorphism. It could be so caused, but there were varieties of this structure, produced by different causes, four of which he mentioned, and generally distinguishable. In his opinion Mr. Ussher's theory was quite untenable. If the fusion of a peripheral portion of the Dartmoor mass was due to crushing, why did we not find signs of extra disturbance for a considerable distance outside that mass, at right angles to the pressure, and a crushed zone (indicating one where the pressure was inadequate for fusion) parallel with and inside of the supposed fused zone? Was there any evidence that a rock could be fused by pressure alone, any more than by a gentle stewing in sea-water, which also had been suggested? Difficulties no doubt there were in accounting for the relation of the granite-masses to the stratigraphy of the country, but these were not confined to granite or to Dartmoor. No good was done for science by proposing hypotheses which, in avoiding one difficulty, raised a number of others far more formidable.

Prof. Hull observed that he fully concurred with the Author that the granite of Dartmoor is intrusive. He thought the flaggy structure ('pseudo-bedding') in granite was not at all uncommon. It was very well developed in the granite of the Mourne Mountains, which was certainly intrusive, and he regarded the structure as originating in planes of cooling more or less parallel to the roof or wall of the stratified masses into which the molten matter had been intruded. This was the case in the granite of Mourne, and had its counterpart in the platy structure not uncommon in dykes of trap, where the planes were developed parallel to the walls of the dyke.

The Author, in reply to Mr. Watts, said that the word used by Mr. Ussher was 'fusion,' and it was applied to the results of the N. and S. squeeze on the rigid and obstructing pre-Devonian rocks. The eruptive origin of the elvans was admitted by Mr. Ussher, and they were said to have appeared *subsequently* to the consolidation of the granite. With reference to Mr. Teall's remarks, the Author stated that he admitted that a 'tesselated' structure might result from dynamo-metamorphism; he was only concerned to show that this structure did not necessarily denote dynamo-metamorphism, and that it was, not unfrequently, produced in other ways. He had not attempted a general criticism on Mr. Ussher's paper, and had rigidly restricted himself to points regarding which his own observations in the field traversed Mr. Ussher's case. In answer to Prof. Bonney, he was of opinion that the exposures of bare granite were being worn away by subaerial agencies at a more rapid rate than the rounded grassy hills on which they rested. The bare granite was broken up by cross joints; the detachment of blocks was continually going on, and the hill-sides were covered with boulders. In reply to Prof. Hull, the Author explained that the dip of the pseudo-bedding coincided with the slope of the existing rounded knolls, or hills, of which there were hundreds, and these quaquaversal dips did not coincide with what they might assume to have been the original surface of the granite, especially as the granite probably rose in a more or less cone-like form to some distance above its present surface.

33. *The* Origin *of the* Crystalline Schists *of the* Malvern Hills.

By Charles Callaway, D.Sc., M.A., F.G.S. (Read April 26th, 1893.)

[Abridged.]

Contents.

I. Introduction.

The crystalline rocks of Malvern are of exceptional importance to the student of the problems of metamorphism, inasmuch as the causes in operation have acted with comparative feebleness, and thus have not obliterated the earlier stages of their work. Hence we are able in numerous sections to observe the details of the process by which a massive igneous rock has been converted into a well-foliated schist.

In my first paper [1] on the subject, I gave an outline of the mode in which some of the schists had been formed. In the second,[2] I described the most important mineral changes that occur at the zones of shearing. It now remains to work out certain structural details, to meet difficulties arising or suggested in the course of the enquiry, and to classify the chief varieties of schist in the light of their mode of origin. I would add that five years' study of these rocks has enlarged my belief in the efficacy of dynamo-metamorphism, to a degree which I should hardly have conceived possible when I presented my first paper to the Society in 1887.

In the present communication, it will be unnecessary to refer to minerals which do not play an essential part in the metamorphic process. Apatite, for example, does not, so far as the writer has observed, undergo any change. Sphene, garnet, and rutile are

[1] Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 525.

[2] *Ibid.* vol. xlv. (1889) p. 475; these papers will (in the following pages) be referred to respectively as No. I. and No. II.

probably secondary products; but the first and second have been noticed in No. II., while the last occurs in very inconspicuous proportion.

Particulars of dips and strikes, and details of rock-distribution, will be found in Dr. Holl's memoir,[1] and descriptions of the principal rock-types in Mr. Rutley's paper.[2]

I have to express my great obligations to Messrs. J. H. Player and T. H. Waller for chemical analyses; also to Dr. G. H. Bailey and Dr. Cohen, of the Owens College, Manchester, for superintending several analyses.

II. Confirmation from other Sources of some Points in the Author's former Papers.

Secondary Minerals produced during Dynamo-Metamorphism.—Prof. G. H. Williams, in describing the 'Greenstone-schist Areas of the Menominee and Marquette Regions of Michigan,' Bull. U.S. Geol. Surv. 1891, No. 62, states that the new minerals formed during the production of these schists are albite, microcline, zoisite, garnet, quartz, hornblende, epidote, biotite, muscovite, sericite, rutile, anatase, and sphene.

This list corresponds with that of the secondary minerals recognized by me in the Malvern schists (No. II.), except that the secondary plagioclastic felspar of my papers could not be specifically identified, owing to its minutely-granular structure; but as the rock containing it is sometimes almost destitute of lime, much of it may safely be referred to albite. Prof. Williams mentions anatase, which I have not recognized at Malvern, and, on the other hand, my list includes calcite, chlorite, and iron oxides, but these are of course very commonly produced in rock-crushing.

Production of Secondary Biotite.—The conversion of *Chlorite into Biotite* is recorded by Salomon, Zeitschr. d. Deutsch. geol. Gesellsch. vol. xlii. (1890) p. 450; also by Lossen, Congrès Géol. Internat. Londres 1888, Compte-Rendu, p. 180, and Rüdermann, Neues Jahrb. v. Beilage-Band (1887) p. 643.

The formation of *Biotite out of Chlorite and Sericite* is asserted by M. A. Michel-Lévy ('Sur l'Origine des Terrains cristallins primitifs,' p. 58, Congrès Géol. Internat. Londres, 1888).

The production of *Biotite in Shear-zones*, when none of that mineral occurs in the walls of the shear-zones, is recorded by Mr. J. F. Kemp in a paper on 'The Great Shear-zone near Avalanche Lake in the Adirondacks,' Amer. Journ. Sci. vol. xliv. (1892) p. 109.

Production of Muscovite from Biotite.—This change has been actually effected in the laboratory by Mr. Alex. Johnstone ('Nature,' vol. xlvi. Sept. 29th, 1892, p. 518). Mr. Johnstone states that "by the continued action of carbonic acid, oxygen, and water, biotite loses magnesia (taken out as carbonate), and iron (removed either as oxide or carbonate), and becomes eventually the

[1] Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 72.
[2] *Ibid.* vol. xliii. (1887) p. 481.

white and yellow muscovite which undergoes no further chemical change." Hornblende, according to the same authority, loses only a trace of magnesia under similar circumstances; but since hornblende is easily decomposed into chlorite, and chlorite may be changed into biotite, it is plain that hornblende may indirectly be a source of muscovite.

III. Stages of Metamorphism.

(1) *Decomposition and Corrosion.*—Ordinary decomposition, such as the passage of hornblende into chlorite, epidote, and iron oxide, or the conversion of plagioclase into calcite and quartz, appears to be associated with the access of mineral solutions. Where the rigid rock is crushed, there is always more or less decomposition, and the presence of water is evinced by the nature of the deposits which fill the cracks. Generally speaking, the crushing accelerates the process. When the pressure has increased so as to produce planes of discontinuity, decomposition is greatest at these planes. Thus, in a diorite the planes of cleavage or shearing are often marked by secondary products, while the intervening seams are comparatively unchanged.

Corrosion requires special mention. Crystals of hornblende, felspar, and some other minerals are very commonly corroded in an excessive degree in and near granite-diorite complexes. Idiomorphic individuals thus appear perforated with holes, or their margins are cut like a dentate or crenate leaf, and frequently the original crystalline form is nearly or entirely destroyed. The change is most common in the medium-black diorite.

The hornblende of this diorite sometimes shows curvilinear outlines at considerable distances from a sheared plexus of veins, and I must not be understood to deny that in these cases the mineral may have originally crystallized in this form; but the characters become more marked towards the zone of shearing, the crystals being more and more deeply eroded until only shreds of them are left. The mineral which remains in contact with the eroded part is generally transparent and water-clear. It is sometimes quartz, sometimes felspar. The latter occasionally displays polysynthetic twinning, but usually it is recognized as felspar only in convergent light. Hornblende can rarely be followed into a granite-diorite shear-zone, since it is normally converted through chlorite into black mica. This mica also frequently suffers corrosion, is reduced to shreds, and sometimes destroyed.

The corrosion of the felspar is very similar. The crystals are invaded by quartz or water-clear felspar, and sometimes the original substance entirely disappears. Frequently, simple felspar-crystals sheathed in biotite are replaced by quartz, the mica remaining intact. More commonly, the corrosion has acted in patches, so that a large part of a slide of modified diorite may be occupied with water-clear granules. Corrosion in felspar and biotite is shown in fig. 3 of pl. xvi. in paper No. II.

The rounded or lobate forms of crystalline grains have long been recognized [1] as characteristic of gneiss, as distinguished from granite.

Corrosion during the primary consolidation of granite has been fully described by Prof. Sollas, who states [2] that muscovite corrodes biotite, albite corrodes biotite, orthoclase and quartz corrode albite.

(2) *Reconstruction.*—In the course of my present enquiry, I have often been met by a demand for signs of mechanical force, such as broken or distorted crystals, shear-planes, decomposition-products, or strain-shadows. These, however, are the effects of an early stage of the metamorphism, and it would be as reasonable to expect them in the completed product as to look for petals and stamens in a strawberry.

Fortunately, at Malvern mechanical force has acted so intermittently that the stages of metamorphism can be followed from beginning to end in scores of sections. For example, the change from felsite or diorite into mica-gneiss can be traced inch by inch, the mineral decompositions and syntheses can be verified step by step, and we are thus forced to unite the extremes by countless intermediate links, and to conclude that the schist has been formed out of the massive rock.

The process of reconstruction often commences almost as soon as the decomposition. Take the case of a granite-diorite shear-zone. While the hornblende of the diorite may be passing into a chlorite, some of the felspar may be replaced by quartz and muscovite, and these are ultimate products. When, within the shear-zone, the chlorite has passed into black mica, more of the quartz and muscovite will have been generated. Iron oxide, liberated in an early stage, is either absorbed later on, as in the change from chlorite to biotite, or it aggregates into definite crystalline forms. The acidic constituents, quartz and felspar, fill up the spaces between the micas and any other basic mineral which may remain. The rottenness and dirty appearance produced by the presence of chlorite and disseminated iron oxide disappear, and a sound clear gneiss results.

The gneissic rocks have undergone but little mechanical change since the secondary consolidation, and their minerals, even the biotite not excepted, rarely show undulose extinction.

IV. Classification of the Malvern Schists.

In paper No. I. the present writer divided the Malvern schists and gneisses into two groups, viz. :—*Simple Schists*, or those formed from one kind of rock, and *Injection-Schists*, or those produced by the interveining of two varieties. The subsequent discovery of the infiltration-gneiss of the Wych makes it necessary to subdivide the latter group into (*a*) Schists of Primary Injection and (*b*) Schists of Secondary Injection.

[1] T. G. Bonney, Pres. Address, Quart. Journ. Geol. Soc. vol. xlii. (1886) *Proc.* p. 92.

[2] 'Contributions to a Knowledge of the Granites of Leinster,' Trans. Roy. Irish Acad. vol. xxix. (1891) p. 492, *et alibi.*

(A) Simple Schists.

The following are the most important varieties :—

Hornblende-gneiss (from *Diorite*). This schist involves the minimum of metamorphism. The constituents have been re-arranged, and quartz has been generated. The change is too well-known to need description.

Biotite-hornblende Gneiss (from *Diorite*).—Between bands of the gneiss just named and the biotite-gneiss which often forms the core of a veined plexus, the rock becomes progressively compressed, and biotite begins to appear. A slide (391)[1] offers the following characters :—

The hornblende has lost its clearness and cleavage, is irregularly stained with iron oxide, and is drawn out in the direction of schistosity into irregular ribbons or even strings. Sometimes, however, it retains perforations and traces of sinuate contours.

The felspar is not so clear, but is here and there clouded by partial decomposition. Quartz invades it in aggregates with mosaic polarization. Quartz also, or a water-clear mineral like quartz, usually occupies the perforations in the hornblende, whether within the crystal or at the margin.

The biotite is well characterized. It is strongly pleochroic, changing from light-brown to nearly black. The laminæ lie parallel to the general schistosity of the rock. A little chlorite is associated with this mica. The felspar and quartz are perfectly moulded upon both biotite and chlorite, as well as upon the distorted hornblende: a flake of mica, or chlorite banded with mica, having sometimes one extremity in the middle of a felspar-crystal, and the other end in the middle of another crystal.

The slide is traversed by a large number (from 12 to 20) of cracks (shear-planes ?) running roughly with the foliation. They cut through crystals of felspar and granules of quartz, and are clearly connected with the distortion of the hornblende, for the latter suffers unusual elongation where they pass through it, and it is often drawn out at the end into a long tail occupying a crack. The formation of the biotite is also dependent upon the cracks. A large proportion of it is seen to lie either in a crack, or in the line which a crack would take if produced. Or a mica-flake tails out in an attenuated film of brown matter, which is continued along a crack. I cannot resist the conclusion that this mica has been formed by the action upon the decomposed hornblende of mineral solutions infiltrated into the planes of discontinuity.

But we are met with an apparent difficulty. The felspar and quartz must have been in a plastic state subsequent to the distortion of the hornblende and the genesis of the mica, for the former two are moulded upon the latter two minerals. How is it then that the cracks still remain? The answer is (1) that to a large extent they have been obliterated: none of them can be traced all the way

[1] These numbers indicate throughout the numbers of the slides in my own collection.

across the microscopic section. And (2) that we can observe under a high power that the thinnest visible cracks are occupied by brown matter (iron oxide ?) in minute particles. This film has apparently been sufficient to prevent the coalescence of the sides of the crack when plasticity supervened.

If the biotite be regarded as an original constituent of the rock, the planes of discontinuity must have been formed after it; and, as the cracks and flakes often coincide, the mica must frequently have been torn and distorted. But such is not the case. While the hornblende is more or less decomposed and deformed, the biotite in the cracks is idiomorphic and clear, frequently showing in section lath-shaped forms, rectangular or oblique, with the ordinary parallel cleavage.

The difference between this schist and the hornblende-gneiss gives us a hint of the important part in metamorphism played by mineral solutions infiltrated along cleavage-planes and cracks. The absence of cracks in the hornblende-gneiss probably accounts for the slight degree of mineral change. Water was of course present, for chlorite has been produced. But the rock which was converted into biotite-gneiss, traversed as it was with countless cleavage-planes, must have been saturated like a sponge. This principle is of wide application.

Muscovite-chlorite Gneiss (from *Diorite*).—This schist is not of wide distribution at Malvern. I showed in No. II. (p. 480) that in or near a granite-diorite complex, muscovite was sometimes formed from the felspar of the diorite, and not biotite from the chlorite.

Sericite-gneiss and *Muscovite-gneiss* (from *Diorite*).—The transition which will now be described is one of the most interesting that I have studied. At one end of the series we have a granitoid diorite; at the other, a fine-grained schist of acidic composition. The typical sections have been repeatedly visited during three years, and 39 slices of the rock have been examined.

The schist occupies the western side of the long spur running from the summit of Ragged Stone Hill in a southerly direction to the village of White-leaved Oak. The band is several yards broad, but possibly extends farther westward under the Hollybush Sandstone. Towards the eastern slope of the spur, the schistose structure becomes fainter, and the rock resembles a roughly laminated grit. In the quarry at the village, this gritty material graduates into the diorite. The complete transformation is seen in section in this quarry. The description will be taken from east to west, that is, from the diorite through the grit into the schist, a distance of about 50 yards. The structural planes, whether in schist or grit, dip at a high angle to the north of east.

We work along the northern side of the quarry, commencing where an irregular buttress is thrust forward, the rock to the east being decomposed and of no interest in the present investigation. The projecting mass is about two yards wide; in the middle of it is the diorite, a vein of granite runs up the eastern side, and several veins of felsite appear in the western surface. In the lower face of the rock the diorite is quite recognizable as the coarse-grey variety (No. 3), but is rather crushed and decomposed. Following this rock up the slope, we see that the crushing and rottenness increase, while aggregation of the constituents becomes very marked. Thus, one hand-specimen is nearly all crushed felspar, with perhaps some infiltrated calcite and chlorite; another is mostly chlorite; in a third, iron oxide predominates. Near the top of the slope, a little to the left of the buttress, a rough schistosity sets in. Felspar in small irregular fragments, sometimes in recognizable portions of the crystals, lies in narrow parallel seams. The groundmass is chlorite, passing into brown mica, with a great quantity of opaque dust, presumably iron oxide. The rock is curiously suggestive of a true sedimentary grit. Much of it is very rotten, and specimens for the microscope are hard to get.

For several yards to the west there is little change. Then the outcrop is interrupted by soil and débris, but the exposures show that the rock is becoming more and more comminuted. Masses of felsite appear here and there up to the end of the section, but no more granite is seen, though there is plenty on the southern side of the quarry. Just before the Hollybush Sandstone is reached, marked reconstruction sets in. The rock becomes clearer and sounder, and the schistosity more strongly marked. The last series of changes is best observed by leaving the quarry and ascending the spur: the gradation from grit to schist is seen at many points on the ridge. Veins of granite sometimes appear in the schist, and are sheared out into bands of thinly foliated, contorted gneiss. A little south of the western summit, granite also veins the grit, but is not schistose. Just at the western summit, the passage from grit to schist may be seen in the same hand-specimen, and even in the same slide. A series of micro-slides in my collection illustrates the above general description.

There is so much crushing and decomposition in the rocks of this locality that I have been unable to obtain a specimen of the diorite that is unaltered. There is no doubt, however, that it is a modified form of the rock which Mr. Rutley has described[1] as a 'hornblende-gabbro.'

Slides Nos. 454, 455, and 456 (fig. 1).—These specimens are taken from the lower part of the projecting wall, and differ very slightly from each other and from Mr. Rutley's type. The hornblende shows very clearly the prismatic cleavages, but is much crushed and distorted. Here and there it has been changed into chlorite, especially along the cleavages. The chlorite is pale green in ordinary light, shows slight pleochroism, and under crossed nicols is nearly black with slight mottlings of grey. Epidote is abundant: it is usually in dirty aggregates without regular boundaries to the individual granules. There is a little white mica in minute flakes: it is clearly secondary, being moulded on the contours of the epidote and the jagged projections of the broken hornblende-prisms.

[1] Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 493.

Quartz is in very minute proportion. Calcite is abundant, either in crystalline aggregates enclosed in other minerals, or forming venules, which sometimes occupy long irregular cracks, that also contain opaque matter and occasionally epidote. There can be little, if any, dolomite in the rock, for it effervesces freely with acids, and under the microscope we can often recognize the polysynthetic twinning parallel to faces of the rhombohedron $-\frac{1}{2}R$, so characteristic of calcite.

Fig. 1 (Slide 456).

Diorite No. 3. The hornblende crushed and distorted. and the felspar moulded upon it. The hornblende is partly decomposed into chlorite, epidote, calcite, and iron oxide. Unshaded portions are spaces where the rock has been torn away in grinding.

The felspar requires special notice. It is certainly secondary, for it is moulded to the jagged and frayed edges of crushed hornblende-crystals, and encloses shreds of that mineral. It is also moulded to and sometimes encloses chlorite and opaque black matter, presumably iron oxide, both of which have been derived by decomposition from the hornblende. The species of this felspar cannot be determined. It is slightly decomposed, preserving in ordinary light a somewhat dingy appearance. Here and there, traces of multiple striping are faintly visible; but many of the forms, though clear enough to show twinning, if it were present, display a uniform colour under crossed nicols.

No. 466.—This slide is from the rock a few feet above that from which the last set were taken. There is a slight approach towards a parallel arrangement of the constituents. All the hornblende has disappeared. Calcite, epidote, and fragments of felspar are scattered in a groundmass of chlorite, and the slide is very much obscured by opaque matter in the form of disseminated dust, which must be iron oxide liberated from the hornblende. The chlorite, which is in irregular strings and patches, is in part similar to the last; but some of it is more strongly pleochroic (sap-green to pale yellow-green), and shows higher interference-colours. Here and there the green shades into brown, and the interference-colours rise still higher, so that there is apparently a passage into black mica. Under crossed nicols, most of the chlorite presents a confused appearance of aggregate polarization; but this is seen to be due to the presence of calcite scattered through the chlorite in numerous minute forms. The epidote requires no special notice.

Much of the felspar is in large crystalline forms, which are more or less cracked and broken, the fragments being sometimes drawn away from each other. The cracks are filled in with chlorite, calcite, and the opaque dust. This felspar is clearer than the last. Only a small proportion of it shows twinning of any kind. The bulk of the felspar polarizes in a rather irregular manner, some of the fragments showing several patches of different shades of colour with vaguely sinuate margins, suggesting an approach towards a mosaic structure.

This rock is traversed by cracks, roughly parallel to the schistosity, and more or less occupied with the products of decomposition. There has been considerable strain in the mass subsequent to the secondary consolidation, both felspar and calcite displaying undulating extinction during rotation of the microscope-stage.

No. 470. Three or four yards farther up the slope.—The crushing is greater, and the parallelism of the constituents more marked. The chlorite passes more frequently into biotite. The slide is traversed by several cracks filled with opaque brownish matter (limonite?), and where these cracks pass through chlorite, they are margined by a narrow band of the mica, as if the mica had been formed out of the chlorite by the addition of constituents supplied in the cracks. The felspar is not so clear as in the last slide. In many of the fragments it passes into a water-clear mineral, with the double refraction and interference-figure of quartz.

No. 473 (fig. 2). About 3 yards farther west.—The groundmass of the rock is chiefly opaque matter and the brownish mineral which replaces the chlorite. I have spoken of this mineral (under No. 466) as suggesting biotite. It has the precise habit of the chlorite, occurring in patches and strings; but, here and there, where the mineral is brownest, an approach to a fibrous structure is seen, and the absorption in these fibres is greatest when they are parallel to the principal section of the polarizer. Under crossed nicols, the extinction is parallel, and the interference-colours are high. In hand-specimens, the glimmer of mica cannot be detected; but as the mineral has not developed distinct lamellæ, with cleavage, and barely even a fibrous structure, we should hardly expect to find reflecting-surfaces. I therefore provisionally describe this mineral as biotite. Some chlorite is associated with it.

The fragments of felspar immersed in this groundmass are smaller than in the preceding slides. Some of them are seen to be parts of the same crystal; while others lie isolated in the matrix. These seams of fragments, being roughly parallel, give to the rock its sedimentary aspect. Both quartz and felspar are present. The

Fig. 2 (Slide 473).

Diorite No. 3. Decomposition further advanced; felspars crushed into minute fragments, which lie in irregular seams. The matrix of the fragments is chiefly brown mica, chlorite, epidote, and opacite.

latter is often water-clear, and polarizes in the patchy manner described under No. 466, but not exactly like a true mosaic. Many of the fragments do not give interference-figures, and the difficulty of distinguishing quartz from felspar becomes yet greater in the following slides, in which the fragments are still smaller and the felspar often polarizes as a true mosaic. In the remaining slides of this series, I shall therefore often refer to the water-clear mineral as 'quartz-felspar.'

A few yards farther west, the rock becomes sounder, and, under the microscope, it is clearer, the disseminated ferruginous matter aggregating in strings, granules, or definite crystalline forms. Reconstruction appears also among the other minerals. The next slide is taken as typical of the partially reconstructed rock.

No. 485. From the ridge north of the quarry.—Black mica does not appear in considerable quantity, the hornblende being represented in great part by chlorite. The latter is partly in irregular patches, as before; but associated with this form of the mineral are numerous, minute, pale-green granules, sometimes shaped like globulites, margarites, and longulites. Microliths of a pale-green transparent mineral are also present. These granules and microliths may perhaps belong to the chlorite family. Many of them run in streams lying in the direction of the general schistosity.

Associated with the chlorite is a small proportion of white mica. It is either in microliths with lath-shaped sections, or in larger crystals more or less rounded, but sometimes with distinct basal cleavage and laminæ projecting in a step-like manner. Elongation is sometimes parallel, sometimes perpendicular, to P. In both cases, the longer axes lie in the planes of schistosity, and accentuate the foliated structure.

The 'quartz-felspar' is very clear, and much of it has assumed a true mosaic structure. The granules of the mosaic, which are often very minute, have usually sinuate, occasionally foliate contours. The fragmental origin of some of the quartz-felspar is still evident; but on the whole there is a less clastic look about the slide, the angles of the fragments being often rounded off. Where they have been in contact, they have coalesced, and a broken stream of the minute microliths and granules of chlorite (?) marks the boundary between them, the quartz-felspar polarizing differently at the two sides of the line. Sometimes the minute chlorite (?)-forms are enclosed in simple granules of quartz-felspar, where a union of fragments is unlikely. It seems therefore evident that the quartz-felspar has been more or less fused or dissolved, so as to permit not only of the coalescence of fragments, but of the inclusion of foreign minerals.

The last rock passes *gradatim* within 2 feet into a well-marked schist, showing in hand-specimens a clear foliation with glistening mica-surfaces. The next slide illustrates the minute structure.

No. 486 (fig. 3).—The slide is quite free from cloudiness, and the parallelism of the constituents is very marked. This is seen in several lines of minute opaque granules, which possibly indicate the position of shear-planes, as well as in the arrangement of the mica, chlorite, and quartz-felspar. The chlorite and the white mica are present in about equal proportions. They sometimes pass into each other by imperceptible gradations, the green colour of the chlorite shading into the transparency of the mica in ordinary light, as the dark shades of the interference-colours of the former graduate under crossed nicols into the bright hues of the latter. As I have already discussed the passage of chlorite into white mica (No. II., p. 488), I need not here repeat the details of this important mineral change; but, as tending to confirm the evidence offered in these papers, I may quote Prof. Judd's[1] observation of a *gradual* transition from basic lime-felspar towards an acid alkali-felspar, the optical characters changing *pari passu* with the diminution of lime.

That the white mica was either formed from the chlorite or generated contemporaneously, is evident from the fact that, in this slide (as in many others), the two minerals are frequently associated

[1] Quart. Journ. Geol Soc. vol. xlv. (1889) p. 180.

in the same crystalline form, the chlorite being regularly intergrown in repeated laminæ parallel to the basal plane of the mica. Some of the mica occurs in irregular patches elongated in the direction of the schistosity, and it is this kind which graduates into the chlorite. Sometimes the mica is in such minute microliths, and is so intimately mixed up with the granules of quartz-felspar, that a graphic representation of the facts is impossible.

Fig. 3 (Slide 486).

Intermediate between the diorite and the schist. The lightly-shaded parts are 'quartz-felspar' and white mica; the darker patches are brown mica and chlorite. Some of the chlorite is intergrown with the white mica. A fracture in the rock passes across the slide. Some traces of shear-planes are accentuated by opaque matter.

The changes seen in the quartz-felspar are very instructive. The outlines have become more rounded, and there is a general elongation in the direction of foliation, so that fusiform shapes are common. The mosaic structure is more frequent, and none but the smallest particles polarize as a unity. In the secondary consolidation, the mica and chlorite are the first formed, and the quartz-felspar is moulded upon their contours.

The rock here described is a true crystalline schist, as seen in the parallelism of the minerals, the absence of clastic structure, the granulation of the quartz-felspar, and the crystalline condition of all the constituents.

Here and there in the band of the schist, specimens (No. 347, fig. 4, p. 411) may be obtained in which the metamorphism has proceeded still farther. The chlorite has almost disappeared, and the rock mainly consists of lenticular or linear mosaics of quartz-felspar enclosed in a meshwork of fibrous white mica, which apparently belongs to the sericite family. The quartz-felspar contains few, if any, cavities. It is largely penetrated by microliths of the mica, which often forms an interrupted sheath to individual granules, representing, it may be, the original fragments. The process of reconstruction is most marked in the ferruginous matter. Besides opaque granules, there are several linear aggregations of iron oxide in regular forms, many of which are seen by their cubic crystallization to be magnetite.

Some confirmatory proof of the secondary origin of the white mica will here be added. The calcite liberated during the decomposition of the diorite often appears in considerable quantities in the schist. It is in single granules, definite forms, or venules. When the venules cross the foliation, they are often shifted in the direction of foliation at the junction of the quartzose folia with the mica-folia. Here and there the continuity of a vein is broken by a flake or bundle of white mica, but is renewed along the same line at the other side of the flake. It would therefore seem that some part of the schist-making process, and the production of some at least of the mica, took place after the liberation of the calcite. In slide 428 the evidence of the secondary origin of the mica is of a different kind. A venule of calcite runs with the foliation, at first tapering almost to a line, then swelling out into a thick lenticle. On each side, the venule is sheathed in bundles of white mica, whose laminæ follow precisely the contours of the enclosed calcite, bending inwards at the narrow neck, and curving outwards to enclose the lenticular head. The curvature of the mica is rendered more distinct by a number of enclosed scales of iron oxide (seen in section), which lie in the general direction of the cleavage, and thus appear to flow round the contours of the calcite. In the same slide is seen another lenticle of calcite wrapped round by a sheath of mica. The mica, being thus moulded to the calcite, must be of contemporaneous or posterior origin.

Another series of slides, taken from the summit of the hill, points to a somewhat different process of schist-making from that just described. The chlorite is first converted into biotite, and this passes into a fibrous or scaly white mica. These changes are described in No. II. (p. 488). The felspar is sometimes replaced by a highly-refracting mineral with low interference-colours, and occasionally a columnar structure: it may be zoisite. This mineral does not, however, appear in the completed schist, in which the felspar is represented by the usual mosaic.

A slide (303) from this locality shows a very interesting passage between the grit and the schist. The field is mostly occupied by fragments of felspar, the highly-refracting mineral, and water-clear mosaic, immersed in a groundmass of chlorite, passing into biotite with a distinctly lamellar structure. The whole has a schistose appearance, which is accentuated by numerous subparallel cracks, more or less marked by the presence of biotite and iron oxide. Towards one margin the schistosity becomes more pronounced. Spindle-shaped mosaics set in; and the chlorite and biotite pass into flakes of white mica, whose cleavage-lines are often indicated by brown iron oxide. The gradation between grit and schist seen in this slide is unmistakable.

The explanation that I have given of the genesis of this schist may throw light upon certain cases in which authors have asserted an epiclastic structure in schists. It is obviously needful in such cases either to trace the origin of the fragments, or to establish reliable tests for distinguishing between epiclastic and cataclastic[1] structures.

Fig. 4 (Slide 347).

The sericite-gneiss. Near the centre of the figure is a little of the fragmental 'quartz-felspar' still remaining.

In summarizing the series of changes by which diorite is converted into sericite-gneiss, we observe that hornblende passes into chlorite, epidote, calcite, and iron oxide, where the crushing is only moderate. In the more highly-sheared rock, epidote is scarce or wanting. The most important part in the metamorphosis is taken by the chlorite: by a process of reconstruction it becomes either biotite or white mica, and the biotite also changes to white mica in the ultimate stage. The white mica is either in twinned crystals (muscovite) or in undulating bundles (sericite ?). The felspar is first crushed into fragments, which are broken up smaller and smaller. Some of it passes into quartz: or a mosaic structure, in which it is often impossible to distinguish between quartz and felspar, is gradually produced. The fragments are then softened, and

[1] Terms proposed by Mr. J. J. H. Teall, F.R.S. (Geol. Mag. for 1887, p. 493). 'Epiclastic,' formed upon the earth's surface; 'cataclastic,' produced during deformation.

become agglutinated where they are in contact. The pressure produces elongation of the fragments and aggregations, which thus assume a linear or spindle-like form. The iron oxide, liberated as dust, passes through the form of granules of various sizes and shapes into regular crystals of magnetite, and sometimes perhaps hæmatite.

It is common in these rocks for contortion to set in when the schistosity becomes very marked and the mica abundant. The development of mica and the contortion of the folia appear to proceed concurrently.

Biotite-gneiss and *Biotite-granite* (from *Diorite*).—These rocks are formed from the diorite which yields the sericite-gneiss just described. The pressure has been comparatively slight, and the resulting changes are proportionately small. There is no sharp line of demarcation between the gneiss and the granite, the former being merely a more strongly-compressed form of the other.

There can be no question that this rock, whether gneissic or granitoid, has been formed from the diorite. Gradations between the two are numberless. They are best seen at the northern end of the range, especially in the North Hill and on the southern and eastern slopes of the Worcestershire Beacon, where there are many granitic intrusions, but only moderate pressures. At many spots the passage from a hornblendic to a micaceous rock is clearly seen to be connected with the intrusion of granite-veins.

Muscovite-gneiss (from *Granite*).—Described in No. I., p. 528.

(B) Injection-Schists.

In No. I. (p. 532) I stated that at Malvern a banded gneiss was produced by the compression of masses of veined igneous rocks, duplex diorite-gneiss being formed from diorite veined by diorite, and granite-diorite gneiss from diorite veined by granite. This explanation received some support from Mr. J. J. H. Teall, who has since applied a similar interpretation[1] to certain banded gneisses at the Lizard. The cases which I then cited are comparatively simple, since the rocks described had undergone little chemical change; but it will be necessary in the present communication to add certain varieties of gneiss which are formed in the same way, but in which the transformation has been carried much farther. The gneisses in which infiltration has played a prominent part will come under the same head. The intrusion of rock in the original veining-process may be called *primary injection*, while we may describe as *secondary injection* the infiltration of mineral matter into rock crushed after consolidation.

The production of gneisses by primary injection has been noticed, among others, by Dr. Ch. Barrois,[2] but in the cases described by him the intrusion of the rock was into sedimentary strata. The changes thus caused differ in degree from those described in this

[1] Geol. Mag. for 1887, p. 484.

[2] 'Granulites du Morbihan,' Ann. Soc. Géol. Nord, vol. xv. (1887) p. 1.

paper, partly because the minerals composing a stratified rock are usually more stable than the constituents of diorite.

The evidence for the exotic origin of the granite is given in No. II. (pp. 494–496). Prof. John Phillips, writing of these Malvern rocks, also regarded[1] the "posteriority of felspathic and granitic veins to the masses they traverse" as "quite certain."

(*a*) Schists of Primary Injection.

Duplex Diorite-gneiss.—This gneiss is of no great importance. It is (or was) well seen in the large quarries at North Malvern. The medium black diorite is interlaced by the coarse grey variety, and a moderate amount of compression has produced a rough parallelism of the veins.

Granite-diorite Gneiss (No. I., p. 533).—It is necessary for the production of this gneiss that the granite-veins should be comparatively few, and that there should be moderate pressure with little shearing. Countless gradations may be traced between a rock in which there is merely a rough parallelism of the veins and a typical gneiss with one or two micas, so that it is impossible to draw a sharp line between a granite-diorite gneiss and a true mica-gneiss.

Banded Biotite-gneiss.—This is a rock in which bands of quartz-felspar (the injected granite-veins) alternate with seams of mixed biotite, felspar, and quartz (the altered diorite). To produce a biotite-gneiss out of a decomposed diorite, the chlorite must be mainly converted into biotite, the disseminated iron oxide must be either crystallized or absorbed, and quartz must be liberated. All these changes are known to frequently occur at Malvern. The conversion of chlorite into biotite and the liberation of quartz from felspar are extremely common. The recrystallization of iron oxide is seen in the section at Ragged Stone Hill, already described, and has been observed by other workers. The re-absorption is frequently illustrated in the present series of papers.

The evidence for the conversion of diorite interlaced with granite-veins into a banded biotite-gneiss is of the most positive and direct kind. One of the best examples is seen in the quarry at the southern end of Swinyard's Hill. The section is given in No. II. (p. 482), and the chief mineral changes are there described.

I cannot too emphatically insist upon the completeness of the gradation between diorite and gneiss. As we approach the plexus of granite-veins, the hornblende changes to chlorite and the chlorite to biotite. The felspar becomes invaded by quartz, and gradually assumes the normal corroded appearance. The parallel structure grows more and more distinct, and near the veins aggregation sets in. Even before we reach the plexus we obtain at contact with granite-veins a partially gneissic structure, a sort of foliated kersantite, seams of which cannot be distinguished from some of the bands in the very core of the plexus.

It does not seem to be essential that the veins in a banded biotite-

[1] 'Geol. of Oxford and the Valley of the Thames,' 1871, p. 62.

gneiss should be granite, though this is usually the case at Malvern. In two or three localities south of the Worcestershire Beacon I have observed a banded gneiss in which the veins were (or rather had been) the coarse grey diorite. Yet the mica was produced abundantly, both in the diorite encasing the veins and in the diorite of the veins themselves. At one inch from the veins the encasing rock, a fine-grained diorite, was highly altered, and consisted of hornblende, white mica, epidote, chlorite, and quartz, but not much felspar, the minerals being arranged with a rough foliation. Near the contact with the veins black mica was developed in fair proportion.

These apparent exceptions to the general principle admit of an easy explanation. In the large number of slides examined I have usually found biotite to be generated in diorite when the rock is sliced by planes of cleavage or shearing, or when traces at least of such planes can be detected. Of course, when the diorite has been transformed into gneiss, planes of discontinuity have largely disappeared; but I am here speaking of rock in which the dioritic structure is still apparent. Diorite is often sheared without the production of mica, especially in Midsummer Hill, in which there is very little granite: but the mass of the Worcestershire Beacon is extensively penetrated by dykes and veins of granite, and it is here that we find so much biotite generated in the diorite.

Gneiss with two Micas.—I described in No. II. (pp. 478–481) a gneiss in which the dark bands (modified diorite) contained both black and white mica, and the light bands (modified granite) white mica. The muscovite was formed from both the orthoclase of the granite and the felspar of the diorite, the biotite being produced in the usual way from the hornblende of the latter.

In closing this account of the origin of the banded gneisses of Malvern, it will be well to summarize the explanations of the banded structure which have been made public.

1. The hypothesis of original sedimentation.

2. That banding is produced when inclusions (say of diorite in granite) are fused and drawn out into parallel strips under earth-pressures. Some of these gneisses are described by Dr. A. C. Lawson.[1] The writer has seen similar structures near the town of Galway, on the east side.

3. By injection of granite along the bedding-planes of sedimentary rocks. See Dr. Ch. Barrois's works, *passim*.

4 By movements in plutonic rocks when in a viscid state (Prof. Bonney and Lieut.-General McMahon, Quart. Journ. Geol. Soc. vol. xlvii. 1891, p. 464).

5. By the deformation of veined complexes of igneous rocks under pressure. (Mr. J. J. H. Teall, Geol. Mag. for 1887, and the Geological Survey, Quart. Journ. Geol. Soc. vol. xliv. 1888, p. 388.) Mr. Teall leaves the origin of the veins an open question; while the

[1] 'Report on the Geology of the Rainy Lake Region,' Geol. & Nat. Hist. Surv. Canada, 1887, p. 137.

Survey regard those observed by them in the Highlands as segregations and of contemporaneous origin.

6. The view expounded in the present series of papers. It approximates to the preceding explanation, but concludes that the veins are intrusive and posterior. How far this theory applies to regions outside Malvern the writer does not presume to suggest.

7. There are suggestions in the preceding pages and in No. II. that segregation during the shearing-process has sometimes produced a banded structure.

Gneissoid Quartzite.—There is not much to add to the explanation of the origin of this rock given in No. II. (pp. 485, 486). I there stated that it was an extreme phase of alteration in diorite. Since it is formed from the gneiss just described, I have included it under 'injection-schists,' although I by no means affirm that injection is necessary to its production. It is not very conspicuous at Malvern, occurring only (so far as I know) in a few narrow bands near the southern end of Swinyard's Hill. Sometimes it constitutes small patches and seams in the biotite-gneiss, and wherever I have seen it there is a gradation between it and the gneiss. In it the biotite has almost disappeared, muscovite is in equally small proportion, and we have little left but dull-looking felspar-crystals invaded by rounded granules of quartz or water-clear felspar, or entirely replaced by them. As there is little parallelism of structure, the rock approximates to a rather felspathic quartzite. Indeed, it is very similar under the microscope to the rock which in Connemara has been usually described as a 'quartzite.'

This theory of the origin of the Swinyard's Hill quartzite receives important confirmation from a paper[1] by Mr. W. S. Bayley, of the Geological and Natural History Survey of Minnesota. Mr. Bayley concludes that a certain quartzite of the Animikie group, "though a completely crystallized quartzite, is nothing more nor less than an extreme phase of gabbro," or "a completely altered gabbro."

This rock will be again considered under Section VIII. of the present paper.

(*b*) Schists of Secondary Injection.

These are, I suspect, rather common at Malvern, but sections in which the process of infiltration can be demonstrated are rare. In No. II. (p. 496) I referred to a shear-zone at the Wych, in which a chlorite-gneiss was formed by the infiltration of chlorite (and iron oxide) from a decomposed diorite into the cracks and shear-planes of an adjacent mass of granite. The mineralogical changes were then briefly described, but the limits of the present paper preclude fuller details.

V. How far the Schists indicate their Origin.

Is it possible among the Malvern rocks to determine the origin of a schist from its structure and composition? The answer is usually

[1] Nineteenth Annual Report, Geol. & Nat. Hist. Surv. Minnesota, 1892.

'Yes'; but where the maximum of metamorphism has taken place, I should sometimes be obliged to reply in the negative. Take the sericite-schists of Ragged Stone Hill. Some of these schists are formed from diorite, some from felsite. Yet, under the microscope, both are sometimes seen to consist of apparently[1] the same materials arranged in a similar manner. The presence of a small proportion of iron oxide and epidote or chlorite does not help us, for those minerals are sometimes infiltrated into the shear-planes of the felsite. The schist produced from diorite is often more or less veined with calcite, which is not the case with the other variety; but slides of the former sometimes show hardly any calcite. However, even in the perfectly formed schist, there is often a residuum of the shearing-process in the form of a crystal or fragment of felspar, crushed, and tapering at each end in water-clear mosaic. This would seem to mark an origin from diorite, for the felsite of the locality never contains, so far as the writer has observed, a porphyritic crystal of felspar.

The case just selected is an extreme one, in so far as Malvern is concerned. I do not think there is any other schist in the district which, in a hand-specimen or a micro-slide, cannot be referred to its origin. A few of the chief types will be taken in illustration.

Banded Biotite-gneiss.—The granite-veins are, of course, easily recognizable. The micaceous seams also usually betray signs of their dioritic origin. There may be slides in which most of the felspar has been invaded by water-clear granules, and in which the mica is arranged in parallel seams; but a large proportion of the specimens examined contain patches of the kersantite-structure which have resisted the metamorphic forces. In these patches very little quartz has been generated, and the crystals of biotite are sprinkled among the felspars just as in the kersantite formed directly from diorite (No. II., pl. xvi. fig. 1).

Simple Biotite-gneiss.—The structure of the original diorite is fairly evident, the place of the hornblende amidst the felspar-crystals being taken by biotite, and the felspar being more or less invaded by quartz.

Muscovite-gneiss formed from Granite.—This variety often shows the 'eyes' of orthoclase so well seen in the *augen*-gneisses, described by Lehmann, Lapworth, Bonney, Teall, and others. Where these are absent, the rock may usually be differentiated from similar rocks which have been formed from diorite by the absence of plagioclase-felspar and of any trace of diorite-structure.

Chlorite-gneiss.—The remarks of the last paragraph will apply here, the infiltrated films of chlorite being interfoliated with the other minerals.

Gneissoid Quartzite.—I should have little hesitation in recognizing the derivation of this rock within the Malvern area. The marks of origin are the presence and arrangement of scraps of biotite, the

[1] Quartz and felspar being undistinguishable when in minute, water-clear granules.

occasional replacement of felspar by zoisite or epidote, and the frequent traces of kersantite-structure.

The traces of original structure in a rock of secondary origin may perhaps be appropriately described as 'residua.' The 'eyes' of an *augen*-gneiss or *augen*-gabbro, and the lenticular cores (lenticles) of granite in a muscovite-gneiss are the direct result of shearing. But the residua of kersantite in a biotite-gneiss are patches of rock which have escaped advanced molecular changes, and they are not as a rule sharply distinguished at their margins from the surrounding mass.

VI. The Nature of the Shearing.

To remove some doubt that appears to exist with reference to my use of the terms 'shearing' and 'shear-plane,' I may state that I accept the definitions of those writers who in this country have been among the pioneers in these new studies.

Prof. Lapworth, describing[1] the process of schist-making in the Highlands, states that many of the rocks "have been crushed, mashed, and dragged out, their component patches, fragments, particles, and crystals *shearing* (or moving over each other with a differential motion, each higher layer moving a little farther than the one below) as the mass gave way." The same writer defines "shear-planes" as "definite planes" along which "the rock yielded to the excessive pressure and torsion" (*op. cit.* p. 114).

The Geological Survey, in their elaborate memoir on the Northern Highlands,[2] adopt a similar terminology. The lines of movement in the rocks are described as "thrust-planes, crush-lines, or lines of shearing, resulting in a newer foliation" (p. 391). In certain of the schists, each "shear-plane" is referred to (p. 435) as a "divisional plane or foliation-surface," and these planes are described a few lines before as the result of "powerful thrusts," producing "slices" in the rock.

The definitions and descriptions of Prof. Lapworth and the Geological Survey agree precisely with those employed in the present series of papers. They apply only to rock in the solid state.

VII. Discussion of the Question whether there has been a Mixing of the Original Magmas.

The great variations of chemical composition seen in the Malvernian rocks have suggested to some correspondents a mixing of the acidic and basic magmas before consolidation. Perhaps the best reply to this suggestion is set forth by the facts contained in the present series of papers. There is evidence to prove an intermixture of chemical constituents, that, for example, potash has passed from granite to diorite, and soda from diorite to granite. But I have never been able to find that the magmas are mixed together, except perhaps

[1] 'Introductory Text-book of Geology,' 1888, p. 112.
[2] Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 378.

occasionally on a small scale at their contacts. We have seen that the grey diorite was injected into the medium-black variety, that granite, felsite, and dolerite were subsequently intruded into the two preceding; yet each of these magmas is nearly always clearly and sharply distinguishable from the others.

The variations of chemical composition seen within the same rock-mass depend largely upon two causes—namely, the degree of mechanical energy, and the nature and quantity of infiltrated mineral matter. In numerous cases chemical change is seen to increase *pari passu* with the mechanical force, as in the conversion of diorite into sericite-gneiss at Ragged Stone Hill (pp. 404 *et seqq.*). The influence of infiltration is well illustrated at Swinyard's Hill (p. 413), where, as we trace the diorite into the granite-diorite complex, the percentage of potash in the diorite rises from 2·8 to 5·3.

VIII. The Chemical Changes.

The Elimination of Magnesia.—Most of the decompositions described in these papers are well known. The action of carbonic acid and alkaline carbonates, at the ordinary temperature and pressure, upon silicates of the heavy bases was described by Bischof. He held that in his experiments silicate of lime and protosilicate of iron were decomposed by carbonic acid in the wet way, but that silicate of magnesia was only slightly acted upon, and silicate of alumina not at all. He admits, however, that in nature silicate of magnesia is decomposed by carbonic acid, even at ordinary temperatures. Thus, he says that in springs carbonate of magnesia has been formed by the decomposition of magnesian silicates by carbonic acid. Again, in the conversion of olivine into serpentine magnesia is eliminated, and Bischof quotes a case said to occur at Snarum, where the serpentine thus produced is surrounded by bitter-spar. He also states that dolomite has been observed in limestone where it was in contact with basalt, the change being produced by the action of meteoric waters.

The researches of Mr. Alexander Johnstone, F.G.S., have an important bearing upon this enquiry. He concludes[1] that water containing carbonic acid exerts no chemical change upon *pure* mineral magnesian silicates; but that, even at the ordinary temperatures, carbonated water extracts magnesia from complex silicates, such as olivine. This mineral was exposed for two months to the action of distilled water saturated with carbon dioxide. The liquid was then found to contain magnesia, and the olivine had lost ·73 per cent. of that base. Mr. Johnstone exposed biotite-mica dust to carbonic-acid water for a year. He states[2] that, at the end of that time, the percentage of magnesia had been reduced from 20·04 to 17·35; and he suggests that an extension of the time of immersion would result in the further elimination of the base. From a long series of experiments, he concludes that

[1] Proc. Roy. Soc. Edin. vol. xv. (1888) p. 436.
[2] Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 367.

"any ordinary hydro-biotite, such as voigtite, vermiculite, or pyrosclerite, exposed for a lengthened period to the action of carbonic-acid water, invariably lost a portion of its magnesia (and iron)." This investigation has been continued, and the results are summarized in Section II. of the present paper (p. 399). It is fair to assume that, at higher temperatures, to say nothing of pressures, the action of carbonated waters would be still more energetic.

The elimination of magnesia during the shearing-process seems to be absolutely demonstrated by the Malvern sections. No one who examines, for example, the section at the southern end of Ragged Stone Hill, and studies a series of the rocks under the microscope, can doubt that the sericite-gneiss was once a diorite. Yet the percentage of magnesia has fallen from 5 in the diorite to less than 1 in the schist. This is seen in the following analyses, the first four of which were very kindly determined for me by Mr. J. H. Player.

The specimens II., III., IV. are taken along the section from crushed diorite to schist. For comparison I append the composition of the same variety of diorite in an uncrushed state (I.) from another Malvern locality.

	I.	II.	III.	IV.
Silica	47·6	49·0	52·8	61·6
Alumina	17·6	19·0	15·8	18·6
Titanic oxide	1·6	1·2	2·6	·8
Ferric oxide	4·8	3·4	5·4	1·3
Ferrous oxide	5·8	7·5	9·5	5·1
Lime	8·6	2·8	·5	·2
Magnesia	5·0	5·3	4·1	2·6
Soda	2·3	2·0	1·3	1·6
Potash	4·3	2·5	1·9	3·7
Loss	2·2	6·5	5·7	3 7
	99·8	99·2	99·6	99·2

I. A typical specimen of the coarse-grey diorite.

II. The same variety crushed (taken near specimen No. 273), being a sort of grit composed of fragments of felspar in a groundmass of chlorite, biotite, and ferruginous dust.

III. The grit just before it passes into schist. The rock has undergone partial reconstruction, the iron oxide has been recrystallized, and there is some free quartz. Sphene is in unusual proportion.

IV. Sericite-gneiss, containing some chlorite. It is within one foot of No. III. in the same mass, and an intermediate specimen furnishes the slide (303) in which the actual gradation between grit and schist is seen. This analysis would give (roughly) the following percentages:—Chlorite = 10, white mica = 25, orthoclase (or microcline, or both) = 15, albite = 15, iron oxide = 5, quartz = 25, which corresponds very well with the appearance of the rock under the microscope.

It will be seen that in this series the silica rises in steps thus:—47·6, 49·0, 52·8, 61·6. Two analyses of other portions of No. IV., made for me at Owens College by the kindness of Dr. Cohen, give the silica percentages respectively as 64·96 and 73·13. The lime in the above series falls in steps thus:—8·6, 2·8, 0·5, 0·2. The magnesia also falls, but less rapidly, thus:—5·0, 5·3, 4·1, 2·6. No. IV. contains a fair quantity of chlorite; but Dr. Cohen's analyses, which are from less chloritic specimens, yield respectively 1·29 and 0·35 per cent. of magnesia.

While lime and magnesia are gradually eliminated in the shearing-process, the alumina and alkalies are tolerably persistent. From this it follows that, in the extreme of metamorphism, there must be much free silica, and a part of the remainder will be in combination with a highly aluminous base. Hence the abundance of white mica.

Another series of analyses by Mr. Player furnishes similar results as regards the loss of magnesia. They illustrate the chemical changes undergone in the conversion of the medium-black diorite into a gneissoid quartzite.

	V.	VI.	VII.	VIII.
Silica	47·1	47·2	66·0	81·9
Alumina	18·1	17·8	16·6	9·2
Titanic oxide	·4	·4		Trace.
Ferric oxide	3·0	6·7	1·6	·6
Ferrous oxide	8·5	5 6	4·2	1·6
Manganic oxide	·1	...	...	...
Lime	6·6	4·8	·5	·9
Magnesia	7·3	6·3	1·9	·5
Soda	2·4	2·2	1·5	1·6
Potash	2·8	3·9	5·3	2·1
Loss	3·6	4·1	2·2	1·1
	99·9	99·0	99·8	99·5

V. Medium-black diorite, Swinyard's Hill.

VI. 'Basic rock' of Mr. Player. It is the same variety of diorite, but it has undergone some change, a parallel structure having been produced, and a little biotite has been generated. Malvern.

VII. Biotite-gneiss formed out of the same diorite at contact with granite-veins. Traced *gradatim* into V.

VIII. Gneissoid quartzite; a more advanced stage of VII. Swinyard's Hill.

It is probable that some, at least, of this magnesia has been removed as carbonate; but I have not been able to find dolomite or magnesite in the rock, and I desire to confine myself to facts actually observed or proved by experiment.

The Fall in the Percentage of Alumina.—The final stage in the conversion of diorite into an acidic gneissic rock is accompanied by a great diminution in the alumina. In the second series of analyses (V.–VIII.) it will be seen that this base falls to about one-half. As it may be contended that this reduction may be due to an original difference of magmas, a series of analyses has been very kindly made for me by Mr. T. H. Waller, B.Sc., from samples taken from the same block, which reveals under the microscope a perfect gradation between the biotite-gneiss and the gneissoid quartzite. One of the slides shows the sample X. (which is intermediate between biotite-gneiss and gneissoid quartzite, and displays very clear kersantite-structure) passing into the gneissoid quartzite (XI.), which differs chiefly in being much more quartzose, and still retains traces of kersantite-structure.

	IX.	X.	XI.
Silica	60·4	65·7	77·1
Alumina	18·6	17·2	10·9
Ferric oxide	3·5	·9	·7
Ferrous oxide	5·3	4·5	2·3
Lime	1·6	1·2	1·3
Magnesia	2·8	1·9	1·4
Soda	4·1	3·9	1·6
Potash	3·0	2·6	1·8
Loss	...	2·3	1·5
	99·3	100·2	98·6

IX. Biotite-gneiss. Swinyard's Hill.
X. Like IX., and from the same block.
XI. Gneissoid quartzite, passing gradually into X.

This fall in the percentage of alumina must arise either from its elimination, or from the introduction of silica. The microscopic evidence points towards the former alternative. In tracing the changes of the different minerals through a series of slides in which diorite and gneissoid quartzite are the two extremes, we observe, not the coming in of quartz between the other minerals, but the progressive destruction of these minerals themselves. The biotite produced out of the hornblende loses its idiomorphic form, and is reduced to shreds. The felspar is invaded by fingers and lobes of quartz, and is often entirely replaced by it, the sheath of mica which often surrounds felspar-crystals continuing to envelop the quartz-replacement. Of course, where the mica has nearly disappeared, and many of the felspars are deeply corroded or replaced by quartz, a considerable proportion of the alumina must have been removed. In some slides of the gneissoid quartzite there are a few crystals of garnet; but the bulk of the alumina cannot be accounted for in this way.

In the felspar of the granite-veins there is also corrosion and replacement by quartz, so that, especially in the small veins of shear-zones, the granite is converted into quartz. Alumina must have been removed in this case also.

What becomes of the eliminated alumina? I am not prepared to answer this question; but I have noted many facts at Malvern and elsewhere which seem to indicate that, during advanced dynamic deformation, there is set up a tendency towards mineral aggregation. In the Malvern district, the diorite which has undergone extreme alteration sometimes occurs as a schist, in which seams which are mainly mica alternate with seams which are almost pure quartz. The conclusion appears inevitable that alumina has migrated from one place to another, probably as silicate. However, I merely suggest this point, with a view to further enquiry.

Elimination of the Oxides of Iron.—A glance at the above analyses reveals a reduction of iron oxide in the process of schist-making. This fact may have some bearing on the origin of iron ores.

IX. Secondary Consolidation.

One difficulty which hinders the acceptance of the new views of metamorphism at Malvern is the sound condition of the gneissic rocks. It is unnecessary to repeat here what I have said in Section III. on decomposition and reconstruction. Most of the minerals of the gneiss are sound and clear, because they were newly formed during the metamorphism, and have not since been crushed. Their reconstruction involves a more or less complete fusion of the rock. This is a demonstrable fact where the fragments of crushed felspar are squeezed out into lenticles and coalesce with each other, as in the sericite-gneiss of Ragged Stone Hill (p. 411), and is a matter of fair inference wherever there is a clear passage between crushed diorite and a sound gneiss.

X. Summary.

It will be convenient to bring together the chief results of my five years' work at Malvern, as expounded in the present series of papers.

1. All the crystalline schists of Malvern have been elaborated out of plutonic igneous rocks, chiefly out of a binary granite and two varieties of diorite.
2. The schist-making process has been confined to certain bands (shear-zones), within which the rocks have been subjected to great compression, the mechanical effects produced varying between slight crushing and a pronounced shearing-movement among the constituents, the two extremes shading imperceptibly into each other.
3. The bulk of the rocks had consolidated before the chief pressures set in. During the metamorphism, partial fusion, resulting in plasticity, took place. This effect is found so often to occur where the shearing is at its maximum, while the adjacent rock is merely a crushed solid, that the generation of heat by the shearing-process becomes a probable inference.
4. A crushed diorite, in course of transformation into a mica-gneiss, sometimes passes through the intermediate state of a laminated grit, which thus simulates a true sediment, the subsequent stages of alteration and cementation resembling the process of metamorphism in some bedded rocks.
5. The chief mineral and chemical changes took place where diorite was interlaced with numerous granite-veins, the effects produced in the diorite being due partly to the shearing, partly to the action of mineral solutions.
6. The massive rocks pass into schists through a process of decomposition, followed and partly accompanied by a process of reconstruction, the newly-generated quartz and felspar in the secondary consolidation crystallizing, the former always, the latter frequently, in a granular form.
7. The chief mineral changes affecting the schist-making process

are the replacement of orthoclase by quartz and muscovite, of plagioclase by quartz and muscovite, of chlorite by biotite and white mica, and of biotite by white mica. The reconstruction of felspar is also a prominent feature in the metamorphism.

8. The granite and diorite have often transferred to each other some of their alkaline bases, so that the diorites often locally show an unusual amount of potash, which has been largely used in the production of the micas. The liberation of potash from the granite is (at least sometimes) accompanied by silicification of the veins and the production of garnets.
9. In the metamorphosis of diorite into a muscovite- (or sericite-) gneiss, lime is removed readily, and magnesia more slowly. The persistence of alumina and the elimination of lime and magnesia favour the formation of white mica, which appears to be one of the ultimate products of the schist-making process.
10. In the conversion of diorite into a gneissoid quartzite, alumina and alkalies are removed, as well as lime, magnesia, and iron.
11. Chlorite and iron oxide, produced by the decomposition of diorite, may be infiltrated into the cracks and cleavage- (or shear-) planes of crushed granite, and may migrate to a considerable distance from the contact with the diorite, thus giving rise to an interfoliation of chlorite and biotite with the quartz, felspar, and muscovite of the resulting gneiss.
12. The schists produced by the means here described are divisible into two groups:—(1) Simple schists, formed from one kind of rock, such as biotite-gneiss, mica-schist, sericite-gneiss, muscovite-gneiss, and hornblende-gneiss. (2) Injection-schists, formed from more than one kind of rock, frequently with a banded structure, divided into (*a*) schists of primary injection, the injected material being an intrusive rock—examples are duplex diorite-gneiss, granite-diorite gneiss, and biotite-gneiss; and (*b*) schists of secondary injection, the injected matter being products of secondary decomposition—the chief varieties are chlorite-gneiss, biotite-gneiss, and biotite-muscovite gneiss.

Discussion.

The President said that the Author was to be congratulated on the completion of his triple memoir on the Malvern Hills. He had brought before the Society an ingenious and bold hypothesis, which involved metasomatosis on a large scale. He (the President) did not feel qualified to express an opinion on the intricate subject of dynamo-metamorphism, but he supposed that the crushing of rocks in Nature's mortar might increase solubility and facilitate chemical change. There appeared to be two schools of chemical geologists at present—one believing that rocks could not be materially changed in composition, the other accepting very great modifications. There was one very important feature about this paper: it was illustrated by many chemical analyses.

Prof. Bonney stated that in Dr. Callaway's leading conclusions as to the genesis of the Malvern rocks he agreed, viz. that largely, if not wholly, they were igneous rocks, gneissoid from pressure; but in some details he could not follow him. He failed to understand how, if magnesia were removed from a rock, the alkalies, as indicated in Dr. Callaway's analyses, remained constant when almost everything else was changed. He could not believe in such a change as the formation of a quartzite from a gabbro, referred to by Dr. Callaway; and he had never seen anything to confirm the idea that biotite was formed out of hornblende by way of chlorite. How were you to add silica and alkalies, and get rid of the water? Generally biotite came direct, either from the crushing or from the melting of felspar and hornblende together.

Mr. Harker found difficulty in understanding some of the chemical changes which the Author believed the Malvern rocks to have experienced, such as the removal of alumina while the alkalies remained practically undiminished. He asked whether the field-evidence would not allow some of the supposed transitions to be explained by the intrusion of one rock into another.

Mr. Rutley agreed with Dr. Callaway, to some extent, in believing that the schists of the Malvern Hills had been formed from plutonic rocks; but he differed from him as to the way in which they had been formed. He had, indeed, already expressed the opinion that they had resulted, in part at least, from the denudation of an old land composed both of eruptive rocks and sediments. With regard to the corroded character of felspars in the proximity of shearing-zones, he pointed out that the most corroded felspars which he had met with in the range occurred in a rock which he had described as 'eukrite,' and in which there was no indication of shearing. The acceptance of some of the Author's statements concerning the genetic sequence of minerals demanded the exercise of faith. It appeared that some of the minute bands occurring in biotite-gneiss, which the Author termed granitic, might merely be the result of mineral segregation. On the whole, he considered that the paper dealt with many interesting questions, and, although the conclusions so boldly expressed in it differed from his own, the perseverance displayed by Dr. Callaway in this, as in his previous communications to the Society, rendered his work deserving of very careful consideration.

Prof. Hull wished that the Author had given some better evidence as regards, at least, one point connected with the metamorphism of the Malvern minerals—namely, the conversion of chlorite into biotite. In all his experience amongst metamorphic and igneous rocks he had never noticed chlorite otherwise than as a decomposition-product; whereas biotite was a primary mineral, as shown by its occurrence in modern lavas. He very much doubted the formation of biotite in the manner stated by the Author.

The Author, in reply to Prof. Bonney, said that the loss of alumina in the change from diorite to gneissoid quartzite was accompanied by a decrease in the alkalies, though perhaps he had not made that point clear in his hasty summary of a long paper; this change was shown by the study of numerous sections and specimens, which demonstrated an unbroken passage between the two extremes; and the potash for the conversion of chlorite into biotite was supplied by the adjacent granite, while the iron was furnished by the decomposition of the hornblende of the diorite.

To Mr. Harker he replied that the gradations described were shown by very exhaustive enquiry in the field, as well as by microscopic slides.

In answer to Mr. Rutley's observations, he pointed out that corrosion was not necessarily connected with schist-making, but as a matter of fact it was so in the Malvern area. The distinction between primary and secondary injection was not hypothetical, but was based upon clear evidence. The banding of diorite by granite-veins took place on a large, as well as upon the small scale; and the grit of Ragged Stone Hill was not sedimentary, but could be traced into crushed diorite.

In reply to Prof. Hull, the Author remarked that the conversion of chlorite into biotite, asserted by him in 1889, had been confirmed by the researches of Salomon, Lossen, Rüdermann, and other foreign observers.

In conclusion, the Author stated that his views, however heretical they might appear to some of the speakers, were based upon six or seven years' careful work in the field, the cabinet, and the laboratory; and he asked that his paper and his specimens should be studied, before a decided opinion was formed by his critics.

34. *The* Llandovery *and* Associated Rocks *of the* Neighbourhood *of* Corwen. By Philip Lake, Esq., M.A., F.G.S., and Theo. T. Groom, Esq., B.Sc., F.G.S. (Read May 10th, 1893.)

Contents.

I. Introduction.

It was for many years a doubtful point whether true Llandovery rocks were represented in the more northern part of Wales, or whether the Tarannon Shales here rested directly on the Bala Beds. Thus, according to the first edition (1866) of vol. iii. of the Geological Survey Memoirs (p. 205 *et seq.*), no Llandovery rocks are known between Conway and the country east of Bala Lake; and the Lower Llandovery first appears near Cefn-bwlan. But it is at the same time noted in the appendix (p. 275) that Lower Llandovery fossils occur on Cyrn-y-brain (north of Llangollen) and, doubtfully, near Pwllheli.

In a paper published in 1877, however, Prof. T. McK. Hughes [1] described a series of grits at Corwen which rest upon Bala Beds, and are overlain by pale beds passing up into the 'Pale Slates' (Tarannon Shales) of the Survey. To these grits he gave the name of Corwen Grits. Near Corwen itself he found in them no fossil except *Favosites alveolaris* (doubtful); but a similar grit occurs in the same stratigraphical position in various other localities, and on Cyrn-y-brain he obtained, in fragments of what seems to be the same grit, *Petraia subduplicata*, *P. crenulata*, and *Meristella crassa*. Hence he concludes that the Corwen Grit is of Llandovery age, and that it forms the base of the Silurian in this area.

Two years later Mr. T. Ruddy [2] described a number of sections in the same district. Everywhere he finds that the Tarannon Shales are underlain by soft blue slaty shales, below which is a series of beds somewhat variable in character, but always more or less gritty or calcareous. This gritty series frequently contains numerous fossils similar to those of the Hirnant Limestone, such as *Orthis biforata*, *O. hirnantensis*, *O. sagittifera*, *Nebulipora lens*, etc. He shows that the Lower Llandovery Grits of Cefn-bwlan occupy the same position with respect to the Tarannon Shales; and it is clear, from Prof. Hughes's observations, that the Corwen Grit does the same.

In his paper on the Dee Valley, Mr. J. E. Marr [3] shows that the Corwen Grit is represented at Cerrig-y-druidion by a series of grey,

[1] Quart. Journ. Geol. Soc. vol. xxxiii. p. 207.
[2] *Ibid.* vol. xxxv. (1879) p. 200.
[3] *Ibid.* vol. xxxvi. (1880) p. 277.

calcareous grits, which rest unconformably on the Bala Beds. Above these grits come blackish mudstones, in which he obtained[1] *Monograptus convolutus*, *M. Sedgwickii?*, *M. tenuis*, *M. gregarius*, and *Climacograptus normalis?* He states that similar black beds occur above the Corwen Grit of Nant Cawrddu, near Corwen.

During the summer of 1892 we devoted some time to the examination of the rocks in the neighbourhood of Corwen, and especially of the Corwen Grit and the associated beds. We have found graptolite-shales above the grit, with graptolites of the *gregarius*-zone similar to those of Cerrig-y-druidion; and these shales occur both in Nant Cawrddu and Nant Llechog. This discovery confirms the view put forward by Prof. Hughes that the grit and the overlying beds are of Llandovery age.

In one point we have a slight correction to make. In the Survey map of the district a small patch of Denbighshire Grits is represented as brought in by a fault near the western end of Corwen. It forms a long low hill, on which a part of the town is built. In his paper Prof. Hughes refers this to the Corwen Grit; but according to our observations it is entirely different from that rock, and on the other hand closely resembles the Denbighshire Grits, so that we hold the Survey map to be correct in this particular. The Corwen Grit, as seen near the top of the hill to the south, is a nearly pure siliceous rock, very hard and compact, containing no felspathic material. The Denbighshire Grits of the neighbourhood are much less compact and contain grains of decomposed felspar; and the grits of this small patch possess the same characters.

II. General Sequence of the Strata.

The rocks in the neighbourhood of Corwen as far up as the Tarannon Shales are coloured on the Geological Survey map (sheet 74) as Bala. But, as Prof. Hughes has pointed out, the Corwen Grit separates two distinct series: blue slates with Bala fossils below the grit, and pale slates above the grit. The general sequence, as determined by us, of the beds below the Tarannon Shales is as follows (in descending order):

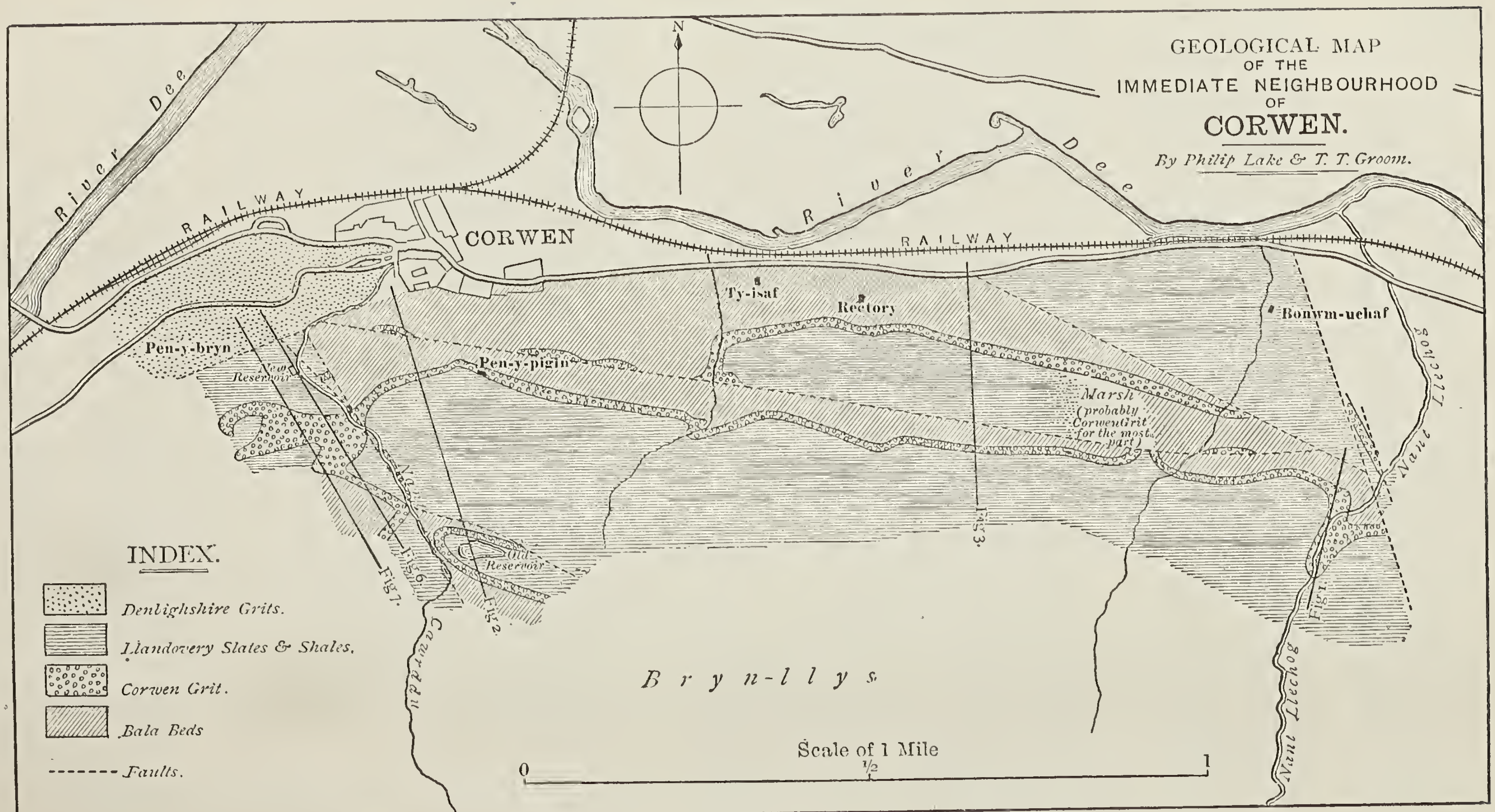
Pale Slates.
Black banded Graptolite-shales (*gregarius*-zone).
Grey Slates, with bands of grit.
Corwen Grit.
Blue Slates, with Bala fossils.

This sequence is best seen in Nant Cawrddu and Nant Llechog.

III. Structure of the Area.

The area which will now be described forms a part of the northern slopes of the Berwyn Hills, and includes a strip of country lying south of the Dee between the town of Corwen and the slate-quarries of Pen-y-glog.

[1] See revised list in his 'Classification of the Cambrian and Silurian Rocks,' Cambridge, 1883, p. 40.



GEOLOGICAL MAP
OF THE
IMMEDIATE NEIGHBOURHOOD
OF
CORWEN.
By Philip Lake & T. T. Groom.
N
River Dee
River Dee
RAILWAY
RAILWAY
CORWEN
Ty-isaf
Rectory
Bonwm-uchaf
Pen-y-bryn
New Reservoir
Pen-y-pigin
Marsh (probably Corwen Grit for the most part)
Old Reservoir
Nant Llechog
Nant Llechog
Cawrddu
Fig 1.
Fig 2.
Fig 3.
Fig 6.
Fig 7.
Bryn-llys
INDEX.
Denbighshire Grits.
Llandovery Slates & Shales.
Corwen Grit.
Bala Beds
Faults.
Scale of 1 Mile
0
½
1

The Berwyn Hills, as is well known, form a tolerably well-defined dome, which is made up almost entirely of Bala rocks. But the dome is by no means perfect, and here, at its northern margin, we have found that it is cut through by a series of parallel faults which run nearly due east-and-west, and, throwing towards the north, have apparently determined the course of the Dee, for the direction of the valley is parallel to the direction of these faults.

The southern bank of the valley close to Corwen is practically the denuded face of one of these faults and forms a scarp, from the top of which the dome proper slopes gently upward towards the south with an undulating or hilly surface. The top of the scarp is some 900 feet above the sea. Farther east, towards Pen-y-glog, the slope of the southern bank of the Dee is much gentler and is interrupted by several low hills.

It is the Corwen Grit which enables us to make out the geology of the district; and accordingly our description of the structure will begin with an account of the lie of this grit. It should be premised that there is near Corwen an important fault, which runs 28° W. of N., and for a considerable distance lies in the course of Nant Cawrddu, and that a nearly parallel fault occurs in Nant Llechog, near Pen-y-glog. For the sake of clearness, the area between these two faults will be described first.

1. *Main Outcrop of Grit.*—Ascending the hill from Corwen to the Prince-of-Wales Memorial on Pen-y-pigin, about half-way up we pass a quarry in grit, which is worked for road-metal. The grit here, however, forms only a small patch, and, as will be shown farther on, has been let down by a fault. Continuing along the path, we find the main outcrop of grit just outside the moorland boundary-wall some distance higher up. The grit here strikes a little north of east to the point known as Pen-y-pigin, and thence onward it forms the crest of the cliff nearly as far as the stream which runs down past the Rectory (about a mile east of Corwen). Here it is covered by glacial drift for a short distance, but is found again on the eastern bank of the stream near the margin of the hill. It no longer forms a well-marked cliff, but may be traced along the top of the hill till it sinks into a tract of marshy land some 600 yards farther east. On the east of this tract it reappears and may be followed to Nant Llechog, where it is cut off by the Nant Llechog faults.

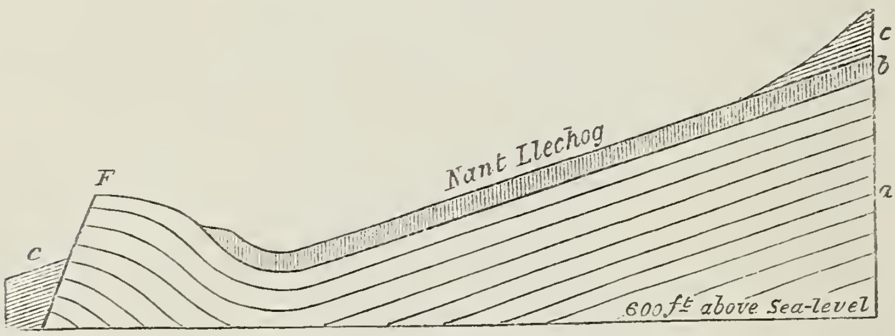
Throughout the whole of this distance the grit dips steeply in a southerly direction, *i. e.* into the hill, and in places is nearly vertical. But in Nant Llechog this dip is continued for a short distance only; a little farther south the grit rises again, dipping at a low angle towards the north, and for a considerable distance forms the bed of the stream. The Bala Beds below the grit show that the synclinal so formed is followed on the north by a faulted anticlinal (fig. 1, p. 430)

2. *Country South of the Main Grit-band.*—Near Nant Llechog, as has just been described, the grit turns up towards the south and forms a synclinal, and this appears to be the case throughout the area. Near Corwen, as already noticed, the main band of grit dips

steeply towards the south, and the dip of the slates above is the same. But the dip of these slates soon changes and becomes northerly, and, as the section in Nant Cawrddu shows, that of the grit does the same. A fault, however, intervenes before the grit can come to the surface; and south of this fault the grit reappears, forming a second synclinal, in which lies the old reservoir of the Corwen Waterworks (fig. 2).

Fig. 1.—*Section in Nant Llechog.*

N. 17° E. S. 17° W.



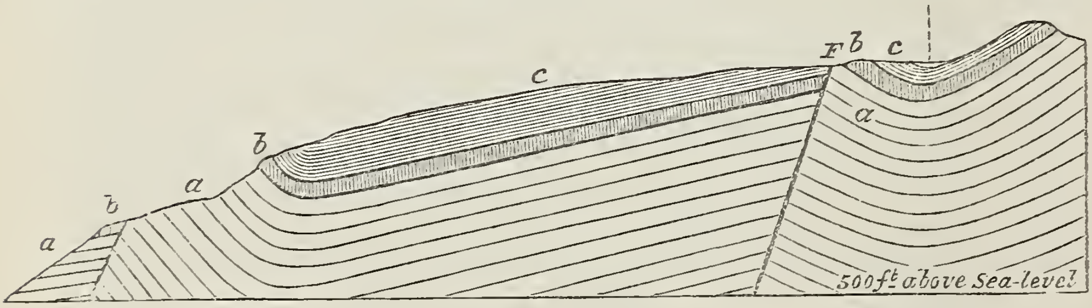
Horizontal scale: 12 inches = 1 mile. Vertical scale: 1 inch = 400 feet.

a = Bala Beds.
b = Corwen Grit.
c = Grey Slates.
F = Fault.

3. *Country North of the Main Grit-band.*—Since the grit forms the crest of the valley-bank and dips towards the south, the whole of the bank below would be formed of Bala Beds, were it not that about half-way down a long fault runs along the side of the valley from 10° N. of W. to 10° S. of E. This fault throws towards the

Fig. 2.—*Section from the Church to the old Corwen Waterworks.*

N. 15° W. Water-work S. 15° E.



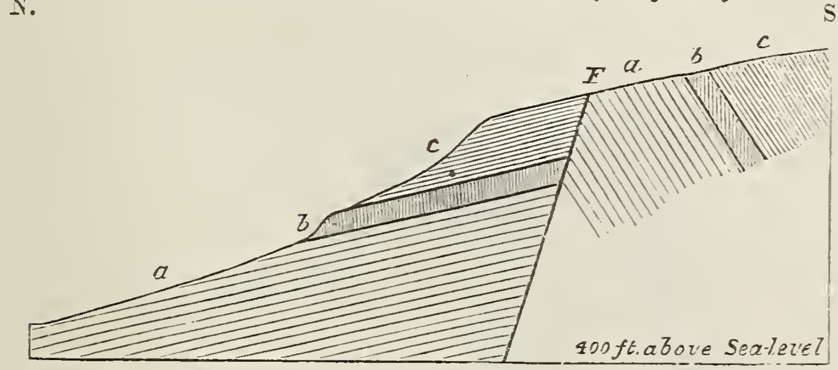
Horizontal scale: 9 inches = 1 mile. Vertical scale: 1 inch = 535 feet.

[For explanation of lettering, see fig. 1.]

north, and on its northern side the beds dip at an angle of about 12° towards the north.

Near Corwen this fault brings in several patches of grit, one of which may be seen in the quarry already mentioned and is shown at the northern end of the section in fig. 2. Other small patches are found in the woods to the east. Farther still towards the east the grit let down by this fault forms for a little distance the bed of the stream which runs down near Ty-isaf. Thence it is continued past, and a little above, the Rectory, for a considerable distance towards the east, and it here forms a well-marked vertical cliff. Below this band of grit are found Bala Beds, while above it come the greyish slates with grit-bands, which extend southward as far as the fault (fig. 3).

Fig. 3.—*Section 500 yards east of Ty-isaf.*

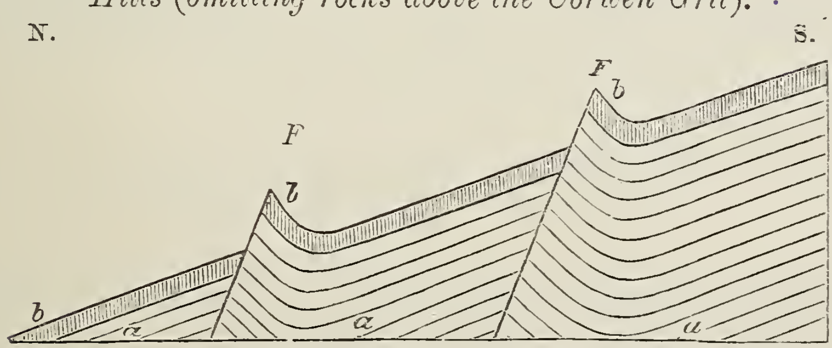


Horizontal scale: 9 inches = 1 mile. Vertical scale: 1 inch = 535 feet.

[For explanation of lettering, see fig. 1.]

Between the Nant Cawrddu and Nant Llechog Faults, therefore, the beds which form the Berwyn dome are thrown into a series of east-and-west folds which follow one another from north to south, and these folds are faulted along the crests of the anticlinals. The southerly dips are short and steep, and the northerly dips are long

Fig. 4.—*Diagrammatic section of the northern slope of the Berwyn Hills (omitting rocks above the Corwen Grit).*

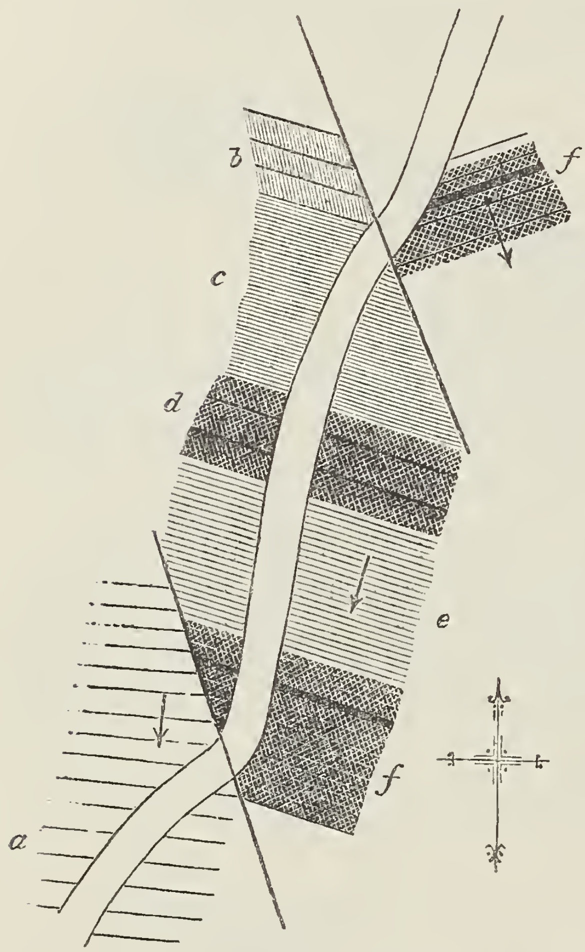


and low. The general result, as may be seen in fig. 2, or in part in figs. 1 and 3, is a series of synclinals which become higher and higher as we proceed towards the south, *i. e.* towards the centre of the dome. Omitting beds above the grit, this structure is shown diagrammatically in fig. 4.

4. *East of the Nant Llechog Fault.*—At the eastern end of the area, in Nant Llechog, two nearly parallel faults are shown running about 17° W. of N.; and since it is here that we found some of the few remnants of the graptolite-shales, it will be necessary to describe the section up this stream in some detail (see Map, fig. 5, p. 432).

From the road upwards for about 500 yards nothing is seen ; but just at the 600-foot contour-line there is on the right bank an exposure of black shales containing graptolites of the *gregarius*-zone.

Fig. 5.—*Sketch-map of Nant Llechog, in the neighbourhood of the two faults.*



a = Bala Beds.
b = Corwen Grit.
c = Grey Slates.
d = Black Shales.
e = Bluish Slates.
f = Black Shales, with graptolites of the *gregarius*-zone.

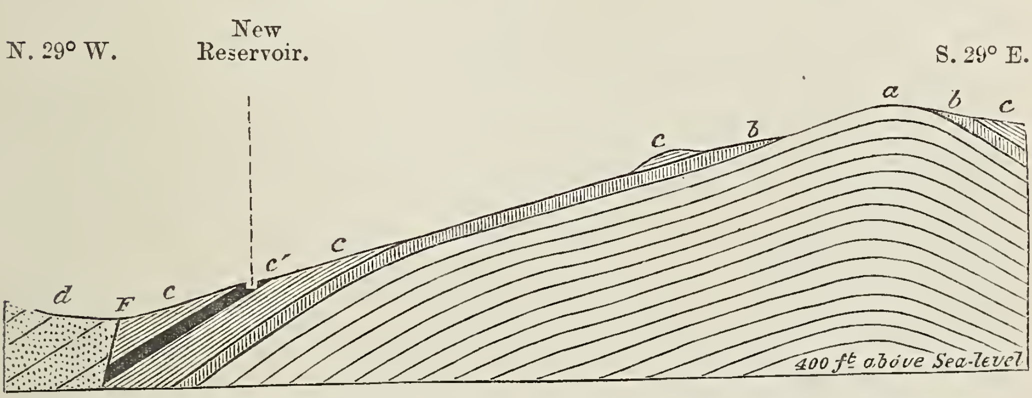
Note.—The dips of the Bala Beds in the south of the map and of the portion of the graptolite-shales in the north have been inadvertently transposed. The former dip S.S.E., the latter (the portion at the northern end of the map) dip 3° W. of S. The beds between the two faults are correctly represented.

Scale: 1 inch = 40 yards (approximately).

These are best seen close to the foot of a waterfall, the basin of which is hollowed out in these shales. The face of the waterfall is made of the Corwen Grit and of the slates above it, and it is the face of a fault which runs 20° W. of N. On the eastern side of this fault lie the black shales, striking 3° S. of E., and on the western side is the grit with the slates above it, striking 23° S. of E. At the waterfall the grit and the succeeding slates dip towards the south, *i. e.* up the stream, and accordingly, as we go up the stream, we reach higher and higher beds. A short distance above the top of the waterfall the slates are succeeded with perfect regularity by black shales like those below the waterfall, and in these we found a few graptolites. Then these graptolite-shales are succeeded by bluish slates, and these again by banded black shales extending up the stream as far as a second waterfall, which closely resembles the other. In these upper black shales we have found *Monograptus convolutus*. The basin of the second waterfall is hollowed out in them, while the face of the fall is the face of a fault which runs 17° W. of N. The fault itself is filled by a quartz-vein, which seems to have been the occasion of certain abandoned workings on the hillside above. The beds on the western side of the fault, over which the water falls, are Bala Slates, yielding *Leptæna sericea*, *Strophomena rhomboidalis*, *Orthis elegantula*, *O. testudinaria*, etc. They strike about E.N.E.–W.S.W., and, dipping towards the S.S.E., are succeeded by the grit, as shown in fig. 1 (p. 430).

5. *West of the Nant Cawrddu Fault.*—To the west of this fault an irregular patch of grit is shown upon the map. The surface of the ground is here nearly parallel to the surface of the grit, and the beds above the grit have been somewhat irregularly denuded. But the structure is tolerably simple and is sufficiently explained in the accompanying two sections (figs. 6 and 7).

Fig. 6.—*Section immediately west of the Nant Cawrddu Fault.*



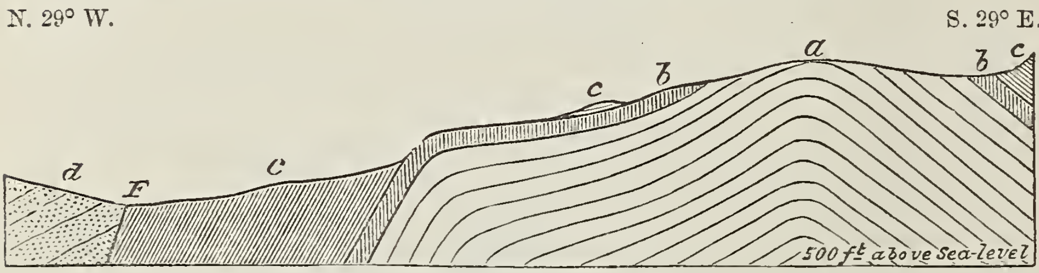
Horizontal scale: 9 inches = 1 mile. Vertical scale: 1 inch = 535 feet.

a = Bala Beds.
b = Corwen Grit.
c = Llandovery Slates and Shales.
c' = Graptolite-shales.
d = Denbighshire Grits.
F = Fault.

Towards the south, the grit partially encircles a mass of Bala rocks. Close to the fault, and on the northern side of this mass (fig. 6), it dips northward at a low angle, and for some little distance outside the moorland boundary-wall it forms the bed of Nant Cawrddu. Following the stream downwards, we find that the grit is succeeded by the grey slates, and these by black banded shales with graptolites of the *gregarius*-zone, which are best seen in the new reservoir cut just to the west of the stream. The graptolite-shales are overlain by bluish slates, and the next rocks exposed towards the north are the Denbighshire Grits brought in by the fault shown on the Geological Survey map.

A little farther west the grit still rests on the Bala Beds and dips northward at a low angle, but before it disappears below the higher beds to the north it plunges suddenly downward, almost or quite vertically. The beds north of it are here very imperfectly exposed (fig. 7).

Fig. 7.—*Section 250 feet west of that shown in fig.* 6.



[For scale and explanation of lettering, see fig. 6, p. 433.]

6. *Faults: Nant Cawrddu.*—The point of most interest, however, in connexion with this patch of grit, is the fault which separates it from the grit to the east. An inspection of the Map itself (p. 428) is sufficient to show that this fault is of remarkable character, inasmuch as at one point in the middle of its course it has no throw at all, and crosses the grit-band without apparently affecting it.

If we examine the walls of the Nant Cawrddu gorge south of the main grit-band—a gorge which has been hollowed out along the line of fault—we find that on both sides of the fault the grit has a general low northerly dip. The throw of the fault appears to be downward on the western side, but it is extremely small until we come to the main grit-band. Here, on the eastern side of the fault, the grit-bed turns suddenly upward (fig. 2, p. 430), and on the western side it turns as suddenly downward (figs. 6 and 7), so that the throw increases enormously within a few yards.

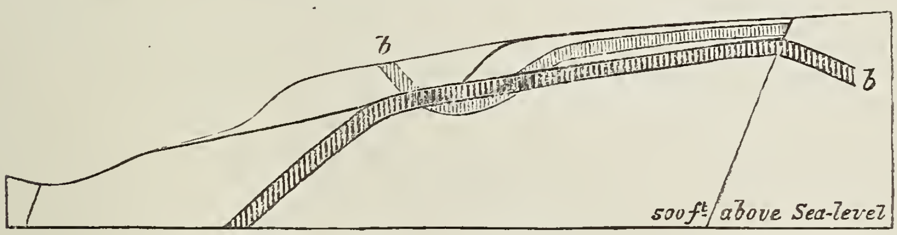
On comparing figs. 2, 6, and 7, which are approximately parallel sections near the line of fault, it will appear that fig. 6, which is close to the line of fault on its western side, is intermediate in character as well as position. It would seem that the bed of rock tried to yield, without breaking, to the upward bend of fig. 2 (p. 430) and at the same time to the downward bend of fig. 7. But the strain at length became too great, and the grit tore along the line of fault. The disposition of the grit on the two faces of the fault is shown in fig. 8.

The other faults do not offer much worthy of remark. As will be seen from the Map (p. 428), there are two series, the one running a little west of north, and the other a little south of east.

The former series includes the Nant Cawrddu Fault and the two faults at Nant Llechog.

The latter includes the fault just north of the old Waterworks (fig. 2, p. 430); the fault which runs along the face of the southern bank of the Dee (figs. 2 and 4, pp. 430, 431); the fault marked on the Geological Survey map, which brings in the patch of Denbighshire Grits at Corwen (figs. 6 and 7, pp. 433, 434); and probably the fault which brings in the grey slates at Bonwm-uchaf, in the north-eastern corner of the map. All these throw downwards to the north, and, with the exception of that marked on the Geological Survey map, which

Fig. 8.—*Disposition of the Grit on the two faces of the Nant Cawrddu Fault.*



b = Corwen Grit.

The heavy shading shows the disposition of the grit on the western face, and the light shading its disposition on the eastern face, of the fault.

Horizontal scale: 9 inches = 1 mile.
Vertical scale: 1 inch = 535 feet.

we have not closely examined, they all come to an end against the Nant Cawrddu and Nant Llechog Faults, showing that the latter are the newer.

IV. Description of the Strata.

The details which have already been given show clearly that in this area at least the grit-bed forms a well-marked and definite horizon. Below it we have bluish slates, which are generally rather irregularly cleaved. Above it is a series of slates which are generally greyish in colour, and which are characterized by the presence of numerous thin bands of grit, most important near the base. In hand-specimens it is not always possible to distinguish the lower slates from the upper ones, but in the field there is little difficulty. The slates below the grit are invariably fossiliferous, the fossils being of Middle Bala age; those above the grit are extremely unfossiliferous, and only at two points have we found fossils which may possibly belong to these slates. In the sections in Nant Cawrddu and Nant Llechog, however, these slates pass up into black shales, which contain graptolites of the *gregarius*-zone, and are therefore of Llandovery age.

If any line is to be drawn between the Llandovery and Bala Beds in this area, it must certainly be placed at the base of the grit. There is no sign of any unconformity between this and the underlying Bala Beds; but there is no passage from the one to the other. On the other hand, there is a kind of passage from the grit to the slates above, for the latter always contain thin grit-bands, and they are most gritty towards the base. Therefore we refer the grit and the beds above it to the Llandovery Series and classify them as follows:—

Llandovery ...	Pale Slates. Graptolite-shales (*gregarius*-zone). Grey Slates, with bands of grit. Corwen Grit.
Bala	Blue Slates.

(a) *Bala Beds.*—In the area under consideration these consist entirely of bluish slates. They are, as a rule, irregularly cleaved and of little economic value; but two quarries have been opened in them close to Corwen, and one at least of these is still worked. In some places small masses of soft ferruginous matter occur in the bedding-planes, and these usually weather out very easily. Near Nant Llechog this ferruginous matter forms regular bands a few inches thick.

Everywhere these slates are more or less fossiliferous, and in many places fossils are extremely abundant. The most abundant in the upper part of the slates are *Leptæna sericea*, Sow., *Orthis elegantula*, Dalm., *Favosites fibrosa*, Goldf., and other Favositid corals, and also crinoids, all of which have a wide vertical range in the northern part of the Berwyns. *Orthis calligramma*, Dalm., and *Pinnatopora Sedgwicki*, Shrubs., are also tolerably common, together with *Phyllopora Hisingeri*, M'Coy, and *Ptilodictya dichotoma*, Portl. In addition to these the following occur more or less frequently:—*Ptilodictya explanata*, M'Coy, *Strophomena rhomboidalis*, Wilck., *Str. simulans*, M'Coy, *Orthis biforata*, Schloth., *O. testudinaria*, Dalm., *O. protensa*, Sow., *O. porcata*, M'Coy, *Orthoceras ibex*, Sow., *Conularia Sowerbyi*, Defr., *Illænus Bowmanni*, Salt., etc.

Of these fossils, some are wide-ranging species of little value for determining the exact horizon of the beds in which they occur. Several (*Orthis biforata*, *O. protensa*, and *Phyllopora Hisingeri*) are forms which belong rather to the Llandovery and Upper Bala Beds than to the Middle Bala; while others (*Orthis porcata*, *Ptilodictya explanata*, and *Pinnatopora Sedgwicki*), which are generally recognized as Middle Bala forms in Britain, occur abundantly in the calcareous grit at Glyn Ceiriog (Llandovery), or in beds immediately below it. The assemblage of fossils has, however, a prevailing Middle Bala aspect, and this, together with the fact that the characteristic Upper Bala fossils are apparently absent, points to the conclusion that the Upper Bala Beds are absent at Corwen, and that the base of the Llandovery rests here, with only apparent conformity, on beds fairly high up in the Middle Bala Series.

We have not as yet distinguished any definite zones. A little distance below the grit a bed occurs which is full of *Leptæna sericea*, while almost immediately below the grit *Favosites fibrosa*, *Pinnatopora Sedgwicki*, and crinoids appear to be specially abundant; but all these fossils have a considerable vertical range. The *Leptæna*-bed is well seen at the eastern end of the hill of Bala rocks shown in fig. 1 (p. 430), and is also found at the side of the stream above (south of) the Rectory.

(b) *Corwen Grit.*—This is an extremely tough and compact grit, quite like a quartzite in texture. It is almost purely siliceous, and contains none of the felspathic grains which are so abundant in the Denbighshire Grits. It is tolerably uniform in character throughout the area, and owing to its toughness it often forms a steep scarp. In places, for example just west of Pen-y-pigin, its structure is platy.

We have not succeeded in finding any fossils in this bed, and if there ever were any they seem to have been obliterated. Prof. Hughes found a badly-preserved form which he referred to *Favosites alveolaris*; and in fragments of a similar rock on Cyrn-y-brain he obtained *Petraia subduplicata*, *P. crenulata*, and *Meristella crassa*. In a calcareous grit occupying a similar stratigraphical position at Glyn Ceiriog, and overlain by similar grey slates with grit-bands, we have found *Streptelasma? equisulcatum*, M'Coy, *Lindstrœmia subduplicata*, M'Coy, *Favosites fibrosa*, Goldf., *Nebulipora lens*, M'Coy, *Heliolites megastoma*, M'Coy, *Orthis biforata*, Schloth.?, *Meristella* sp., *Murchisonia*, *Pleurotomaria*, etc. These fossils, together with the fact that at Corwen itself the grit occurs immediately above Bala Beds, and a little below beds with a Birkhill fauna (*gregarius*-zone = the upper zone of the Lower Birkhill), leave no doubt that the Corwen Grit is of Llandovery age.

(c) *Grey Slates*.—The slates which are found above the grit are generally greyish in colour, but sometimes blue, like the Bala Beds. They are softer and more finely cleaved than these, and are distinguished by the presence of small bands of grit ½ to 1 inch in thickness. Towards the base these slates become more gritty, and in Nant Llechog they may almost be said to pass down into the grit. They usually weather deeply along the cleavage and along the bedding-planes, and this gives to large masses of them a very striking and characteristic appearance.

In general they are quite unfossiliferous, and thus contrast strongly with the Bala Beds. In a little rill, however, just above the main grit-band, due south of Ty-isaf, we found fragments containing fossils. So far as we could see, these must have come from the grey slates, and in them we obtained (badly preserved) *Leptæna sericea*, Sow., and *Orthis elegantula*, Dalm. On a ridge of these slates, some 500 yards farther south-south-west, we found *Calymene Blumenbachii*, Brongn., and some badly-preserved brachiopods, including *Leptæna sericea* (?) and *Rhynchonella* sp.

(d) *Graptolite-Shales*.—These have been found in two places only, namely in Nant Cawrddu and Nant Llechog. Their relation to the neighbouring beds has been already described, and in each case they overlie the grey slates.

In Nant Cawrddu they have recently been excavated just west of the stream, apparently to form a reservoir, and thus we obtained a clear section. They are here black, glistening slates with paler bands, and they dip 20° due north. They contain numerous grains and small nodules of pyrites, and also large numbers of graptolites, which are, however, strongly compressed and not very perfectly preserved. Mr. J. E. Marr, F.R.S., has kindly determined them for us, and he finds the following species:—

Monograptus tenuis, Portl.
—— *gregarius* (?).
Monograptus leptotheca? Lapw.
Diplograptus sinuatus, Nich.

In Nant Llechog the graptolite-shales are very similar in character; but the graptolites are not so strongly compressed, and are much better preserved. Near the foot of the first waterfall we found a band made up almost entirely of graptolites. The species found here (also determined by Mr. J. E. Marr) are:—

Monograptus convolutus, His. (abundant).
—— *leptotheca*, Lapw.
—— *Nicoli*, Harkn.
—— *tenuis*, Portl.
Monograptus fimbriatus ? Nich.
Diplograptus tamariscus, Nich.
—— *sinuatus*, Nich. (very abundant).
Petalograptus ovatus ? Barr.
Climacograptus normalis, Lapw.

On the western side of this fault the grey slates with grit-bands are, as already described, followed by black shales in which one or two unrecognizable graptolites were found; these are again followed by bluish slates, and these by banded black shales. In the latter we found *M. convolutus* and one or two other forms, and they evidently correspond with the graptolite-shales just mentioned.

All these graptolites belong to the *convolutus*-subdivision of the *gregarius*-zone—the upper zone of the Lower Birkhill—and it is clear therefore that these shales are of Lower Birkhill age.

(e) *Pale Slates.*—In Nant Cawrddu the graptolite-shales of the new reservoir are succeeded by pale bluish slates, which extend as far as the Corwen Fault.

In Nant Llechog the graptolite-shales are followed by somewhat lighter-coloured beds; and in the hill just above old workings have thrown out pale slates, such as frequently lie immediately below the Tarannons in this area. But the whole of the rocks between the *gregarius*-shales and the slates of Pen-y-glog (Denbighshire Slates) are covered by drift, and no section in this area exposes the higher beds of the Llandovery Series.

V. List of Fossils found at and near Corwen.

Corwen.

Grey Slates.

Leptæna sericea, Sow.
Orthis elegantula, Dalm.
Rhynchonella ?
Calymene Blumenbachii, Brongn.

Beds immediately below the Corwen Grit.

Leptæna sericea, Sow. (abundant).
Orthis elegantula, Dalm. (abundant).
—— *testudinaria*, Dalm.
—— *calligramma*, Dalm.
—— *biforata*, Schloth.
—— *porcata*, M'Coy.
Strophomena rhomboidalis, Wilck.
—— *simulans*, M'Coy.
Lingula ovata, var.
Orthoceras ibex, Sow.
Conularia Sowerbyi, Defr.
Phyllopora Hisingeri, M'Coy.
Ptilodictya sp.
Pinnatopora Sedgwicki ? Shrubs.
Illænus Bowmanni, Salt.
Crinoids (abundant).
Favosites fibrosa, Goldf., and other Favositids (abundant).

Beds not far below the Corwen Grit.

Leptæna sericea, Sow. (abundant).
Strophomena rhomboidalis, Wilck.
Orthis elegantula, Dalm. (abundant).
—— *testudinaria* ? Dalm.
—— *protensa*, Sow.
—— *calligramma* ? Dalm.
—— *porcata* ? M'Coy.
Conularia Sowerbyi, Defr.
Holopea striatella ? M'Coy.
Phyllopora Hisingeri, M'Coy.
Ptilodictya dichotoma, Portl.
—— *explanata*, M'Coy.
Pinnatopora Sedgwicki, Shrubs.
Illænus sp.
Crinoids (abundant).
Favosites fibrosa, Goldf., and other Favositid corals (abundant).
Dendrograptus ?

Lower Beds.

Leptæna sericea, Sow. (abundant).
Atrypa marginalis, Dalm.
Orthis elegantula, Dalm. (abundant).
—— *porcata* ? M'Coy.
—— *testudinaria*, Dalm.
Conularia Sowerbyi, Defr.
Pinnatopora Sedgwicki, Shrubs.
Trinucleus seticornis, His.
Calymene senaria, Conrad.
Illænus Bowmanni, Salt.
Crinoids (abundant).
Favosites fibrosa, Goldf., and other Favositid corals.

Glyn Ceiriog.[1]

Grey Slates at Glyn Ceiriog.

Leptæna sericea, Sow.
Meristella crassa.
Orthis elegantula ? Dalm.
—— *porcata*, M'Coy.
Orthis hirnantensis ?
Strophomena rhomboidalis, Wilck.
Retzia ?

Calcareous Grit at and near Glyn Ceiriog.

Leptæna sericea, Sow. (tolerably abundant).
—— *transversalis* ? Dalm.
Lingula ovata, M'Coy.
Orthis biforata, Schloth.
—— *calligramma*, Dalm. (abundant).
—— *elegantula*, Dalm.
—— *porcata*, M'Coy.
Strophomena rhomboidalis, Wilck.
Pentamerus ? sp.
Rhynchonella Lewisii, Dav.
Meristella cf. *nitida*, Hall.
Ptilodictya explanata, M'Coy.
Pinnatopora Sedgwicki, Shrubs. (abundant).
Calymene sp.
Homalonotus bisulcatus ? Salt.
Phacops apiculatus, Salt.
Favosites fibrosa, Goldf., and other Favositid corals.
Nebulipora lens, M'Coy.
Heliolites megastoma, M'Coy (tolerably abundant).
—— *tubulata* ?, Lons.
Streptelasma equisulcatum ? M'Coy.
Lindstrœmia subduplicata, M'Coy (abundant).
—— ——, var. *crenulata*, M'Coy.
Halysites catenularia ? Linn.
Gasteropods (*Pleurotomaria*, *Murchisonia*, *Holopella*, *Straparollus*, *Bellerophon*) and crinoids often abundant.

Discussion.

The President said that this paper contained a very pretty little bit of stratigraphical work. Tough grits were of great value in

[1] Glyn Ceiriog lies about 8 miles E.S.E. of Corwen. Here also we have a grit (calcareous) succeeded by grey slates with grit-bands, as at Corwen; but both grit and slates are fossiliferous. The lists are inserted for purposes of comparison, to supplement the poverty of the corresponding beds at Corwen.

geological mapping, and it was fortunate for the Authors that such a rock occurred in the area they had described.

Prof. Hughes said that one of the great difficulties in tracing this basement-series was that it rapidly varied horizontally; that fossils were found only here and there in lenticular beds and patches; and that the border-ground was much disturbed. Therefore a careful bit of mapping like that offered by Messrs. Lake and Groom was of the greatest value. He thought that the Hirnant Limestone should be divided into (1) an upper, sandy, pyritous, calcareous, often pisolitic rock, weathering into a gingerbread-coloured mass, which was the equivalent of the Corwen Grit and of the calcareous grit of Ponthafodcynfor; (2) a lower portion consisting of bands of limestone or limestone-nodules in cleaved rock which belonged to the Bala Beds; and that, whether by the discordant creeping of the basement-bed of the Silurian over the various members of the Upper Bala, or by the dying out of the nodular limestone, it was only here and there seen, as at Aberhirnant, immediately underlying the basement-bed to which the name 'Hirnant Limestone' should properly be confined.

He enumerated some of the characteristic fossils of that horizon, pointing out some sources of error, if surface-specimens were collected, arising out of the circumstance that casts only were preserved and those mostly fragmentary, while there were unfortunately some more or less close resemblances between certain fossils of the adjoining horizons,—such as *Orthis hirnantensis* and *Strophomena siluriana*; *Orthis biforata* and *O. spiriferoides*; the dwarfed and clean-cut variety of *Meristella crassa* and *M. tumida*, *M. angustifrons*, and others. He thought that *Pentamerus lyratus* occurred in North Wales, but he had never been able to verify the occurrence of *P. oblongus* in the northern area.

Mr. Groom agreed with Prof. Hughes as to the difficulty of obtaining palæontological evidence to decide the age of the grit at Corwen; and said, with reference to the occurrence in the northern part of the Berwyn Hills of the unconformity mentioned by Prof. Lapworth as existing in the south-east, that the Authors' researches were still insufficient to show whether Upper Bala rocks were absent or not from the whole region, although the evidence at Corwen itself seemed distinctly in favour of a break.

Prof. Lapworth also spoke, and Mr. Lake briefly replied.

35. *On the* Felsites *and* Conglomerates *between* Bethesda *and* Llanllyfni, North Wales.

By the Rev. J. F. Blake, M.A., F.G.S. (Read May 10th, 1893.)

Contents.

I. Introduction.

A paper which was read to this Society on December 9th, 1891,[1] had for its primary object the proof that certain felsites, occurring in North-west Caernarvonshire, which had been claimed to be of pre-Cambrian age, were in reality part of the Cambrian succession. This conclusion had indeed been previously arrived at in an earlier paper,[2] and had been confirmed by Sir Archibald Geikie in his Presidential Address;[3] but further proofs were brought forward from a study (1) of the Cambrian succession, (2) of the felsite itself. The latter part of the paper, however, with its somewhat startling assertion of the 'post-Cambrian' age of certain conglomerates which had hitherto been considered either to mark the base of the Cambrian or to be an integral portion of it, required perhaps, considering the weight of authority to which the statements were opposed, somewhat more argumentation than was there given to it. Since the date of that paper further information has been obtained, which, while it has necessitated some minor corrections, is found in the end to greatly strengthen the main contention.

With regard to the felsite, or, as one ought properly to say, the felsites, in spite of Dr. Hicks's latest assertion that "there is abundant evidence to show that the Llyn Padarn quartz-felsite is of pre-Cambrian age [4]," it seems to me like flogging a dead horse to prove any further their Cambrian age. They occur, as will be seen, at so many horizons that they could only be one mass if they were intrusive; and of their being this, even where they appear at first sight to behave as such, there is no evidence, but very much to the contrary.

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 243.
[2] *Ibid.* vol. xliv. (1888) p. 271. [3] *Ibid.* vol. xlvii. (1891) *Proc.* p. 90.
[4] *Ibid.* vol. xlviii. (1892) p. 261.

With regard to the conglomerates, I am perfectly at one with Dr. Hicks and all other recent writers on the district in recognizing that in every case they are derived in part from, and are therefore posterior in date to, some felsite; but this will only prove the pre-Cambrian age of the latter (for which purpose they have been principally considered of importance), if they lie at the base of the Cambrian Series. That none of those which are found on the eastern side of the faulted Silurian strip do this is an easy matter to show; indeed, it has been already abundantly shown, though further proofs will be found in the present paper; but it is another thing to demonstrate that any of them are of later age than the workable slates. It must at once be admitted that this is not immediately evident: the proof requires a careful consideration of the whole obtainable evidence, and this is doubtless the reason why the fact has not been recognized before. There are indeed several sections and dispositions of the rocks that are in themselves highly unfavourable to this view, all of which will be noted further on. There is not, however, a single one which cannot be explained, whereas those on which this view is founded admit of no other explanation.

It will easily be seen that if my contention is correct, and there is really an unconformity above the workable slates of Llanberis and Penrhyn, this has far-reaching consequences of greater interest than the mere controversy as to the expunction of the supposed pre-Cambrian rocks from the district; and it is from this point of view that I am chiefly anxious to propagate the conviction at which I have arrived.

In the descriptions which follow, the evidence as to the felsites and the conglomerates is so interwoven that I shall take the localities in geographical order, and set forth the whole of the information on either subject obtainable in each.

II. The Penrhyn Quarry Tunnel.

In his description of the Cambrian rocks of Caernarvonshire Sir Andrew Ramsay mentioned that felsite was met with in a shaft sunk on the site of the old St. Ann's Chapel, near Bethesda,[1] and on the strength of this occurrence, though the rock does not reach the surface, he continued the felsitic area of Clegyr and Moel Goronwy to this point. Within the last few years two other shafts have been sunk at about 200 yards to the east of the former one, and from the bottom of one of these there is a tunnel running for about 200 yards in a S.S.E. direction to the lowest level at which the slates are worked. This tunnel I have examined under the guidance of Mr. Morris, one of the superintendents of the mine, and a series of specimens has been collected for me by Mr. Robert Lloyd, of Cilgeraint St. Ann's, of trilobite renown. Felsite occupies a considerable length of the tunnel; it is of various kinds, some being nearly white and of a waxy lustre, and

[1] Mem. Geol. Survey, vol. iii. (1866) p. 144.

some being dark purple in colour. Both varieties are massive in some parts, and in others cleaved and drawn out into a slate-like form. These felsites are followed towards the S.E. by a band of fine green grit, which (neglecting dykes) becomes still finer till it is almost a slate, light green, and very obscurely banded. Then comes (after another dyke) a band of peculiar rock called 'whetstone'. It is green and translucent, and of course extremely fine in grain. I have not analysed it, but would suggest that it may be composed of the finest felsitic dust. Next in succession after another dyke is a band of conglomerate whose matrix is a green grit, and whose pebbles, which are not numerous and are coated with sericite, are of red felsite, not like any of the samples obtained *in situ*. Immediately after this is the 'Hard Blue' slate, which continues to the entrance of the tunnel.

The second shaft is not yet completed. It commences in the whetstone, and after a considerable depth, the dip of the strata being high, it reaches the grit, and, passing through this, enters the felsite, in which it is likely to end. East of this we find on the surface skirting the edge of the quarry the green grit and conglomerate of the tunnel. The pebbles are seen to be scarce and confined to narrow bands; *per contra*, they are of large size up to the diameter of a soup-plate. Thus the section in the tunnel is confirmed.

Now, in this case, we know exactly where we are in the series; for the workings of the quarry lay bare all the strata up to the Bronllwyd Grit. Succeeding the Hard Blue comes the Red Band, then the Old Blue, and above that the Bastard and Pale Slates. Under ordinary circumstances I should dismiss this section with the remark that the felsite and conglomerate are on the horizon of the St. Ann's Grit, and simply point out that the last-named is thus shown to be occasionally conglomeratic. But if the matter has to be argued out, I must say that we are here left with a triple alternative—either (1) the workable slates of the Penrhyn Quarry are the *only* rocks which can be rightly called Cambrian, so that this conglomerate lies at the base of that system; in this case all the other conglomerates would have to be pre-Cambrian, though they also have been claimed as basal Cambrian; or (2) the beds to the west of this spot are repetitions of the Penrhyn Slates in another form, as is claimed to be the case by Dr. Hicks, in the district a little farther south; in this case we have beds which remain constant for 15 miles in a N.E.-and-S.W. direction, and even appear again in a recognizable form in the centre of the Harlech anticlinal, suddenly changing their character in $1\frac{1}{2}$ mile in a north-westerly direction, so as to retain no resemblance whatever to their old form; or (3) if, as I hold, both the above alternatives are to be rejected, the beds to the west are lower ones in the Cambrian succession and the felsite is a mass poured out or intruded in the middle of the Cambrian period, and the succeeding conglomerate is not at the base of the Cambrian.

In the above section no question arises as to any later conglomerate; but before leaving this district it may be well, for the sake of comparison, to call to mind the phenomena here shown by the Bronllwyd Grit. In my former paper it was stated that no definite proof of its unconformity could be given, though several things pointed that way. I would here call again to remembrance how, in spite of the main mass being limited to the east of a well-marked line, the rock spreads over the surface to the west, as shown even in the Geological Survey Map, round Frid Fedw, and at quite low levels on either side of the River Ogwen at Bethesda, where, lying to the west of Purple Slates, a careless stratigraphy might put it below them. The basal beds here exposed have a coarse slate-breccia at the bottom, wherever that can be seen; then comes a grit with small white quartz-pebbles; and then some curious alternations of 1- or 2-inch bands of slate and grit, with cleavage confined to the former. The importance of noticing this is that we have here an example of a set of beds which are generally accepted as post-Llanberis [1] and which certainly have the workable Purple Slates underlying them, separated from the main mass and comparable in position to those which are claimed to be of the same age farther south.

III. Between Moel Rhiw-wen and Moel-y-Ci.

In this area I have marked on my map (Quart. Journ. Geol. Soc. vol. xlviii. 1892, p. 243) a patch of supposed 'post-Cambrian' conglomerate. The evidence in this case is not of the clearest. The mass appears to have a much wider surface-distribution than would be expected if it were a bed in the series around it, and the greatest length does not quite run in the expected direction. If it were taken as part of the adjacent Cambrian Series, its position between the Banded Slates and Lower Purple Slates would indicate it to be part of the Rhiw-wen Grit. The principal reason for considering it of later date is its close resemblance, in its irregular character and in containing slate-fragments, to the conglomerate at Llyn Padarn, which latter is thought to be proved post-Llanberis. This, of course, is an argument which cuts both ways and has no independent value. We note, however, that if the conglomerate here be not post-Llanberis, then (1) it is not connected with any felsite; (2) it would occur, not at the base, but in the middle of the Cambrian Series; (3) it would not be on the same horizon as that in the Penrhyn Tunnel, for it would lie below the Lower Purple Slates which are actually here overlain by the St. Ann's Grit.

IV. Llyn Padarn and Y Bigl.

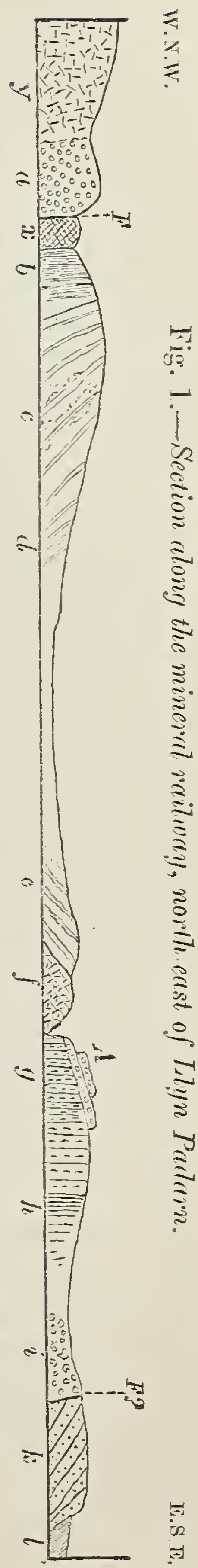
The section exposed along the mineral railway is so accessible and easy to see that it has often been examined and several times described; and the supposed structure of the district has been mainly founded on its teachings. It will be necessary, therefore, for purposes of reference to give the section once more, as now interpreted.

[1] [At the reading of the paper these were called 'post-Cambrian,' but the uglier term now adopted is less liable to lead to confusion.—July 15th, 1893.]

Commencing from the felsite (y), we have first a narrow, vertically-bounded band of coarse conglomerate (a), then a greenstone dyke (x), then some hälleflinta-like material, very much pulled out and becoming purplish at the top (b), then some bluish-green felspathic grit, dipping more gently up the lake (c), and then a large mass of banded green slate with a lower dip in the same direction (d). After some interval without exposure we come to some more banded slate dipping down the lake at about 45° (e), followed by a mass of greenstone or green grit (f) [not properly examined]. Then, after a hollow, is seen a cliff of remarkable breccia commonly called a conglomerate (g), which is vertically bedded, changing in a horizontal direction to more and more felsitic material till it is almost a felsite or pure felsitic ash (h). Then, after some slight obscurity, comes a massive conglomerate (i), followed by a hard, blue banded grit with an easterly dip (k), and finally comes the Red Purple Slate (l).

I do not think it is at all surprising that this section should have been interpreted as showing a triple repetition of the same conglomerate by means of a synclinal and anticlinal.[1] The position of the conglomerate (a) in a horizontal section between the felsite and the slates and grits (b–d) is naturally explained by its being intermediate in age; yet, owing to the intervention of the greenstone-dyke, we have no definite proof of this: it is quite as likely that the dyke lies along a fault. Then there is undoubtedly a synclinal, d corresponding with e, possibly also c with f, and it may well be suggested that the breccias (g) correspond with the finer hälleflintas (b), leading to h corresponding with the felsite (y). On the other side of h, however, we get into difficulties; the conglomerate i resembles a, but not g, and there is nothing but the thin mass of grit k [the section is drawn to scale] between it and the worked

Fig. 1.—*Section along the mineral railway, north-east of Llyn Padarn.*



y = Felsite. b = Hälleflinta. f = Greenstone ? or Grit. i = Conglomerate.
x = Greenstone Dyke. c = Grit. g = Slate-breccia. k = Green Grit.
a = Conglomerate. d, e = Banded Slate. h = Felsitic Rock. l = Purple Slate.
A = Unconformable Conglomerate. [Horizontal Scale: 1 inch = 100 yards.]

[1] See T. G. Bonney, Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 315.

Purple Slate, to which latter nothing between *b* and *e* corresponds. It seems to me that this sudden change proves that there is no anticlinal, but a fault somewhere between *h* and *k*, in which case the conglomerate *i* may be let down in the trough. When seen in contact with *k* the relations are not certain; it partly appears to interosculate, and partly to have a different direction of bedding and to be slickensided; we must therefore leave it undecided whether this band lies naturally below the grit *k* or is faulted against it.

But the main point in this section has been left as yet unnoticed —the occurrence of another conglomerate of large stones lying on the top of the peculiar breccia (*g*). These two had been confounded with each other till Prof. A. H. Green described their unconformity.[1] His account of the general section agrees very closely with the above, while his description of the relations of the unconformable conglomerate (*A*) to the beds below (*g* and *h*), and of the characters of each, is so wonderfully true to nature that I can only quote him *verbatim* from the words 'the first rock' (*op. cit.* p. 74) to 'their character' (p. 77), and I must demur entirely to the words of the President (Prof. Bonney) on that occasion, that 'the section is not so clear in nature as in the diagram.' The apparent unconformity is considered, however, by Sir Archibald Geikie to be due to the cleavage of the 'fine tuffs,' as he designates the breccias, and the non-cleavage of the conglomerate. The urger of this objection at least recognizes the difference between the two, which others have failed to do; but neither Prof. Green's reasoning nor my own has any connexion with the cleavage or otherwise; it is that a conglomerate lies in nearly horizontal beds, or at least with a nearly *horizontal* line of separation, upon a mass of another rock, different *vertical* sheets of which have different characters. I cannot imagine a more satisfactory proof of unconformity in a single section.

Nevertheless, were this section only studied and the unconformity admitted, the most natural suggestion would be that made by Prof. Hughes in the discussion on Prof. Green's paper, that the beds *g*, *h* belong to an older series than the beds *a*–*f* (including therein the unconformable *A*). It is when we follow the beds over the surface of the country that the difficulties begin. The accompanying map (p. 447), in which several minor details are omitted, will enable the argument to be followed.

The first difficulty in the old interpretation is connected with the eastern boundary of the conglomerates, etc. At 19, 24 we find them to the east of the felsite; a little farther north they are close to the Purple Slate at 3, 4; and at 5, 6 there is none between the felsite and the slate. This difficulty, however, may be due to a fault suggested by the section in the railway, though not introduced into the map. The main difficulty is the supposition that the conglomerates (*a*, *A*, etc.) underlie the mass of banded slates, etc. (*b*–*e*). The non-correspondence of the sequence at *A*, *g*, *h*—2, 7 in the section—with that at *a* (8, 9) on the opposite side of the synclinal cannot be accounted for by a fault between *a* and *y*, as suggested by

[1] Quart. Journ. Geol. Soc. vol. xli. (1885) p. 74.

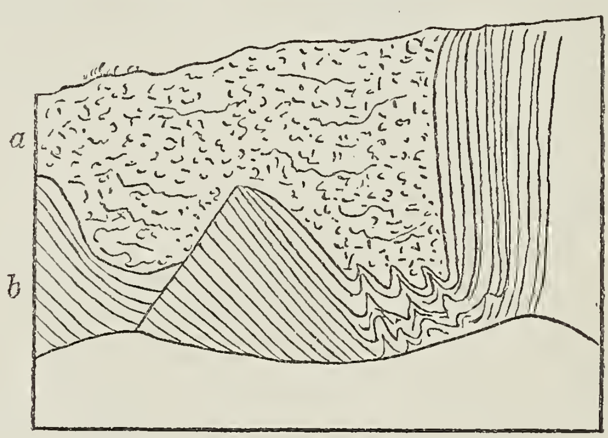
Prof. Bonney, for at 10 the conglomerate shades so gradually into the reconstructed felsite that only an occasional quartz-pebble indicates the nature of the rock, and it is impossible to draw the line (though we know it must exist) in the field. This difficulty disappears if the conglomerate is younger than all.

Fig. 2.—*Map of Country from Llyn Padarn to Y Bigl.*

Next, on the western side, the conglomerate (*a*) may be traced up in great crags from 8 by 10, 25, as far as 11; but there it suddenly stops, and Pale Slate is found at 12, at a lower level and close against the felsite, 13. It is true that this slate contains pebbles at 14, 15, 16, but the whole rock is very different from the crag of conglomerate which comes on again at 17. These observations are well enough explained if the conglomerate overlies, and is let down in a fold or by a fault at 8; but to account for them, if it lies below throughout, would require a very rapid and discontinuous change in its character. On the other side of the area the observations seem more decisive. The unconformable conglomerate (*A*) at 2 can be traced up thence by 18, 19 to 3 and 20, and again along from 21 to 22, and is seen also at 23. This, according to the old interpretation, forms the eastern part of a synclinal, of which the line from 8 to 17 forms the western part. Now between the exposures at 2 and 8 in the railway-section there is a very considerable mass of Banded Pale Slate and other easily recognizable rocks; if therefore there is here such a continuous synclinal, we ought to find the same series between 19 and 25, and between 23 and 11; but this is by no means the case. All the area of which 26 and 27 show good exposures is a valley occupied by the Pale Slates; but the line across from 19 to 25 is occupied by rough weathering crags of coarse felspathic grits (some of them with small white quartz-pebbles), and the same kind of rock continues to the summit of Y Bigl. The very fact of the highest hill in the district following on the line of strike of a broad valley seems to denote some change in the strata, such as we actually see, and these strata being horizontal and on the eastern side certainly continuous with the conglomerates, the whole must overlie the Pale Slates.

There are, however, spots where we can actually see this to be the case. Thus at 30 we find the following section exposed in a crag (fig. 3). Much contortion is here seen; but there can be no question

Fig. 3.—*Y Bigl: Grits overlying Pale Slates.*

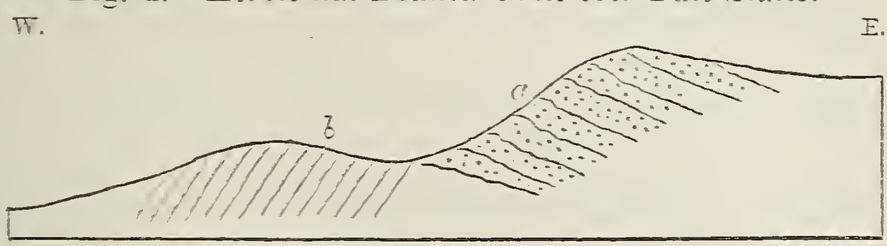


a = Grits. *b* = Pale Slates.

that the grits, which are continuous in the same form to the summit, overlie the Pale Slates. They show also obscure signs of horizontal lamination, and from the contortions we learn that it would be very possible for the underlying rocks to protrude occasionally in unexpected spots. Thus at 32 a curious patch of felsitic ash associated with banded purple slate (probably the band alluded to by Sir Archibald Geikie) may be accounted for perhaps in this way.

Something very similar to the above is seen at 31; compare fig. 4, p. 449. Here we mount over one boss composed of Pale Slates, cleaved at a high angle, and reach a higher one showing easterly-dipping beds of fine irregular grit. Even if this latter point were a mistaken observation, and the grits by a reversed dip were under the slates, they would still be to the east or on the wrong side; and if we correlated them with *c* they should be followed by the Banded Slates, which is not the case. A third example is above 28, where we find conglomerate lying on the surface of Pale Slates.

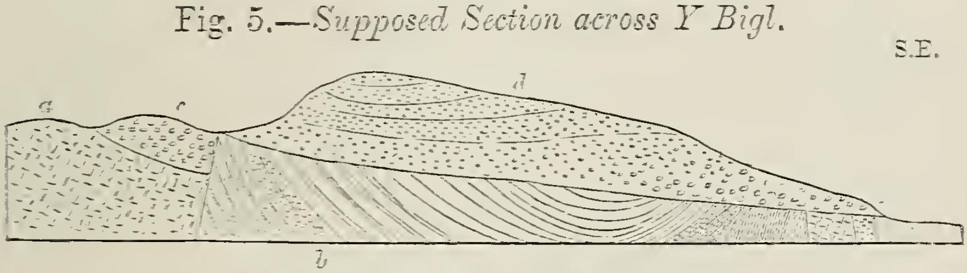
Fig. 4.—*Horizontal Bedded Grits over Pale Slates.*



It is not, however, always easy in particular spots to distinguish the beds which for the above reasons I refer to a later date, for they are a curious mixture, very inconstant in some respects. But when one gets familiar with them, the irregular stratification in crinkly lines, the apparent false bedding, and the mottled colour due to the intermixture of various detritus appear very characteristic: although where one or other material preponderates the result may be more or less mimetic of the rocks from which the detritus has been derived.

My general notion of the structure of Y Bigl, after eliminating contortions, is represented in fig. 5, where the post-Llanberis beds

Fig. 5.—*Supposed Section across Y Bigl.*



a = Felsite. *b* = Cambrian Beds.
c, *d* = Post-Llanberis Conglomerates and Grits.
[Horizontal Scale: 10 inches = 1 mile.]

may possibly be represented too thick. At all events, we have the following broad facts to go upon. Over the centre of a synclinal we have a vast continuous mass of conglomerates and grits rising to a height of 300 feet above the main exposures of the slates, while we find these slates in the low ground on either side to the north and south along the line of their strike; and while in no locality can we find the former underlying the latter, in several localities we find them actually overlying. It is true that we do not here see the conglomerates transgressing over the Purple Slates, unless the approximation of 3 and 4 is a natural one; but they do so in the area next to be described.

A further argument for their unconformity—and indeed the one which originally led me to believe that there was something wrong in the accepted explanation—is afforded by Moel Goronwy. On the north-western side this is skirted by conglomerate (21, 22), but all along the margin from 5 to the eastward no sign of such a rock, nor of the rocks of Y Bigl, nor of the Banded Slates can be seen. But after a narrow band of curious breccias derived from the felsite (33, 34), we come at once to the Purple Slates, and farther east to the St. Ann's Grit, whose horizon is determined by the fact that it overlies purple slate in Chwarel Fawr. I can account for these facts in no other way than that this felsite is a later eruption than that of Clegyr (from which it differs in being more compact) and coeval with that of the Penrhyn Tunnel, that its natural successor is the breccia made of its fragments, and therefore that the conglomerate overlying it on the north-western side must be a still later formation—later, therefore, at least than the Lower Purple Slates,—in which case it *must* be unconformable on the Banded Slates. Thus the present interpretation holds together everywhere, which is what no other interpretation does.

V. The South-western Side of Llyn Padarn.

In this district also we have a continuous section exposed along a railway, which has been made the basis of most of the conclusions hitherto drawn, but of which a new interpretation, not originally suggested by the section itself, will now be given.

Commencing at the north-western end (see fig. 6) near the tunnel, on the far side of the inlet crossed by the railway, we find the felsite [1] (*y*). Passing this we come to the massive conglomerate (*a*) in crags by the side of the inlet, rising over the back of the next crag of felsite. This felsite comes into immediate contact along a vertical line with a mass of Purple Slate (*b*) in which another thin band of felsite is intercalated.[2] The slate continues in mass, along the lower levels only, and forms the first few feet of the cutting. It is there succeeded by a band of coarse conglomerate (*c*), dipping E.S.E. at about 70°, which soon becomes laminated parallel to the line of junction. Conformable with this is a massive grey slate (*d*) with a band of fine conglomerate, and into this has been pushed another double band of conglomerate (*e*), followed by some grey-green grits (*f*), which undulate, become horizontal, and end by turning up the other way, so as to bring in the conglomerate again (*g*), which mounts over the back of a dyke of greenstone (*x*). On the other side of this is some green grit (*h*), interrupted by another dyke followed by Purple Slates (*i*) dipping, to judge by one of the bands, at a high angle to the E.S.E. It is hereabouts that the upper part of the mass shows some curious zigzag lines, above which, apparently, are some curious green crinkly grits (*k*), with what

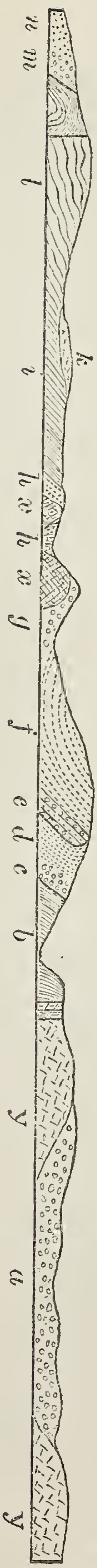
[1] Hereabouts much of the 'felsite' is really felsitic ash; but, as we are dealing now with the stratigraphy alone, all may be classed under one title.

[2] I have not, as Dr. Hicks asserted without seeing more than the specimens I exhibited, 'mistaken some crushed and cleaved pre-Cambrian felsites for Cambrian Purple Slates.' It is he who has mistaken these Purple Slates for something else.

look like empty lenticles or shrinkage-cracks, possibly dipping towards the lake. These latter may possibly be unconformable, as suggested by Mr. Maw,[1] especially as they are just about where a patch of the supposed newer rocks might come on; but the exposures are now, at least, too obscure to have much independent value. The greater part of the rest of the cutting is occupied by greenish banded grits (*l*) in broken masses, which have a *general* dip towards the E.S.E.; they seem to overlie some of the purple slates, and at the other end, after a fault, certainly underlie others in a small anticlinal. Finally we come to a slickensided junction, on the other side of which is some more coarse conglomerate (*m*) like that at the other end of the cutting, followed by a blue grit (*n*) in which the section ends.

This description will be found to correspond very closely with that of Mr. Maw, and I now proceed to discuss its teachings. The conglomerate (*a*) lies in a hollow of the felsite, hence that felsite must have been exposed when the conglomerate was formed, and its upper surface must have been that which is now nearly horizontal; but the felsite comes into vertical connexion with the Purple Slate (*b*) *with no conglomerate between*. The nature of the connexion seems at first sight to be an intrusion on the part of the felsite, for this runs into tongues in the slate. I now, however, perceive that this appearance must be deceptive, for an examination of a polished surface of the junction shows that the slate is all broken to fragments, which will account for the semblance of intrusion, the felsite also being broken. But in spite of this, it is seen that coarser bands in the slate must originally have run parallel to the junction—*i. e.* the slate must have been deposited on the felsite. At that time, therefore, the surface, which is now vertical, must have been nearly horizontal, and hence the conglomerate must have been deposited at a later date, after the felsite was turned on end, *i. e.* after the deposit of the Purple Slate. In point of fact, though not actually seen in contact with the slate between *a* and *c*, at the latter spot it has passed over to the other side of it, and is therefore unconformable both to it and to the felsite, provided, of course (of which I think there can hardly be a doubt), that the conglomerates at *a* and *c* are parts of the same mass. With this conglomerate go the grey slates and grits (*d* and *f*), in fact all the beds in the synclinal

E.S.E.

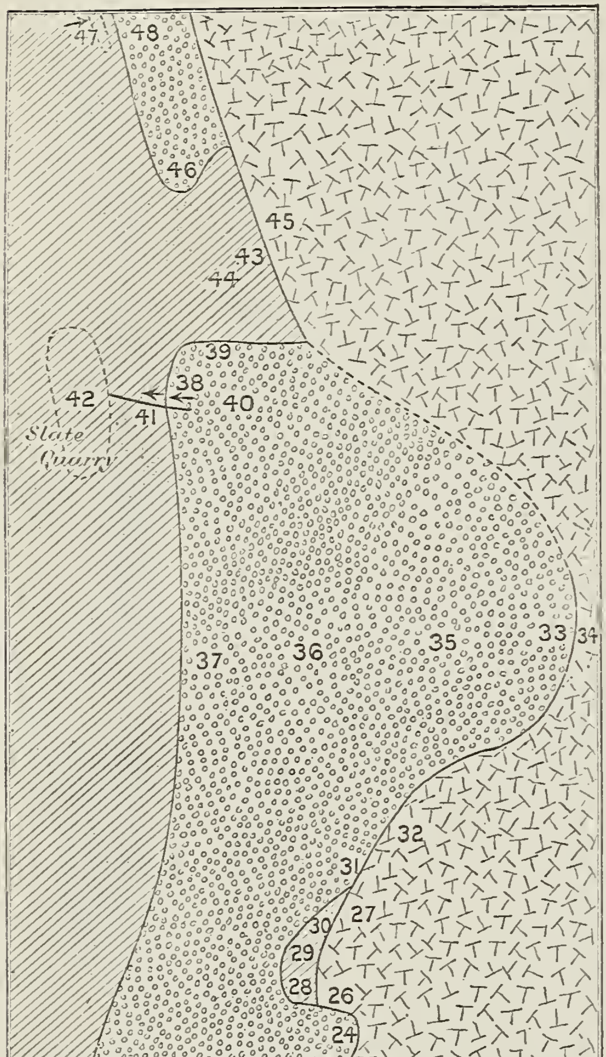


W.N.W.

Fig. 6.—*Section along the Llanberis Railway* (Scale: 1 inch = 100 yards).

[1] Geol. Mag. for 1868, p. 121.

Fig. 7.



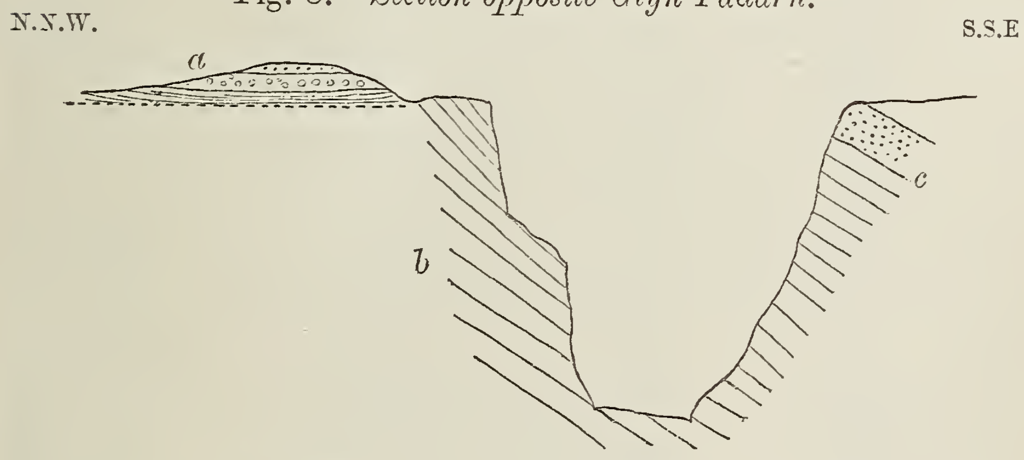
[For Index to the geological symbols, see fig. 2, p. 447; x, x at 12, 13 should read y, y.]

as far as g, and it is plain to me now that I have previously confounded some of these more slaty beds with the Pale Banded Slates of the Cambrian. From h to l, with the possible exception of k, it is plain that all the beds are well-known members of the Cambrian Series, while the conglomerate m and the grit n must in any case overlie them—*i. e.* be higher than some of the workable slates. It seems to me, therefore, that here we can find no escape from the conclusion that the conglomerates and associated beds are of 'post-Llanberis' age. The opposite conclusion can be maintained only by denying that b is Purple Slate, by missing the synclinal bringing up the conglomerate at g, and by supposing m and n to be faulted up from great depths.

For greater satisfaction, however, we must follow these beds inland, and it will be best to begin at the eastern end. In fig. 7 we have a map of the country about here which differs somewhat from my former one, on account of the discovery that some of the patches of rock interpreted as Rhiw-wen Grit and Banded Slates really belong to the upper series—a discovery which simplifies matters greatly.

Beginning with the eastern end of the section and tracing inwards the conglomerate *m*, we cannot find it in the road above owing to the presence of a mass of greenstone; but in the grounds beyond, opposite Glyn Padarn at 2, we come to the corresponding rocks again. Along the south-eastern edge of these grounds we find the Purple Slates at 3, which are worked in the adjacent quarry (4) to a depth of quite 100 feet. In this quarry they are seen to dip at angles varying from 45° to 60° to the south-east; that is to say, they are rising in the direction of 2. If then these Purple Slates were continued regularly, we ought to see them cropping out all over these grounds; instead of which we find within a few yards of the edge a number of crags of grit, grey slate, and conglomerate (see fig. 8).

Fig. 8.—*Section opposite Glyn Padarn.*



a = Conglomerates and Grits. *b* = Worked Slates. *c* = Grit-band in ditto.

In these, if we pass along an E.N.E.–W.S.W. line, that is, *parallel to the strike of the Purple Slates*, we cross a definite succession of different rocks, with a gentle dip towards the E.N.E. (see fig. 9, p. 454), so that the lowest bands, which are grey slates of the 'Silurian'[1] type, are farthest from the road; next above them come slightly-dipping bands of very coarse conglomerate with many slate-fragments, including a large mass of purple slate lying horizontally on the top of finer conglomerate; and nearer the road again are crags, which seen on their strike-face appear horizontal, composed of alternations of hard grey slate (transversely cleaved) and coarse grit. This peculiar alternation of thin beds of slate and grit is unknown to me in any part of the series below the Bronllwyd Grit, in which it has been noted twice, viz., at Bethesda and on Elidr Fach; and even at Llanberis, only half-a-mile from here, on the opposite side of the Purple Slates, something similar is seen in the overlying grits. Thus

[1] By this term I mean that they have a peculiar ashen-grey colour, and in weathering show brown manganiferous patches on them, which, so far as my experience goes, is very characteristic of all the lower beds that have *ever* been called Silurian.

then we have here a series of rocks of different character, nearly horizontal, and with a strike at right angles to the highly-dipping Purple Slates; so that they are all but actually *seen* to overlie them unconformably. Moreover, if I understand rightly the section given by Mr. Maw (*op. cit.* fig. 1) of an adit in "the neighbouring Glyn Quarries," it runs beneath these very grits and conglomerates, yet it passes through 200 feet of Purple Slate, including the dyke of greenstone, without meeting any of these rocks that are seen on the surface. I do not see, then, how the rocks here described can possibly lie naturally below the Purple Slates. Their position in the cutting at a lower level and with a different dip is easily explained by the slight fault which is there seen.

Fig. 9.—*Section across Grits, Glyn Padarn.*

a = Grey Slates. b = Conglomerate. c = Alternating Grits and Slates.

Along the road we easily trace the banded green grit *l* at 5 (which is to be correlated in all probability with the St. Ann's Grit, though each development has its own peculiarities), followed by the Purple Slate *i* at 6, and then, near the Glyn Peris Hotel, we enter on a remarkable group of rocks, which I formerly mistook in part for the representatives of the Rhiw-wen Grit and in part for those of the Banded Slates. This mistake arose from an insufficient understanding of the railway-cutting, which, with its demonstrated synclinal with conglomerate at the base, now proves the whole group to belong to the overlying series,[1] and explains the curious remark made to me by a local quarryman, that he could not understand these rocks, "they seem to lie like a nightcap on the workable slates." In the grounds between the Glyn Peris Hotel and the railway we find at 7, etc., the conglomerate and breccia well exposed; but in parts, as at 8, the crags show the grey slaty grits *f* (formerly called Pale Slates). In places the bedding is seen to be horizontal, but it gets very disturbed near 8, just as we should expect from the cutting. My former attempt to separate here the slatier parts from the conglomerates and fine grits led to a rather complicated map, which may now be simplified, by uniting them all as interchangeable portions of one post-Llanberis

[1] It follows that the words in Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 254, referring to the Rhiw-wen Grit, 'and is seen also to overlie Pale Banded Slate in the cliff at the bend of the Cwm-y-glo road;' and on p. 256, 'we find similar Pale Banded Slates beautifully exposed in the crag at the bend of the road, west of the Glyn Peris Hotel. Here they certainly come below the Rhiw-wen Grit,' must be deleted.

series. It is this series alone which occupies all the ground above the road from the Glyn Peris Hotel to the commencement of the felsite, and spreads southward in the hills and crags above. Nowhere are the felsite and Purple Slate, which are seen at the level of the railway (11, 12), to be found above; but we can trace the conglomerate step by step from 13 by 14, etc., to 19, thus showing a distinct overlap. The associated rocks show that peculiar crinkly lamination and mottled colour that have been before noted at Y Bigl, and almost wherever seen these laminæ, etc., are horizontal—as especially at 18, 16, and 10—a circumstance which first excited my suspicions that they were not what they had been taken for.

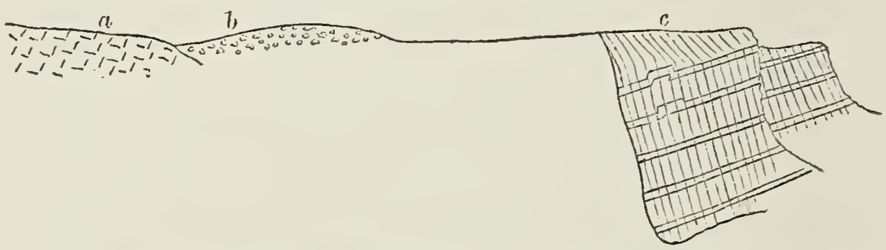
If now we trace the boundary between felsite and conglomerate, starting at 13, we find them in contact there, and all along as far as 20, and farther on we get red grit (23) and conglomerate (24) close against the felsite (25); but at 21 a knob of hard Purple Slate intervenes between the felsite at 22 and the grit at 10; and beyond 24 again the felsite at 26, 27 is followed by Purple Slate at 28, 29, 30, which is of the peculiar mixed character it often shows as it approaches the felsite, as was noted in the inlet at 11. After this we can trace the junction between conglomerate and felsite without any intervening Purple Slate from 31, 32 to 33, 34. These details are given to show how thoroughly the conglomerate behaves as an unconformable deposit in its surface-distribution. The surface-breadth of these upper rocks is here considerable; conglomerates continue as far as 35 and are then succeeded by felspathic and other grits at 36, 37.

Farther up the hill we get into some difficulty. An amphitheatre of crags of coarse grit extends from 38 to 39, and at 40, at a lower level, is a felspathic grit. The relation of these to the slates of the adjacent quarry (42), which dip S.E. at about 30°, is seen in a tunnel-section (41). Here a conglomerate certainly underlies the slate, with a junction making an angle of 60°, and beyond the conglomerate comes the coarse grit of 38. This, no doubt, is an observation opposed to the conclusions derived from others, but it seems to be easily explained, for the junction is slickensided and the order of the conglomerate and grit is reversed from what would be expected; so that probably the slate has here been slightly pushed over the grits. That some such explanation is required is seen from the fact of Purple Slate being obtained at 43, 44, and felsite at 45; so that 1000 feet away there are no grits below the slate.

Quite at the summit, however, we find another proof to counterpoise this last difficulty. Here a patch of coarse grit (46) is overlain by a green ashy grit, on three sides of which are slate-holes, and a little way farther on the conglomerate is seen lying upon the felsite. The best observation, however, is to be made at the slate quarry (47) and adjoining boss of conglomerate (48), fig. 10, p. 456. On the surface it will be seen that the order of the rocks is felsite, conglomerate, slate; but at a distance of only 60 feet from the conglomerate we find in the quarry 70 feet of the slate actually dipping, as seen by the well-marked bands, at about 30° *towards* the felsite, and therefore beneath the conglomerate.

I regard this district as affording the most satisfactory proofs of the unconformity of the conglomerate on the Purple Slate. The problem here, in fact, is reduced to its simplest elements; we have three rocks to consider: felsite, slate, conglomerate. By common consent the felsite is the oldest, and the order of succession of the other two on the surface is sometimes slate and conglomerate, sometimes conglomerate and slate; and the change from one order to the

Fig. 10.—*Slate Quarry at Cefn Du.*



a = Felsite. *b* = Conglomerate. *c* = Banded Purple Slate.

other takes place along irregular lines. This can only be accounted for in any natural way by one or other of these two being unconformable. It can scarcely be the slate which is unconformable on the conglomerate, for it is invariably found either at a lower level, or else descending to a much lower level in the immediate neighbourhood. It must therefore be the conglomerate that is unconformable on both of the others.

VI. The supposed Slates intercalated in the Felsite.

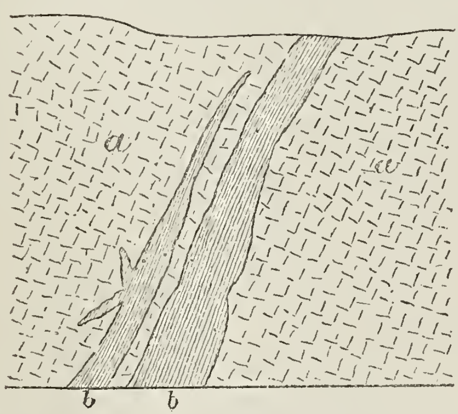
Certain very slaty-looking bands in the felsite of the above district have been referred to by Prof. Bonney[1] as contemporaneous deposits, helping to prove the non-intrusive character of the felsite, in the following words:—"On the western side of Llyn Padarn there is a band of slate intercalated in the felsite. This is a rather soft black slate, not conspicuously altered. We found exposures (probably of the same band) both by the roadside and in the railway-cutting... the material of the slate can be traced filling a crack in the felsite." As I know no such black slate as forming any part of the Cambrian succession in this district, and have been myself deceived, before I was familiar with that succession, by a similar slaty-looking band, I have carefully examined the rock thus indicated, at the eastern entrance to the tunnel and in the road above. At the latter spot its disposition is indicated in fig. 11 (p. 457).

Had the dark-coloured rock been deposited on the felsite, the

[1] Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 312.

upper band would hardly die out above in the solid rock nor be separated by so narrow a band of felsite from the lower; nor, if it filled cracks in the felsite, would these occur on the *upper* side as they are seen to do. The behaviour of the rock is rather that of an intrusive one. Of the rock itself Prof. Bonney says:—"Microscopic examination shows the structure of the slate to resemble that of the groundmass of some of the chiastolite-slates." There is certainly a superficial resemblance to that of the Skiddaw chiastolite-slates, which, by the kindness of Mr. Teall, I have been able to examine in the Jermyn Street collection, and at the time of Prof. Bonney's paper the effects of dynamo-metamorphism on igneous rocks were not so well understood as they are now; but there can be little doubt that this 'slate' is merely an unusually squeezed example of an igneous rock of fairly basic composition. The slaty structure is produced

Fig. 11.—*Intrusive bands of altered Lamprophyre (?) in the Felsite of Llyn Padarn.*



a = Felsite. *b* = Altered Lamprophyre (?).

by innumerable subparallel but interosculating lines of sericite, and gives, therefore, no indication of origin. Eliminating these, the bulk of the rock consists of much-obscured lath-shaped areas now occupied by a minute mosaic, but occasionally retaining remains of a plagioclase, with the interspaces filled with a green chloritic (?) material of secondary origin, and over all are pretty uniformly dotted black specks, which are probably magnetite. There are also occasional insets, composed of broken and separated fragments of felspar and some infilled round cavities. This is the description of a diabase, but I am not sure that the rock has not been derived from a lamprophyre.

My reason for saying so is that it appears to belong to the same family as two other rocks in the district. One of them occurs on the opposite side of Llyn Padarn, almost in a line with this; it is quite as slaty, runs in the same way into the felsite, and has the same general microscopic structure, but it shows a number of large black-looking scales, which are really plates of chlorite, and there are many smaller specks of the same. The other is a massive rock, to be presently noted as occurring in the adit of Moel Tryfaen. This is built in the same way, but its original structure is not so much obliterated, and it is uniformly speckled with small scales of chlorite lying parallel to each other, thereby producing so close a resemblance to specimens of lamprophyre in my collection that, considering the chlorite is doubtless secondary, it may well have been derived from such a rock. If the rock in bulk was a lamprophyre we ought, I should suppose, to call the tongues of it by the same name, though this particular one shows no chlorite-*scales*.

VII. Bettws Garmon Valley.

On one side of this valley we have the large and complex mass of felsite forming Moel Smythaw, and on the other the tiny boss of Gareg-fawr. I have to thank Mr. Marr for calling attention, in the discussion of my former paper, to the occurrence of conglomerate in connexion with these masses, for I had certainly missed it. There are large crags of it under Moel Smythaw, due west of Bettws Garmon; the south-eastern side of Gareg-fawr is also conglomerate, and the line joining these is parallel to the junction of the Purple Slates with the overlying 'Silurian.'

There can be no question that anyone seeing this succession alone would consider it self-evident that the felsite, conglomerate, and slate are in chronological order. It is not, indeed, impossible that they should be. The conglomerate would then correspond to that seen in the Penrhyn Quarry tunnel, and in the adit of Moel Tryfaen, only here there is no associated green grit that I could find. On the other hand, the 'Silurians' (which are only 1000 feet away) may have formerly overlapped as far as here. They would then have to be brought down by a fault, just as we find has happened farther south, along a line which is a continuation of the line of junction here. And this seems to me the most likely interpretation of what we see.

VIII. Moel Tryfaen.

It would be scarcely too much to say that the structure of Moel Tryfaen is up to the present time entirely unknown. It is worse than unknown—it is wrongly imagined. Had my own account of it been published last year it would not have been correct. The section in the adit is a very complete one, and is quite different from what had been supposed. It is curious that this adit, which was the spot where pre-Cambrian rocks were first supposed to be seen in this part of Caernarvonshire, should be also the spot that is calculated to give the *coup de grâce* to the idea of there being any pre-Cambrian rocks in the district at all.

In 1877[1] Prof. Hughes "described the beds," "and thought there was much reason for considering them pre-Cambrian, but they appeared to him to resemble more the Dimetian . . . than the Pebidiauc beds." This brought Dr. Hicks into the county, who, by the aid of "some half-dozen dip candles," discovered "at the entrance and for some distance inwards . . . a greenish, sometimes pinkish or flesh-coloured, schistose rock containing disseminated quartz-grains; farther in, a more porphyritic-looking rock, mostly dark-coloured, with spots of highly vitreous quartz in a base of felsitic matrix, undoubtedly a greatly metamorphosed rock and probably of ashy origin";[2] and this was all, before the Purple Slates were reached. Prof. Bonney restricted himself to the examination of the fragments outside. There he found four varieties of rock besides the Purple Slates: "(1) a rather gritty greenish slate, banded with rounded grains of a pinkish or purplish felsite and light-coloured felspar; (2) a rock of mottled and streaky aspect containing larger fragments of the same felsite; (3) a conglomerate of the same; (4) a number of greenish slates and grits."[3] He also states that the felsite here must be very thick.

Misled by the poverty of these results, and finding felsite at the entrance, I unfortunately did not think it necessary to explore this dirty adit before; but on taking the members of the Geologists' Association there I found that we had in it an exhibition of the ordinary Cambrian rocks of the northern part of the district, all in their proper order. This was a result so different from what I had expected that I have since made a careful examination. Accompanied by Mr. Robert Lloyd, and provided with two good paraffin lamps and a large wax-candle, I made a measured section from the purple Cambrian slates to the entrance by stretching a piece of string 450 yards in length from one end to the other, tying pieces of tape at the spots where the strata changed, and collecting samples of each, with the following result:—

[1] Quart. Journ. Geol. Soc. vol. xxxiii. p. 241.
[2] *Ibid.* vol. xxxiv. (1878) p. 147.
[3] *Ibid.* vol. xxxv. (1879) p. 310.

Section along the Moel Tryfaen adit.

Horizons.		ft.	in.	
	Massive Purple Slate	*ad lib.*		
Rhiw-wen Grit.	1. Compact green grit	6	11	
	2. Conglomerate of quartz-pebbles in a green gritty matrix; pebbles not abundant	3	6	
	3. Irregular, small-pebbled conglomerate with matrix more felsitic	8	0	
Pale Banded Slates.	4. Very fine-grained, obscurely-laminated slaty grits	32	0	
	5. Compact massive green grit, without visible grains, changing to compact green slate	151	3	
Bangor Conglomerate.	6. Pink felsite changing to felsitic grit	4	5	F
Pale Banded Slates.	7. Fine green grit to slate	124	5	
	8. Beautifully banded green slate	50	0	
	9. Very compact green slate	191	4	
	10. Small breccia of purple and green fragments	32	4	
	11. Massive *dark* purple slate	35	0	
Laminated Grits with finer Bangor Breccia.	12. Dark purple grit	42	0	
	13. Rather coarse felsitic grit; quartz-grains from insets abundant	72	0	
	14. Compact dark purple grit	47	0	
	15. Coarse grit similar to 13	54	6	
	16. Compact dark purple grit, like 14	16	7	
	17. Coarse purple grit	9	10	
	18. Compact purple grit	4	0	
	19. Earthy grit, like 10	6	5	
	Dyke [20. Black-scale rock (? altered lamprophyre)	39	4	
	Dyke [21. Fresher ditto	32	6	
	22. Purplish quartz-grit	28	9	
Tairffynnon Breccia.	23. Cleaved felsite-tuff, or felsite containing small foreign fragments	11	10	F
	24. Loose felsitic agglomerate, lapilli of decomposed felsite [1]	20	9	F
	25. Felsite-tuff, like 23	21	0	F
Lower Laminated Grits.	26. Earthy-looking felsitic grit	5	0	
	27. More compact ditto	54	3	
	28. Compact green felsite	24	0	F
	29. Light crystalline felsite	64	0	F
	Dyke [30. Dark purple basic rock	40	0	
	31. Green, very felsitic grit	56	6	
	32. Mylonized green felsite	79	0	F
		1368	5	

[1] A far more compact felsitic breccia, collected on a previous occasion, probably belongs here, but the exact type was not again met with.

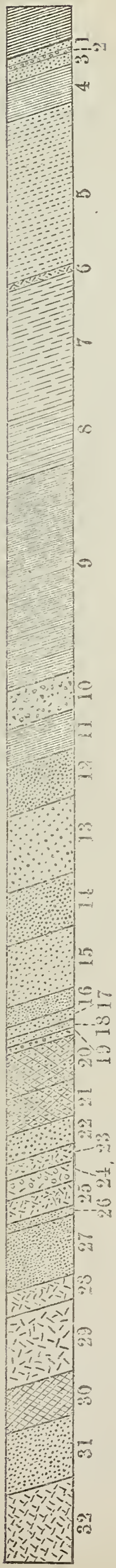


Fig. 12.—*Horizontal Section along the Moel Tryfaen adit.* (Horizontal scale: 1 inch = 200 feet.)

W. E

The measurements here given would be the thicknesses only if the beds were vertical and unfaulted. They dip, however, at various angles above 45°. If we take an average of 60°, this would give a total thickness below the Purple Slates of 1183 feet. But there are also several breaks which may possibly be faults, as marked by lines in the accompanying section.

First, with regard to the conglomerate No. 2, it is a very thin band—in fact, merely a minor feature in a thicker band of green grit. Moreover, it lies at the top of a whole series of rocks which can be perfectly correlated with well-known Cambrian strata, and which are not in the least more metamorphosed than all Cambrian rocks are. It occupies, in fact, the position of the Rhiw-wen Grit. Nor has it anything to do with any felsite; the pebbles, indeed, are of quartzite. If, therefore, the conglomerate on the summit of Moel Tryfaen were the same as this, it would prove nothing as to any pre-Cambrian beds, except their non-existence here.

Next, with regard to the felsite. There are at least four bands of this in various parts of the series. So much we have anticipated from surface-observations elsewhere, but here all the bands occur in a single section, and it is absolutely impossible to say that they are all at the bottom of the series. It is seen also that they are not intrusive, for one of them lies conformably on the surface of a grit, they are for the most part associated with tuffs, and most of the grits are obviously formed of their *débris*. They are not at all 'metamorphosed,' but only cleaved. They are here, then, absolutely demonstrated to be part and parcel of the Cambrian Series.

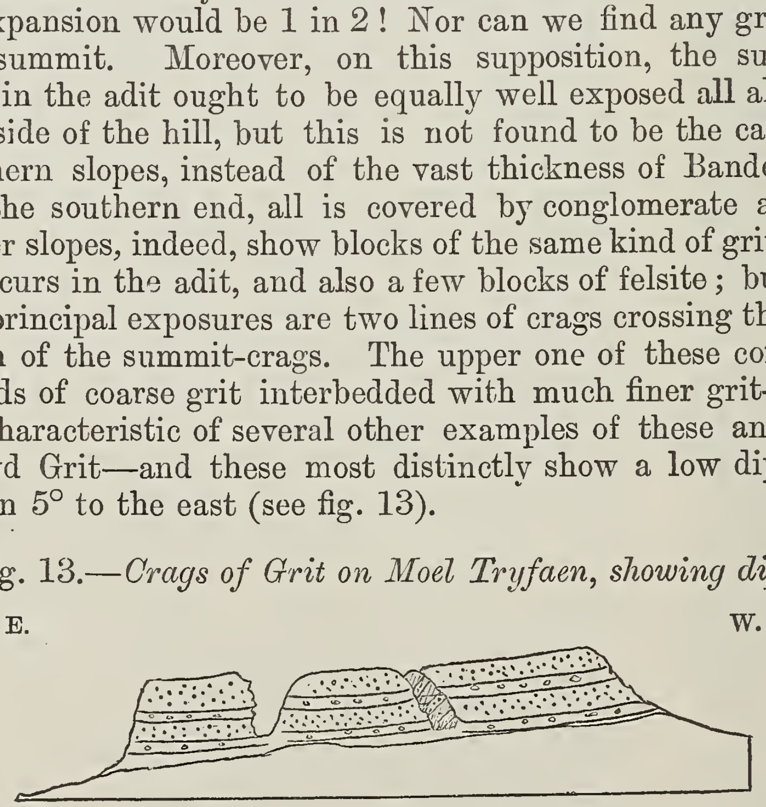
With regard to the remainder of the beds, their correlation is fairly obvious as marked in the section. Attention may be called to the dyke of altered lamprophyre, 20, 21, which has been already referred to. Seeing that we here reach nearly to the base of the Cambrian succession, as seen elsewhere, it is a matter for speculation whether the country to the east contains still lower beds, or whether part of the same succession has been left behind in the lower ground when the other part was pushed up into this hill. The thick covering of drift gives us little opportunity of determining this point, but the latter supposition is perhaps the most probable, as the rocks seen at Groeslon and Craig-y-Dinas are not very unlike some of the lower beds here, and something like Banded Slates is seen south of the latter spot.

We must now proceed to examine the surface-exposures of Moel Tryfaen in the light of what we learn in the adit. Along the southern slopes, the weathered blocks are so little moved that we can almost trace the same succession there. Most of the upper part is occupied by the Banded Slates, which are also thrown out on the *other* slope of the hill between the summit and the Moel Tryfaen quarry—though whether they are *in situ* here cannot be determined. Farther down are many blocks of the coarse grit, and towards the base some blocks of felsite; one of these shows the curious phenomenon of enclosing a circular mass of coarse purple grit, which passes gradually into it by an indefinite aureole, the colour also changing from purple to light green—a state of things which seems to indicate that this felsite is later than one of the grits.

In the tramway-cutting at the bottom we find the junction of the felsite with a conglomerate. It is now evident that this cannot be the same as that observed at the summit or in the adit, but must be another one not seen elsewhere; it is really of a different character, being more compact, with a more gritty matrix and with pebbles more commonly of quartzite.

And now, as to the conglomerate of the summit. If this were an expansion of the thin bed No. 2, the expansion would have to be abnormally rapid, for the breadth of outcrop at the top is 55 yards, and this is only about 350 feet above the adit, so that the rate of expansion would be 1 in 2! Nor can we find any green grit on the summit. Moreover, on this supposition, the succession observed in the adit ought to be equally well exposed all along the western side of the hill, but this is not found to be the case. On the northern slopes, instead of the vast thickness of Banded Slate seen at the southern end, all is covered by conglomerate and grit. The lower slopes, indeed, show blocks of the same kind of grit as that which occurs in the adit, and also a few blocks of felsite; but above this the principal exposures are two lines of crags crossing the hill to the north of the summit-crags. The upper one of these consists of thin bands of coarse grit interbedded with much finer grit—in the way so characteristic of several other examples of these and of the Bronllwyd Grit—and these most distinctly show a low dip of not more than 5° to the east (see fig. 13).

Fig. 13.—*Crags of Grit on Moel Tryfaen, showing dip.*



The lower crags are of conglomerate like that of the summit, and they show a lenticle of fine grit running almost horizontally.

From these observations—the great mass of the conglomerate as compared with anything in the adit, its peculiar character in being full of large slate-pebbles, the nearly horizontal bedding of the associated grits, and the concealment of the great thickness of the Banded Slate—I do not see how we can avoid the conclusion that the conglomerate lies unconformably on, and is independent of, the underlying members of the Cambrian Series.

IX. Mynydd-y-Cilgwyn and Llanllyfni.

After a certain interval from the southernmost exposure of conglomerate on Moel Tryfaen (about half-a-mile) new deposits, obviously continuing the same line, come on at Bwlch-y-llyn. The northernmost seen are some curious brown-weathering greenish-grey grits not to be matched by any known rock in the Cambrian Series, but more like those found at the 'Silurian' base in the Bettws Garmon Valley. On reaching the tram-line cutting we find that these are underlain on the west, though the line of junction has a high dip, by conglomerate identical with that of Moel Tryfaen, in which fragments of purple slate are conspicuous. East of these, though the contact is not seen, comes Purple Slate. At first sight this section might be taken to indicate a chronological succession, but it is fairly (I might almost say quite) certain that the latter line of junction is a fault; for to the north there is much more grit, a little way to the south there is none, and at $\frac{2}{3}$ mile to the south along the same line the slate and felsite are seen within a yard, the former dipping *towards* the latter; and half-a-mile farther south again the fault is actually seen in the quarry.

Now, if this conglomerate has to be *faulted* to make it appear to underlie the slate, its natural place is somewhere else; and, as the dip of the slates indicates a downthrow of the felsite, we may conclude that that natural place is *above* the slates. This is all we can learn with reference to the slates; but by tracing the boundaries of the conglomerate we find that it spreads over a wide and irregular area, mostly on the northern and western slopes of Mynydd-y-Cilgwyn, that it is followed by banded grits on the west and north-west, as it was also on the north-east at Bwlch-y-llyn, and that it rests everywhere on a large continuous mass of felsite. In all these points it contrasts absolutely with the conglomerate in the Moel Tryfaen adit, while it agrees in character, succession, and expansion with that at the summit, and is distinguished from it only by lying upon an altogether different rock. What can such a rock be but an unconformable deposit?

The rock at Tal-y-sarn, brought forward as pre-Cambrian by Dr. Hicks, and described by the late Mr. Thos. Davies as a quartz-felsite breccia,[1] is of course nothing more than part of the felsite-mass of this area, which is in places, as noted by Sir Archibald Geikie, intensely cleaved. Beyond the main mass, at a spot half-a-mile due east of Llanllyfni, there is a long, isolated boss of very much cleaved quartz-felsite with workings of Purple Slate on either

[1] Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 152.

side of its longer axis; its relations to the slate are not further indicated; but, seeing that it lies in the continuation of the line already shown to be a fault, its appearance may be very well accounted for by some complication and breaking up of this, without assuming that the felsite is intrusive.

X. Distribution of the Felsites in the Cambrian Series.

It may be useful to summarize our present knowledge on this subject, so as to be able to appreciate how abundant were acid volcanic eruptions in the Cambrian period. Probably the oldest known acid eruption is that in Baron Hill Park, near Beaumaris, which underlies everything Cambrian and is in contact with the Monian rocks. Next in order comes the mass between Bangor and Caernarvon, which lies below every rock known on the mainland. Then there is a small mass on the eastern slopes of Dinas Dinorwig which cannot be far from the base; it has its own appropriate conglomerate, but may correspond to the Tairffynnon Breccia. To about this period may belong the igneous rocks of Craig-y-Dinas and of Gwyrfai River, and the two isolated bosses lying near Rhos Tryfaen: certainly this is the age of some of the felsite on the west of Moel Tryfaen; and, owing to faulted conditions, this or any later age may be assigned to the large masses of Mynydd-y-Cilgwyn and Moel Smythaw. It seems difficult to believe that the two masses on either side of Llyn Padarn, *i. e.* Clegyr and Careg Lefain, are of different ages; but the former is followed by some of the Banded Slates, and the latter has Purple Slates on both sides; it may be noted also that on Clegyr dykes of a newer felsite are seen traversing the more decayed mass. It is to the Clegyr mass that we must assign the formation of the Bangor Conglomerates, and that some part of Moel Smythaw must also belong here is suggested by the felsite No. 6, which occurs in the Moel Tryfaen adit in the midst of the Banded Slates. Of the same age as Careg Lefain is the mass of Moel Goronwy, and either to this or a later eruption must be assigned the felsite in the Penrhyn Tunnel.

This is a tolerably persistent group of eruptions, if we are justified, as I think we are, in assigning them to the periods which their stratigraphical position indicates. More than this, the coarse Bangor Breccias and the brilliant grains of quartz in many of the Laminated Grits indicate their derivation either from the felsites or from rocks broken up by them; and even the Banded Slates are just such rocks as might be derived from the finer dust, while the Purple Slates themselves are peculiar rocks which may well be obtained from volcanic material. Of course all slates are originally derived from either plutonic or volcanic masses, but those of the Cambrian period seem to be more directly so derived.

XI. Age of the overlying Conglomerates and Grits.

Assuming that these have now been proved to be later than the Purple Slates, the question remains, how much later? At one time I thought they might be Arenig, partly because of the known overlap of Arenig rocks at Caernarvon, and partly because they contain masses of grey and greenish slates which I can nowhere find in the Cambrian succession. But, if this were their age, we ought certainly to find the broken-off ends of similar rocks cropping out somewhere on the flanks of Snowdon between the summit and Llanberis. Last year, however, when I sought such rocks there, they were nowhere to be found, so this idea must be given up. The difficulty about the slate-fragments may be got over if the conglomerates are unconformable, since there may be covered beds above the Purple Slates from which these may be derived, and it will be remembered how many resemblances there are between the associated grits, etc., and the Bronllwyd Grit and overlying beds; indeed, till I found the former *in situ*, I took their loose blocks for erratics from the latter. It seems to me, therefore, most probable that they are extensions of the immediately overlying rocks.

XII. Concluding Speculations.

If this conclusion be accepted, it follows that the Bronllwyd Grits and associated rocks are unconformable to the Purple Slates, etc., of the Cambrian Series, so that it is scarcely desirable to class them under the same title. Before, however, such a matter is settled it is desirable to know whether this unconformity is any more than a local one. This is a question which I cannot at present answer; for, though I have spent about a week examining the Merionethshire anticlinal, I have not as yet succeeded in finding any unconformity there. On the other hand, there is plenty of room, below the beds containing *Paradoxides* in North Wales, for *Olenellus* to occur *above* the Bronllwyd Grit and its equivalents. Should it be ever found there, which seems to me far more likely than its occurrence below the Pale Slates with *Conocoryphe*, this—the unconformity which I have here attempted to prove—would force on us the question, for *which* of the groups of rocks thus separated is the name 'Cambrian' to be retained?

Discussion.

The President said he had no doubt that the paper contained several interesting and important points, but only those who were intimately acquainted with the district could follow the Author. The sections referred to by the Author had been examined by many distinguished geologists, and it was remarkable that in spite of this there was still great difference of opinion. The Moel Tryfaen adit had been frequently referred to, but no previous observer had given a detailed description of it.

Prof. Hughes thought that the difficulty of following a controversial paper like that before them was unnecessarily increased by the manner in which it had been presented, with maps on which no dips were shown, and sections to which no reference-index was given. He protested also against the use of old familiar names in new senses. So far as, from his own knowledge of the ground, he was able to follow the Author's remarks, he could not agree with his conclusions, and was unable to endorse the accuracy of the observations on those parts of the area on which the Author said he chiefly relied for establishing them.

Mr. Rutley said that those points in the paper which appeared to him to be open to doubt were the determination of some of the felsites and the order of succession of certain beds. Such doubt probably resulted from the Author's treatment of his subject. The frequent association of grit-bands with slates rendered it possible that some of the so-called felsites might be felspathic grits, which often resembled felsites. It was to be hoped that Prof. Blake would examine the doubtful rocks microscopically, and embody his results in another paper. The high angles at which some of the beds dipped indicated that, in certain cases, a slight inclination on one or other side of the vertical would materially affect conclusions as to stratigraphical sequence.

Mr. Marr also spoke.

The Author, in reply, said he hoped he understood the President aright to say that he did not believe in any pre-Cambrian rock in the district discussed. He admitted that under the general term 'felsite' he included any of its clastic accompaniments, and the term 'post-Cambrian' was used in a special sense, meaning only later than the Purple Slates.

36. *On* SOME RECENT BORINGS *through the* LOWER CRETACEOUS STRATA *in* EAST LINCOLNSHIRE. By A. J. JUKES-BROWNE, Esq., B.A., F.G.S. (Read May 24th, 1893.)

CONTENTS.

[Map and Section on pp. 474, 475.]

THE information on which this communication is based has been in my possession since 1889, but pressure of other work had prevented me from preparing it for publication until the present time.

The results of the borings which are here described are important, because they give information concerning the geological structure of the platform which underlies the Glacial Drift on the eastern side of the southern part of the Lincolnshire Wolds. We learn from them that the outcrop of the Lower Cretaceous sands and clays extends much farther northward beneath the Drift on this side of the Wolds than there was any reason to suspect at the time when I mapped the area for the Geological Survey.

§ 1. THE BORING AT WILLOUGHBY (1887).

Willoughby is a village between the towns of Burgh and Alford, and the site of the boring is at the station on the East Lincolnshire Railway, which is the junction for the new branch-line to Sutton. The boring was made for the Railway Company in 1887, and a good supply of water was procured at a depth of 245 feet.

For information regarding the beds passed through I am indebted, in the first place, to Mr. H. Cheetham, the engineer of the railway; but the description of the strata furnished by him being only a well-sinker's account, and not sufficiently accurate to enable me to identify the strata, I wrote to my friend, Mr. Meaburn Staniland, F.G.S., asking if he could take an opportunity of looking over the samples of the cores which were preserved in the Engineer's office at Louth, and access to which was most kindly promised by Mr. Cheetham. This Mr. Staniland was good enough to do, and it is mainly from his description of the samples and from the sight of very small pieces of one or two of them that the following account has been drawn up; but the thicknesses of the several beds are, of course, taken from the particulars supplied by Mr. Cheetham.

The boring commenced in the Boulder Clay shown on the Geological Survey Map (Sheet 84) as occurring at that spot, and this clay proved to be 28 feet thick; below it were sands with small pebbles of chalk and flint (29 feet thick), and then coarse reddish sand with grains of oolitic iron down to 63 feet. There can be no doubt that down to this depth the materials belong to the Glacial series; but the underlying silty clays are of a more doubtful nature; these are 33 feet thick, and are described as firm, silty clays varying in colour from light to dark brown. A specimen sent me from between the depths of 86 and 96 feet is a brown sandy clay with oolitic grains of iron, closely resembling some of the ferruginous marl or 'Roach' which underlies the Carstone at the southern end of the Wolds. As all this mass of clay seems to have been perfectly clean and free from stones, I regard it as of Lower Cretaceous age, and would place the base of the Glacial deposits at 63 feet. The materials of the red sand found between 57 and 63 feet appear to have been derived from the destruction of Carstone and 'Roach.'

At 96 feet, red sandstone with oolitic grains of iron was found, and continued to 106 feet. This is doubtless the equivalent of the ironstone-beds seen at Skendleby Lodge, a place only 2 miles west of the site of the boring; they are described in the 'Geology of East Lincolnshire'[1] as "brown shaly sandstone, with bands of harder dark-brown oolitic ironstone," 5 or 6 feet being there exposed.

At 106 feet, the bore entered a stiff, dark-grey clay, exactly like the Tealby and Donnington clay which crops out below the 'Roach' on the western side of the Wolds near Skendleby, Dalby, Langton, etc. Clays of the same kind, but varying in colour, and some containing selenite, extended down to 214 feet. Their thickness (108 feet) is in accordance with the facts published in the Survey Memoir; for it is there stated that though apparently only 70 or 80 feet thick near Dalby, borings at Skendleby Salter show a greater thickness of clay; and in the Skegness boring on the coast a much greater thickness was found.

At 214 feet red (brown) ferruginous stone occurred, followed by ferruginous sandy loams with oolitic iron grains down to 232 feet. These beds are evidently like those which underlie the clay west of Spilsby, and are described in the Survey Memoir (p. 19) as "yellow loams, with occasional beds of oolitic ironstone."

At 232 feet the bore seems to have entered the Spilsby Sandstone. The first bed (1 foot thick) is described by Mr. Staniland as a semi-compact sand with pieces of shell and Belemnite, and a piece of chalk; the last must have fallen down the borehole, but the shell and Belemnite may belong to the sand. Below came 6 inches of compact coarse-grained sandstone, and then light-coloured earthy sandstone $10\frac{1}{2}$ feet thick, taking the bore to 244 feet; a sample of this sent to me was a firm, light-grey, calcareous sandstone. A harder rock was found below, and if the sample preserved is to be

[1] Mem. Geol. Surv. sh. 84 (1887), p. 20.

trusted, it was a tough red-brown marlstone crowded with oolitic grains of iron. I suspect, however, that this sample has been misplaced, and that the hard rock was really a calcareous sandstone. As soon as this was pierced, water came up with a rush, bringing up at first large quantities of sand, but gradually clearing to a strong, steady flow of 4619 gallons per hour, the water rising to more than 30 feet above the surface of the ground.

The following are the particulars of the boring, the strata being classified in accordance with the preceding observations:—

		Thickness.	Depth from surface.
		feet.	feet.
Glacial Deposits 63 feet.	Red Boulder Clay, with pebbles of chalk	28	28
	Coarse red sand, with lydianite and quartz-grains	22	50
	Compact sand, with chalk-pebbles	1	51
	Running sand, with chalk and flint-pebbles	2	53
	Angular grey sand	4	57
	Coarse red sand, with oolitic grains of iron	6	63
'Roach' Beds 43 feet.	Light brown silty clay	4	67
	Dark " " "	1	68
	Light " " "	9	77
	Dark " " "	6	83
	Darker " " "	13	96
	Red (brown) sandstone, with oolitic iron-grains	10	106
Tealby Clay 108 feet.	Dark clay	29	135
	Lighter-coloured clay	6	141
	Blue clay, with selenite	19	160
	Sandy clay	5	165
	Brown clay	10	175
	Blue clay, darker below	11	186
	Brown clay, darker below	22	208
	Sandy clay	6	214
Ironstone Beds 18 feet.	Red sandstone, with oolitic grains of iron	4	218
	Red sand and clay, with oolitic grains	2	220
	Dark brown clay, containing sand coated with oxide of iron	12	232
Spilsby Sandstone.	Semi-compact sand with a piece of chalk, a broken Belemnite, and shell-fragments	1	233
	Compact coarse-grained sandstone	$0\frac{1}{2}$	$233\frac{1}{2}$
	Light-grey sandstone	$10\frac{1}{2}$	244
	Dark-brown, oolitic, ferruginous marlstone	1	245

§ 2. The Boring at Alford (1889).

Alford lies $2\frac{1}{2}$ miles north of Willoughby, and it is consequently very interesting to have proof of the existence of Lower Cretaceous strata at no great depth beneath this place. The boring was made in 1889 at the Alford Grammar School, and the results were communicated to me by Mr. Eardley Mason, one of the Governors of the School. I have also to thank him for sending me samples of the different beds, the details which follow being largely obtained by examination of these samples.

After passing through alternating beds of Boulder Clay and gravel to a depth of 34 feet, the boring entered Chalk, which is described as white in the upper part and reddish below; 10 feet lower down, however, they passed out of this chalk into coarse gravel, so that the chalk must be a large boulder or transported mass like those in the Cromer cliffs. In a sample of the gravel (from 68 feet) I found pebbles of grey and white chalk, red and pink chalk, angular bits of grey flint, bits of a dark-grey limestone, light-grey limestone, oolitic ironstone, quartz-grit, porphyritic felstone, and a small fragment of granite or syenite.

At 69 feet red clay was found, and continued for 11 feet. Two samples of this were sent me: one was a light-red Boulder Clay full of small chalk-stones, the other is a small piece of red-and-pink marl, with quartz-grains and small bits of lydianite, having the characters of the mottled sandy marl which forms the passage-bed from the Red Chalk to the Carstone. It would seem, therefore, that part of this red clay is Boulder Clay, while part may be red marl *in situ*. Probably the Boulder Clay sticks to and rests on the marl, and though the exact thickness of the Glacial clay is not ascertainable, it probably extends to between 75 and 78 feet. This accords with the depth proved by wells at Bilsby, one mile N.E. of Alford.

Below the 'red clay' coarse greenish-brown sand was encountered; this is unquestionably Carstone of the ordinary Lincolnshire facies, a coarse quartz-sand in angular and subangular grains, embedded in dull, greenish-grey, silty material. This sand was only 12 feet thick, much less than its normal thickness along the main outcrop; but (as stated in the Survey Memoir) there does not seem to be more than 12 or 15 feet of Carstone in the inlier of Skendleby Salter, which is less than 3 miles S.W. of Alford, so that the sand appears to thin towards the north-east while the underlying clays thicken in that direction.

At a depth of 92 feet the boring entered 'blue clay,' the samples sent showing that the upper 2 feet consisted of dark bluish-grey clay, and the lower 6 feet of light-grey marly clay which effervesced with acid. In one sample there were two small fragments of chalk, but these must have fallen down the borehole, for the mass of the clay was quite clean, compact, and homogeneous. A sample from 100 feet was a very dark, almost black clay, containing scattered oolitic grains of iron; and one from 105 feet was a fine greenish material, almost entirely composed of small, round, oolitic iron-grains.

It is unusual for the Carstone to be immediately underlain by grey clay; but the Roach subdivision is very variable, and the lower beds are similar to those found at Skendleby and in the Willoughby boring. The boring was carried to a depth of 7 feet 2 inches in the greenish clay, and then abandoned at a depth of 112½ feet from the surface.

Water was found at three horizons, (1) in the chalk, (2) in the gravel beneath, (3) in the greenish clay. The last proved quite unfit for use, while that in the gravel was a weak spring; so the bore was plugged with clay up to the base of the mass of chalk, and the supply from that was found to be satisfactory and sufficient, though not abundant. Mr. Eardley Mason informs me that the results of analysis were as follows:—

Total solid residue	33·04	grs. per gallon.
Lime	12·07	„ „
Magnesia	3·13	„ „
Oxidizable organic matter only ..	0·11	„ „

The following is an abstract of the results obtained by this boring:—

		Thickness.	Depth from surface.
		feet.	feet.
Glacial Deposits.	Brown Boulder Clay	30	30
	Gravel	10	40
	Brown Boulder Clay	2	42
	Gravel	6	48
	Boulder Clay	6	54
	Chalk, part white, part reddish	10	64
	Gravel	5	69
Lower Cretaceous Beds.	Red clay, partly Boulder Clay, partly reddish marl with quartz-grains	11	80
	Coarse greenish-brown sand	12	92
	Blue clay	2	94
	Light-grey clay	6	100
	Blackish clay, with oolitic grains	5·4	105·4
	Dark, greenish, silty clay, with oolitic grains ...	7·2	112·6

In the 'Geology of East Lincolnshire' (p. 148) some details are given of a boring made at Mr. Soulby's Brewery in Alford. At this spot chalk was met with at a depth of 38½ feet, and continued to 65 feet. This is evidently part of the same boulder-mass as that pierced in the Grammar School well; and though its thickness is greater, its base is within a foot of the same level. Chalk was also met with at only 41 feet from the surface in another well in the southern part of the town; so that a large transported mass or several such masses appear to lie in the Drift under the town.

This explanation of the occurrence of Chalk will be the more readily accepted, when it is remembered that the Drift is believed to be banked against a buried range of Chalk-cliffs within a mile of Alford, and consequently that the conditions are such as to make the existence of large transported masses a very probable matter. None have yet been proved to exist in East Lincolnshire; but very large boulders of Chalk have been seen west of the Wolds, and a large transported mass of Chalk in which a quarry has been opened occurs at Martin, about 10 miles south-east of Lincoln. See 'Geology of the Country around Lincoln,' Geol. Survey Mem. sh. 83 (1888), p. 137.

Recurring to the well at Mr. Soulby's, no record of thickness was kept by the well-sinkers below the base of the chalk-mass; but Mr. Eardley Mason informs me that he watched the boring while it was being made, and he believes it was carried to a depth of about 200 feet, chiefly through blue and grey clays. Some of these clays were, he says, like those of the Grammar School boring, but the lowest he saw was dark and shaly like Kimeridge Clay. He believes the chalk was underlain by gravel and sand, and that the rest of the depth was clay. No water having been found, the boring was abandoned and the hole plugged up to the base of the chalk, as in the case of the more recent boring. If the Brewery boring was carried to 200 feet, it must have been abandoned when another 35 or 40 feet would have taken them into the Spilsby Sandstone, and doubtless have secured as good a supply of water as at Willoughby.

§ 3. The Boring at Skegness (1886).

In the 'Geology of East Lincolnshire' (Appendix B, p. 168) particulars were given of a deep boring at the Skegness Waterworks; but it seems that two borings were made at these works, one of them not being carried beyond 130½ feet, while the second was carried to over 400 feet.

The details which follow have been obtained from Mr. Crauford, the foreman in charge of the boring; and they were communicated to me by my colleague Mr. W. Whitaker, F.R.S. They differ in some important particulars from the account given in the Survey Memoir, and consequently it seems desirable to publish them for comparison with that account and with the Willoughby boring, Skegness being only 7½ miles south-east of Willoughby.

		Thickness.	Depth from surface.
		ft. in.	ft. in.
Marsh Beds 34 feet.	Made ground	1 6	1 6
	Loamy clay	7 6	9
	Black and brown mud	25	34
Glacial Deposits 26½ feet.	Brown clay, with stones	4	38
	Dry gravel	1	39
	Brown clay, with stones	5 6	44 6
	Dry dead sand and rock	6	50 6
	Rock-chalk	21	71 6
	Red marl	20	91 6
Carstone ...	Green sand	10	101 6
Roach 28½ feet.	Light-coloured clay	8	109 6
	Blue clay	7	116 6
	Ironstone-shale	13 7	130 1

		Thickness. ft.	in.	Depth from surface. ft.	in.
Clays 159 feet.	Pale blue and grey clays	69	11	200	
	Hard dark-blue clay	1		201	
	Brown and blue clay	10		211	
	Hard clay	9		220	
	Clay and sand	6		226	
	Blue clay, sand, and shells	18		244	
	Clay and sand, fossils	1		245	
	Sand	2		247	
	Clay and sand	14		261	
	Hard brown clay and stones [? Septaria]	3		264	
	Blue clay, sand, and fossils	9		273	
	Clay and fossils	7		280	
	Blue clay	8	6	288	6
	Brown clay	—	6	289	
Oolitic Ironstone Beds 13½ feet.	Brown clay and stone	1		290	
	Brown clay and soft sandstone	6		296	
	Blue clay and fine white sand	6		302	
	Hard stone	—	6	302	6
? Clays 18½ feet.	Hard dark-blue clay	10	6	313	
	Light-blue clay and silt	6		319	
	Stone band	—	6	319	6
	Hard light-coloured clay	1	6	321	
Spilsby Sandstone 26 feet.	Grey sand, with water	2		323	
	Brown sand and sandstone	10		333	
	Sandstone	4		337	
	Grey sandstone	8		345	
	Hard stone	2		347	
Kimeridge Clay 78 feet.	Clay-stone	1		348	
	Hard blue clay	15		363	
	Light-blue clay, with flints [? Septaria]	1		364	
	Blue clay and fossils	40		404	
	[Not described]	9		413	
	Blue clay and fossils	2		415	
	Blue clay, fossils, and black-brown dirt	10		425	

Very few remarks on the above section will suffice. The 'red marl' probably includes pink and red chalk, and possibly some Carstone mixed with red marl carried down by the boring-tools.

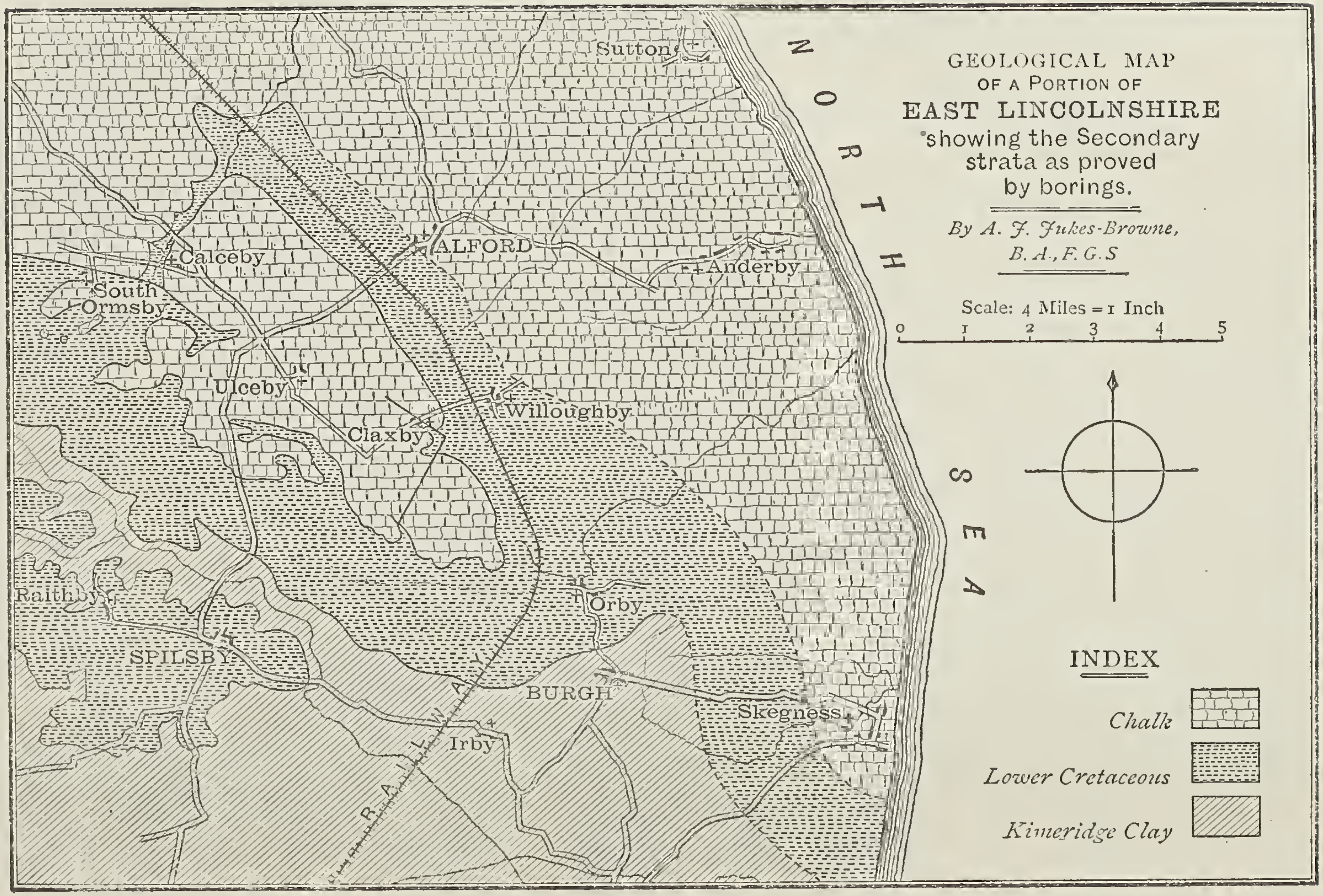
A sample from 297 feet was a hard oolitic marlstone with grains of iron peroxide.

This account gives a greater thickness to the Spilsby Sandstone: 26 instead of 19 feet, which is more in accordance with probability.

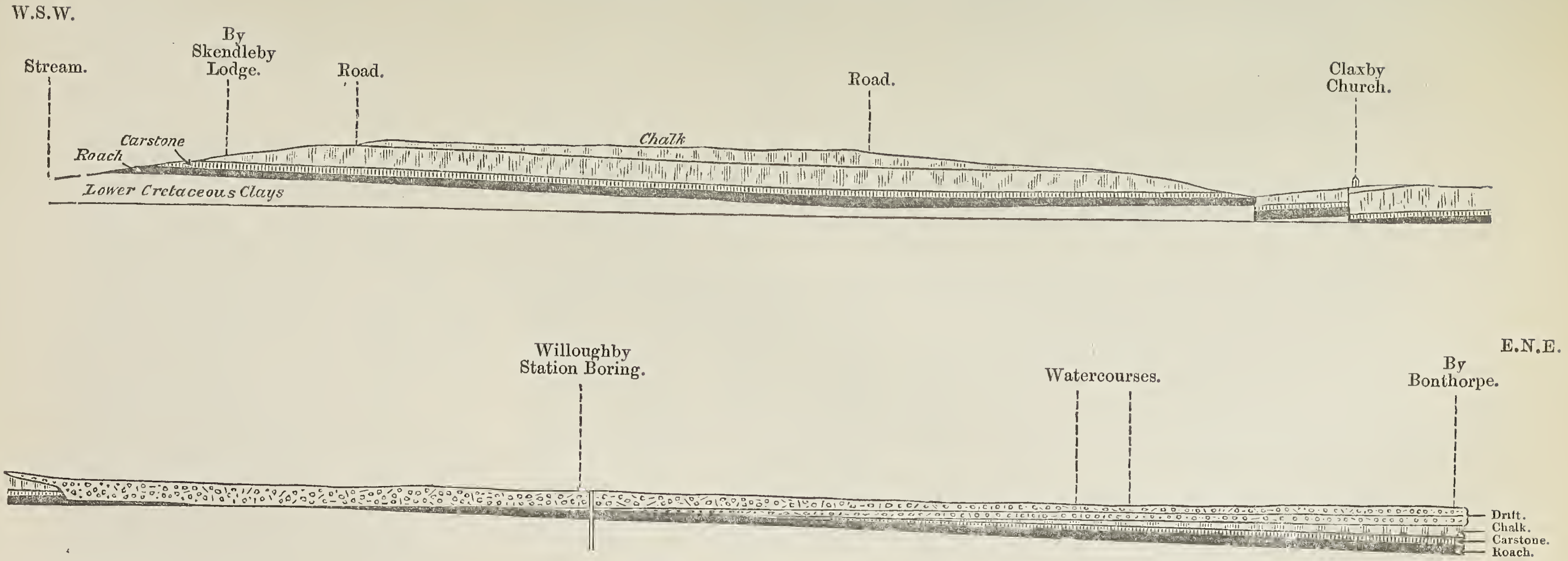
Comparing it with the Willoughby boring, the greatly increased thickness of the clays and ironstones is here the principal feature, the total thickness between the base of the Carstone and the top of the Spilsby Sandstone at Skegness being nearly 220 feet, while at Willoughby it is only 169 feet.

§ 4. General Conclusions.

The most important conclusion to be derived from the results of the borings above described is that the subterranean outcrop of the


GEOLOGICAL MAP
OF A PORTION OF
EAST LINCOLNSHIRE
showing the Secondary
strata as proved
by borings.
By A. J. Jukes-Browne,
B.A., F.G.S
Scale: 4 Miles = 1 Inch
0 1 2 3 4 5
NORTH SEA
INDEX
Chalk
Lower Cretaceous
Kimeridge Clay
Sutton
Anderby
ALFORD
Calceby
South Ormsby
Ulceby
Willoughby
Claxby
Raithby
Orby
SPILSBY
BURGH
Skegness
Irby
RAILWAY

Section from Skendleby Lodge through Claxby and Willoughby.



Section { Horizontal scale: 4 inches = 1 mile.
Vertical scale: 1 inch = 800 feet.

Lower Cretaceous strata extends northward for a much greater distance on the eastern side of the Wolds than was previously supposed. When the country was mapped by me for the Geological Survey, no information could be obtained respecting the nature of the platform on which the Drift rested between Alford and Willoughby; but it being uniformly reported by well-sinkers that Chalk underlay the Drift at all the villages between these places and the coast, it was naturally inferred that a platform of Chalk extended westward from beneath the coast-line up to the base of the range of buried cliffs where the Chalk rises into the Wolds.

It was, of course, seen that the outcrops of the Lower Cretaceous sands and clays curved round the southern end of the Wolds, and must run northward for a certain distance; but a fault being found at Claxby which had a considerable downthrow to the north-east, and cut off the surface-outcrops of the Carstone, it was supposed that this fault was prolonged south-eastward beneath the Drift, and that a Chalk-platform extended north-eastward below Willoughby and Earlsthorpe. The recent borings at Alford and Willoughby have, however, shown this to be a mistake, and prove that, in spite of the Claxby fault, the outcrops of the Lower Cretaceous strata extend northward at least as far as Alford, and in all probability for some distance still farther to the N.W. (See Map, p. 474.)

It is, however, certain that the Chalk does eventually come in again to the eastward; this is proved by the boring at Skegness and by the unanimous testimony of borings at Ingoldmells, Addlethorpe, Chapel, Hogsthorpe, Cumberworth, Anderby, and Huttoft. Moreover, two different well-sinkers report chalk at the bottom of borings at Bilsby, only 1 mile east of Alford, at depths of 74 and 76 feet respectively, and strong springs are found in chalk below the Drift under the town of Alford, east of the Grammar School, a fact which suggests that the Chalk comes on in mass below Alford. We may therefore conclude that the area which is underlain by the Lower Cretaceous strata forms a long tract, the direction of which is roughly parallel to that of the Wolds, as indicated in the Map on p. 474.

Such an arrangement suggests the existence of an anticlinal flexure bringing up the lower beds between two flanking synclines, and the dips observable in the chalk-pits along the eastern border of the Wolds are in accordance with this supposition. Thus between Welton and Claxby there are dips of from 5° to 15° S.W. Near Claxby the strata are much broken by faults, but the most frequent dips are westerly and south-westerly. In a quarry 1½ mile S.W. of Alford, there is a dip of 5° to W.S.W., at Rigsby one of 8° to S.W., and at Haugh one of 4° to S.W. Along the main outcrop on the western side of the Wolds the dip is, as a rule, north-easterly, consequently the structure of this southern end of the Wolds seems to be that of a broken syncline (see Section, p: 475), with steeper inward dips on the eastern than on the western side. Such a structure ought perhaps to have suggested to me the possibility of a parallel anticlinal beneath the Drift to the eastward; it furnishes, at any rate, strong confirmatory evidence of the existence of this anticlinal.

It is indeed very probable that the outcrops of the strata below the Chalk are prolonged north-westward beneath the Drift as far as Claythorpe and Belleau, and into the transverse valley which traverses the Wolds by Calceby and South Thoresby. This valley is filled with Glacial clays and gravels to a depth of at least 30 or 40 feet. On the northern side the basal Red Chalk is exposed at a level of about 80 feet,[1] while that of the stream in the valley is only 50 feet. On the southern side, at South Thoresby, there is a quarry with Lower Chalk dipping south-west, and bringing in the base of the Middle Chalk at a level of about 100 feet. Assuming the Lower Chalk to be 75 feet thick, the base would be reached at a level of 25 feet above O.D. under the Drift to the north-east, even if there were no dip to the south-west. Now, the surface of the ground falls in that direction to less than 50 feet, while at Claythorpe Station, where the surface is 54 feet, a boring is said to be 66 feet deep, finding water in gravel at that depth. There must therefore be a large area near Claythorpe where the Drift rests on beds older than the Chalk, and there is nothing to prevent this area from being united to that near Alford.

The result of the information thus obtained makes it probable that the Chalk tract which lies to the S.E. of the Calceby valley is completely isolated from the rest of the Chalk area, being separated from the Chalk under the marshland by the anticlinal above mentioned, and cut off from the more northern Wolds by the Lower Cretaceous outcrops along the Calceby valley.

Postscript.—Since the above was written, my colleague, Mr. A. Strahan, was instructed to visit some of the localities in this district. He confirms Mr. Hill's identification of the basement Red Chalk in the small pit east of Swaby, and has drawn its outcrop on the 6-inch map for the short distance along which it is visible, as well as its probable continuation beneath the Drift along the north-eastern side of the Calceby valley.

Discussion.

The President said that the lesson of the paper was that it was never safe to take anything for granted when one had to deal with Boulder Clay.

Mr. Strahan remarked that the tract referred to in this paper was one that could be mapped only by the aid of wells and bore-holes. The records of a great number of these had been collected by Mr. Jukes-Browne and tabulated in the Memoir, their positions being noted on a copy of the Map kept in the Geological Survey

[1] In a quarry near Swaby. In the Survey Memoir, 'Geol. of E. Lincolnsh.' p. 53, the Red Chalk seen here was referred by me to the higher beds, but information supplied by Mr. William Hill, F.G.S., who visited the place in 1887, has convinced me that the section is really in the basement-beds.

Office for reference. When the ground was surveyed, the existence of an anticlinal along the eastern margin of the Wolds was suspected, but it was not until the borings now described had been made that Mr. Jukes-Browne felt justified in indicating on the map this large tract of Lower Cretaceous rocks. A knowledge of the structure of the Drift-covered region was of some importance in respect to water-supply. The most promising water-bearing stratum was the Spilsby Sandstone. A few years ago this bed was tapped by a boring at Skegness, but proved thin and compact. At Willoughby, however, it was loose, and yielded such a supply as might have been anticipated. The speaker agreed with Mr. Jukes-Browne's interpretation of the structure of the district.

37. *The* Bajocian *of the* Sherborne District: *its* Relation *to* Subjacent *and* Superjacent Strata. By S. S. Buckman, Esq., F.G.S. (Read June 7th, 1893.)

Contents.

Introduction.

Definition of the Term 'Bajocian.'—For the strata which are equivalent to the upper part of the Inferior Oolite, with a portion of the Fullers' Earth, d'Orbigny proposed the term 'Bajocien.' Like our own terms 'Inferior Oolite' and 'Fullers' Earth,' its boundaries were somewhat uncertain; and like them, too, it would seem that the same palæontological horizon has received different geological names at different localities—for this, probably, a difference in lithological characters may be blamed. In the present paper I use the term 'Bajocian' in a merely conventional sense—for the lower beds of the upper part of the 'Inferior Oolite'; but I do not express any opinion as to its merits. I may, however, remark that the division of the Jurassic period on palæontological grounds—disregarding the details of its inconstant and merely local lithology—is a necessity. Ammonites have been chosen as the indicators of horizons, and their rapidity in development makes them peculiarly suitable. Therefore, as far as possible, the chronological unit and the Ammonite-species should go together; and any system of grouping the chronological units should depend on the epacme, acme, and paracme of Ammonite-families. No doubt, in practical application, the epacme of one family would be found contemporaneous with the paracme of another, so that possibly it might be necessary to consider only two of the developmental phases.

Such terms as Bajocian, Toarcian, etc., might be used from the chronological point of view only, to express the successive portions of time of which the developmental phases of Ammonite-families gave evidence. They could be used for palæontological purposes, and only indirectly would have reference to such strata as might have been deposited during the times they represent. The details of this scheme cannot be discussed now. At present I use the term 'Bajocian' simply because it is the most exactly descriptive term we possess for the strata intended. In a former paper laid before the Society, I advocated a particular use of the term 'Toarcian.'[1] In the present paper the Bajocian will commence where the Toarcian, as then defined, finished.

The Limits of the District.—For the purpose of this paper I define the Sherborne district as follows:—A straight line from Stoford to Milborne Wick, a distance of about $7\frac{1}{2}$ miles in a north-easterly direction, enters the border of Dorset a few yards from its starting-point at Stoford Quarry, and travels for some six miles before it leaves Dorset for Somerset. The exposures of Bajocian in the Sherborne district are to be found not far from this line. For rather more than the first four miles—the Bradford area—the strata are thinly and but partially represented; only in the neighbourhood of the eastern part of the line—the Sherborne area—is there anything like a regular sequence.

The *lower* part of the Bajocian of this portion of the district was most imperfectly known, and has never been described. That a certain quarry near Sherborne—Sandford Lane (Combe)—yielded an Ammonite-fauna differing from anything else in the district was an acknowledged fact; but, as the quarry had not been worked for some sixteen years, complete ignorance prevailed concerning the relationship of its strata to superjacent and subjacent deposits. In order to clear up this mystery, Mr. Hudleston and myself undertook, in the summer of 1892, an investigation, during which, with the kind consent of the landlord, J. K. D. Wingfield-Digby, Esq., M.P., we opened, on our own account, certain long-closed quarries. Our thanks are due to Mr. Digby, his agents and his tenants, for their kind assistance, which materially contributed to the success of our investigations.

On Zonal Correlation.—The geological unit for the correlation of strata has hitherto been the 'zone.' Gradually, however, it has been felt that either the zones must be increased in number, or

[1] 'Cotteswold, etc., Sands,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 440.

some modification adopted, if the true faunal sequence is to be expressed with that accuracy which is now necessary. Thus, in 1887, Hudleston, in his very able survey of the Inferior Oolite,[1] although he adopted the zonal divisions which I had briefly sketched out in 1881,[2] showed plainly that the strata required more subdivision; and this subdivision he accomplished by the term 'beds,' and by designatory letters. In dealing with the Toarcian I have shown the necessity, for the purposes of correlation, of adopting greater accuracy in division than the existing zones allowed; and for my subdivisions I used the term 'beds.' Quite recently, in communications to the Geological Society of France, Munier-Chalmas[3] and Haug[4] have shown the geological value of small divisions. The work of the former in Normandy is most valuable for its exactness; in comparison, our researches on this side of the Channel are still much behindhand.

To such subdivisions, however, H. B. Woodward[5] is opposed; but then he is not looking at the matter from a biological point of view. For correlation in certain cases fewer zones may be used; but any such correlation is deficient in the precision which the biological palæontologist demands, and fossils labelled on such a plan are useless to him. In this connexion it may be remarked that the more minute the correlation the better for the student: he can easily dispense with detail; but if such detail as he does need be not given in any paper, he searches in vain for information.

The term 'zone' is said to be used in geology in a zoological sense; but in zoology it is really used in a different sense. However, I take it that of late years the stratum (or strata) characterized by an assemblage of organic remains, more or less peculiar thereto, has been regarded as a zone; and, as H. B. Woodward practically implies, though his definition of a zone is faulty,[6] the presence of any of the species known to be sufficiently peculiar to a given horizon is considered to denote the zone in localities from which the index-species is absent. This may be called the geologist's zoological use of the term. Charles Moore[7] seems to have been the only one to use the term in a strictly palæontological sense: he confined it to the exact horizon of a particular fossil.

The term 'Hemera.'—It is for a palæontological purpose similar to Moore's use of 'zone' that I propose the term 'hemera' (ἡμέρα).[8] Its meaning is 'day,' or 'time;' and I wish to use it as the chronological indicator of the faunal sequence. Successive 'hemeræ'

[1] 'British Jurassic Gasteropoda,' Palæontograph. Soc. 1887, No. i. pt. 1.
[2] 'Ammonites from the Inferior Oolite,' Quart. Journ. Geol. Soc. vol. xxxvii. p. 588.
[3] Compte-rendu sommaire des Séances, No. 14, p. 164, 1892.
[4] *Ibid.* p. 174.
[5] 'On Geological Zones,' Proc. Geol. Assoc. vol. xii. (1892) p. 295.
[6] *Ibid.* p. 298.
[7] Proc. Somerset Archæol. Soc. vol. xiii. 1865–6.
[8] [Originally the word 'emar' (ἦμαρ—the Homeric form of ἡμέρα) was chosen; but in deference to the wish expressed by the Council of the Geological Society I have substituted the term 'hemera.'—July 5th, 1893.]

should mark the smallest consecutive divisions which the sequence of different species enables us to separate in the maximum developments of strata. In attenuated strata the deposits belonging to successive hemeræ may not be absolutely distinguishable, yet the presence of successive hemeræ may be recognized by their index-species, or some known contemporary; and reference to the maximum developments of strata will explain that the hemeræ were not contemporaneous but consecutive.

The term 'hemera' is intended to mark the acme of development of one or more species. It is designed as a chronological division, and will not therefore replace the term 'zone' or be a subdivision of it, for that term is strictly a stratigraphical one. Our present 'zones' give the false impression that all the species of a zone are necessarily contemporaneous; but the work of Munier-Chalmas in Normandy, and my own labours in other fields, show that this is an incorrect assumption. The term 'hemera' will therefore enable us to record our facts correctly; and its chief use will be in what I may call 'palæo-biology.'

Description of the Strata.—Anyone unacquainted with the Dorset-Somerset Inferior Oolite, and the richness of its deposits, would scarcely credit the difficulty experienced in these investigations from want of names for the Ammonites. Species which have been perfectly well known for years as indicators of certain horizons are altogether devoid of any specific name. They could not, therefore, be recorded with precision—only the generic name could be given.

In this connexion the great value of the new generic names becomes most apparent. By their aid it is possible to narrow the identity of new or unnamed species within reasonable limits, and to record the fact with brevity in a paper. With their help, the characteristics and chief features of unnamed species can be described in a way comprehensible to other workers in the same field, by the use of a single word. Lastly, by employing them in the case of known species, the remarkable changes in the Ammonite-faunæ of successive deposits can be illustrated; and this important fact it is impossible to show by any other means.

I consider the strata dealt with in this paper to have been deposited during at least twelve hemeræ; and the names of these hemeræ will appear in the Sections at the tops of the respective divisions of strata assigned to them. These hemeræ[1] are as follows:—

1. *Fuscæ* and 2. *Zigzag.* (*Oppelia fusca*, Quenst., sp., and '*Stephanoceras*' *zigzag*, d'Orb., sp.) Owing to the unfossiliferous nature of the strata deposited during these hemeræ, in this district, an exact apportionment of the beds to each one

[1] In connexion with the specific names which designate the hemeræ, I have considered it advisable to use the genitive inflexion as more truly expressing what is intended. Thus '*fuscæ* hemera,' which is short for '*Oppeliæ fuscæ* hemera' = the hemera of the tawny *Oppelia*, means the hemera of the tawny one (*Oppelia* understood); whereas '*fusca* hemera' might seem to suggest the 'tawny hemera.'

separately was not possible in the time at my disposal. In the neighbourhood of Broad Windsor the strata of these hemeræ may be studied to far more advantage.

3. *Truellii* (*Strigoceras Truellii*, d'Orb., sp., *sensu stricto*).
4. *Garantianæ* (*Parkinsonia Garantiana*, d'Orb., sp.).
5. *Niortensis* (*Parkinsonia niortensis*, d'Orb., sp.).
6. '*Humphriesiani*'[1] (*Stephanoceras Humphriesianum*, Sow. sp.).
7. *Sauzei* ('*Stephanoceras*' *Sauzei*, d'Orb., sp.).
8. *Witchelliæ*, sp.[2] There are numerous species of *Witchellia* in the strata of this hemera; but, as very few are named, it is desirable not to appropriate any particular specific name at present.
9. *Discitæ* (*Hyperlioceras discites*, Waag., sp.).
10. *Concavi* (*Lioceras concavum*, Sowerby, sp.).
11. *Bradfordensis* (*Lioceras bradfordense*, S. Buckm.).
12. *Murchisonæ* (*Ludwigia Murchisonæ*, Sow., sp.).

It may be noted as a matter of history that in my paper of 1881[3] the divisions—

1–4	were included as		*Parkinsoni*-zone,
5–8 (*pars*)	,,	,,	*Humphriesianum*-zone,
8[4] (*pars*)–10	,,	,,	*Sowerbyi*-zone,
11, 12	,,	,,	*Murchisonæ*-zone.

Subsequently the divisions 9–10 were called the *concavum*-zone; and Waagen's term '*Sowerbyi*-zone' was given to that which on palæontological grounds was assumed to be an horizon situated between 7 and 9. Practically speaking, the correctness of the surmise has been confirmed.

In describing the following Sections I have introduced the quarrymen's names for the beds, when they could be ascertained: these names are given in small capitals between inverted commas. The names by which the beds are known to geologists I have placed also in inverted commas, but in ordinary type. The quarries are taken from west to east, as directly as their position and features allow.

The first section, known as Stoford Quarry, lies just on the borders of Somerset, on the north side of the South Western Railway, and a few yards west from Yeovil Junction, which is in Dorset.

[1] The confusion concerning this specific name, and the large number of species of *Stephanoceras*, make this appellation very unsuitable. It would be desirable to apply the name of a species belonging to a less prolific genus.

[2] This term has been suggested by French authors as a name for the strata of this horizon, from the prevalence of species of this genus in France; see later, p. 519.

[3] Quart. Journ. Geol. Soc. vol. xxxvii. p. 588.

[4] So far as the Ammonites from Sandford Lane were concerned; but the strata were covered up—I had not seen them.

Section I.—*Section at Stoford, Somerset.* (From Sherborne Abbey 4 miles 5 furlongs west-south-west.)

			Feet.	Inches.
Fuscæ	A.	1. Earthy clay, below soil		
&		2. Sandy limestone		8
Zigzag.		3. Earthy clay	1	0
		4. Sandy limestone		2
		5. Earthy clay		8
	C.	6. Yellow sandy limestone, hard, and blue-centred	1	4
Truellii?	D.	7. Soft, yellow, earthy stone, *Parkinsonia* sp.		3
Garantianæ.	F.	8. Marly limestone, *Astarte subquadrata*, S. Buckm.		2
		9. Hard, grey, shelly limestone. (In the neighbourhood of vertical joints it is decomposed to a soft yellowish-white marl, forming a conspicuous horizon in the quarry. Chief bed for gasteropoda (Mr. Bloomfield). *Trochus duplicatus*, Sow.; *Rhynchonella parvula*, Desl.; *Aulacothyris carinata* (Lam.) and '*Meriani*;' *Terebratula Stephani*, Dav.; *Oppelia* sp.; *Pentacrinus*)		7
Sauzei.	J.	10. Hard, blue limestone with rather large grains, which fall out, leaving the stone with numerous holes, '*Stephanoceras*' *Sauzei*, *Sonninia* aff. *Sowerbyi*. "At the top of this bed large masses of Serpulæ" (Mr. Bloomfield)		6
Discitæ? *Concavi.*	L? M.	11. Blue and yellow stone, with small iron grains. *Rhynchonella Forbesi*, *Ludwigia rudis* (*Lioceras concavum* loose, matrix agreeing), gasteropoda		8
Murchisonæ.	O.	12. Hard, blue-centred limestone, the horizon of the reversed gasteropoda, *Cirrus nodosus*, Sow., etc., especially towards the top ...	1	9

Note.—The thickness, colour, and hardness of the beds are very variable. Planes of division uneven—the lower beds being 'pocketty.' Bed 10 thickens to about 1 foot at the south of the quarry.

Bed 10 is the most interesting for the present. Several specimens of '*Stephanoceras*' *Sauzei* have come from here at different times—the matrix is unmistakable. The 'incompleteness of the record' and the attenuation of the deposits are especially noticeable.

About $1\frac{1}{2}$ mile in a north-easterly direction lies the famous East Hill Quarry of Bradford Abbas. The section of this has been often given; but, considering how remarkably rich is the fauna here stowed away in a small compass, the section has never been described with sufficient detail. In fact the necessity for the detail has not been taught, and was not appreciated. The present section is far from satisfying my requirements in regard to specific horizons, but the quarry was not 'in work.'

SECTION II.—*Bradford Abbas; East Hill Quarry.* (From Sherborne Abbey 3 miles 1 furlong west by south.)

				Feet.	Inches.
Fuscæ & *Zigzag.*	A (*pars*) & B.	1.	White limestone, and distorted stone at top. *Oppelia* cf. *fusca*, *Œcotraustes conjungens* (May.), *Oppelia*, various sp.	6	6
	C.	2.	Yellow, sandy stone		5
Truellii.	D.	3.	Soft, whitish limestone, with *Parkinsonia Parkinsoni*, &c.		3
Garantianæ.	F.	4.	The 'DIRT BED,' the 'Marl Bed.'—Soft earthy parting. The horizon of *Rhynchonella parvula*, Desl.; *Dictyothyris Morieri* (Dav.); *Aulacothyris carinata* (Lam.); *Astarte subquadrata*, S. Buckm.; *Ostrea Knorri*; '*Oppelia* sp.,' etc.		2
		5.	Soft, bluish-white limestone, irregularly and indistinctly separated from the bed above. *Astarte obliqua*, Desh.; *Ast. Manseli*, S. Buckm.		4
Sauzei.	J.	6.	The 'IRONY BED.'—Bluish limestone with large iron grains, which fall out, leaving holes. *Sonninia mesacanthus* (Waag.); *Sonn.* sp.; *Witchellia* sp.; *Astarte excavata*, Sow.		4
Discitæ.	L.	7.	Yellowish-blue ironshot limestone, darker coloured than the bed below. *Sonninia* and *Hyperlioceras*		7
Concavi.	M.	8.	Yellow and bluish ironshot limestone. *Lioceras concavum*-forms abundant; *Ludwigia cornu*, S. Buckm.[1]	1	4
Bradfordensis.	N.	9.	Soft yellow marl: *Lioceras bradfordense*, *L. v-scriptum*		1
Murchisonæ.	O.	10.	The 'PAVING BED.'—Yellow and blue shelly limestone. *Ludwigia Murchisonæ* (Sow.).		5
		11.	Soft, yellow parting		1
		12.	Yellow and blue shelly limestone. (The hard blue sandy limestone of the bed below runs up into it unevenly, in some places as much as one-half.)		10
	R.	13.	The 'DEW BED.'—Hard, blue-centred, sandy, shelly stone. *Dumortieria Moorei* (Lyc.); '*Rhynchonella Beneckei* (Haas)'		11
		14.	Yellow sands		...

In the line of parting between Beds 7 and 8, and in vertical joints through the same beds, the stone is decomposed into a soft yellow paste. In this paste the gasteropoda are found most easily.

For palæontological, lithological, or stratigraphical reasons, whether combined or separately, I correlate the beds marked by the same letters—in fact, most of the Stoford beds are repeated at Bradford; but there is an increase in general thickness, due to the introduction of new strata. The 'DEW BED' belongs to the *Moorei*

[1] Beds 7 and 8 are the 'FOSSIL BED'=*concavum*-zone (*auctorum*). For the gasteropoda from the '*concavum*-zone' see Hudleston, 'British Jurassic Gasteropoda,' Palæont. Soc. 1887 *et seq.*; for the Ammonites, see the Author's 'Inf. Ool. Amm.,' *ibid.*

hemera, as the time of the *Moorei*-beds may now be called;[1] but part of Bed 12 of Stoford may belong to the same time. The strata of the *discitæ* and *bradfordensis* hemeræ were not recognized at Stoford, and are presumably absent.[2]

It may be noted that the celebrated 'Marl Bed' of Bradford Abbas, which forms so conspicuous a bench-mark in the quarry, is only a local and accidental decomposition of the top of Bed 5; these two beds, 4 and 5, find their equivalents in 8 and 9 of Stoford. Bradford Beds 2 and 3 may also be correlated with Stoford 6 and 7; but above this the strata, compared with Stoford, have increased in thickness at Bradford, where the top of the section is incomplete.

At Bradford Abbas, by the Vicarage, there is the following section in the 'top beds.'

SECTION III.—*Bradford Abbas; Quarry near the Vicarage.*

			Feet.	Inches.
Fuscæ.	A.	1. Sandy limestone and earthy clay	3	0
		2. Sandy limestone	2	0
		3. Sandy 'REFUSE'	2	0
		4. Bluish limestone in several beds.....................	3	0

Denudation has left only a thin deposit of the 'Fullers' Earth Clay' to cap this section. There are 10 feet of strata shown here, and most of these may be added to those exposed at East Hill. This would give about 15–16 feet of 'top beds' as against $2\frac{1}{2}$ feet at Stoford. The lower part of the 'top beds' at East Hill belongs to the *zigzag* hemera, which is possibly not represented at Stoford. The upper part at East Hill, and possibly all of the beds at the Vicarage, belong to the *fuscæ* hemera, during which, therefore, there was a deeper deposit than at Stoford.

A little more than 1 mile north-east from East Hill are the well-known exposures of Halfway House, giving the following sections:—

SECTION IV.—*At Halfway House, Compton, Dorset.* (About $2\frac{1}{4}$ miles due west of Sherborne.)

Beds 1–3, the 'LIMESTONE BEDS,' measured on the south side of the road; the others on the north.

			Feet.	Inches.
Fuscæ & *Zigzag.*	A.	1. Hard, whitish limestone, in blocks, just below the soil. *Œcotraustes conjungens*? (May.)		
		2. Soft, white limestone, with clayey partings	7	10
	A (*pars*) B.	3. White limestone in blocks, with earthy partings, about	25	0

[1] Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 443.

[2] In the Broad Windsor district a much thicker and more noticeable deposit was laid down during the *bradfordensis* hemera.

				Feet.	Inches.
Truellii.	D.	4.[1]	The 'Fossil Bed.'—Whitish limestone, with large *Parkinsonia dorsetensis* and Nautili, *Park. Parkinsoni, Strigoceras Truellii, Pleurotomaria bessina*, d'Orb. .	1	1
Garantianæ.	F.	5.	Marl bed, not always to be detected. (The equivalent of the well-known Bradford-Abbas Marl Bed.)...........................		1–2
Niortensis.	F. & G.	6.	The 'Shell Bed' (the 'Rotten Bed'), '*Astarte*-Bed.' — Soft, yellow stone with rotten shells. *Parkinsonia Garantiana, 'Lima proboscidea,' Astarte obliqua, Curvirostrum striatum*, J. Buckm.; *Myoconcha crassa*, Sow.; *M. unguis*, Whidborne. (At the base a thin marly bed may sometimes be detected.).		4
Humphriesiani or *Sauzei.*	H?	7.	The 'Irony Bed.' — Hard, grey limestone of variable thickness, not always well separated from the bed below		5
Sauzei or *Discitæ.*	J? or L?	8.[2]	Dirty yellow, ironshot stone, line of separation from bed below not always marked		5
Concavi.	M.	9.	Blue-centred, yellow, ironshot limestone. *Lioceras concavum* abundant; *Terebratula Eudesi*, Oppel, large; *T. perovalis*, Sow.	2	7
Bradfordensis.	N.	10.	Blue-centred, yellow ironshot stone. *Rhynchonella ringens* towards the top, with *Lioceras concavum.*		
Murchisonæ.	O.		Lower down *Ludwigia Murchisonæ, Lioceras bradfordense?, Rhynchonella subringens, Cucullæa oblonga, Opis trigonalis, Trigonia striata*		10
	P.	11.[3]	Hard, grey, shelly limestone. The top of this yields *Pseudomelania procera*, Desl., and *Terebratula Etheridgii*, Dav.	2	0
		12.	Yellow sands. (The blue, very shelly limestone, known to cap the sands, was seen on the stone-heaps, but could not be found *in situ.*)		....

Section V.—*Halfway House.* (Quarry in the field behind the Chapel. North part of the exposure recently worked.)

				Feet.	Inches.
			Soil.		
Concavi.	M.	1.	Beds with *Lioceras concavum* abundant ...	3	0
Bradfordensis.	N.	2.	Yellowish, ironshot limestone with *Rhynchonella ringens*		4
		3.	A yellow limestone in 3 or 4 layers		10
Murchisonæ.	O.	4.	A yellowish, rather soft bed, with perished fossils: *Cucullæa oblonga* and *Trigonia striata*		2
		5.	A very flat-topped bed, with many oysters on the top of it.		....

[1] Beds 4–7 are also to be seen on the south side.
[2] Beds 8–10 are called the Blue Beds.
[3] Corals and brachiopoda are at the lower part of Bed 10, and there are also bored portions of 11 enclosed in the bottom part of 10.

In the field-quarry the divisional planes are more numerous, owing to the proximity of the lower beds to the surface; therefore a better idea of the divisions can be gained than in the big quarry, where, owing to the beds being cemented together, the stratigraphical and palæontological planes do not necessarily coincide.

In the lower beds of Section IV. there is an increase in thickness, compared with those of Bradford, but the same sequence up to 8. I cannot say whether this bed should be J, and part of 9, L; or if this be L, and J be absent. I place No. 7 as H? from evidence of fossils marked 'Halfway House,' which could only have come from this horizon, as the next section will explain. To Bed 4 the name 'Fossil Bed' is given—how different the position from that at Bradford is worthy of note; and this horizon is more prolific here than anywhere else to my knowledge. Above the 'Fossil Bed' it may be seen that, in place of and equivalent to the 16 feet of 'top beds' of Bradford, there are, here, about 33 feet; and, even then, the limestone is very probably not finished with, while at Bradford it presumably has come to an end.

Before leaving this section it should be noted that *Rhynchonella ringens* forms a very good bench-mark in the lower beds, and it is an abundant fossil. At Bradford it is extremely rare; but as only the thinnest edge of the strata deposited during this hemera is found there, the scarcity is not surprising.

About half-a-mile in a south-easterly direction is the quarry of Louse Hill, with the following strata exposed:—

Section VI.—*Louse Hill.* (About $1\frac{3}{4}$ mile nearly due west of Sherborne: about $\frac{1}{2}$ mile south-east from Halfway House.)

			Soil.	Feet.	Inches.
Garantianæ.	E.	1.	Rotten yellow stone with numerous *Aulacothyris* '*Meriani*, var.'		4–5
		2.	Earthy stone		5
Garantianæ & *Niortensis.*	F. & G.	3.	'*Astarte* or Rotten Bed.'—A rotten yellow stone, with *Astarte obliqua*, and *Ancyloceras*, *Parkinsonia Garantiana*, and other species; *Oppelia* sp.; *Terebratula Phillipsi*, Morris, *Natica* sp. Also enclosed portions of bed below—nodular-shaped masses in an irony coating		5
Humphriesiani.	H.	4.	The 'Irony Bed.'—A hard, greyish-brown, sometimes pinkish stone, with a somewhat cherty appearance; very unevenly separated from the bed below, into the hollows of which it dips. In many places part of it is attached to the bed below like a scale. *Stephanoceras* cf. *Humphriesianum*, '*Steph. Braikenridgii*,' *Sphæroceras Brongniarti*, *Pœcilomorphus cycloides.* Many species of *Pleurotomaria.* Several peculiar brachiopoda, viz.: *Rhynchonella dorsetensis*, S. Buckm., *Aulacothyris Haasi*,		

			Feet.	Inches.
		S. Buckm., *Plesiothyris Brodiei*, S. Buckm., *Terebratula gravida*, Szaj., *Glossothyris curviconcha* (Oppel), *Zeilleria* sp. nov., '*Terebr. Buckmani* and '*Buckmaniana*,' etc., *Curvirostrum striatum*, J. Buckm.		2–3
Sauzei or *Discitæ*.	J. or L?	5. Bluish-yellow, slightly ironshot limestone—in many places no line of separation from the bed below		5
Discitæ.	L.	6. The same—*Hyperlioceras* and *Sonniniæ*; *Lytoceras confusum* in lower part		10
Concavi.	M.	7. The same, *Lioceras concavum* abundant; *Ludwigia cornu*, *Pleurotomaria* aff. *actinomphala*	1	2
Bradfordensis.	N.	8. The same (*Rhynchonella ringens*, near the bottom; *Terebratula shirbuirniensis*, S. Buckm., just above it)	1	6
Murchisonæ.	O.	9. Greyish-yellow, slightly ironshot limestone. *Zeilleria anglica* (Dav.), *Ceromya bajociana*, d'Orb. (a bed with a markedly level top)		10
	P.	10. Yellowish, sandy limestone (markedly level top)	3	0

Here the beds below the horizon of *Rhynchonella ringens* are evidently thicker than at Halfway House—3 feet 10 inches as compared with about 2 feet 6 or 7 inches—and the sands were not reached. *Rh. ringens* appears just above an existing divisional plane, instead of just below it; but these divisions are merely local and accidental, as the field-quarry at Halfway House proves. Strata of the *discitæ* hemera may be recognized here, and very likely the succeeding bed was deposited during the *Sauzei* hemera. Above that is the most remarkable bed in this part of the district, Bed No. 4. It contains a fauna characteristic of the *Humphriesiani* hemera, which, excluding the doubtful Halfway House Bed 7, had not been previously noted in the district by the route travelled. It contains some remarkable brachiopoda; in fact, by working beds of this description I was able, after a few months' labour, to add to the brachiopod fauna of the district very many species that had not been obtained before.[1]

Above this bed is seen the same '*Astarte*-bed' which is found both at Bradford and Halfway House; but here evidently a lower horizon is included in this bed than is the case at Bradford—namely that of the *niortensis* hemera with *Ancyloceras*, the 'Bifurcaten-Schichten' of Quenstedt. Fossils labelled 'Halfway House' suggest that this horizon is included in Bed 6 at that place; but there is no such evidence with regard to Bradford.

In the top of the Louse Hill Quarry a small species of *Aulacothyris*[2] is found, and this fact becomes important for comparison with Sherborne quarries.

[1] See Davidson, 'British Fossil Brachiopoda,' Appendix to Supplement, Plates xviii.–xx., Palæont. Soc. 1884.

[2] It has usually been known as '*Waldheimia Meriani*, variety;' but it is certainly not the same as the Cotteswold fossil.

Between Louse Hill and Sherborne, a distance of about 2 miles, there is no opening in the lower beds; and considering how great is the change at Sherborne, this is much to be regretted. To follow the beds properly it is necessary to go about $1\frac{1}{2}$ mile north from Louse Hill to Marston Road Quarry, which gives the following section:—

SECTION VII.—*Section on the right-hand side of the road from Sherborne to Marston* (just beyond the second milestone). *Quarry in a field* (*'Marston Road Quarry'*) *and cutting on the road exposing sands, etc.*

THE QUARRY.

				Feet.	Inches.
Bradfordensis.	N.	1.	Soft, yellowish limestone with many iron grains. *Rhynchonella ringens*, Dav., *Lioceras bradfordense*, *Ludwigia cornu.* (Top of quarry at the southern end.)	2	0
Murchisonæ.	O.	2.	Soft, grey limestone with grains of iron oxide. *Ludwigia Murchisonæ.* Fossils scarce	4	6
	P.	3.	Hard, grey, crystalline limestone with numerous fossils. *Ludwigia Murchisonæ* (Sow.), *Tmetoceras scissum* (Ben.), *Lioceras opalinum* (Rein.), *Erycites gonionotum* (Ben.), *Opis trigonalis* (Sow.), *Cucullæa oblonga*, Sow., *Pholadomya fidicula*, *Ceromya bajociana*, d'Orb., *Terebratula perovalis*, Sow.	1	6
	Q.	4.	Bed of sand. (Probably the horizon of the rare *Terebratula euides*, S. Buckm.) There is perhaps a small hiatus here, as this bed of sand could not be detected in		
			THE ROAD-CUTTING.		
		5.	Hard, sandy, crystalline limestone	5	0
	R.	6.	Yellow sands.		

There is a very considerable increase in the thickness of the strata with *Rhynchonella ringens*, and those below that line, when compared with the previous sections. There is as much as 11 feet between the horizon of *Rh. ringens* and the strata marked R, which stands for the Yeovil Sands—a greater thickness than the whole 'Inferior Oolite' (*plus* part Fullers' Earth equivalent?) shown at Stoford. This thickening is to be accounted for by the presence of strata P and Q, which are absent or very feebly developed in the Bradford area. Certainly P was deposited before the hemera of *Murchisonæ* proper, while at Bradford, Halfway House, and Louse Hill are signs of erosion and cessation of deposition which may have been contemporaneous with P of this section.

It should be noted that the strata of the *bradfordensis* hemera with the characteristic *Rh. ringens* have now assumed respectable proportions. These proportions are maintained in the next section, that of Holway Hill, about $2\frac{1}{4}$ miles to the north-east.

SECTION VIII.—*Section at Holway Hill* (on the left-hand side of the Bristol road, just before the third milestone from Sherborne).

			Feet.	Inches.
		1. Limestone with *Belemnites*	1	6
		2. Grey, earthy parting		9
Bradfordensis.	N.	3. Limestone with *Rhynchonella ringens* abundant, especially at the bottom	2	0
		4. Irregular earthy parting with *Rh. ringens* and *Terebratula shirbuirniensis*, S. Buckm.		3
Murchisonæ.	O.	5. Hard, grey limestone; *Ludwigia Murchisonæ* (Sow.), *Ceromya bajociana*	6	6
	P.	6. Sandy, crystalline limestone; *Ludwigia Murchisonæ*: in depth at least	3	0
	Q?	7. Sand.		

Below the *Rhynchonella ringens*-horizon in this section are shown nearly 10 feet of strata. It is, however, extremely probable that there is, below Bed 7, limestone equivalent to Q at Marston Road, for it should be noted that Q is not worked in the Marston Road Quarry, which stops at the sand-bed.

The strata of this section are practically repeated in a quarry near the fourth milestone from Sherborne on the Bristol road—that is, about 1 mile farther north; but at the time of my visit in 1891, the quarry was almost filled in, and not fit for measurements. About ten years before then I had collected many fossils from it. A little farther on, on the right-hand side of the road, is another quarry which I knew well at that time. It also was almost filled in at my last visit, but I could estimate that it showed about 9 feet of earthy limestone with thick partings of blue clayey marl. *Terebratula Eudesi*, Oppel, *T. cortonensis*, S. Buckm., and *Rhynchonella Forbesi*, Dav., with numerous *Belemnites*, are the chief fossils found—*T. cortonensis* especially. *Lioceras concavum* is very rare.

About ¾ mile south-east from here is a quarry on the edge of Pointington Down, just below 'Seven Sisters,' with a similar section, 8 feet thick. The fauna is similar; *Terebratula Eudesi* is very fine. Poor specimens of the *Lioceras concavum*-type are fairly frequent, and one *Sonninia submarginata* was obtained. This section and that on the Bristol road evidently show strata deposited during the *discitæ* and *concavi* hemeræ; but it is curious that I cannot record any *Hyperliocerata* from either. At the Bristol Road Quarry, in stones in the soil at the top, there is evidence of species of a hemera later than that of *discites*; while the greater abundance of *Lioceras concavum*-forms at Pointington Down impels me to consider that quarry lower than the one on the Bristol road. I cannot say what gap there may be between it and the topmost bed of Holway Hill—the 'limestone with *Belemnites*'; and, working back to Sherborne, I am unable to show the junction in this district of the *ringens*-beds with those containing *concavum*. A quarry at Ambers Hill[1] which would perhaps have settled this

[1] A little knoll capped with Inferior Oolite. It is coloured 'Sands' on the Geological Survey map, but is not named. It is said to have been the signal-station between High Stoy and Glastonbury in the days of semaphores. It is ¾ mile west of White-post Gate, in the south-eastern corner of the cross-roads.

point is now entirely grassed over. Two points, however, are certain from the sections described, and from those to be given—a very great increase in the thickness of the strata deposited during the *concavi* and *discitæ* hemeræ, and an entire change in lithological conditions in the Sherborne compared with the Bradford area.

Two and three-quarter miles south-west by south from 'Seven Sisters' lies the quarry of Sandford Lane. It has generally been known as 'Combe Quarry,' a name also given to other quarries near. The workmen of the district now confine the name 'Combe Quarry' to one nearer Sherborne, and distinguish this one as 'Sandford Lane,' an appellation which it is advisable to adopt. It gives the following section :—

Section IX.—*Sandford Lane Quarry* (*Combe*). From Sherborne Abbey 1 mile 1 furlong N.N.W.

			Feet.	Inches.
	E.	1. Irregularly-arranged limestone in masses, with earthy marl intermixed. Limestone-lumps with clusters of *Aulacothyris* '*Meriani* var.,' 7 feet 6 inches above Bed 2. '*Perisphinctes triplicatus*' (Quenstedt), 4 feet 3 inches above Bed 2	12	0
Garantianæ.	F.	2. Limestone in fairly large blocks	5	0
		3. Sandy limestone with *Parkinsonia*, n. sp.[1]	1	4
		4. Five courses of grey limestone with sandy partings. Clusters of *Terebratula sphæroidalis* in the third from the top	5	0
		5. Dark-brown, sandy limestone in several layers. No fossils found	2	3
Sauzei & *Witchelliæ.*	J & K.	6. The 'Fossil Bed.' A single bed of hard oolitic limestone. Where not protected by overlying strata it splits into two fairly equal portions, of which the bottom part is mostly greyish-green with enclosed lumps of a green-grained, white marl, and the upper part, especially the top 4 or 5 inches, is brown and dark. Where protected by overlying strata, as in the north end, the rock is one solid bed, coloured, etc. thus :— Inches.		
		J *a*. Greyish-brown, ironshot ... 4		
		K *b*. Blue, oolitic, ironshot in places ; the blue colour not in the neighbourhood of the joints 7		
		c. Grey-green oolitic limestone with enclosed lumps of green-grained white marl . 6		
		d. Dirty brown, rather soft, sandy stone without fossils 4		
		Total	1	9
		(The top of the bed is planed off quite smooth, and is remarkably level.)		
		7. Sand		1

[1] The same species is found at Louse Hill in Bed 3.

				Feet.	Inches.
Discitæ.	L.	8.	Greyish-green, sandy limestone Fragments of two or three species of a smooth *Sonninia*, indeterminable on account of their rotten condition. The septate half-whorl of a giant '*Sonninia*' *ovalis*[1] 41 centim. (16 2/5 inches) in diameter, *Astarte excavata*....................		6
		9.	Brown, sandy parting with some stone. *Terebratula cortonensis* and allied forms abundant. *Trigonia striata*, Miller, *Gryphæa* aff. *sublobata*, *Ostrea*, *Lima Etheridgii*, Wright, *Gervillia Hartmanni*, *Terebratula Eudesiana*, S. Buckm., *Hyperlioceras discites*, and *H. Walkeri*....................................		5
		10.	Grey, sandy stone, *Hyperlioceras discites*, *Terebratula Eudesi*, slight parting		4
Concavi.	M.	11.	Grey, sandy stone. *Lioceras concavum* (Sow.) and its allies abundant. *Ludwigia rudis*, *Sonninia* sp.[2]		11
		12.	Earthy parting		3
		13.	Grey sandstone. *Lioceras concavum* (Sow.), *Ludwigia cornu*, *Sonninia crassispinata*, S. Buckm.	2	0

Notes on the 'Fossil Bed' *of Sandford Lane.*—Although this bed comes out as one compact block, yet it requires little observation to see that the upper part of the bed is not only lithologically different from the lower, but contains a different fauna. During the excavations every precaution was taken to note the position of the Ammonites in relation to the bed. In many cases this was done—the specimens being labelled at the time; but in the various operations of blasting and quarrying the bed was frequently turned over, and the workmen would also misplace the parts, particularly when using the sledge-hammer for breaking the bed, unless very closely watched. It may be noticed that the matrix affords very substantial evidence as to the position of those specimens which it was not possible to label on the spot, as well as those collected many years ago. Attention to this matter, with the assistance of the specimens of known position, together with notes made during the progress of the work, will enable the position of each species to be determined with fair accuracy, when they fall to be described in the forthcoming parts of my monograph (Palæont. Soc.). Meanwhile the list on the following page will give an idea of the faunal contents of the bed:—

[1] *Ammonites Sowerbyi ovalis*, Quenstedt.—Possibly when complete this giant exceeded 2 feet (61 centim.) in diameter, for, admitting that the body-chamber at once followed the septa seen, at least half a whorl must be added. Such dimensions far exceed those of any species of the *Sonninince* known to me. No other specimen of this species is in my cabinet.

[2] Monogr. 'Inf. Ool. Ammonites,' Palæont. Soc. 1893, pl. xc. figs. 7–9.

UPPER PART.—*Sonninia patella* (Waag.), *S. propinquans*, Bayle, and allied forms. Species of the *Sonninia Zurcheri*-group. '*Stephan.*' *Sauzei* (d'Orb.), *Oppelia* aff. *præradiata* (Douv.), and other species. *Stephanoceras* sp. (cf. *Ammonites Humphriesianus macer*, Quenstedt).[1] '*Witchellia læviuscula*,' *Strigoceras* sp., *Acanthothyris paucispina*, B. & W., *Terebratula ventricosa*,' Zieten. The chief horizon for gasteropoda (mostly *Pleurotomaria*) is about 3 to 4 inches from the top of this bed.

MIDDLE PART.—'*Sonninia*' *pinguis*, *S. gingensis*, *S. gracililobata*, Quenstedt,[2] *Witchellia* sp., *Sphæroceras* aff. *Manseli*, S. Buckm., *Sph. Brocchi*, *Sph. Sauzei*, and a thinner form. *Lima proboscidea* very abundant. Various species of '*Sonninia*.'

LOWER PART.—'*Stephan.*' aff. *Sauzei*, *Sphær. Brocchi*, '*Sonninia*' *Stephani*, *S. rudis*,[3] and allied forms; *Sonninia fissilobata* (Waag.) and allied forms; *S. arenata* (Quenst.); several species of spinous *Sonninia* allied to '*Sowerbyi*;' several species of 'mammillate'[4] *Sonniniæ* of the *Ammonites mesacanthus*-type, but not that species itself; *Witchellia Sutneri* and allied species.

The predominance of the *Sonninia fissilobata*-type of Ammonite in the lower part of the bed is a feature sure to attract attention. When the quarry was worked several years ago (about 1875) these fossils received the appellation of the 'Combe Ammonites.' In the middle of the bed the most striking feature is the large number of *Lima proboscidea* or *pectiniformis*—at any rate a species of *Ctenostreon*—which usually leave their shells with too great readiness. Towards the top of the bed the *Pleurotomariæ*, especially those of the *granulata*-type, the numerous examples of *Acanthothyris paucispina*, and the presence of true *Sonniniæ*—compressed, high-keeled species of the *propinquans*-type, very different from the small-keeled, stouter species of the *fissilobata*-series—are the most striking features.

This section, placed on the top of that of Marston Road Quarry —which is only about 5 furlongs distant,—makes the sequence apparently complete; yet for many reasons I anticipate that some 2 or 3 feet of strata are wanting between the top of Marston Road and the base of Sandford Lane. These strata would contain *Lioceras concavum* and allies. Beds 9 and 10 can certainly be correlated with the strata on Pointington and Horethorne Downs. Those beds may be a very considerable expansion of these horizons only, or they may be equivalent to Beds 8–12 inclusive. Above Bed 8 is the 'FOSSIL BED' of Sandford Lane—at a totally different horizon from that of Bradford or Halfway House, and yielding a totally different fauna. Any equivalent of the lower part of this bed has been wanting from the sections so far given, and very few localities in this country show the horizon at all. Broadly speaking, it may be said that no other locality in England yields the same fauna as the lower part of this bed. Dundry is the

[1] Two forms, one much more spinous than the other, are shown by Quenstedt ('Amm. d. schwäbischen Jura') under this name. Both occur here.

[2] *Ammonites Sowerbyi gracililobatus*, Quenstedt, 'Amm. d. schwäb. Jura,' pl. lxii. fig. 2.

[3] *Ammonites Sowerbyi rudis*, 'Amm. d. schwäb. Jura,' pl. lxi. fig. 12.

[4] This term will be easily understood by those who know the adult of *Sonninia mesacanthus*, with its small pimples as shown in Waagen's work.

only locality which can be named with it; a few of the peculiar Sandford Lane species have been obtained from there.

The few inches of the upper part of the bed are lithologically different, and yield a fauna very distinct from that of the lower part. By the fauna it is possible to identify the horizon of this part of the bed over a wider area than that of the lower part. My own impression is that if the strata were more developed, it would be seen that the species which lived during three hemeræ are contained in the 'Fossil Bed' of Sandford Lane: (*a*) species of the *Sonninia propinquans*-type, (*b*) *Witchellia* and allies, (*c*) species of the '*Sonn.*' *fissilobata*-type. Not unlikely the bed below—No. 8—ought to be added to this lowest division: it represents something later than L at Bradford Abbas.

Nothing is more remarkable than the complete change of fauna in the 'Fossil Bed' of Sandford Lane, compared with strata of the *concavi* or even *discitæ* hemeræ. Not a single species of the *Hildoceratidæ* is found in the 'Fossil Bed' of Sandford Lane. The *Sonnininæ* dominate the bed entirely—one division of the genus *Witchellia* has, in its most retrogressive types, curiously enough a great external resemblance to the last survival of the *Hildoceratidæ*[1]—*Hyperlioceras*; the *Oppelidæ* are fairly numerous individually, but not specifically; and the same may be said of the *Stephanoceratidæ*, but not of *Stephanoceras*. In the lower part of the bed the *Sonnininæ* are still in the acmastic stage, but their paracmastic stage is certainly pronounced in the upper part. The *Oppelidæ*, though they have increased in numbers somewhat since the *concavi* hemera, are still in the epacmastic stage.

The 'Fossil Bed' of Sandford Lane has a remarkably level top; and there is a considerable geological gap—the missing strata being seen at Frogden (Sect. XV., p. 500). All the strata above it I consider as contemporaneous with the '*Astarte*-bed' of Halfway House, and perhaps in part with the 'Fossil Bed' of that locality—so that the increase of deposition is very great in comparison. It may be noted that the same small species of *Aulacothyris* as that found at Louse Hill occurs here; but it is now about 20 feet above *Lioceras concavum*, instead of about 20 inches; yet there is abundant evidence that it occupies the same palæontological horizon.

These 'upper beds,' as they are generally called, though they are by no means contemporaneous with the upper beds of the Bradford area, as has usually been thought, may be advantageously studied in the following sections:—

[1] *Pœcilomorphus* being excluded as doubtful. Dr. Haug (*in litt.*) considers this genus to be one of the *Sonnininæ*.

Section X.—*Combe. Limekiln Quarry.*—Situated between Sandford Lane and the Marston Road. (From Sherborne Abbey, ¾ mile N.N.W.)

			Feet.	Inches.
Truellii	D.	1. The 'Rubbly Beds'	12	0
&	&	2. Grey shelly limestone with fossils	1	2
Garantianæ.	E.	3. Shelly and earthy limestone, with irregular earthy partings. The 'Stone used for Lime'	15	0
	F.	4. The 'Building-stone.' Sandy limestone in thick layers	15	0

Notes.—*Parkinsonia Garantiana*, *P. dorsetensis*, and *Strigoceras Truellii*, loose—collected by the workmen from the quarry. *Parkinsonia* and fossils of the 'Fossil Bed' of Halfway House begin about 7 feet above the 'Building-stone'; but their principal bed is about 12 feet from the top of the quarry. *Aulacothyris* '*Meriani* var.' was found solitary *in situ* at about 6 and again at about 12 feet above the 'Building-stone.' Clusters of this fossil could not be traced, although there was evidence of them in loose blocks. *Ancyloceras* sp. occurs 7 feet above the 'Building-stone.'

Section XI.—*Redhole Lane, Sherborne.*—(About 1 mile N. of the Abbey.)

			Feet.	Inches.
Truellii. *Garantianæ.*	D. E.	1. Rubbly limestones, mostly of a grey, shelly appearance, with frequent and irregular earthy partings. About 4 feet above Bed 2 several *Terebratulæ*, usually called 'flat forms of *T. sphæroidalis*.' Just above these occur *Oppelia* sp. and a poor specimen of '*Perisphinctes*' *triplicatus*? On the spoil-heaps, with, in many cases, matrix agreeing with this horizon, were found *Parkinsonia Garantiana*, *P. præcursor*, and *P. rarecostata*	20	0
	F.	2. The 'Building-stone.' Yellow, somewhat blue-centred sandy limestone in large blocks. Very bare of fossils; but from this horizon came the *Megalosaurus Bucklandi*	25	0

Section XII.—*Clatcombe.*—(Old disused quarry just below the Farmhouse, converted into a place for town-rubbish.)

			Feet.	Inches.
Garantianæ.	E.	1. Grey, shelly, rubbly, irregularly-bedded limestone. *Parkinsonia* sp. (fragments) between *rarecostata*, Buckm., and *Parkinsoni*	3	0
		2. Similar limestone; earthy partings	1	8
		3. Seam of lignite in a blue, earthy parting. Fragments of *Parkinsonia Garantiana* abundant		3
		4. Yellow and grey shelly limestone	1	8
	F.	5. Yellowish limestone. Towards the bottom in thicker blocks and more sandy	2	4
		6.[1] Yellowish, sandy limestone in large blocks	18	0

[1] Beds 5 and 6 would be no doubt 'Building-stone.'

All these sections show the same features—namely, upper beds of rubbly stone which is burnt for lime, lower beds of freestone, which forms the chief building-stone of Sherborne. As will be seen presently, the freestone rests on the strata of the *niortensis* hemera, which is also partly represented by the '*Astarte*-bed' of Louse Hill. On the other hand, only the upper part of the rubble-beds can be exactly contemporaneous with the 'Fossil Bed' of Halfway House, for most of the Ammonites are of an earlier biological type, though of the same genus. Therefore round Sherborne as much as 45 feet of strata was deposited during the same time that only 1½ feet was laid down at Halfway House, a locality only about 2 miles distant.

In the next section the 'Rubbly Beds' and the 'Building-stone' are seen resting on beds which were not represented at Sandford Lane—namely, strata of the *niortensis* hemera. The following is the section, which is only a few yards from the one last given, but reaches a lower horizon.

Section XIII.—*Lower Clatcombe, by the new Farmhouse.*—(From Sherborne Abbey, 1 mile N.)

			Feet.	Inches.
Truellii? & *Garantianæ*.	D? & E.	1. Rubbly shelly limestone with irregular partings. *Parkinsonia* aff. *præcursor*, *P. rarecostata*, *P. Parkinsoni*, and a form between these two found at the top of the quarry	10	0
	F.	2. Yellowish and blue sandy limestone in large blocks with several partings, ... about	14	0
		3. Several beds of grey, sandy limestone and partings	6	0
		4. Grey, sandy limestone	1	6
		5. Blue sandy parting		3
		6. Blue and brown sandy limestone. *Terebratula sphæroidalis* and *Acanthothyris* sp.		6
Niortensis.	G.	7. Blue-centred (brown outside) ironshot limestone of very open texture. *Parkinsonia Caumontii* (d'Orb.), and allied forms. '*Stephanoceras Braikenridgii*,' *St. Banksi* (Sow.), very large, *St. Blagdeni* (Sow.), *Parkinsonia niortensis*, and another species. '*Perisphinctes*' *Davidsoni*, S. Buckm. A small *Sphæroceras*, *Oppelia* sp., *Terebratula Craneæ*, Dav., *T. gravida*, var. *T. Phillipsi* (Morris), *Glossothyris curviconcha* (Oppel), *Plesiothyris reversa*, S. Buckm., *Rhynchonella plicatella* (Sow.), *Trochus duplicatus*, *Pseudomelania lineata*, *Natica bajocensis*, *Pleurotomaria* between *Palemon* and *granulata*	1	0
		8. Blue-centred ironshot limestone with dwarf '*Stephanoceras Braikenridgii*' and *Oppelia* (umbilicate sp.)		5
		9. Earthy parting. *Oppelia* aff. *subradiata*	....	

This quarry has been closed for many years. We reopened it in the summer of 1892 in the hope of penetrating to the equivalent of the Sandford Lane 'FOSSIL BED'; but it soon became evident that this was an impossibility, without blasting to a dangerous extent. Having found strata of the *Humphriesiani* hemera close to the surface elsewhere, I determined to make a special opening; the result was entirely successful. The following section shows the strata opened up, and, as will be proved by a section to follow, it may be actually regarded as a continuation of Section XIII. I may remark that each bed was taken off separately as carefully as possible, the contents noted by breaking up the stone, and all that stone put aside before the next bed was attacked. Owing to the proximity of the beds to the surface, it was possible to make more precise separation than at Sandford Lane.

This opening is not far from several old filled-in workings, which have probably yielded many fossils labelled 'Clatcombe'; in fact, at one time it had evidently been worked to a shallow depth itself.

SECTION XIV.—*Clatcombe Farm.*—(Section north of the new farm-house, and on the left-hand side of the road to Clatcombe Barn.[1]) The place, which was opened on purpose and then filled up again, is 1 mile 3 furlongs due north of Sherborne Abbey.

			Feet.	Inches.
Humphriesiani.	H.	1. Hard, brown, ironshot oolite, broken up from being close to the surface. *Terebratula sphæroidalis*, *Pœcilomorphus cycloides* (d'Orb.), '*Stephanoceras Braikenridgii*,' *St. subcoronatum* (Oppel), and other species of the '*Humphriesianum*-type;' *Dorsetensia Edouardiana* (d'Orb.), *Oppelia* aff. *subradiata*, *Œcotraustes* aff. *genicularis* (Waag.), *Sphæroceras Brongniarti* (Sow.), *Sph. Orbignianum* (Wright)	1	3
	I.	2. Hard, brown, ironshot oolite, very fissile, in thin layers. No fossils seen. (The top of this bed is very flat.)		8
Sauzei.	J.	3. Hard, greyish-brown ironshot oolite. *Witchellia* sp., *Sonninia* sp. (young example with small spines). Several Ammonites of the *Sonninia Zurcheri*-type. *Terebratula ventricosa*, Zieten, *Acanthothyris paucispina*, Buckm. & Walker, *Pleurotomaria granulata*, *Cucullæa ornata*		7
		4. Yellowish limestone, slightly ironshot. Chief horizon for gasteropoda, several species of *Pleurotomaria*; *Oppelia* aff. *præradiata* (Douv.), *Sphæroceras Brocchi*, *Sonninia patella* (Waag.), *Witchellia* sp., *Acanthothyris paucispina*		2

[1] Spelt incorrectly on the Ordance Survey Map, which reads 'Chatcomb Barn'.

			Feet.	Inches.
Witchelliæ.	K.	5. Grey limestone with green grains. *Sphæroceras Brocchi* (Sow.), *Stephanoceras* sp. ('planulate'), *Strigoceras* sp., *Sonninia fissilobata* (Waag.)		2
		6. Bluish-grey limestone, much bored by annelids and *Lithodomi*, *Sphæroceras Brocchi*, *Oppelia* sp.	1	1
		7. Similar limestone; *Lima Etheridgii*, Wright		7
Discitæ.	L.	8. Bluish-grey, sandy, glistening limestone. *Witchellia* sp., *Sonninia* sp., *Oppelia* sp. Fragment of outer whorl of large costate *Sonninia*, *Pecten barbatus*, *Rhynchonella buteo*, Szajn. *Belemnites* n. sp. (an extremely short form). Numerous annelid borings ...		8
		9. Earthy parting		4
		10. Brown, sandy limestone in two layers, *Hyperlioceras Walkeri* young, *Ludwigia rudis*, *Witchellia*? sp., *Lissoceras* cf. *Etheridgii*, S. Buckm., but more finely ribbed, *Rhynchonella* sp.		5
		11. Earthy parting		1
		12. Hard, bluish, sandy, glistening limestone, *Rhynchonella Forbesi*[1] (Dav.)		4
		13. Earthy parting		1
		14. Sandy limestone		3

Bed 1 was not found at Sandford Lane, but can be correlated with Bed 4 at Louse Hill. The flat top of Bed 2 suggests correlation with the flat top of the 'Fossil Bed' at Sandford Lane, but this is a mistake. The true explanation is that here, as well as at Sandford Lane, a hiatus exists; but that the erosion, to which the flat top probably points, removed more strata at Sandford Lane than here. In fact, probably a part of the next bed is unrepresented at the former locality.

The agreement of Bed 4 with an horizon a few inches from the top of the Sandford Lane 'Fossil Bed' is absolutely exact; and the lower part of that bed is represented by Beds 5 and 6. Ammonites, however, are scarcer here; and many large (unnamed) species, so characteristic of Sandford Lane, are conspicuous by their absence. In the next 20 inches of strata we are on an horizon evidently lower than that of the 'Fossil Bed' of Sandford Lane, and Bed 10 can be correlated with Beds 9 or 10 at Sandford Lane. The strata of the true *concavi* hemera were not reached, and without a larger excavation it was difficult to go deeper down. It was considered that the evidence as to having reached an horizon decidedly below the 'Fossil Bed' of Sandford Lane was sufficient.

The identity or otherwise of the Sandford Lane 'Fossil Bed' and the green-grained marl of Frogden Quarry, Oborne, still remained to be settled. I therefore made a fresh section at Oborne, but, as the quarry was not being worked, the *exact* position of a large

[1] A characteristic fossil of the Bradford Abbas 'Fossil Bed.'

number of species known to have been obtained from the ironshot beds—Nos. 3–7—could not be determined. Those quoted are what were obtained *in situ* at the time.

Section XV.—*Frogden Quarry, usually known as the Oborne Quarry.* (From Sherborne Abbey, $1\frac{1}{2}$ mile N.E.)

			Feet.	Inches.
Garantianæ.	F.	1. Hard, grey limestone in several layers...	4	0
		2. Yellowish, sandy stone and sandy partings,—six layers of each, varying from 2–10 inches in thickness	4	9
Niortensis.	G.	3. Hard, and soft, brown stone irregularly mixed—the soft sandy, the hard ironshot. Fossils mostly towards the top. '*Œcotraustes cadomensis*,' *Parkinsonia niortensis* (d'Orb.), *Park.* n. sp., *Ancyloceras*, *Strigoceras*, various species. *Terebratula sphæroidalis*. (*P. niortensis* apparently confined to the top, *P.* n. sp. running through the bed)...	1	0
		4. Hard, brown ironshot stone, *Terebr. sphæroidalis* numerous, '*Perisphinctes*' *Davidsoni*, *Parkinsoniæ* (spp. aff. *Caumontii*), *Œcotraustes genicularis* (Waag.). *Sphæroceras* sp. *Brongniarti*?		10
		5. Thin, earthy parting in some places, preceded by brown, sandy limestone, somewhat ironshot, with *Parkinsoniæ* sp., *Stephanoceras Banksi* (Sow.), & '*Perisphinctes*' *Davidsoni*..............	1	4
Humphriesiani.	H.	6. Brown, ironshot, rather soft limestone with *Belemnites*	1	0
		7. Hard, brown, ironshot limestone, *Stephanoceras Blagdeni*, '*Steph. Braikenridgii*'		8
	I? J *pars*?	8. Hard, greyish-brown, ironshot limestone with *Oppelia* sp. and *Terebr. sphæroidalis*		7
Sauzei & *Witchelliæ.*	J & K.	9. Soft, green-grained, white marl, with numerous fossils, *Witchellia Sutneri* and '*læviuscula*,' *Sonninia* aff. *patella*, '*Stephanoceras*' *Sauzei*, *Sphæroceras Brocchi*, *Oppelia* sp., *Pleurotomaria granulata*, *Amberleya obornensis*, etc.[1]		5
		10. Hard, blue, sandy limestone with some green grains		7
		11. Brown, sandy parting		2
		12. Hard, blue, sandy limestone		6
Discitæ?		13. Unseen .... about	11	0
Concavi.		14. Hard, blue limestone with earthy partings. *Lioceras concavum*, *Terebratula Eudesi*, *T. perovalis*, *T. cortonensis*, *Rhynchonella Forbesi*, *Lima Etheridgii*, *Gryphæa* like *sublobata*, *Pleurotomaria actinomphala* (cast)	2	0

[1] Bed 9 = *Sauzei*-bed or zone *auctorum*. For the gasteropoda, see Hudleston, Palæont. Soc. vol. xl. *et seq.*

Note on Frogden.—The ironshot oolite, Beds 3–8, quarried for road-metal, has yielded a large series of Ammonites; but, as it was thought sufficiently precise to label them '*Humphriesianum*-zone,' simply, exact information as to their position is wanting. Mr. Hudleston first pointed out the necessity of distinguishing the upper part by name when he called it '*cadomensis*-beds.'[1]

Bed 5, with the numerous large specimens of *Stephanoceras Banksi*, is an easily-noted horizon. It seems to be a separable, third portion of the Ironshot. The two or three beds below are those from which have come numerous Stephanocerata of the *Humphriesianum*-type, and also, subject to correction, *Pœcilomorphus cycloides*, *Dorsetensia Edouardiana*, *D. pulchra*, *D. liostraca*, *D. complanata*, *D. tecta*, *D. subtecta*, *Sphæroceras Wrighti*, *Sph. Gervillii* (Sow.), *Lissoceras oolithicum* (d'Orb.). At this horizon is the acme of *Stephanoceras*, and apparently the last stage of the paracme of the *Sonnininæ*.

Beds 1, 2 are the base of the 'Building-stone,' or equivalent thereto. Beds 3, 4, and perhaps 5, may illustrate a thicker deposit laid down contemporaneously with that at Clatcombe (p. 497) marked *niortensis* hemera; beds 3 and 4 are certainly equivalent thereto. Bed 7 must be correlated with the top bed of Section XIV., whereby this Section (XV.) proves that there can be little wanting between the top of Section XIV. and the bottom of Section XIII. I think it very probable that part of 8 is equivalent to part of 3, Section XIV., and Bed 9 is equivalent to all or part of the Sandford Lane 'Fossil Bed.' I say 'part,' because I have never been able to record from this quarry any of the *fissilobata*-type of Ammonite, nor any of the species allied to '*Sonninia*' *Stephani*, which are so characteristic of the bottom part of the Sandford Lane 'Fossil Bed.' The commonest and most characteristic Ammonites belong to the genus *Witchellia*, of which there are many unnamed species; and this genus is far more numerously represented at Frogden than at Sandford Lane. Species of the *propinquans*-type and '*Stephanoceras*' *Sauzei* indicate the correlation of part of this bed with the upper part of the Sandford Lane 'Fossil Bed.' I seem to have been far more fortunate than Mr. Hudleston in finding *Sauzei* in this bed; though it cannot be called the dominant fossil, it is the one most easily identified.[2] Little of the strata below this bed was exposed, which is to be regretted. About 12 feet below it strata of the *concavi* hemera were found, and some belonging perhaps to that of *discites*: at any rate there is no difficulty in correlating the 2 feet shown with the Beds 9–11 of Sandford Lane. In that case there is a great thickness of strata between *concavum* and *Witchellia* which certainly wants investigation.

Some twelve years ago, when I had the opportunity of working in this quarry frequently, I found *Rhynchonella ringens* in the bank below and recorded it.[3] I could not do so on this occasion.

About ½ mile east from here, on the other side of the village,

[1] 'British Jurassic Gasteropoda,' p. 47, Palæont. Soc. 1887. [2] *Ibid.* p. 48.

[3] Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 589. The specimens are in my cabinet now.

there is a road-section which is remarkable because of the attenuation of the strata deposited during the *Humphriesiani* and *niortensis* hemeræ. The following is the section:—

SECTION XVI.—*Oborne; Quarry and Road-cutting east of the village.* (From Sherborne Abbey, 1 mile 7 furlongs N.E.)

			Feet.	Inches.
Garantianæ.	F.	1. Yellow, sandy limestone in blocks, about	20	0
Niortensis.	G.	2. Hard, grey, shelly limestone. *Parkinsonia niortensis, Park.* n. sp. aff. *Garantiana, Œcotraustes cadomensis, Terebratula sphæroidalis*, abundant	1	3
Humphriesiani.	H.	3. Brown, ironshot limestone. In the bottom part of this bed *Lima proboscidea* was found in a lump of green-grained matrix, apparently redeposited		3
		4. Hard brown ironshot limestone enclosing green-grained lumps of marl, *Sonninia* sp.		3
Sauzei.	J.	5. White marl with green grains, partly cemented to the bed below by a shelly matrix. '*Witchellia læviuscula*,' *Witch.* sp., *Sphæroceras Brocchi.* Two species of *Stephanoceras*, one 'crassicostate,' the other 'planulate,' *Lima proboscidea, Acanthothyris paucispina*, Buckm. & Walker, *Pleurotomaria granulata* (Sow.), *Amberleya obornensis*, Hudl., *Cerithium* sp.		4
Witchelliæ.	K.	6. Hard, bluish limestone, in several layers with earthy partings. At the top a large *Witchellia*, 16 in. (40 cm.) across, in very poor condition	3	0

Bed 5 may obviously be correlated with the marl-bed of Frogden. Above this some erosion and re-deposition evidently took place; and certainly an extremely small amount of sediment was deposited during the *Humphriesiani* hemera. Rather more was deposited during that of *niortense*; but its lithological condition is quite different from that of Frogden. Altogether only 1 foot 9 inches of strata at the most intervenes between the 'BUILDING-STONE' equivalent and the green marl, while at Frogden, half a mile distant, there is more than 5 feet.

About 1 mile and 3 furlongs northward is the last section to be described.

SECTION XVII.—*In a road-cutting at Milborne Wick, Somerset.* (On the road to Pointington, about 3 miles N.E. of Sherborne Abbey.)

			Feet.	Inches.
Garantianæ.	F?	1. Light yellow, sandy limestone ... about	8	0
Humphriesiani.	H.	2. Soft, white, chalky limestone (forms a paste when wet). '*Stephanoceras Braikenridgii*,' *Pœcilomorphus cycloides, Sphæroceras Wrighti, Oppelia* aff. *subradiata, Dorsetensia liostraca*, S.Buckm.,		

			Feet.	Inches.
		Pleurotomaria granulata, Sow., *Astarte spissa*, S. Buckm., *Terebratula sphæroidalis*, Sow.		4
		3. Grey limestone, with iron grains. *Stephanoceras* cf. *subcoronatum* (Oppel), *St.* cf. *Blagdeni*, '*St. Braikenridgii*,' *Terebratula sphæroidalis*		6
Sauzei.	J.	4. White limestone, with *Pleurotomaria granulata*, *Sphæroceras perexpansum*, S. Buckm., *Sph. Brocchi* (Sow.), '*Stephanoceras Braikenridgii*'		6
		5. Hard, grey crystalline limestone. At the top softer, speckled with green grains, and containing *Astarte spissa* and *Belemnites*..............................	1	2
Witchelliæ.	K.	6. Grey sandy limestone, with large *Witchellia* sp., 1 ft. 6 in. from the top. Part of the periphery of a large Ammonite of the *Sphær. Brocchi*-type, showing in the rock 9 feet from the top. Ditto of a large *Sonninia* 9 ft. 8 in. from the top of the bed	13	2
Discitæ.	L.	7. Brown limestone. *Rhynchonella Forbesi* and *Belemnites*		10
		8. Grey, sandy, crystalline limestone, with earthy partings	2	6

In this section may be remarked, first the apparent absence of strata of the *niortensis* hemera, or any indicating fossils; secondly, the very great thickness of the strata which I correlate with the lower part of the 'Fossil Bed' of Sandford Lane. Fossils seem to be somewhat scarce at this horizon; but, evidently, from a geological point of view, a workable opening of this and 'the lower beds' in this neighbourhood would be very desirable.

Review of the Sections.—The chief point which is noticeable is that during any given hemera there was a very large amount of strata deposited at one place, and at another extremely little; further, that the localities of maximum and minimum deposits continually changed. The most striking example is Halfway House, as compared with Sherborne.

Hitherto the top beds of Halfway House and the top beds of Sherborne have been considered as the '*Parkinsoni*-zone'; and in the absence of any explanation to the contrary, this term left it to be understood that the strata were contemporaneous. Further, the use of the term '*Parkinsoni*-zone' in so comprehensive a manner was fatal to any appreciation of the true sequence; it not only suggested that further distinction of horizon was unnecessary, but it gave to the fossils so labelled a supposititious contemporaneity which they did not deserve. In this paper I can show the true relations of these 'top beds.'

In regard to the maxima and minima of deposits, it is interesting to notice not only how they shift from one place to another in successive hemeræ, but how they are connected with the horizontal extension of the strata. The following analysis will demonstrate these points.

In the *Murchisonæ* hemera the strata overstepped those of the preceding hemera, for certainly at Bradford Abbas and at Stoford the sequence leading up to the strata of the *Murchisonæ* hemera is not complete. The thickness of the strata deposited during this hemera increases towards the north-east; and the greatest thickness noted is 11 feet at Marston Road Quarry as compared with less than 2 feet at Stoford. In the *bradfordensis* hemera the facts are similar. In the *concavi* and *discitæ* hemeræ the maximum of deposition was probably at Frogden, or eastwards thereof. Horethorne Down gives 9 feet, which seems to belong mostly to the *discitæ* hemera; but the section is incomplete. Frogden gives about 12 feet between *Lioceras concavum* and the *Witchellia*-beds; so that perhaps as much as 15 or 16 feet of strata may have been deposited in the district during these hemeræ.

During the hemera of *Witchellia* sp., the horizontal area of deposition appears to have contracted; for the signs of any *Witchellia*-fauna, which is shown to such perfection at Sandford Lane and Frogden, are of the feeblest in the Bradford area—one might almost say there is practically no sign. There was evidently, however, an overstep again in the *Sauzei* hemera, for the strata of this time are clearly shown as far west as Stoford. It may be noted that the thickest accumulation of deposit during the above hemeræ is about 14 feet at Milborne Wick—the most easterly point.

With the *Humphriesiani* hemera there was again a recession, for certainly Halfway House is the most westerly point at which the strata of this time can be properly identified. The same is the case with the *niortensis* hemera. It may be noted that the deposits formed during both these hemeræ at Louse Hill are evidently complete, and have suffered no denudation; for there are the two distinct beds overlain by the band with *Aulacothyris* '*Meriani*, var.' It is simply a case of slow deposition. At Sandford Lane, however, about 2 miles to the east, it would appear that any strata deposited during the *Humphriesiani* and *niortensis* hemeræ have been removed, some time before the deposition of the bed with *Aulacothyris* '*Meriani*, var.' The idea of removal is suggested by the very flat top of the Sandford Lane 'Fossil Bed.' Then about $\frac{1}{2}$ mile to the east the strata deposited during the *Humphriesiani* and *niortensis* hemeræ are preserved, and at Frogden, $1\frac{1}{2}$ mile distant, as much as 5 feet of very fossiliferous strata was deposited during these two hemeræ.

Was this the locality of maximum deposition during these hemeræ? Looking at the strata laid down during the preceding hemeræ, it may be seen that the localities of maximum deposits noted are a few miles eastward of the localities which are most fossiliferous; and there seems to have been a gradual advance of the fossiliferous area eastward. For instance, during the *concavi* hemera Bradford Abbas was certainly the headquarters of the mollusca, and the neighbourhood of Frogden the place where, so far as we know yet, most deposit accumulated; during the *Witchelliæ* hemera the molluscan headquarters had shifted to Sandford Lane, and the most sediment was collected at Milborne Wick; during the *Humphriesiani* and *niortensis* hemeræ the mollusca evidently congregated at Frogden, and in that case, considering the conditions found to have obtained during previous hemeræ, the maximum deposit of sediment should be looked for eastward or south-eastward of Milborne Port.

Now, however, came a very great change; and it is noticeable that this change almost coincides with the commencement of the Bathonian, as advocated by some French authors. During the *Garantianæ* hemera the maximum deposit is found to have moved back westward—it is in the neighbourhood of Clatcombe. The fossils are not there in any great numbers, nor are they very numerous at Halfway House or Bradford Abbas, where the deposit was so small; perhaps they lie unseen between Halfway House and Sherborne—the area of no openings. This is not unlikely, for, rather later, in the *Truellii* hemera, mollusca were plentiful at Halfway House, in the 'Fossil Bed'; and this means a decided westerly faunal migration.

During the succeeding hemeræ, however, the westerly faunal migration, followed by westerly movement of deposit, is still more remarkable. The deposit at Halfway House is very great in the 'top beds'; but the mollusca left the district altogether before such an accumulation of sediment. It is necessary to go nearly 11 miles W.S.W. from Halfway House, in fact to Crewkerne Station, before the mollusca are found sufficiently numerous to constitute a 'fossil-bed.'

In order to bring these variations of deposit more clearly into view, I have constructed a tabular analysis of the various sections (Table I. p. 506). The localities are arranged from east to west in their order, with regard to a line from Stoford to Milborne Wick, those off the line being placed in the position where they would meet the line at right angles.

The maxima of deposit given in the last column are certainly instructive, for they show that the 'Inferior Oolite' of the district is really very much thicker than was supposed to be the case. When the various maxima are added together, a result of 130 feet is obtained. Putting Marston Road, Sandford Lane, Combe, and Clatcombe together as exposures in a limited area, showing nearly the full sequence, we obtain 72 feet 6 inches as possibly to be found in one section in the neighbourhood; and adding to this, say 20 feet, for the top beds, which have been denuded, and which probably lie on the dip under Sherborne, a possible 92 feet is obtained.

The results of the analysis of the deposits I have shown diagrammatically in Table II. (facing p. 508); and very interesting these results are. This Table must be read in conjunction with Table I., and some of the measurements are necessarily not of absolute accuracy, owing to incompleteness of exposures; but the chief deficiencies

Table I.—*Showing the Thickness of Deposit during the various Hemeræ at the different Localities, and also the Maxima of Deposit.*

Hemeræ.	Stoford.	Bradford Abbas.	Halfway House.	Louse Hill.	Marston Road.	Sandford Lane and Combe.	Clatcombe.	Upper Clatcombe.	Frogden.	Oborne Village.	Holway Hill.	Horethorne Down.	Seven Sisters.	Milborne Wick.	Maxima of Deposits.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Fuscæ .... } *Zigzag*	3 10	17 0	33 6	...	...	...	...	...	...	...	...	...	...	...	33 6
Truellii	3	3	1 1	...	...	20 0	...	...	...	...	...	...	...	...	20 0
Garantianæ	9	6	... } 6	... 5	...	30 0	29 0	...	...	...	...	...	...	...	30 0
Niortensis	...	...	...	...	...	...	1 6	...	3 2	1 3	...	...	...	...	3 2
Humphriesiani	...	...	... } 5	3	...	[1]	...	2 0	2 3	3	...	...	...	10	2 3
Sauzei	6	4	...	5	...	4	...	9	} 1 0[2]	4	...	...	...	1 8	1 8
Witchelliæ	...	...	...	...	...	1 5	...	1 3	...	...	...	...	...	13 2[1]	13 2
Discitæ	... } 8	7	5	10	...	1 3	...	...	} 13 0	...	...	9 0[3]	8 0[3]	...	13 0
Concavi	...	1 4	2 7	2 4	...	3 0	...	...							
Bradfordensis	...	1	4	4	2 0	...	...	...	...	...	2 3	...	...	...	2 3
Murchisonæ	1 9	1 3	2 6	3 10	11 0	...	...	...	...	...	9 6	...	...	...	11 0
														Total	130 0

[1] Has probably been removed by erosion.
[2] Lower part somewhat hidden; may probably be thicker.
[3] Sections incomplete; probably thicker.
[4] Possibly a little too thick; some may belong to *discitæ*.

are pointed out in Table I. From these two Tables it may be seen that from the *Murchisonæ* to *Sauzei* hemeræ the area of maximum deposit was apparently shifting from west to east, and from *Garantianæ* to *fuscæ* it was shifting from east to west. Apparently the line of inclination shown for the strata of the *Truellii* hemera is against this statement; but it is noticeable that the line begins to rise before that of *Garantiana*. I suggest that, if we had an opening between Halfway House and Sherborne, the area of maximum deposit would be found, and that the line would then run as shown by the dots.

It should be noted that the various localities have been placed in order according to their position at right angles to the line, as in Table I.; but here they are to scale. As very different vertical and horizontal scales have been used, the inclination is excessively exaggerated. As a matter of fact, in the steepest of the inclinations shown, the rise is not more than 1 in 400.

I have marked the most fossiliferous localities by means of circles. It must be understood that these are not the only localities where fossils occur, but the best localities. It will be noticed that there is the same recession eastward up to *Humphriesiani-niortensis*, and later a progression westward. The following list gives the principal strata in their relative descending order, and it will show the different localities and horizons of the 'fossil-beds.'

The 'Inferior-Oolite' Strata of the Sherborne District (*generalized*).

The top beds, the limestones of Halfway House.
The 'Fossil Bed' of Halfway House.
The 'Building-stone' of Sherborne.
The 'Road-stone'—the Ironshot Oolite of Frogden. The 'Fossil Beds.'
The 'Fossil Bed' of Sandford Lane.
The 'Fossil Bed' of Bradford Abbas.
The 'Paving Bed' of Bradford Abbas.
The 'Dew Bed' of Bradford Abbas, etc.

Correlation of the Strata.

1. Correlation with adjacent Districts.

(a) *Correlation with South Dorset.*—In this connexion it is not my intention to enter into any particular details. I hope to investigate the beds of that district still more closely than I have hitherto done, and in such work the knowledge obtained from the Sherborne district will be especially valuable. The results of that future work I hope to lay before the Society. At present, all that I need say about the South Dorset strata as compared with those of Sherborne is this: that Hudleston's P_1[1] can be correlated with great exactness with the 'Building-stone' of Sherborne, *plus* part of the overlying ragstones. It comes in, in fact, exactly where Hudleston supposed it did, so that my researches confirm his critical knowledge of the deposits. Speaking of the *cadomensis*-beds of

[1] 'British Jurassic Gasteropoda,' p. 31, Palæont. Soc. 1887.

Frogden, he says (*op. cit.* p. 48) :—" This horizon or sub-stage cannot be very far from that of P_1 at Burton Bradstock. However, this must be lower in the geological scale, though not much." As his *cadomensis*-beds were deposited during my *niortensis* hemera, the above remarks state the case exactly.[1]

(b) *Correlation with Dundry.*—The chief interest which attaches to correlation with Dundry is in regard to what has been hitherto considered as the typical '*Humphriesianum*-zone' of that locality, though I had ventured to place it somewhat lower, namely, the 'Ironshot.' The following outline-section will explain the beds sufficiently for correlation at present.

Section XVIII.—*Outline Section of the top of Dundry Hill.*[2]

		Feet.	Inches.
	1. Coral-bed and Building-stone ....about	25	0
Sauzei.	2. The 'Ironshot.' Hard brown Ironshot Oolite with a very level top. The horizon of Sowerby's types of *Ammonites Sowerbyi* and *corrugatus*[3] (probable horizon of his *contractus* and *Braikenridgii*, the latter presumably not the same as is called '*Amm. Braikenridgii*' generally; neither of these two types to be found). '*Stephanoceras*' *Sauzei*, *Sonninia* cf. *propinquans*, *Sonn.* cf. *mesacanthus* (Waag.), *Acanthothyris paucispina*, numerous *Pleurotomariæ*	1	0
Witchelliæ.	3. 'White Ironshot.' White stone with numerous iron grains, which decrease in size downwards, giving the stone a still whiter appearance. Softer than the bed above, more affected by the weather. The horizon of Sowerby's types of *Ammonites læviusculus* and *A. Browni*. Contains a large assortment of *Witchelliæ*, also '*Sonninia*' *Stephani*, *Sonn.* cf. *fissilobata*, numerous *Oppeliæ*	1	6
Discitæ. *Concavi.*	4. Limestone and marl. *Lioceras concavum*, *Hyperliocerata*, *Terebratula Eudesi*, *T. cortonensis*	6	0

It is easy to see that Beds 2, 3, 4 were deposited during the hemeræ of *Sauzei-concavi*; in fact, that they were contemporaneous with Beds 6–13 of Sandford Lane. To be more precise, Bed 2 of Dundry was contemporaneous with the upper four inches of Bed 6 of Sandford Lane, and Bed 3 with the rest of the Sandford Lane 'Fossil Bed.' It is noticeable that at Dundry the thickness of strata in the *Witchelliæ* and *Sauzei* hemeræ is greater than at Sandford

[1] It is necessary to explain that, as a designation for the hemera during which the '*cadomensis*-beds' were deposited, *niortensis* has been chosen instead of *cadomensis*, to avoid any risk of confusion in discriminating between various species of *cadomensis*-like Ammonites, which occur at different horizons.

[2] This is only an outline-section, but sufficient for the present purpose. Mr. Edw. Wilson, F.G.S., and myself hope to make a more detailed investigation of Dundry shortly.

[3] I speak from examination of the matrix of the type-specimens.

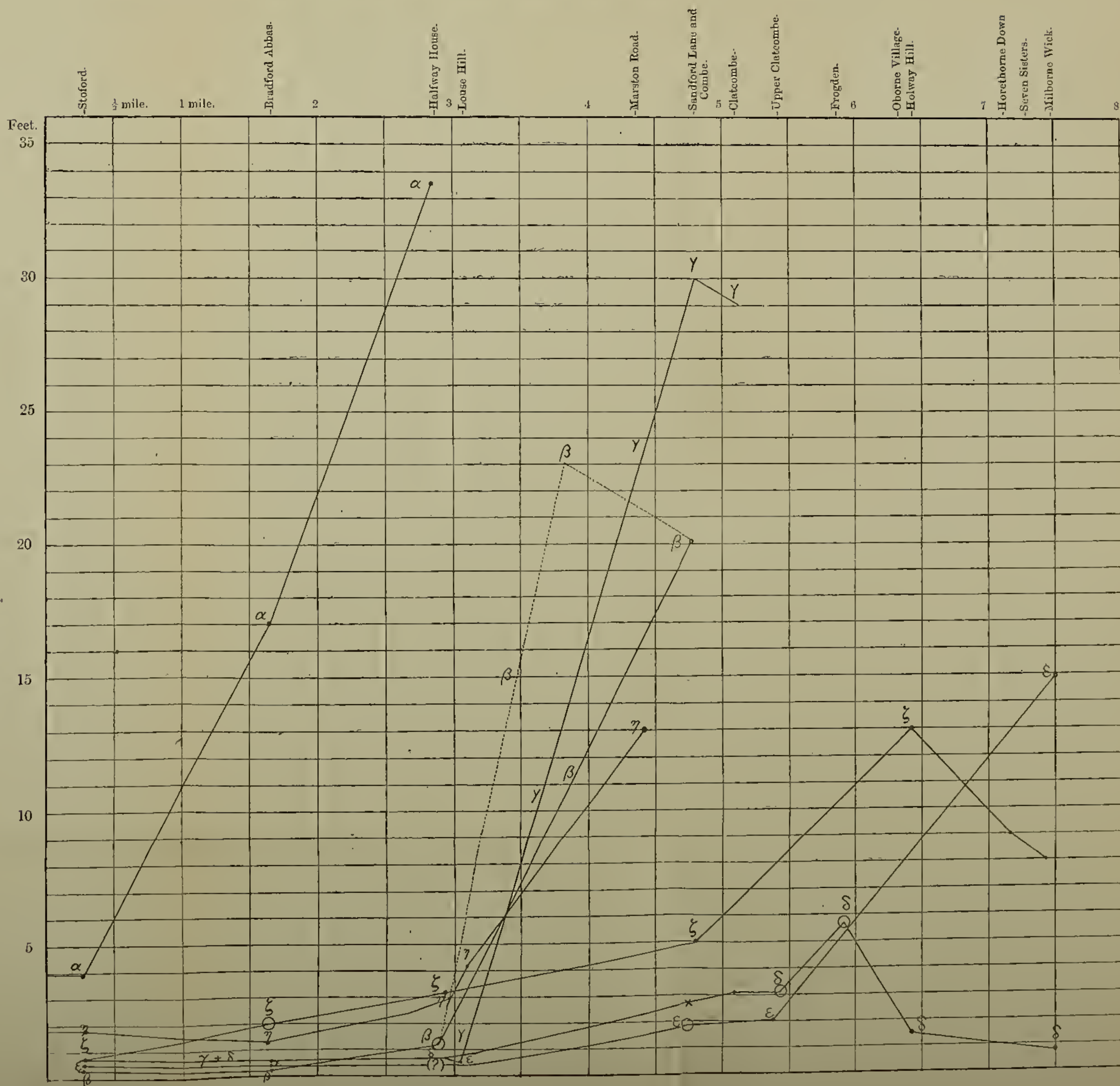
TABLE II.—*Diagrammatic Table showing the Thickness of Deposit at various times.*

Horizontal scale (in half-miles) 1 inch = 1 mile. Vertical scale (in feet) 1 inch = 5 feet (1 cm. = 2 feet).

Hemeræ.

- *Fuscæ* and *zigzag* = α.
- *Truellii* = β.
- *Garantianæ* = γ.
- *Niortensis* and *Humphriesiani* = δ.
- *Sauzei* and *Witchelliæ* sp. = ϵ.
- *Discitæ* and *concavi* = ζ.
- *Bradfordensis* and *Murchisonæ* = η.
- Molluscan headquarters (most fossiliferous localities) = ○.

The best fossiliferous localities of η and α are west or south-west of the district.



Lane, and the necessity for distinction is the more obvious, more particularly as the lithology differs. A more detailed investigation than it is possible to make in casual visits—for the beds most wanted by the geologist are those least worked—will reveal how much of Bed 4 was deposited during the *discitæ* hemera, and whether some of it may not have been laid down during the hemera of *Witchellia* sp., or inversely. It will fill in the details to this outline, but is not likely to alter the main facts. One of these—that the 'Ironshot' of Dundry must not be correlated with the 'Ironshot' of Sherborne, or the 'Oolithe ferrugineuse' of Bayeux, but is of earlier date, *Sauzei* hemera, is most important. This is the key to the enigma which the correlation of the Dundry strata has always presented; it was the excavation at Sandford Lane that furnished this key.

There is a closer agreement between Dundry and Sandford Lane in many respects than between Sandford Lane and neighbouring quarries. From both, the strata of the *Humphriesiani* and *niortensis* hemeræ are absent; and even such a small detail as the remarkably level top of the bed of the *Sauzei* hemera is common to both.

(c) *Correlation with the Cotteswolds.*—The strata which make up what has been usually known as the 'Inferior Oolite Limestone' have been subdivided and distinguished by certain names. These names, though they have no more than local significance, are yet extremely useful within certain limits. They will indicate the beds with sufficient precision for my present purpose, and I therefore give the following list of the succession in descending order:—

THE COTTESWOLD 'INFERIOR OOLITE.'

'Fullers' Earth Clay.'	Characteristic Fossils.
Limestone-beds above the *Clypeus*-grit.[1]	
The *Clypeus*-grit.	*Clypeus Plotii*, *Terebratula globata*.
The Upper *Trigonia*-grit.	*Rhynchonella subtetrahedra*, Dav., *Rh. hampenensis*, S. Buckm.
The Notgrove Freestone.[1]	
The Gryphite-grit.	*Gryphæa sublobata*, *Sonninincæ*.
Sandy limestones (no name).	*Terebratula Buckmani*.
The Lower *Trigonia*-grit.	*Aulacothyris Meriani* (Oppel).
The Harford Sands.[1]	
The Upper Freestone.	*T. fimbria*, the very plicate form.
The Oolite Marl.	*T. fimbria*, the less plicate; '*T. curvifrons*.'
The Lower Freestone.	
The Pea-grit.	*Rhynchonella oolitica*, *Rh. subangulata*, *Terebratula plicata*.
The Lower Limestone.[2]	
The Sandy Ferruginous Beds.[2]	*Rhynchonella subdecorata*, Dav.
The 'Cephalopoda-bed.'	

[1] 'The Inferior Oolite, etc.,' Proc. Cotteswold Nat. Field Club, vol. ix. (1887) p. 108.

[2] E. Witchell, 'Basement Beds Inf. Oolite,' Quart. Journ. Geol. Soc. vol. xlii. (1886) pp. 264 *et seqq.*, and Proc. Cotteswold Nat. Field Club, vol. viii. (1882) pp. 35 *et seqq.*

The series just given is the most complete that has yet been recognized, but many of the beds are of only limited horizontal extension. They occur, however, over a wider area than is usually supposed, and the above are their relative positions in the complete sequence.

Beginning the correlation at the bottom, the Sandy Ferruginous Beds are to be exactly identified with Bed 3 of the Marston Road section. The Cotteswold area shows clearly enough that the greater part of them were laid down after the *Opalini* hemera, and long before the *Murchisonæ* hemera. The large amount of sediment deposited in the Cotteswolds demonstrates the fact clearly; in Dorset and Somerset the paucity of sediment obscures it. The fact, however, remains, and for determining the true chronological succession appeal must be to where most strata were deposited. It will no doubt be necessary to recognize the space of time during which these strata were deposited as a hemera with a separate name.

The Lower Limestone is too bare of fossils to be correlated with certainty. It is usually classed with the Pea-grit Series.

The Pea-grit has yielded *Ludwigia Murchisonæ*; and its brachiopod-fauna also shows that it was deposited during the *Murchisonæ* hemera.

The Lower Freestone is bare of fossils; it is generally classed with the Pea-grit.

The Oolite Marl and Upper Freestone are connected by the presence of *Terebratula fimbria* and other brachiopoda; and they have yielded poor Ammonites of the *Lioceras bradfordense*-type. Though Wright[1] did arbitrarily separate the Upper Freestone from the Oolite Marl to place the former in the *Humphriesianum*-zone, and the latter in the *Murchisonæ*-zone, there is to my mind neither any reason for their separation[2] nor any ground to doubt that they were both deposited during the *bradfordensis* hemera.

Of the Harford Sands I can say nothing, except that from their position there is just the chance that they may have been deposited during the *concavi* hemera. It may, however, be remarked that their position below the Lower *Trigonia*-grit is founded on the assumption that the beds which lie above them in the Northern Cotteswolds are really contemporaneous with the Lower *Trigonia*-grit of Leckhampton. This may, perhaps, be considered as an open question.

I make the above remark because the correlation of the Lower *Trigonia*-grit has actually been obscured by confounding it with the Gryphite-grit. A *Gryphæa* occurs in both, but from observations recently made at Leckhampton I should say that the *Gryphæa* of the Lower *Trigonia*-grit has certainly a smaller anterior expansion (commonly 'wing') than the form of the Gryphite-grit proper, in which the wing or lobe is abnormally developed. Further, in the Gryphite-grit proper the *Gryphæa* is very abundant; in the Lower *Trigonia*-grit it is not more prevalent than other lamellibranchiata.

[1] Wright, 'Lias Ammonites,' pp. 151 *et seqq.*, Palæont. Soc. 1879.

[2] See Witchell, 'Geology of Stroud,' 1882, p. 52. The Upper Freestone is included in the *fimbria*-stage of Lycett, 'The Cotteswold Hills,' 1857, p. 44.

From what he called 'Gryphite-grit' of Frith Quarry and of Rodborough Hill, near Stroud, the late Mr. E. Witchell, F.G.S., obtained Ammonites of the genera *Hyperlioceras*, *Sonninia*, and *Stephanoceras*. The particular species of these genera found are all known as characteristic of the '*concavum*-zone' of Bradford Abbas, and with such I therefore correlated the Cotteswold Gryphite-grit.[1] However, for the greater precision aimed at in the present paper, such a correlation is not sufficiently exact. The question now is whether these strata were deposited during the *concavi* hemera, or the *discitæ* hemera, or both.

The species of *Hyperlioceras* indicate that these strata were laid down during the *discitæ* hemera, and the absence of any species of the abundant *Lioceras concavum*-type makes it appear very improbable that we have as yet detected any Cotteswold strata which were deposited during the *concavi* hemera.

On correlating the so-called 'Gryphite-grit' of Frith Quarry with the Lower *Trigonia*- and Gryphite-grits of Leckhampton, I was forced to the conclusion that Witchell's application of the term 'Gryphite-grit' to the Frith bed cannot be maintained. In lithological composition, in the relative paucity of the *Gryphæa*, in the possession of several *Trigoniæ* and numerous other lamellibranchiata it agreed exactly with the strata called 'Lower *Trigonia*-grit' at Leckhampton.[2] Further, I found in the true Gryphite-grit of Leckhampton Ammonites of the hemera above *discites*, viz., that of *Witchellia* sp.

This becomes very important. The identification of, and the distinction between, Lower *Trigonia*- and Gryphite-grits must be rigidly exact. It is not, as has usually been taught, the Lower *Trigonia*-grit, but it is the Gryphite-grit which is absent from Frith Quarry, if anything is wanting. Further, by the identification of Witchell's Gryphite-grit=*concavum*-zone, and the superjacent Upper *Trigonia*-grit=*Parkinsoni*-zone, the Cotteswolds were supposed to be deficient in any strata equivalent to the typical Normandy Bajocian; but as the true Gryphite-grit was deposited during the hemera of *Witchellia* sp., strata equal to the commencement of the Bajocian, strictly so-called, *are* developed in the Cotteswolds.

As this is an important matter in regard to correlation, I give the following section of what are called the 'Ragstones' of Leckhampton.

Section XIX.—The 'Ragstones' of Leckhampton Hill.

		Feet.	Inches.
Garantianæ?	1. 'Upper *Trigonia*-grit.' Hard shelly limestone. *Terebratula globata*, Sow., *Rhynchonella subtetrahedra*, Dav., *Zeilleria Hughesi* (Walker). The lower bed, some 10 inches thick, is called by the workmen the 'Middle Bed'	5	0

[1] 'Inferior Oolite Ammonites,' p. 91, Palæont. Soc. vol. xlii. 1889.
[2] Wright, 'Lias Ammonites,' p. 151, Palæont. Soc. vol. xxxiii. 1879.

		Feet.	Inches.
Witchelliæ.	2. The 'Bored Bed.'[1] Grey oolitic limestone, much bored by annelids		7
	3.[2] Grey oolitic limestone. The equivalent of the 'Notgrove Freestone.' Being close to the surface, it is split into thin beds. *Sonnininæ*, poor casts	1	2
	4. The 'Dirt Bed.' Earthy parting		4
	5. The 'Sandy Bed.' Oolitic limestone, with numerous broken shells		9
	6. The 'Bottom Bed.' Ragstones with *Gryphæa sublobata*. This bed is in two seams, with an earthy parting. The Ammonites[3] occur in this parting (so said the workmen)	1	1
	7. Earthy parting. Ammonites[3] occasionally (*dixerunt* workmen)		2
	8. The 'Rockery Bed.' Ragstone, with numerous specimens of *Gryphæa sublobata*...		5
	9. Earthy parting, with *Gryphæa*, *Sonniniæ* of the *fissilobata*-type *in situ*....................		3
	10.[4] 'Beds below the Rockery.' Two beds, with *Gryphæa sublobata* abundant	2	3
Discitæ.	11. Shelly ragstone, with *Trigoniæ*, bored for some inches at the top		9
	12. Yellow sandy limestone, with sandy partings. A *Gryphæa* occasionally. *Terebratula Buckmani* and varieties .... about	10	0
	13. A bed of fine, bright yellow sand, like the Cotteswold Sands		5
	14. Brown limestone in thick, compact beds, with *Terebratula Buckmani*. (These beds are almost inaccessible. They are on the brow of the hill, by the windlass.)	3	0
	15. 'Lower *Trigonia*-grit.' Yellow ironshot limestone, mixed with marl and irregularly bedded. Numerous lamellibranchiata, especially *Mya*, *Homomya*, *Gresslya*, and the like. Several *Trigoniæ* and *Aulacothyris Meriani*. Occasional *Gryphææ*[5] ...	7	0
	16. Bed of earthy oolite-débris.	....	
	17. 'Upper Freestone.'	....	

[1] See 'The Inferior Oolite, etc.' Proc. Cotteswold Nat. Field Club, vol. ix. (1887) p. 111.

[2] Beds 2 and 3 are called by the workmen 'The Pitching.' At the quarry near the brow of the hill they measure 2 ft. 3 in. in thickness, at the quarry on the left only 1 ft. 2 in., and there they are bored as much as 9 in. vertically.

[3] Several large Ammonites had been recently extracted. One 18 in., one 15 in., and one 12 in. in diameter were noted, as well as several smaller. There were at least three species, and they were of the *Sonninia fissilobata*-type, inclining to *S. ovalis*. The condition was poor, that of inferior casts, without any costæ, but the septa were well shown. Specimens accurately labelled as to horizon ought certainly to be preserved in local museums, for the information of those who may visit the district. It would probably be found that there were more species than anyone anticipated, some, perhaps, not known elsewhere.

[4] Beds 6–10 form the 'Gryphite-grit.' It consists of five beds of ragstone separated by earthy partings, the *Gryphææ* abundant throughout.

[5] The *Gryphææ* found in Bed 15 have not so large and well-developed a wing as those on a higher level, in Beds 6 to 10 for instance.

In this section, assuming that Bed 15 is the same bed which has yielded species of *Hyperlioceras* at Stroud—and it occupies exactly the same position with regard to the Upper Freestone—the correlation of Bed 14 with Bed 9 of Sandford Lane (Section IX., p. 493) is rather interesting. In the Cotteswolds, *Terebratula Buckmani* is thus brought to be contemporaneous with its morphological equivalent in Dorset, *T. cortonensis*. These two *Terebratulæ* are really derivations from a common ancestor—the *punctata*-stock; and it may reasonably be supposed that the differences between them were due to the physical isolation of the Cotteswold area.[1] There is a curious parallelism and a certain contemporaneity in the development of the brachiopoda of the Cotteswolds and Dorsetshire; but the Cotteswold forms are mostly quite distinct from those of Dorset, and are peculiar to their own district.

The correspondence of Beds 6 to 10[2] of Leckhampton with the lower part of the 'Fossil Bed' of Sandford Lane in regard to its Ammonites is certainly demonstrated by the species found, and therefore Beds 11–13 of Leckhampton can only be correlated with Bed 8 of Sandford Lane. Then, up to Bed 2 of Leckhampton, are strata which, from the few ill-preserved Ammonites, seem to point to the hemera of *Witchellia* sp. rather than to that of *Sauzei*; but they are not Ammonites of the *fissilobata*-type. This becomes interesting in connexion with the suggestion that the Sandford Lane 'Fossil Bed' was deposited during more than two hemeræ (p. 495). No specimens I have seen from the Cotteswolds give any proof of any strata having been deposited during the *Humphriesiani*[3] or *niortensis* hemeræ. Such proof may be found in the northern part of the Cotteswolds; at Leckhampton it is certainly very unlikely. The 'Bored Bed'—the same bed to which I first drew attention on the Banbury and Cheltenham Railway[4]—indicates a break in the continuity of the deposition.

From such evidence as I have been able to collect at present—rather fragmentary Ammonites—the Upper *Trigonia*-grit of the Cotteswolds is equivalent to the 'Building-stone' of Sherborne; that is to say, it was deposited during the *Garantianæ* hemera.

The *Clypeus*-grit which overlies the Upper *Trigonia*-grit—in the northern Cotteswolds it exceeds 30 feet in thickness[5]—is rather a misnomer, for the *Clypeus* occurs only in the upper part of it in any noticeable numbers. Its general position with regard to the Dorset

[1] 'Relations of Dundry, etc.' Proc. Cotteswold Nat. Field Club, vol. ix. (1889) p. 374.

[2] Species of the genus *Witchellia* found by my father many years ago, labelled 'Leckhampton,' probably came from these beds; but the species of the *Sonninia fissilobata*-group are sufficiently unmistakable.

[3] No reliance can be placed on the reported occurrence of '*Ammonites Humphriesianus*,' as the incorrect use of this name is notorious. The specimens so-named which I have seen from the Cotteswolds have no resemblance to that fossil, except that they are 'coronate' Ammonites, nor do they approach any of the *coronati* of the *Humphriesianum*-beds of Dorset.

[4] Proc. Cotteswold Nat. Field Club, vol. ix. pp. 111 *et seqq.*

[5] *Ibid.* p. 133.

beds is, of course, governed by the correlation of the Upper *Trigonia*-grit; but its exact correlation is very uncertain. This is a matter which requires to be worked out by one of two methods, the geological and the palæontological, or by both combined.[1]

Table III. (facing this page) summarizes the conclusions arrived at in regard to the correlation of certain localities of the Sherborne district with themselves, with Dundry, and with Leckhampton. As the diagrams are drawn to scale, the fluctuations in accumulation of sediment may be noted.

2. Foreign Correlation.

(a) *Correlation with Württemberg.*—The correlation of the strata deposited during the different hemeræ in Dorset with the zonal divisions of Oppel, and with the α, β, γ arrangement of Quenstedt, is too obvious to need discussion here; all that requires to be noticed is the remarkable absence from Quenstedt's works of any Ammonites which lived in the *concavi* hemera; and, in fact, that they are new to science generally is fully attested by the plates in my Monograph.[2] What is necessary for me to do, however, is to point out how the Dorset strata agree with Waagen's '*Sowerbyi*-zone.'

It is evident, from what Waagen says in reference to the Dorset and Somerset strata,[3] that he regarded what we now call '*concavum*-zone' as either equivalent to or part of his '*Sowerbyi*-zone.' From the date when his work was published, and from what I know of the Sandford Lane Quarry and its working, I should doubt whether he saw any of the species of the Sandford Lane 'Fossil Bed.' However, Section IX. (p. 492) shows that this bed lies well above the strata which yield *Lioceras concavum*—that it is separated therefrom, in fact, by strata which yield *Hyperlioceras*; yet it is this 'Fossil Bed' which alone yields Ammonites of the same species as Waagen figures in his work.

Closer examination, too, shows how exactly this 'Fossil Bed' corresponds with the strata which Waagen designates *Sauzei*- and *Sowerbyi*-zones. He gives at Gingen[4]:—

1. Yellow clay, with *Belemnites giganteus.*
2. Sandy limestone, *Ammonites Sauzei*, *A. polyschides*, about 4 feet.
3. Sandy clay, *A. patella*, 20 feet.
4. Sandy clay, *A. Sowerbyi*, 2–3 feet.

It is noticeable that he places *A. patella* above *A. Sowerbyi*, although he states that he found *patella* with *Sowerbyi*, *fissilobatus*, etc., in Bed 4. Excepting *patella*, the series of Ammonites which he

[1] Owing to the scarcity of Ammonites in the Cotteswolds, fragments become of value, provided they are obtained *in situ* and are authenticated by a good label, stating the locality and the number of feet above a certain datum-line, say 'base of Upper *Trigonia*-grit,' 'top of Upper Freestone,' etc., as may be most convenient.

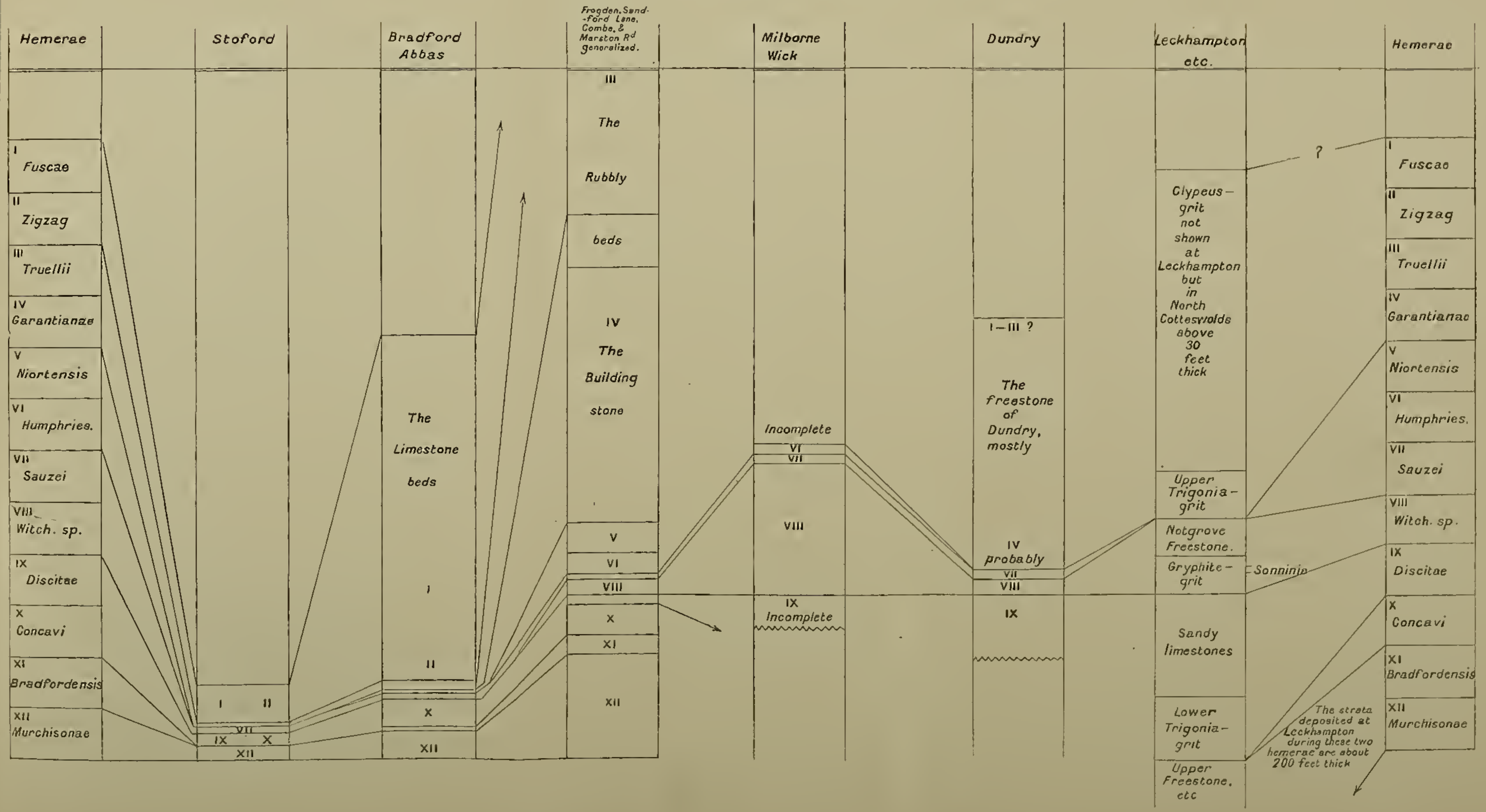
[2] Palæontographical Society, 1887–1892, *et seq.*

[3] Ueber die 'Zone d. *Amm. Sowerbyi*.' Geogn.-pal. Beiträge, Bd. i. (1867) Heft 3, p. 573 *et seq.*

[4] *Ibid.* p. 531.

TABLE III.—*Correlation of Strata: Dorsetshire, Somersetshire, and Gloucestershire.*

Drawn to scale: 1 inch = 12½ feet (1 cm. = 5 feet).



quotes for this Bed 4 (*op. cit.* pp. 532, 533) agree with those from the lower part of the Sandford Lane 'Fossil Bed'; he says nothing about these species occurring any higher, only *patella* is mentioned. In the main, then, the agreement with the Sandford Lane 'Fossil Bed' in such a particular is rather remarkable, because, though about 30 feet of the strata at Gingen are represented by 20 inches at Sandford Lane, Ammonites of the *patella*-type occur at the top, and those of the *fissilobatus*-type at the bottom.

His location of *A. Sauzei* above *patella* seems at first to conflict with my statements about its position; but it is probably explicable by a somewhat wider interpretation of '*A. Sauzei*' on my part. In the time of the *concavi* or *discitæ* hemera there were species of the *Sauzei*-type; and the series continued nearly until the time of the *Humphriesiani* hemera. Which of the various forms will eventually be found to be the true type I have not yet had time to fully investigate.

Waagen figures *A. discites* as a species of the *Sowerbyi*-zone, but not from Gingen. This, however, suggests that in certain places his *Sowerbyi*-zone strata included some which were deposited during the *discitæ* hemera. It is not difficult to see, by looking at the Sandford Lane section, that one or two of the beds below the 'Fossil Bed' might be the equivalent of the lower strata which Waagen included as *Sowerbyi*-zone. What, however, it is possible to say with very great precision is this: that Waagen's Bed 4 at Gingen, and the lower part of the Sandford Lane 'Fossil Bed,' were, by the evidence of the Ammonites, deposited at exactly the same time. The use of the name *Sowerbyi* to designate the strata of this hemera cannot, however, be allowed. The species which Sowerby figured has been incorrectly identified, and it is moreover a species which belongs to a somewhat later date; at least at Dundry it is found associated with '*Stephanoceras*' *Sauzei*. Had it been a species of the hemera of *Witchellia* sp., it would have been only just to Waagen to continue its use for that hemera.

(b) *Correlation with Normandy.*—A very interesting communication was made by Munier-Chalmas to the Geological Society of France on Dec. 5th, 1892.[1] He has evidently studied the Ammonite-horizons with very considerable care, and it is advisable to note his results, especially as they were not published till some five months after my investigations in Dorset were finished.

I. On p. 164 he says that the various strata (*les différentes assises*) of *Ludwigia Murchisonæ* can be divided into three zones:—

A. "The lower zone .... characterized by the typical *Ludwigia Murchisonæ*," also by "*Ludwigia Murchisonæ*, var. *Haugi*, Douv.; *Ludw. Murch.* var. *obtusa*, Quenst."; and "*Tmetoceras scissum* (Ben.)" is present.

B. The middle zone with "*Ludwigia Murchisonæ*, var. *Baylei*; a *Hammatoceras* near to *H. Sieboldi*; and two species of

[1] 'L'Étude préliminaire des Terrains jurassiques de Normandie.' Compte-rendu sommaire des Séances, Soc. géol. France, No. 14, 1892.

Lytoceras of the *jurense*-group"; also *Erycites*,[1] and what should be very interesting, species of *Sonninia*.

C. "The upper horizon represents only the base of the beds of *Ludwigia concava*. . . . . The middle and upper beds . . . are wanting in Normandy. . . . The numerous forms of *Ludwigia* derived from *Ludwigia Murchisonæ*[2] abound (*pullulent*) at this horizon. . . . *Ludwigia concava*, var. *v-scripta* (Buckm.), *L. cornu*, Buckm., *L. aperta* (Buckm.), *L. decipiens* (Buckm.), *L. rudis*, Buckm. *Sonninia* and *Zurcheria* are also represented."

II. "The beds of *Ludwigia v-scripta* . . . support a stratum remarkable for the important change in the genera of the cephalopoda. Numerous *Witchelliæ*, some *Pœcilomorphi*, *Lissocerata*, and *Cœlocerata*, all mostly new species, are found at this horizon."

III. "The strata with *Sonninia patella*, *S. propinquans*, . . . and *Cœloceras Sauzei*" follow.

IV. "Beds with *Witchellia Romani*, *Sonninia deltafalcata*, and *S. furticarinata* are not known in Normandy."

In comparison with what I had noted in Dorset, as shown in this paper, it will be seen that the following correlations may be made:—

I.—A	*Murchisonæ* hemera.
B	*Bradfordensis* hemera.
C	*Concavi* hemera, *pars*.
II.	*Witchelliæ* sp. hemera.
III.	*Sauzei* hemera.
IV.	Unnoticed.

It is interesting to observe that Munier-Chalmas speaks of middle and upper beds of '*Ludwigia concava*.' Not improbably his upper beds equal the "strata of the *discitæ* hemera;" but I have made no separation into two lower beds. It is, however, very evident that much attention will have to be given to these lower strata. Comparatively speaking, it is but recently that the fossils have been collected with anything like precision as to their horizons; yet far greater exactitude in noting these horizons is evidently required. In the Cotteswolds it is easy to note horizons with the greatest

[1] Munier-Chalmas calls attention to the occurrence of this genus, which has usually been considered, as he rightly observes, peculiar to the Mediterranean borders. Species of the genus from this country have been known to me for some twelve years, and I was under the impression that I had called attention to their occurrence. Such was, in fact, the case; but the statement did not make its appearance in print. The MS. was presented in 1891 to the British Association for the Advancement of Science; but in the 'short abstract' published (see Geol. Mag. for 1891, p. 502) it was not possible to advance this and other scientific facts.

[2] From my friend Dr. Haug I know that Prof. Munier-Chalmas has always held this opinion concerning the relationship of Ammonites of the *concavus*-type. I took a different view in my Monograph, but a study of the very large series of specimens contained in the collection of Mr. Darell Stephens, F.G.S., convinced me some little while back that I was in error. I had evidently been deceived by morphological equivalents.

It seemed to me not to be advisable to make this confession until I was in a position to give the fullest details at the end of the first volume of my Monograph; but in justice to Prof. Munier-Chalmas I cannot omit the present opportunity. I may say that I have also been in error concerning the derivation of *Hyperlioceras*; this genus is also closely connected by descent with *Ludwigia*.

accuracy—at least in the strata known as 'Sands and Cephalopoda-bed'; because the beds are thin, and it is possible to excavate them with the hammer at any time. In Dorset, to work the quarries, men with heavy tools and gunpowder are required, so that, if the quarries be not in work at the time of a visit, nothing precise can be done as to determination of horizons.

No. 2 of Munier-Chalmas, and again his No. 3, agree exactly with what obtains in the bottom and top of the Sandford Lane 'Fossil Bed' respectively.

The change of genera which he notes for No. 2 also conforms with our bed, compared with its predecessors; while his *Pœcilomorphi* are no doubt what I have referred to in this paper as "species allied to *Zurcheri*," and his *Cœloceras* = '*Stephanoceras*,' pars.

That this bed is overlain by strata with *Sonninia propinquans*, *S. patella*, and *Stephanoceras Sauzei* shows how necessary it was to be precise in noting the difference in the fauna of the top and bottom of the Sandford Lane 'Fossil Bed.' It can thus be shown that there is the same faunal succession in Dorsetshire, in Normandy, and in Württemberg.

No. 4 of Munier-Chalmas is apparently more restricted than the zone of '*Sonninia Romani*' of Haug.[1] I think it possible that this is an horizon which has escaped notice in our own country. There are, in my cabinet, Ammonites from the collections of Mr. Darell Stephens, F.G.S., and Mr. T. C. Maggs, F.G.S., with a matrix unknown to me, although they came from Sherborne. Their biological characters suggest that they may have lived in a hemera between that of *Sauzei* and *Humphriesianum*.

The fauna of the *Humphriesiani* hemera is given by Munier-Chalmas as occurring in strata superior to the beds of *Witchellia Romani*—his No. 5 [A], *op. cit.* p. 164. Haug's 'zone of *Sonninia Romani*' evidently combined this horizon and the preceding one.

Under No. 5 B Munier-Chalmas gives a list of Ammonites which agrees with that I have noted from the strata of the *niortensis* and *Garantianæ* hemeræ. I should remark, however, that I venture to translate his '*Oppelia Truellii*' as not the type-form of d'Orbigny. '*Cœloceras Daubenyi* (Gemm.)' occurs in this country at Burton Bradstock; but from the evidence before me—its matrix—I should assign it a date later than the *Garantianæ* hemera. Considering, however, that one by one discrepancies of this kind disappear with more precise work, no stress need be laid on it. The same may be said concerning other discrepancies—they will certainly be explained as the Ammonite-faunæ become better known.

There can be no doubt that No. 6 of Munier-Chalmas equals the *Truellii* hemera; but in No. 7 there is shown apparently a division not yet attempted in this country. In No. 8, "calcaires à *Perisphinctes zigzag*," there is no difficulty in recognizing the fauna of the *zigzag* hemera.

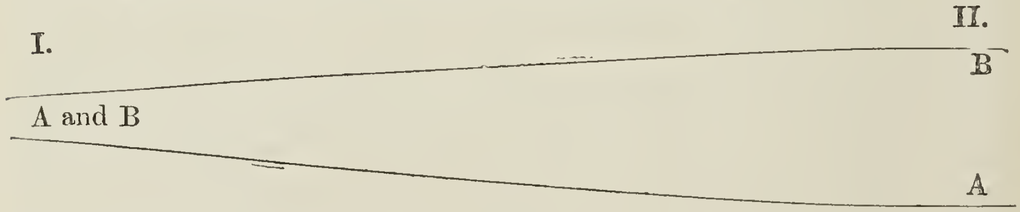
[1] 'Les Chaînes subalpines entre Gap et Digne,' Bull. Serv. Carte géol. France, tome iii. No. 21, 1891–92, p. 69. The information concerning Ammonite-horizons in this work is very interesting, especially in comparison with those of Dorsetshire. I regret that I cannot refer to it more fully now.

In the memoirs of Munier-Chalmas and Haug the identification of Ammonite-species is evidently very exact. Herein lies the value of their works for purposes of correlation; and much might be said concerning the remarkable correspondence in the faunal succession in the French Alps, in Normandy, and in Dorset. In this connexion the Table on the opposite page should be useful; it compares the faunal succession according to these authors and myself.

Conclusion.

By way of conclusion I would make a few additional remarks concerning the proposed term 'hemera.' It must be particularly understood that it is used in a chronological sense as a subdivision of an 'age.' Here I would take occasion to state what seems to be a paradox—that species may occur together in the rocks, yet such occurrence is no proof that they were contemporaneous. If the species have not been proved to be successive in other places, then their joint occurrence in the same bed may be assumed to indicate that they were contemporaneous until such proof be forthcoming. It is, however, only negative evidence. If they have been proved to be successive species, then their occurrence together only shows that the deposit in which they are embedded accumulated very slowly. Had this been rightly understood we should have been spared the stress that has been laid upon a so-called intermixture of zonal species; though I must say that too often an investigation of such supposed intermixture proves it a fiction due to inaccurate palæontology or incorrect geology.

It may be remarked that much depends on the interpretation given to 'together.' However, in this paper, in many cases—especially as regards Halfway House and Sherborne—it will be seen that species which occur together in a thin band of rock at the one place are proved to be not contemporaneous when the very much greater accumulation of strata at the other place is examined. The following diagram will show how this can be:—



In palæo-biology it is of the utmost importance to have recorded a fact such as that, at certain places, B always marks a distinctly higher horizon than A. If they are only labelled as being from the same zone, those who are unacquainted with the strata in the field may be forgiven for supposing that B may have lived before A. Several mistakes in genealogy have arisen from this cause. If, however, there be a record that B lived during a later hemera than A—that when A and B occur together it is only because of very slow deposition during the same length of time as when they occur widely separated—such mistakes can be avoided.

Table IV.

Correlation of the Zones and Hemeræ.

<table>
<tr><th rowspan="2">Haug,[1] 1891.</th><th colspan="2" rowspan="2">Munier-Chalmas,[2] 1892.</th><th>Buckman, 1893.</th></tr>
<tr><th>Hemeræ.</th></tr>
<tr><td rowspan="2">Zone à Oppelia fusca.</td><td rowspan="3">Assise à Stomechinus bigranularis.</td><td rowspan="3">VIII.
VII.
VI.</td><td>fuscæ.</td></tr>
<tr><td>zigzag.</td></tr>
<tr><td rowspan="3">Zone à Cosmoceras subfurcatum.</td><td>Truellii.</td></tr>
<tr><td rowspan="3">Assise à Oppelia subradiata.</td><td rowspan="2">V. B.</td><td>Garantianæ.</td></tr>
<tr><td>niortensis.</td></tr>
<tr><td rowspan="2">Zone à Sonninia Romani.</td><td>V. [A.]</td><td>Humphriesiani.</td></tr>
<tr><td>Assise à Sonn. deltafalcata.</td><td>IV.</td><td></td></tr>
<tr><td rowspan="2">Zone à Sphæroceras Sauzei.</td><td>Assise à Cœloceras Sauzei.</td><td>III.</td><td>Sauzei.</td></tr>
<tr><td>Assise à Witchellia sp.</td><td>II.</td><td>Witchelliæ sp.</td></tr>
<tr><td rowspan="2">Zone à Harpoceras concavum.</td><td rowspan="2">Assise à Ludwigia concava.</td><td></td><td>discitæ.</td></tr>
<tr><td rowspan="3">I. { C.
B.
A.</td><td>concavi.</td></tr>
<tr><td rowspan="2">Zone à Harpoceras Murchisonæ.</td><td rowspan="2">Assise à Ludwigia Murchisonæ.</td><td>bradfordensis.</td></tr>
<tr><td>Murchisonæ.</td></tr>
</table>

[1] 'Les Chaînes subalpines entre Gap et Digne,' Bull. Serv. Carte géol. France, tome iii. No. 21, 1891–92, pp. 61–81.

[2] Compte-rendu sommaire des Séances, Soc. géol. France, 1892 No. 14, pp. 164–167.

Summary.

The following is a summary of the facts and conclusions advanced in this paper:—

I. The term 'hemera' is proposed as a chronological subdivision of an 'age.'

II. The strata referred to in the paper are considered to have been deposited during at least 12 hemeræ.

III. The 'Building-stone' of Sherborne was deposited before the 'Fossil Bed' of Halfway House, and is not contemporaneous with the 'top beds'—'limestone-beds'—of that place.

IV. That the lower part of the 'Fossil Bed' at Sandford Lane contains the same species as Bed 4 of Waagen's *Sowerbyi*-zone at Gingen (Württemberg).

V. That there is the same faunal succession in Dorsetshire, in Somersetshire, in Gloucestershire, in Normandy, in Southern France, and in Württemberg.

VI. That the upper and lower parts of the Sandford Lane 'Fossil Bed' were contemporaneous with the 'Ironshot' and 'White Ironshot' of Dundry respectively.

VI. That the lower part of the Sandford Lane 'Fossil Bed' was deposited contemporaneously with the *Gryphæa*-grit of Leckhampton.

VIII. That the strata of the Lower *Trigonia*-grit of the Cotteswolds were deposited during the *discitæ* hemera.

IX. That in the district reviewed the area of maximum accumulation of deposit moved eastward from the hemera of *Murchisonæ* till that of *Sauzei*, and westward from that of *Garantiana* till that of *fusca*; that the mollusca similarly shifted their headquarters from west to east and from east to west, but that they remain always westward of the large accumulations of sediment.

X. That there was a westerly overstep of the deposit-area in the hemera of *Murchisonæ*, and then, with a little exception during the hemera of *Sauzei*, a recession eastward until *niortensis*. Then followed an immense overstep.

XI. That species which are found practically together are not thereby proved to have been contemporaneous.

Postscript.

[To prevent any misconception, I may perhaps be allowed to add the following remarks:—

A. That the work which this paper represents has confirmed my opinion concerning the Toarcian.

B. That the words 'subjacent strata' were introduced into the title of the paper expressly because the earlier hemeræ were considered to be Toarcian.

C. That the change in the generic constitution of the Ammonite-fauna of the *Witchelliæ* sp. hemera compared with that of the *concavi* hemera is a most remarkable fact.

D. That the fact of this change warrants a chronologico-palæontological line of separation either before or after the *discitæ* hemera.

E. That if the fact of *Sonninia* being in its acme in the *discitæ* hemera be proved, and if this fact be considered of more chronological importance than that of the *Hildoceratidæ* being in their paracme at the same time, then the line of division will be drawn *before* the *discitæ* hemera. Otherwise it will be drawn after it.

F. That, in the former case, if the Bajocian were used as a chronological term to coincide with the acme and paracme of the *Sonnininæ*, it would comprise the hemeræ *discitæ*, *Witchelliæ*, *Sauzei*, *Humphriesiani*,—and an age of hemeræ with richer Ammonite-faunæ it would be difficult to find in the Jurassic period.—August 8th, 1893.]

Discussion.

The President said that the absence of the Author was much to be regretted, as the paper was evidently one of importance. Speaking with reference to the so-called *Sowerbyi*-zone, he said that Mr. Buckman in former years had maintained that this was represented by the *concavus*-bed of Bradford Abbas, which is there the principal fossil-horizon. He now recognized it in his *Witchellia*-beds, which also contained *Sonninia Sowerbyi*, and there was little doubt that in so doing he was on the right track.

He (the President) supposed that the Author referred all the deposits he was describing to the Bajocian. If so, he had somewhat modified his views on this point also, for in a former paper he had regarded at least three of his ‘emata’ as Toarcian.

These were matters of detail, but a still more important question was involved, namely, that of method. We were no doubt coming to a crisis—he might almost say to a revolutionary period—in the history of geological investigation. He remembered the time when the subdivision of the Inferior Oolite into three zones was regarded as involving almost unnecessary detail; but what were three zones compared with twelve ‘emata’? Such a subdivision, based on changes in the Ammonite-faunæ, could only be effected by one well versed in the morphology of the group. He could not test the accuracy of the Author's work, but he was satisfied that, although something like three zones were necessary for general grouping, sub-zones or ‘emata’ were useful as adjuncts, and he consequently believed that the Author was working in the right direction. His own work on the Gasteropoda had led him to recognize that special forms were limited to certain horizons. It was scarcely too much to say that if rocks were to be studied in this minute way the whole of stratigraphical palæontology would be revolutionized.

It was obvious to those acquainted with the Inferior Oolite of North Dorset that the deposits, as a rule, thickened to the eastward, and when this occurred they frequently became less valuable to the collector. He had not noticed that this was reversed in the very highest beds.

The great value of such work as that contained in the paper lay in the fact that it allowed a close correlation of deposits in different districts to be made, and he had little doubt that Mr. Buckman's paper would be of assistance to those who were studying the Jurassic deposits in detail in other countries.

Prof. Blake considered the paper a very interesting one from a palæontological point of view. The development and succession of any single group of organisms, whether Ammonites or Graptolites, could scarcely be traced too minutely; and, so far as the succession of forms in different districts coincided, it showed that the development of the group took place upon lines which were independent of the environment, and this had a biological significance. But from a stratigraphical point of view we had no reason to conclude that corresponding stages in different areas were synchronous, nor could he imagine it possible that divisions of this kind could be traced in the Midland counties or in Yorkshire. He called attention to the fact that, though *Ammonites bradfordensis* was a large form and *A. Humphriesianus* a still larger one, their zones or 'emata' in some of the sections were represented as 1 in. and 3 in. respectively; so that any single specimen of such an Ammonite would have some difficulty in getting into its own zone—in fact, we should have to draw geological lines, not only in the middle of a band of limestone, but in the middle of a fossil. He pointed out also that several of these 'emata' were unrepresented in the different quarries, and enquired whether such a circumstance indicated an unconformity or not, for these cases seem very numerous in deposits over an area said to be less than 7 miles square and of average thickness about 90 feet.

The Rev. H. H. Winwood regretted the absence of the Author of the paper, whose accurate and painstaking work in the Sherborne district and elsewhere was so well known to geologists. He wanted to know why so many foreign terms were used when English ones would answer the purpose as well; and he hoped that the President would not endorse with his approval the introduction of the words 'emar' and 'emata.' If Mr. Buckman found it necessary to subdivide his zones in that typical district, might not 'horizon' or 'sub-zone' answer his purpose equally well?

Mr. Marr also spoke.

38. *On* Raised Beaches *and* Rolled Stones *at* High Levels *in* Jersey. By Andrew Dunlop, M.D., F.G.S. (Read June 7th, 1893.)

[Abridged.]

The valuable paper of Prof. Prestwich on 'The Raised Beaches, and 'Head' or Rubble-drift, of the South of England,'[1] which has thrown so much light on the Quaternary geology of that area, is especially interesting to me. for in Jersey there are well-marked post-Glacial deposits which have hitherto received little attention from geologists. The brick-clay or brick-earth, which covers so much of the island, I have already described,[2] and I am now desirous of directing attention to the higher raised beaches, and to other evidences of alteration in the height of the land, more especially of considerable and probably long-continued subsidence.

Several writers have already described or mentioned the low-level raised beach, found in places all round the island—as, for example, Mr. Trevelyan,[3] Lieut. Nelson,[4] Prof. Prestwich,[5] and Father Noury.[6] The last-named geologist, however, seems to doubt its being a raised beach in the proper sense of the term. Mr. T. W. Danby, on the authority of the late Dr. M. Bull, mentions[7] a raised beach on the west coast of the island, said to be about 100 feet above the level of the present beach; and in Latham and Ansted's work on the Channel Islands[8] it is stated that a raised beach about 30 feet above the present mean level of the sea was laid bare during the construction of Fort Regent.

The most elevated raised beach which I have as yet observed is that on the top of the southern part of the hill on which Fort Regent is built, a hill formerly known, I believe, by the name of 'Mont de la Ville.' This hill, a detached, outlying mass of hornblendic granite, towers above the harbour of St. Helier to the height of 170 or more feet above equinoctial spring-tide high-water mark. The southern portion of it—South Hill—partly separated by a slight depression from the main mass on which the fort stands, rises about 135 feet above spring-tide high water, or 155 feet above mean tide at its highest part. The whole hill forms an oblong about 200 yards wide, the main part of it being some 500 yards, and South Hill about 250 yards in length.

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 263.
[2] 'On the Jersey Brick-Clay,' *ibid.* vol. xlv. (1889) p. 118.
[3] 'Indications of Recent Elevations in the Islands of Guernsey and Jersey,' Proc. Geol. Soc. vol. ii. p. 577, Nov. 1837.
[4] 'Geol. Survey of the Island of Jersey,' Quart. Journ. Sci., Lit., & Art, n. s. vol. vi. (1830) p. 359.
[5] 'Geology,' vol. ii. (1888) p. 518.
[6] 'Géologie de Jersey,' 1886, pp. 159 *et seq.*
[7] 'Elevation and Subsidence of Land in Jersey,' Geol. Mag. for 1876, p. 144.
[8] 'The Channel Islands,' 1862, p. 280.

High 'Raised Beach' at South Hill, Jersey.

A wide cutting passes through the eastern side of South Hill from the shore in a more or less northerly direction, and it is on the top of the cliff forming the western side of this cutting that the raised beach is situated. It is shown in a somewhat cup-shaped section—a hollow in the rock—with a steep grassy bank rising above it to the top of the hill, and it is about 11 feet deep, and 25 feet wide at its upper part. This depression is filled with well-rounded granite-pebbles, mostly from 1 or 2 to 6 or 8 inches in their longest diameter, mixed with many much larger rounded stones, and angular and subangular fragments. In the lower part the pebbles are closely packed together, but higher up the stones may perhaps be more correctly described as thickly studding the brick-clay which fills up the interstices and covers the whole. The height of this 'beach' is perhaps about 120 feet above spring-tide high-water mark. On the top of the hill, some 10 feet or more above the 'raised beach,' the solid rock which shows through the turf is well worn, as if it had been long exposed to the action of the waves.

On the southern side of South Hill, at a somewhat lower level, the top of the cliff shows the section of a depression about 110 feet long, and 3 or 4 feet deep, filled up with brick-clay resting partly on the rock and partly on rubble, and at one spot there are one or two well-rounded pebbles at the base of the clay.

On the side of the cutting opposite the high raised beach, and nearer the sea, perhaps some 80 yards from the present shore, a section of brick-clay is exposed, about 15 feet in thickness, which has a band of pebbles running diagonally across it. This band begins low down in the clay nearest the shore, and passes upwards at an angle of about 40° until it is lost in the soil above. This layer of pebbles is about 8 to 12 inches thick, and the stones, which are not very closely packed together, are mostly flattened, and from 1 to 3 inches in their greatest length. There are also some small angular fragments, and one or two rounded stones, embedded in the clay both above and below the layer. It is interesting to note that though the pebbles are nearly all pieces of the neighbouring granite and diorite, a certain number of well-rounded flints occur amongst them. Flint-pebbles are found on the present beach on the southern and eastern coasts of the island, but not in such large proportion as here. As there is no Chalk in Jersey, it has been supposed that the flints found on the shore may have been derived from the Cretaceous rocks on the opposite coast of France, or from the waste of a former extension of this formation in the direction of the Channel Islands.

About 50 yards to the seaward of this section and at a lower level, the line of rails which runs up the cutting is carried through the lower part of the southern slope of South Hill. On one side of this narrow cutting there is a section exposing a mass of angular and subangular blocks of granite closely packed together, most of them 1 or 2 feet in longest diameter; over them and amongst them is the clay, and beneath them are numerous large, well-rounded pebbles. The opposite side of the cutting mostly exposes massive rock—here diorite—but some patches of clay containing rounded stones are also to be observed. The bottom of this cutting is about 20 feet above spring-tide high-water mark, and not more than 100 feet from the shore.

About 600 yards farther inland, and nearly in a line with the South Hill cutting, the Jersey Eastern Railway is carried through the rock at the base of the eastern side of the main hill under Fort Regent. This cutting shows a section of the brick-clay about 100 feet long, and perhaps 6 or 7 feet thick, which rests on hard undecomposed granite. Passing along this deposit almost horizontally, and mostly at a height of about 1 foot above the rock, is an irregular layer of well-rounded pebbles; others are scattered about beneath the main layer, some resting on the subjacent rock, and there are also rounded stones and angular fragments here and there in the clay above it. The height of this bed above spring-tide high-water level is perhaps 50 feet, or a little more.

About 2 miles east of St. Helier one of the main roads is carried through a low ridge near St. Clement's Church, and as it slopes gently up the western side it cuts through an interesting 'beach' with its overlying clay and angular fragments. The best section is that on the northern side of the road, though it is now too much covered with ivy and grass to be well seen. At its upper or eastern end there is a steep slope of decomposing diorite, which passes westward and downward, under the layer of rolled stones. Covering this sloping rock and old beach is a bed of brick-earth, varying from a few feet to 15 feet in thickness, according to the slope of the ground above and that of the rock and beach below. The pebbles of the raised beach—mostly a few inches in longest diameter, though some are much bigger—are of fine red granite and of diorite, those of granite considerably predominating. In the brick-earth a short distance above the rounded pebbles—generally about 2 or 3 feet—is a straggling layer of angular pieces of fine red granite. These fragments are chiefly from 1 or 2 to 6 or 8 inches in greatest length, but near the lowest and most westerly part of the section there is a sharply angular block, the projecting sides of which measure 1 ft. 4 in., 1 ft. 2 in., and 2 ft. 7 in. respectively. As before mentioned, the underlying rock is diorite, while the nearest observable outcrop of granite is 440 feet to the eastward of this block, and some 20 or 30 feet above its level, on the top of the ridge. The average height of this beach is about 50 to 60 feet, or perhaps a little more, above spring-tide high water, and it is 600 yards distant from the nearest part of the seashore.

About 1 mile to the east of St. Clement's Church, near the same main road, a small hollow or rather cleft in the rock (here a fine-grained red granite), at about the same level as the lower part of the raised beach last described, is filled with small, well-rounded stones, mostly diorite. It looks like the remaining fragment of a larger beach, saved by its protected position from being carried away with the rest.

On the eastern coast of the island, near Anne Port, a roadside-cutting shows a section of clay about 100 feet long, and from

10 to 15 feet thick. The clay is very considerably thicker here, but the road and the bank below prevent its lower part from being seen. Along the top of this section, not far from the surface of the ground—in fact, in some places close up to the vegetable soil—there is a layer of small rounded pebbles thickly, though not closely, scattered through some 3 or 4 feet of the clay. These pebbles vary from about 1 to 3 inches in diameter, and they appear to be all of rhyolite or granite, like those on the present beach close by. This bed is perhaps from 40 to 50 feet above spring-tide level. Farther along the coast small round pebbles are frequently met with in the clay, but generally at lower levels.

On the southern coast, a little north of Millbrook, on a roadside just below the shoulder of the slope down from the inland high plateau, I found a subangular piece of coarse granite about 6×9 inches in size embedded in small shale-rubble below about 4 feet of clay. A little higher up the road, on the top of the plateau (which is here, perhaps, a little more than 100 feet above high-water spring tide), there is exposed a bed of small round pebbles, mostly of fine diorite and greenstone (?), but among them are some of granite, of hardened shale (?), and one or two of flint. This bed is about 200 feet long, and lies beneath some 3 or 4 feet of brick-clay. The rock below, which is not seen at this point, is shale. The bed is about $\frac{3}{4}$ of a mile from the coast. As I am, however, unable to exclude the possibility of artificial introduction here, this bed cannot be brought forward as evidence with entire confidence.

About 1 mile farther west, behind the village of Beaumont, where the widening of a road had laid bare some 7 feet of clay, I found a smoothly-rounded piece of granite measuring 5×4 inches, some 4 feet beneath the surface. Other rounded pieces of about the same size were lying about, probably derived from the same source. The underlying rock is shale, and the nearest granite is about 1 mile farther west, with two intervening valleys. The roadside where this stone was found is 500 or 600 yards from the shore, and it is perhaps 30 or 40 feet above spring-tide mark. This estimate of level, however, is a mere guess. At several other places on the south and east coasts I have found rolled stones under or in the clay, at from 40 to 50 feet above the spring-tide mark. Unfortunately, I have never had time to examine the more distant western and northern parts of the coast; but the raised beach mentioned by Mr. Danby, already alluded to, is on the west coast, and recently a writer in the 'Jersey Times' described one, said to be about 30 feet above 'sea-level,' at Grève-au-Lançon, near the extreme north-western corner of the island. Very probably a careful search would lead to the discovery of others.

Rolled stones have not only been found near the coast, they have also been discovered on the high ground in the interior of the island; but, as I did not actually pick them out of the clay myself, I cannot bring them forward as evidence with the same confidence as if I had seen them *in situ*. There is no reason, however, to doubt the statements of the finders, who are intelligent men accustomed to work in the clay.

In a brickfield at Five Oaks, about 2 miles from the coast, and some 240 feet above spring-tide high-water mark, the proprietor, Mr. Copp, told me that some twenty years ago three round smooth stones had been found lying near each other near the bottom of the clay, where it reached a depth of from 14 to 20 feet. A fragment of one of these stones, forming about two-thirds of its original bulk, was shown to me. It was a smooth oval piece of fine red granite with one end knocked off, and its longest axis had originally measured over 14 inches. The other stones had not been preserved.

At another brickfield, on the St. John's Road, probably over 200 feet above spring-tide mark and about 2 miles from the coast, the proprietor (Mr. Champion) told me that he had often found rounded pebbles—"just like potatoes"—in the yellow clay. At a subsequent visit he gave me five pebbles which he had recently found. They were all about 2 or 3 inches in their greatest length, smooth and rounded, one being nearly a perfect sphere. Three of them were of fine-grained red granite, one was of diorite, and another of hard, dark-bluish felsite (?). The nearest granite, of a texture somewhat similar to that of the granite-pebbles, occurs at Mont Mado—the highest part of the island—about 3 miles to the northward, and to the west of Mont Mado there is some diorite, from which the pebble of that rock may have been derived. Whence the felsite-pebble could have originated I cannot say. These stones were found at depths varying from 5 to 9 feet below the surface.

The facts now brought forward sufficiently prove, I think, that Jersey has undergone submergence to a greater extent than has been hitherto suspected. The high beach at South Hill and the well-worn rock above it show that the island was at one time depressed at least 130 feet below its present level, and that this submergence was of considerable duration. The rolled stones in the clay at Five Oaks and at the brickfield on the St. John's Road would seem to indicate a still greater degree of subsidence, one that must have brought by far the greater part of the island under water. The number of beaches at the 40 or 50-foot level may possibly be the result of the shore remaining at that height for some length of time; the low beaches seen at different points nearly all round the island, a few feet above the present high-tide mark, show a pause slightly above the level of to-day. When the land rose after these periods of submergence it would appear that the upheaval went on until it reached a height somewhat above the present level, and that this elevation lasted long enough to leave well-marked traces behind it, for nearly all round the coast remains of sunken forests and trunks of large trees have been found.[1] Also,

[1] 'Forêts sous-marines, etc.,' Rév. Père Noury, in Compte-rendu du Congrès Scientif. Internat. des Catholiques, Paris, 1891; 'Sinkings of Land,' Peacock (1868) pp. 19–22; 'Recueil des matières . . . touchant les envahissements de la Mer,' Col. Le Cornu, Bull. Soc. Jersiaise, 1883.

on the southern and south-eastern shores of the island, if not elsewhere, there is a blue clay under the sand, lying on the brick-clay below. In many places it is merely a few inches beneath the surface, very sandy, and only a few inches thick, but sometimes it is covered with some feet of sand and shingle, and is a stiff plastic clay. For example, in the harbour of St. Helier, about 25 feet below spring-tide high-water mark, there is a bed of stiff blue clay, 4 feet thick, under 4 feet of sand and shingle, resting on 14 feet of brick-clay, with angular rock-fragments at its base. It is evident that this clay must have been formed when the land stood at a higher level than now.

The question of the mode of deposition and spread of the brick-clay, brick-earth, or loess, with its contained rock-fragments, is a difficult one. There seems to be no doubt that this took place while the island was submerged, or during emergence. But the action of ordinary water-power would hardly account for the situation and position of many of the fragments embedded in it—some occurring in long lines or layers, and some of them standing up on edge as if they had been dropped into it while it was forming. The mass of stones studding it on the slopes is susceptible of more easy explanation.

On March 9th of the present year Prof. Prestwich read an important paper before the Royal Society,[1] in which he brought forward a mass of observations from various parts of Western Europe and the Mediterranean coasts in support of his theory that the 'rubble-drift,' etc., had been spread out by the rush of water off suddenly rising land after a short submergence. With regard to the Channel Islands, he said that the high grounds there are often covered by loam or loess, which, he thinks, was deposited from turbid sea-waters during submergence, while the 'head' results from the surface-débris, together with a portion of the previously-deposited sediment swept off by divergent currents during upheaval.

In the case of Jersey, the submergence during which the raised beach at South Hill was formed was at least long enough to wear and smooth the hard granite above it, and the beaches at lower levels seem to show that there were pauses of some duration in the subsidence or elevation, probably the latter. Even if we suppose a second short submergence and sudden upheaval, during which the brick-clay was deposited, the beach at Anne Port at the top of the clay, the layer of rounded pebbles in it, and in the cutting at South Hill, as well as that in the railway-cutting, seem to indicate that beaches were formed after some of the clay had been deposited. A succession of sudden upheavals may, however, have taken place, with intervals of some duration between them. The theory of its being deposited by the tumultuous rush of water off a violently-uplifted surface would certainly explain most of the peculiarities of the clay and its contents.

[1] 'On the Evidences of a Submergence of Western Europe, etc.' Proc. Roy. Soc. vol. liii. p. 80.

Also, if the submergence took place, as seems most probable, at the end of the post-Glacial period, the peculiar conditions due to melting ice and previous severe climate may have played their part in the formation of this deposit. In describing the 'diluvial' deposits of la Manche (the neighbouring part of France), Bonnissent[1] states that at Éroudeville some blocks of a granite foreign to the neighbourhood were found at a depth of about 15 metres (say 49 feet) in the 'diluvium,' the largest of which must have weighed about 120 kilogrammes (say 264 lbs.).

Mr. Danby, on the authority of Dr. M. Bull, says that the raised beach on the west of the island of Jersey contained quantities of recent shells. In none of the beaches which I have examined, however, have I as yet found any fossils. A bone of *Bos primigenius* (?) was found in the brick-clay near Pontac while the Eastern Railway was being laid down.

Discussion.

The President had no doubt that the paper would be of interest to students of Pleistocene geology. It was curious that the maximum submergence (130 feet) referred to by the Author coincided exactly with the height of the raised beaches at Goodwood.

The Rev. H. H. Winwood said he was familiar with raised beaches in the South-west of England, and he asked what evidence had been brought forward that this was a raised beach at all. The presence of rolled stones alone, without any trace of fossil shells, was hardly sufficient to establish the writer's theory.

Mr. Monckton also spoke.

[1] 'Essai géologique sur le Département de la Manche,' p. 393.

39. NOTES *on an* INTRUSIVE SHEET *of* DIABASE *and* ASSOCIATED ROCKS *at* ROBIN HOOD, *near* BASSENTHWAITE. By J. POSTLETHWAITE, Esq., F.G.S. (Read June 21st, 1893.)

THIS sheet of igneous rock extends in an E.N.E.-and-W.S.W. direction from Bassenfells, across Bassenthwaite Common, to a point about $\frac{1}{4}$ mile S.E. of Over Water, the total distance being about $2\frac{1}{4}$ miles. The sheet varies considerably in thickness, and is much broken up and shifted by faults; generally the thickness is from 8 to 12 feet, but near the western end, where the diabase is exposed on lower ground, it measures from 80 to 100 feet in thickness. This portion of the intrusive sheet, which is about $\frac{1}{4}$ of a mile in length, is divided into two sections by a fault, the western section being nearly double the length of the eastern section; the latter has been shifted about 100 feet to the north by a fault. Two quarries have been opened in the western section for building-stone and road-metal. The next or third exposure, which is a little over half-a-mile in length, has been shifted still farther, namely, about 350 yards to the north, and the diabase is contracted to a thickness of 10 or 12 feet. Eastward of this point, the ground is traversed by several north-and-south faults, and the beds, in some cases, have been shifted a considerable distance. In the first half-mile the diabase is not visible, the surface of the ground being partly covered by swamp; then there is a portion of the sheet of diabase exposed, about 220 yards in length, but it has been shifted about one-third of a mile to the north. Still proceeding eastward, the next exposure, about 300 yards in length, has been shifted back about 300 yards to the south, and the next exposure eastward, which is about 200 yards in length, is on the normal line of strike of the diabase, while the most easterly exposure, which is about 350 yards in length, has been shifted half-a-mile to the north.

The contour of the ground along the strike of the intrusive sheet of diabase is very irregular; the most westerly exposure occurs at an elevation of about 180 feet above Bassenthwaite Lake, or 406 feet above sea-level. From this point the ground rises rapidly to an elevation of 750 feet; thence there is an almost equally rapid descent to the level of Tarn Nevin, 450 feet; then another rapid rise to 700 feet above sea-level.

The rocks associated with the diabase consist chiefly of soft Skiddaw Slate of the ordinary type, but there are, interstratified with it, some thin beds of grit. The dip of the strata is at a high angle, being generally from 15° to 20° S.E., but occasionally it is reversed, and at one point, near the summit of the hill, the dip is about 25° N.W.

Like the dioritic picrite of White Hause and Great Cockup, the intrusive diabase at Robin Hood is shown on J. Clifton Ward's Geological Map of the Northern Part of the English Lake District (now in the Keswick Museum of Local Natural History), but it has not been described in any of his published works.[1] My first hurried visit to the locality took place in the spring of 1890, when I was engaged in preparing a paper on 'The Metallic and other Minerals surrounding the Skiddaw Granite,' and on that occasion, owing partly to the faulted nature of the ground, and partly to the imperfect examination I was then able to bestow upon it, I concluded that the intrusive sheet was not more than half-a-mile in length. A more thorough examination of the ground on a subsequent visit enabled me to trace it over a mile and a half in length, and on referring to J. C. Ward's map I found that there was still an extension of the sheet to the east of Tarn Nevin which I had failed to discover.

The diabase of which the intrusive sheet is composed is of a light grey colour; it varies a little in texture, being fine-grained, hard and compact in some places, and in others moderately coarse-grained. The rock is often much decomposed near the surface. There are in some places, associated with the diabase, a good deal of opaque white quartz and some calcite, the latter occasionally filling cavities and joints. The presence of the quartz and calcite, and the knowledge that antimony had been obtained near Robin Hood, led me at first to believe that there was a metallic vein associated with the diabase; further investigation, however, proved that this opinion was incorrect, the vein-material only occurring in irregular patches. Prof. Bonney submitted a fragment of the diabase to Mr. Morris W. Travers, of University College, London, to be tested for antimony, and that gentleman ascertained the presence of the metal, in small quantity, in the calcite, but he found that the rock-substance of the diabase did not appear to contain any of the mineral. It is probable, therefore, that the deposition of the quartz, calcite, and antimony has been the result of thermal action following the intrusion of the diabase; and the thermal action seems to have been most intense near Robin Hood House, as it is said that about 20 tons of antimony were obtained there and sent to market some 50 years ago. A shaft was sunk at the place, and a level was driven some distance, partly to drain off the water, partly for the purpose of making further exploration, but apparently without success. Small excavations were also made at several other points along the course of the intrusive sheet, but the ore does not appear to have been present in sufficient quantity to warrant further operations.

About 300 feet north of the intrusive sheet of diabase, there is a parallel bed of very fine-grained grit, from 5 to 6 feet in thickness. The materials of which this grit is formed have probably been derived to some extent from the denudation of ore-bearing veins, as it contains a very high percentage of silica, with small quantities of manganese, antimony, and lead. Minute grains of these minerals

[1] [I find, however, that it is mapped by the Geological Survey, Sheet 101 N.E., issued to the public about the end of April of the present year.—July 31st, 1893.]

may be seen with the aid of a pocket-lens, shining with a bright metallic lustre, but they are rarely large enough to be seen with the unaided eye. The miners who obtained antimony from Robin Hood Mine were also aware of its presence in the grit, and made several small excavations in it similar to those in the diabase.

The following are analyses of typical specimens of the diabase and grit, the former taken from the head of the old shaft near Robin Hood, and the latter from one of the excavations about one-third of a mile north-east of the shaft. The specimens were analysed in the laboratory of Mr. R. Hellon, Ph.D., F.I.C., Public Analyst for the counties of Cumberland and Westmoreland, by that gentleman and his assistant, Mr. J. E. Brockbank, F.C.S.

I. Diabase.

Silica	48·42
Alumina	24·35
Ferric Oxide	1·00
Ferrous Oxide	8·22
Lime	5·22
Magnesia	3·20
Manganous Oxide	·09
Carbon Dioxide	6·97
Sulphur Trioxide	1·08
Arsenic	·06
Antimony	·02
Lead	trace
Copper	trace
Cobalt	trace
	98·63

II. Grit.

Silica	79·92
Alumina	5·10
Ferric Oxide	trace
Ferrous Oxide	3·73
Lime	·89
Magnesia	·85
Manganous Oxide	3·76
Carbon (in carbonaceous matter)	·44
Sulphur	·09
Phosphoric Acid	·02
Antimony	·06
Lead	·02
Potash	·68
Soda	1·55
Water (combined)	2·15
	99·26

The above analysis was made on the rock freed from hygroscopic water by drying at 212° Fahr.

I had a number of slides prepared from specimens of the diabase and associated rocks. Prof. Bonney, F.R.S., very kindly examined them for me, and he has given me permission to make use of his notes in the following paragraphs.

Slide A was taken from a specimen of the diabase obtained from Bassenfells Quarry, at the western end of the intrusive sheet. The rock, which appears to have had an ophitic structure, consists of felspar, much decomposed, probably plagioclase, viridite replacing a pyroxenic mineral, grains and granules of iron oxide (the exact species difficult to determine, probably in part hydrous), also some grains of a clear mineral which look like quartz—but the possibility of a secondary felspar must not be overlooked. There is a vein of calcite showing marked twinning with rather unusually bright colours. The rock may be grouped with the diabases, but if the clear grains *are* quartz the percentage of silica would probably be rather high; still diabase, in the sense of altered dolerite, will be a safer name than diorite.

No. 2 was taken from a specimen of the diabase obtained in a quarry near the summit of the hill. It is a rock of somewhat intermediate character, containing much felspar and a little quartz, slightly porphyritic, but very rotten, the crystals being so much decomposed that it is difficult to determine what they have been. One or two suggest a pyroxenic mineral, but their general dirty look accords better with felspar. There are also some grains of the clear mineral like quartz which occurs in Slide A. The rock has been slightly affected by pressure.

Slide B was taken from the diabase at Tarn Nevin, about half-a-mile from the eastern end of the intrusive sheet. It is a finer-grained and seemingly more felspathic rock than that at the western end of the sheet. It too is very decomposed, but the constituents are generally similar to those of the former rock (Slide A). The pyroxenic constituent, however, seems to have been less in proportion; some of the crystals have been plagioclase. It is difficult to make out the exact structure, but it is more probably granular than ophitic. The slide was taken from nearer a weathered surface than was the case with Slide A.

No. 1 is the opaque white quartz associated with the diabase; it was taken from the head of the old shaft near Robin Hood, and seems to be chiefly vein-material, quartz with rosettes or groups of a mica-like mineral, and there is a kind of chlorite, also some limonite, but not quite enough of the matrix to be sure of its nature. It has been a little affected by contact-action.

Slide 4 was taken from a specimen of the grit obtained in an excavation on the eastern side of the hill. It consists of fragmental quartz, felspar (much decomposed), mica, and possibly a little tourmaline, also some iron oxide, or manganese. The slide is traversed by a quartz-vein. There are no signs of cleavage or contact-metamorphism.

It was from a specimen of this rock that Analysis II. (p. 533) was made.

Slide 3 was taken from an excavation in the grit, about 200 yards west of that from which Slide 4 was obtained. It is a fine-grained grit of somewhat similar character, but with some rather distinct indications of cleavage. There is at least one grain of tourmaline in the slide.

In the middle of the grit at this point there is a thin band of slate, and from this band Slide 6 was taken. The rock is a kind of gritty mudstone, rather schistose, and distinctly cleaved. The schistose structure seems to be partly due to contact-metamorphism, but if so, the appearances are in favour of contact first and pressure afterwards.

Slide 5 is from a specimen of soft Skiddaw Slate obtained about 20 feet north of the diabase, opposite the point from which Slide 2 was taken. The slate is a moderately fine mudstone containing some fragmental mica, other constituents being much as is usual in such rocks. The face of the slate roughly coincides with the bedding, the cleavage (not very strong) cutting it at a high angle.

The beds of Skiddaw Slate are more or less hardened where they are in contact with the intrusive sheet of diabase, but beyond that there is not much evidence of metamorphism, either in the diabase itself or the adjacent rocks, the grit from which the slides were taken being apparently too far away to be affected by the heat from so small a body of molten magma.

There is no section exposed where the diabase can be seen breaking through or across the adjoining beds, although it is possible that, in some of the places where it appears to be shifted by faults, the appearances may in reality be due to the diabase breaking through the strata, and not to the effect of faults. Further investigation may perhaps throw more light upon this point.

My best thanks are due to Prof. Bonney and Messrs. Hellon, Brockbank, and Travers, for the valuable help I have received from them in the preparation of this paper.

40. *On* Composite Dykes *in* Arran. By J. W. Judd, Esq., F.R.S., V.P.G.S., Professor of Geology in the Royal College of Science, London. (Read June 21st, 1893.)

[Plate XIX.]

Contents.

I. Definition and Classification of Composite Dykes.

Those dykes which are filled with materials differing one from another in chemical composition or mineralogical constitution may be conveniently spoken of as 'composite dykes.' In some cases the diverse rocks found in the same dyke may be only varieties of a single type, exhibiting dissimilarities in the proportions or arrangement of their several mineral constituents; but in other cases two or more rock-species, absolutely distinct, may be found to enter into the constitution of a single dyke.

A careful study of these composite dykes shows that they fall naturally into two classes, as follows:—

(A) *Composite dykes in which a differentiation has gone on in the material that has filled the dyke.*—This differentiation usually results in the separation, or partial separation, of the vitreous base of the rock from the crystals scattered through it; but in some cases the crystallizing process, acting selectively within the dyke, has led to the formation of rocks which, in different parts of the dyke, show marked variations in chemical composition or texture, and even in mineralogical constitution. The separation of the glassy from the crystalline materials in this variety of composite dykes takes place in various ways; the vitreous material may form lateral bands ('selvages') or irregular patches, or it may fill 'amygdaloidal' cavities. But in all cases there is found to be a more or less perfect gradation from the one type of rock to the other.

(B) *Composite dykes in which there has been injection of different materials into the same fissure.*—In these the later injected rock, though it may contain minerals and fragments derived from the older injection, exhibits no trace of gradation into it, but can always be recognized as another type of material, distinct in chemical composition or mineralogical constitution. In such cases we may infer that differentiation must have taken place in the magma deep down in the earth's crust, and far below the fissure which is now filled with the two products resulting from the differentiation. While, however, it is probable that such composite dykes are usually filled with materials coming from the same subterranean reservoir, it is possible that, in certain exceptional cases, a dyke may be reopened in such a way as to allow of molten material from *a source totally different* from that which supplied the earlier injection finding its way into the fissure. In such exceptional cases the composite character of the dyke must be regarded as an accident.

In many instances, the younger injection is found occupying the centre of the dyke; for, owing to the cooling of the mass from the sides, a plane of weakness (often very manifest in columnar dykes) may originate along the middle of the dyke; in this plane, indeed, contraction due to crystallization not unfrequently leads to the formation of numerous cavities. But there are other instances where the junctions between the dykes and the enclosing rock constitute planes of weakness, along which the later ejected material has forced its way. In such cases, the older rock occupies the centre of the dyke.

While the two classes of composite dykes to which I have just referred are usually very distinct and clearly recognizable, the one from the other, there are certain examples which seem to constitute a link between them. These are the composite dykes in which the dyke-rock appears to be intersected by veins, of the nature of the 'contemporaneous' or 'segregation-veins' so common in plutonic rocks. It is difficult in such cases to be certain whether the differentiation has taken place in the dykes themselves, or in the reservoirs beneath, from which they have been supplied.

The question of the order of succession of different lavas issuing from a volcanic vent is one to which the attention of geologists has long been directed. Quite recently, however, interest in the subject has been revived, owing to certain theoretical suggestions having been put forward to account for the observed facts. It is obvious that the study of the succession of igneous rocks at any centre of eruption may throw light upon the processes of differentiation, which appear to have been carried on within many molten rock-masses.[1] In connexion with this important problem, the study of

[1] For a summary of the work already done in connexion with this subject Mr. Iddings's memoir 'On the Origin of Igneous Rocks,' Bull. Phil. Soc. Washington, vol. xii. (1892) pp. 89–214, may be consulted.

composite dykes of both classes must be regarded as having, at the present time, a special interest.

The first class of composite dykes—including those in which differentiation has clearly gone on within the dyke itself—has been treated of with much ability in two very interesting memoirs that have recently appeared. Dr. A. C. Lawson has described the great diabase dykes that intersect the Archæan rocks of the Rainy Lake region in Canada. By the aid of a series of chemical analyses made by Mr. F. T. Shutt, Dr. Lawson has been able to show how great an amount of differentiation has sometimes taken place within the very wide dykes of that region; and the various rocks thus produced have been made the subject of careful microscopic study.[1]

In the Stop Island Dyke, 150 feet wide, the sides of the dyke are shown to present the characters of an altered augite-andesite (porphyrite) and to contain 47·8 per cent. of silica. Tracing the rock towards the centre of the dyke, it is found to pass first into an ophitic dolerite (diabase), and finally into a uralitic quartz-gabbro, containing 57·5 per cent. of silica,—a rock in which various accessory minerals are much more abundant than in the rock of the sides of the dyke.

The Whitefish Bay dyke, 120 feet wide, is at its sides composed of fine-grained ophitic rock (diabase) with 47·5 per cent. of silica; but it passes, towards the centre, into a rock which is partially granular or granitic in texture, and has a silica-percentage of 52·5. Hypersthene, which is abundant at the sides of the dyke, disappears in the central part, while quartz and hornblende come in instead.

Similar differentiation of the materials within a fissure is shown by Dr. Lawson to have gone on in many other dykes in the district. As a general rule, the centres of the dykes are richer in silica than the sides; and not only is there a difference in the degree of development of crystalline structure, so that a 'trachytoid' or 'ophitic' rock at the sides passes into a perfectly holocrystalline (granitic) rock at the centre, but certain minerals, like enstatite, which abound at the sides disappear in the middle of the dyke, being replaced by others, such as quartz, hornblende, and garnet. Dr. Lawson has also called attention to the curious circumstance that the crystals of the same mineral may show marked differences in susceptibility to chemical change, when they are found developed in different parts of the same dyke.

Even more striking than the examples of composite dykes from Canada is the case of the Huk dyke of Norway, recently described by Prof. J. H. L. Vogt.[2] This dyke occurs in the Christiania

[1] 'Petrographical Differentiation of Certain Dykes of the Rainy Lake Region,' by Andrew C. Lawson, with Analyses by F. T. Shutt, 'American Geologist,' vol. vii. (1891) pp. 153–164; see also 'Notes on some Diabase Dykes of the Rainy Lake Region,' Proc. Canad. Inst. 1887, ser. 3, vol. v. p. 173, and 'Report on the Geology of the Rainy Lake Region,' by the same author, Geol. & Nat. Hist. Surv. Canada, Annual Report, 1887–88, part F.

[2] 'Om Dannelsen af de vigtigste i Norge og Sverige representerede Grupper af Jernmalmforekomster,' af J. H. L. Vogt, Geologisk. Förening. Förhandl. vol. xiii. (1891) pp. 476 & 683, and vol. xiv. (1892) p. 211; see also Geol. Mag. for 1892, pp. 82–86, and Zeitschr. f. prakt. Geol. vol. i. (1892) p. 4.

district and is over 30 feet wide; its centre is a 'mica-syenite-porphyry' with 63 per cent. of silica; but it passes at its margins into a fine-grained kersantite or mica-diorite containing only 47 per cent. of silica. Not only magnetite, but pyrites and apatite occur in much greater abundance at the sides of the dyke than in its centre.

These examples may be taken as sufficiently illustrating the first class of composite dykes; but it is to the second class—in which it is impossible to explain the differences between the rocks in the dyke by segregation going on during its consolidation—that I desire to call especial attention in this paper. It is a fortunate circumstance that we have in the Island of Arran some very beautiful, if not indeed actually unique, examples of this class of composite dykes, and some of the most remarkable of them will be described in the following pages.

II. The Latest Volcanic Rocks of the British Isles.

In describing the succession of volcanic ejections in the Western Isles of Scotland, and comparing them with those of Hungary and the Lipari Islands, I pointed out many years ago that the nature of the latest erupted lavas suggests the conclusion that a differentiation of the materials poured out during earlier eruptions must have taken place.[1] Mr. Iddings has recently shown how very constantly the phenomenon of the ejection of lavas of intermediate composition, followed, after an interval, by the extrusion of markedly acid and basic types respectively, is exhibited at volcanic centres, in widely distant districts and belonging to every geological period.[2] The same conclusion was strongly insisted upon as early as 1868, though perhaps without certain very necessary qualifications, by Baron von Richthofen in his 'Natural System of Volcanic Rocks.'

The latest erupted of the igneous masses of the Western Isles of Scotland are of peculiar interest to geologists, not only from the circumstance that they afford evidence concerning the most recent volcanic outbursts in our area, but on account of the illustrations which they supply concerning the process of differentiation in igneous magmas.

There are only two localities known at present at which the surface-ejections of these most recent British volcanoes can be studied—namely, Beinn Hiant in Ardnamurchan and the Sgùr of Eigg.[3] In the case of the former I have shown how the differentiation of

[1] Geol. Mag. for 1875, p. 60; Quart. Journ. Geol. Soc. vol. xxxii. (1876) pp. 315–316; 'Volcanoes, what they are and what they teach,' 1881, pp. 199–205.

[2] 'The Origin of Igneous Rocks,' Bull. Phil. Soc. Washington, vol. xii. (1892) pp. 89–214.

[3] Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 371–382. The fact that the Sgùr of Eigg is not a dyke, as supposed by Hay Cunningham, but a lava-stream, overlying the deposits with *Pinites eiggensis*, was recognized by Hugh Miller ('Cruise of the Betsy,' a work which was published in book-form in 1857, the substance of it having appeared as a series of newspaper articles some years earlier). Sir Archibald Geikie made this conclusion perfectly clear, and added new details in 1871 (Quart. Journ. Geol. Soc. vol. xxvii. pp. 303–309).

the crystalline and vitreous portions of the magma has led to the formation of rocks ranging in silica-percentage from 52·7 to 65·8, and differing in a very marked manner in texture and appearance. In the fragment of a lava-stream which forms the Sgùr of Eigg we have only the more acid type of rock represented.

The reason why such small relics of this latest period of volcanic activity are preserved for our study is not difficult to explain. There is clear evidence that while the eruptions of this period took place over a very wide area—being traceable from Yorkshire on the east to Donegal on the west—the superficial manifestations of the igneous activity were usually small and inconspicuous. Indeed, it is only at a few points, like Beinn Hiant in Ardnamurchan and the Sgùr of Eigg, that the erupted material was poured out in such abundance as to escape removal by subsequent denudation. I long ago pointed out that these widespread ejections must have resembled the *puys* of Auvergne, and have consisted of cinder-cones and lava-currents ejected at a number of points, along lines of fissure which radiated from the great eruptive centres, and were probably developed after the central volcanoes had become extinct.

While, however, most of the volcanic materials poured out at the surface have long since been swept away by denudation, the dykes, or filled-up fissures beneath the volcanic vents, remain as witnesses to the number and widespread character of these latest eruptions. In the study of these dykes we find abundant and very interesting evidence of the process of differentiation of lavas; nor can it be doubted that several kinds of lava were successively poured out from certain of the vents supplied from these fissures.

III. The Chief Types of Volcanic Rocks represented in these late Ejections.

The materials found in the latest volcanic dykes of the British Islands, which traverse alike the Secondary and all older strata as well as the igneous rocks of the Hebrides and the North of Ireland, represent two very distinct types of rock.

The first of these has been admirably described by Mr. Teall in his account of the North-of-England dykes.[1] In the Cleveland dyke and similar eruptive masses of late date we find a series of rocks which may be classed with the augite-andesites. They seldom, if ever, contain free olivine, the chief porphyritic constituents being a lime-soda felspar, which is usually zoned, and a magnesian augite; while their silica-percentage ranges from 52 to 58. They sometimes contain but little vitreous matter, and in these cases not unfrequently assume an ophitic structure and may be classed with the dolerites (diabases). When a small quantity of glass is present, it is often seen to be caught up between the felspar-crystals, thus giving rise to the structure styled by Rosenbusch 'intersertal,' and entitling the rocks to be called in that petrographer's nomenclature 'tholeites.'

[1] Quart. Journ. Geol. Soc. vol. xl. (1884) p. 209; see also 'British Petrography,' 1888, pp. 200–207.

But occasionally, as I have shown to be the case at Beinn Hiant, these rocks may contain much glass, and they then pass into the 'vitrophyric' types,[1] the 'pitchstone-porphyries' of older authors.

There is one characteristic which all these rocks present, namely, a tendency for the glass—which is dark in colour and sometimes approaches to tachylyte in the abundance of its dusty particles and skeleton-crystals of magnetite, as well as in its forked microlites of felspar—to separate from the crystalline portion of the rock. This separation may take place in three different ways. Sometimes the glass tends to form a selvage at the sides of the dyke, or to accumulate at its centre. At other times, as is so well illustrated in the account given of the Eskdale dyke in Dumfriesshire, by the officers of the Geological Survey (Sir Archibald Geikie, Mr. B. N. Peach, and Mr. J. S. Grant Wilson),[2] the glass may segregate in more or less irregular patches or bands. Again, when gas-cavities are formed in these rocks, there is a great tendency for the glass to ooze out from between the crystals, and to fill these cavities, as pointed out by Mr. Teall in the Tynemouth dyke, and by myself in the Beinn Hiant rocks.[3]

The other type of rock is represented by the various 'pitchstones' of the Western Isles of Scotland. These rocks are of much more acid composition than the augite-andesites already described. Their silica-percentage in the varieties containing much free quartz ranges from 70 to 75, and in those with little or no free quartz, but containing more or less felspar, from 65 to 70.

There is considerable difficulty in defining the place of these vitreous rocks according to modern systems of petrographical nomenclature. This arises from the circumstance that all these systems of classification take note of the crystalline minerals, while they to a great extent ignore the vitreous groundmass which, in the rocks under consideration, usually forms by far the larger proportion of the mass. It is the glassy basis which is so characteristic of all the rocks of the type we are now considering, and it is the glassy basis which retains its uniformity of character, while great variations are seen in the quantity and nature of the crystallized minerals that occur as porphyritic constituents.

The glassy basis, with the minerals that have separated from it (including the dust-like crystallites, with their 'courts of crystallization' and their fern-like or star-like groups of hornblende-microlites), is well known to petrographers by the descriptions and figures published by Zirkel,[4] Allport,[5] Teall,[6] and others. I shall

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 378.
[2] Proc. Roy. Phys. Soc. Edinb. vol. v. (1878–80) pp. 219–254; and Trans. Roy. Soc. Edinb. vol. xxxv. (1888) pp. 40–44.
[3] Geol. Mag. for 1889, pp. 481–483; and Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 379.
[4] Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxiii. (1871) p. 1.
[5] Geol. Mag. for 1872, pp. 1–10 & 536–545; also *ibid.* 1881, p. 438.
[6] 'British Petrography,' 1888, pp. 344–347.

have to show in these pages, however, what an important part hyalite and tridymite play in some of these rocks.

The crystallized minerals which are present consist of pyroxene (either augite or enstatite), magnetite, titanoferrite, quartz, and numerous felspars. According to the usually accepted systems of petrographical nomenclature, the name to be given to these rocks would be determined by the presence or absence of free quartz and by the characters of the felspar-crystals; and it is to the exact determination of the felspars, therefore, that especial attention must be directed in fixing the place of these rocks in the petrographic series.

At first sight it appears that the majority of the felspar-crystals, which are scattered through the glass, are destitute of lamellar twinning, and should be referred to orthoclase. It is scarcely necessary, however, to point out that, while the presence of lamellar twinning may be regarded as characteristic of plagioclase-felspar, the absence of that character, as Hawes so well showed, is no proof that the crystals do not belong to the triclinic system. A very careful examination of these crystals in polarized light, with properly adjusted illumination, shows that many of the apparently untwinned crystals exhibit the delicate lamellar structure so characteristic of 'anorthoclase' or 'cryptoperthite.' In addition, moreover, to these orthoclase- or anorthoclase-crystals, a considerable number of very distinctly twinned plagioclase-crystals nearly always occur, and these are sometimes so abundant as to predominate over the untwinned felspar-crystals. It will thus be seen that, taking the crystallized minerals as our guide, as is customary with petrographers, and remembering that in some cases quartz-crystals are present, and in other cases entirely absent, the rocks would be variously classed as trachytes or rhyolites, pantellerites or quartz-pantellerites, andesites or quartz-andesites (dacites), according to the absence or presence of quartz, and the predominance of orthoclase, anorthoclase, or plagioclase among the felspars.

That these rocks are not simple rhyolites, as has sometimes been assumed, is proved by the fact that most of the analyses which have been made of them reveal the presence of a very large proportion of soda, and in many cases the soda predominates over the potash. The researches of Lagorio show that the potash will probably abound in the glass, and the soda in the porphyritic constituents. Isolation and analysis of the felspars in these rocks are usually rendered difficult by the frequency in them of glass and other inclusions; but tests by Szabó's method of flame-reactions, made upon examples selected as freest from inclusions, show that these felspars are almost always very rich in soda. I am convinced that in many cases the rocks should be classed with the 'pantellerites' and 'quartz-pantellerites,' and this view is confirmed by the most trustworthy of the analyses which have been made of them.

But no one can study these rocks without being convinced that it is the *glassy base*, and not the crystallized minerals scattered through it, which constitutes their distinctive feature; and that it is this groundmass, and not the enclosed crystals, which ought to be recognized in the name given to the rocks. The glassy forms are known as 'pitchstones,' but the devitrified varieties are usually called in this country by the name of 'felsites.' We find every gradation from one type to the other, while occasionally the rock has the perfectly vitreous lustre of an obsidian. I propose in this paper to speak of the stony varieties as simply 'felsites' or 'quartz-felsites,' according as quartz-crystals are absent or present, while the glassy forms will be referred to by the old names of 'pitchstone' and 'pitchstone-porphyry.'

That the two very strongly contrasted classes of rocks are present in the dykes of the Noith of Ireland, as well as in Scotland and England, has been recently shown in a very interesting paper by Prof. W. J. Sollas.[1]

IV. The Cir Mhor Dyke—Earlier Notices.

One of the most interesting examples of the union of the two types of late Tertiary lava—the basic augite-andesites and the acid 'pitchstone'—in a single dyke, is found in the midst of the great mass of Tertiary granite occupying the northern half of the Island of Arran. This dyke can be traced from the summit of Cir Mhor, which may be regarded as the central peak of this granitic mass, and runs almost due eastwards for about one-third of a mile till it is lost near the north-western spur of Goatfell. Along nearly the whole of this line the dyke is traceable, and at many points its characters may be very distinctly made out.

The earliest notice of this dyke that I have been able to discover is in Jameson's account of the Island of Arran, published in 1798, in which the author speaks of it as a basalt-vein, rising perpendicularly through the granite, while near it were several masses of green pitchstone.[2] In his later work the dyke is referred to in almost the same terms, and he adds that, "after considerable labour," he was unable to discover the source of the "columns of leek-green coloured pitchstone" which were lying near among the granite-débris.[3]

Macculloch in his account of Arran, published in 1819,[4] while referring to the existence of both basalt and pitchstone-dykes traversing the granite, does not directly mention this composite dyke.

The first geologist to give a clear account of this remarkable dyke was the late Sir Andrew Ramsay. He pointed out its exact position on the southern side of Cir Mhor, and described it as crossing the ridge dividing Glen Rosa from Glen Sannox. He stated that at one point five distinct bands of rock can

[1] 'On Pitchstone and Andesite from Tertiary Dykes in Donegal,' Scient. Proc. Roy. Dubl. Soc. vol. viii. (n. s.) 1893, p. 87.
[2] 'Outline of the Mineralogy of the Shetland Islands and of the Island of Arran,' 1798, pp. 72–3.
[3] 'Mineralogy of the Scottish Isles,' vol. i. (1800) p. 40.
[4] 'Western Isles of Scotland,' vol. ii. p. 416.

be made out in the dyke. At the sides are masses of 'trap,' weathering into balls which exhibit a concentric structure; in the middle is a band of 'green pitchstone,' and, between the 'pitchstone' and 'trap,' layers of 'claystone-porphyry' make their appearance. Higher up the mountain the 'claystone-porphyry' was found to be absent, and the dyke consists of 'pitchstone' in the middle, with 'trap' at the sides.[1]

Dr. James Bryce added some details to those given by Ramsay concerning the Cir Mhor dyke.[2] He referred to bands of a material like 'hornstone' occurring between the 'pitchstone' and the 'claystone-porphyry,' and his measurements of the several layers of rock differ somewhat from those of his predecessor.

In his account of the microscopical characters of the Arran pitchstones, Mr. Allport refers to the rock of this dyke at Cir Mhor as having a banded structure similar to that seen in a dyke 1 mile south of Tormore.[3]

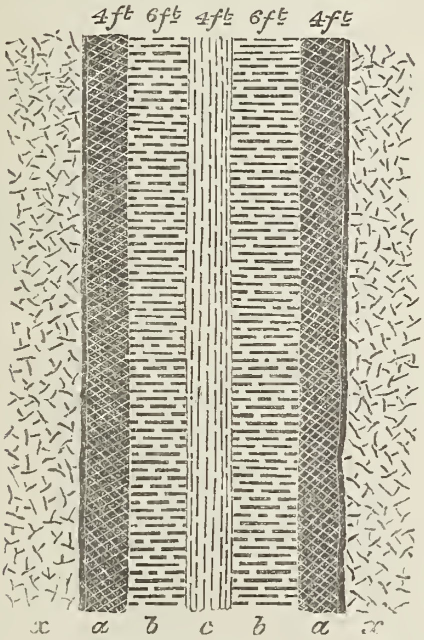
It may be that a dyke traversing the granite of Ceum-na-Caillich is, as suggested by several authors, connected with that of Cir Mhor. The Ceum-na-Caillich dyke seems also, as Jameson pointed out, to be an example of a 'composite dyke,' or, as he called it, a 'stratified vein.'[4]

V. General Structure and Chemical Composition of the Cir Mhor Dyke.

Although I have visited this dyke on a number of different occasions, it is but little that I can add to the excellent general descriptions given by Ramsay and Bryce. The width of the dyke is found, when the sides can be seen, to vary considerably, from 12 or 14 up to nearly 30 feet. Evidently there are two perfectly distinct rocks present, which appear to be sharply divided the one from the other. The centre of the dyke is a 'pitchstone-porphyry,' which contains conspicuous crystals of quartz and felspar, is sometimes banded, and not unfrequently more or less spherulitic in structure. This vitreous rock passes into a 'hornstone-like' modification, and finally into a 'lithoidal' rock or quartz-felsite, the 'claystone' or 'claystone-porphyry' of Ramsay and Bryce. The sides of the dyke, however, are composed of a totally distinct rock, a porphyritic augite-andesite ('trap,' 'greenstone,' or 'basalt' of the older authors), which shows a very marked tendency to weather into balls with concentric structure. The width of the felsite-and-pitchstone centre, and of the andesite sides, varies greatly in different parts of the dyke, but the acid and basic rocks are always completely distinct the one from the other. The relations of the rocks, as seen at the place where they are best developed, are shown in the diagram on the opposite page (fig. 1).

[1] 'The Geology of the Island of Arran from original Survey,' 1841, p. 26.
[2] 'The Geology of Arran and the other Clyde Islands,' 4th ed. (1872) p. 164.
[3] Geol. Mag. for 1872, p. 6.
[4] 'Mineralogy of the Scottish Isles,' vol. i. (1800) p. 81, footnote.

Fig. 1.—*Diagrammatic Plan of the Cir Mhor Dyke.*



x=Granite.
a=Augite-andesite.
b=Quartz-felsite. } Quartz-pantellerite.
c=Pitchstone-porphyry. }

By the kindness of my colleague, Prof. Thorpe, F.R.S., I have been able to obtain analyses of the two varieties of rock of this dyke; these were made under his superintendence in the Chemical Laboratory of the Royal College of Science, South Kensington. In order that the identity of the vitreous and stony varieties of the acid rock might be made perfectly clear, analyses were obtained both of the quartz-felsite and of the 'pitchstone-porphyry.'

The specific gravities of these rocks have been determined for me with very great care by my assistants, Mr. G. Cullis and Mr. T. Barron.

	I. Augite-andesite (' *Trap-porphyry* '). *Outside of Cir Mhor Dyke.*	II. Quartz-felsite (' *Claystone-porphyry* '). *Centre of Cir Mhor Dyke.*	III. ' Pitchstone-porphyry.' *Centre of Cir Mhor Dyke.*
Silica	55·79	75·31	72·37
Alumina	15·97	13·62	11·64
Ferric oxide	12·50	2·31	1·42
Ferrous oxide	...	...	1·08
Lime	7·06	0·97	1·30
Magnesia............	2·22	0·20	0·52
Soda	2·21	3·02	4·15
Potash	1·86	4·07	3·98
Sulphur	0·45	trace	—
Water, and loss by ignition ...	2·43	1·48	4·86
	100·49	100·98	101·32
Specific gravity...	2·70–2·71	2·52–2·53	2·36–2·37

I. Analysis by Mr. J. A. Schofield, A.R.C.S., of the augite-andesite taken from the side of the Cir Mhor dyke. The sulphur was evidently present as iron disulphide, which is so frequently conspicuous in these Tertiary igneous rocks. The rock nearly always shows some sign of alteration, which accounts for the water present in it.

II. Analysis of a specimen of the quartz-felsite from the central part of the dyke. The rock selected was a perfect 'lithoidite' or quartz-felsite, and, as will be seen, the proportion both of potash and soda is high. This analysis was also made by Mr. J. A. Schofield.

III. Analysis by Mr. E. C. Thomson, A.R.C.S., of the 'pitchstone-porphyry,' taken from the centre of the dyke. As in most glassy rocks, the proportion of water is very high; but, seeing that more than 2 per cent. of the water was lost at 120° C., it is probable that a part of it must be regarded as hygroscopic. The soda in this rock is in excess of the potash. The numbers given are, in each case, the means of two closely concordant determinations.

It will be seen that, while Analysis I. corresponds with that of normal augite-andesites, and shows a very close agreement with the Tertiary North-of-England dykes described by Mr. Teall, Analyses II. and III. indicate a magma of totally different chemical composition, and one which is of an extremely acid character.

The differences between Analyses II. and III. are accounted for when we remember that the rocks contain numerous crystals of quartz, felspar, pyroxene, and magnetite very irregularly distributed through them; and that, without elaborate sampling of large masses of rock, it would be impossible to get good average specimens for analysis. Moreover, the quantity of water in III., as is usually the case with vitreous forms of rock, is abnormally high. Considering the two analyses together, we may safely regard them as representing varieties of the same rock, and hold that II. differs from III. only by the devitrification of the glassy groundmass. A very marked feature is the high percentage of soda, which, in III., is in excess of the potash. If, with Lagorio, we regard most of the potash as belonging to the glass, then we must have a felspar present very rich in soda. This conclusion, as we shall find, is supported by the microscopical study of the rock and also by Szabó's flame-reactions. We thus see that the chemical analysis fully supports the conclusion that the rock is a 'quartz-pantellerite' with a very large amount of glassy base, which may have undergone more or less devitrification.

VI. Microscopical Characters of the Rocks composing the Cir Mhor Dyke.

The study of the two varieties of rock of the Cir Mhor dyke in thin sections under the microscope reveals their essential differences in an even more striking manner than does their chemical analysis. The characters of the rocks—crystals and groundmass alike—are such as to compel the inference that no separation of the crystalline and vitreous material, like that which sometimes takes place within dykes themselves, will account for the startling dissimilarity of the two rocks.

Beginning with the rock of the sides of the dyke, we at once see that we are dealing with an undoubted augite-andesite, which has for groundmass a 'microlitic felt' of the typical andesitic character. (See Pl. XIX. fig. 2.) When the crystalline elements are numerous and well developed the glassy groundmass is seen to be caught up between crystals, so as to give rise to the 'intersertal' structure; while occasionally, by the crystallization of augite around the lath-shaped felspars, the ophitic structure is developed. We may therefore conclude that the typical augite-andesite passes into a 'tholeite' or into an ophitic dolerite (diabase).

Among the porphyritic minerals present, the most abundantly represented species are lime-soda-felspars, the crystals of which are usually zoned; and there is not unfrequently a considerable variation in the extinction-angles between the centre and the concentric zones, indicating a change in composition from more basic to less basic felspars. Many of the felspar-crystals are much corroded by the action upon them of the surrounding vitreous material, and there is clear evidence that during the development of the crystals the work of growth and of corrosion went on alternately. Many of the crystals are surrounded by a ragged fringe of very clear and fresh felspar-substance, which often extinguishes at a markedly different angle from that of the main body of the crystal. There can be no doubt, I think, that these ragged outgrowths have been formed at a much later date than the crystals which they surround, and probably, long after the consolidation of the rock, at the expense of the glass in the groundmass.[1]

The lath-shaped felspars in the groundmass are sometimes plagioclase, but in other cases may be orthoclase. They are occasionally clustered in cruciform and sheaf-like groups. In addition to the larger crystals of plagioclase, there appear to be some few felspars derived from an acid rock. These are always greatly corroded, and are often reduced to mere skeletons by the action of the magma upon them; they appear to be either orthoclase or anorthoclase ('cryptoperthite').

The augite-crystals, which are not very abundant, are either brown or almost colourless. They have all the characteristics of the highly magnesian varieties of the mineral.

Both magnetite and titanoferrite occur abundantly as crystals, sometimes of considerable size, the latter mineral often exhibiting the first stages of the change into 'leucoxene.'

Apatite is often enclosed in the felspars and augites, while pyrites is among the most common of the secondary constituents.

Quartz-crystals, greatly corroded and surrounded by zones of secondary augite, are occasionally found in the rock, but were evidently derived from some more acid rock.

[1] Quart. Journn. Geol. Soc. vol. xlv. (1889) p. 175.

The groundmass is remarkable for the tendency of the vitreous material to separate both from the larger crystals and from the mesh of lath-shaped felspars. This vitreous material often forms irregular nests in the midst of the rock, but when, as sometimes occurs, there are steam-holes in the rock, these become filled with the easily separated glass (see Pl. XIX. fig. 2).

This glass, studied in thin sections, is found to present many characters in common with tachylyte. It is often full of dusty particles and skeleton-crystals of magnetite; while felspar occurs as doubly-forked microlites. In addition, there are sometimes long, brown, needle-shaped crystals which have the extinction and pleochroism of hornblende.

The glass of this rock appears to be somewhat unstable, and the vitreous matter filling the spherical cavities (steam-holes) shows every stage of change, till it passes into amygdaloids composed of various zeolites, calcite, chalcedony, chlorites, etc.

Turning our attention to the material forming the centre of the dyke, we find rocks of a totally different composition and character. While the vitreous matter in the rock at the sides of the dyke is subordinate to the crystalline part of the rock, exactly the opposite is true of the central part, in which the more or less perfectly glassy groundmass forms the larger and, at the same time, the most characteristic part of the mass.

Taking the predominance of quartz and of an alkali-felspar, which appears to be a soda-orthoclase, into account, we must refer this rock, according to Rosenbusch's terminology, to the 'quartz-pantellerites' (see Pl. XIX. fig. 1). It may be sufficient for our purpose, however, considering the abundance and distinctive character of the glassy base, to refer to it by the old name of 'pitchstone-porphyry.'

Among the porphyritic constituents, quartz in idiomorphic crystals, with large glass-cavities, is the most abundant. The crystals are sometimes much corroded, but not unfrequently retain their sharp angles.

The felspar-crystals nearly all show, under proper illumination with polarized light, the fine lamellæ characteristic of anorthoclase; they are not unfrequently fractured, and are sometimes corroded. True plagioclase is rare in the rock.

The augite-crystals, which are not numerous, are of a green colour and exhibit a faint pleochroism; they are probably to be referred to the acmites or soda-augites. There are also crystals that appear by their pleochroism, extinction, and double refraction to be a variety of enstatite which is not highly ferriferous.

Magnetite occurs in scattered grains of various sizes.

In addition to these ordinary porphyritic crystals, we find grains of zoned plagioclase, often much corroded, and of a brown augite, both of which have evidently been derived from a rock similar in character to that forming the sides of the dyke.

In the vitreous base we at once recognize the green glass, so familiar to all who have studied the Arran pitchstone or the drawings of it given by Zirkel, Allport, and Teall. Disseminated through the colourless glass basis we find the dust of fine microlites, and among this—each group surrounded by its clear space (' court of crystallization ')—are seen the exquisitely beautiful, fern-like tufts of skeleton-crystals of hornblende. That the reference of these crystals to hornblende is correct is proved in this particular rock by the cleavage and extinction-angles of the larger shafts.

The 'pitchstone' of the Cir Mhor dyke sometimes exhibits, as pointed out by Allport, a distinct banded or fluidal appearance and, occasionally, an approach to perlitic structure.

There is one feature, however, presented by this pitchstone which is of especial interest, and which has not hitherto, I believe, been observed in any rock of the same kind. Each of the quartz-crystals and the angles of many of the felspar-crystals are found to be enveloped in globular aggregations of a perfectly clear and glassy material, and similar globules are found scattered through the mass (see Pl. XIX. fig. 1). Under polarized light, these globules exhibit the black cross resolving itself into hyperbolas, evidently due to strain, the double refraction being negative (see Pl. XIX. fig. 1 *a*).

When very thin sections of the rock are examined with high powers, additional details of much interest are revealed by the study of these globules. They are seen to be made up of two or three concentric coats, the surfaces of the inner ones being ragged, while those of the outside layers are usually smooth and mammillated. Careful study with properly adjusted illumination shows that the ragged surfaces are due to a number of overlapping plates like those so generally recognized by petrographers as tridymite, being attached to the surfaces of the glassy coats. In the case of the isolated globules, not formed round large crystals in the rock, a group of these overlapping scales of tridymite may usually be detected forming a nucleus to the globules; and scattered plates of the same substance may often be detected diffused through them. The white glassy substance usually exhibits a distinctly radial appearance; in some cases high powers show this to be due to needles of hornblende radiating from the crystals, and there is such a perfect gradation between these radiating rods, of which the character can be ascertained, and those which are too minute for determination, as to point to the conclusion that the radiated structure is due to similar hornblende-microlites of ultra-microscopic dimensions. (See Pl. XIX. fig. 1 *b*.)

The optical characters of these globules lead one to conclude that they are hyalite; but as this is a perfectly new mode of occurrence of that mineral, I sent a specimen of the rock to my friend Prof. Rosenbusch, who has very kindly given me the benefit of his wide knowledge and experience. While fully confirming the optical and other characters which I have described, he suggests the possibility that globules of very clear glass might separate out from the matrix, and under the influence of strain simulate the appearance of globules of hyalite.[1] In order to arrive at more definite conclusions on the subject I have submitted the globules to the following microchemical tests. Treated with caustic potash, the globules are slowly but surely attacked, while the glass of the rock is unaffected; this slow action of caustic potash on it is a well-marked character of hyalite. After long treatment with caustic potash, too, these globules lost their perfect clearness and acquired the opalescence of ordinary opals. The globules also show their permeability by liquids when they are treated for some time with a solution of fuchsine, and when, after long immersion in a solution of sugar, they are acted upon with sulphuric acid. I think, therefore, that there can be little doubt that these globules are really composed of the form of opal known as hyalite or 'Müller's glass.'

Although opal often occurs in cavities or fissures in rocks, this is the first occasion, I believe, in which it has been shown by microscopical study to be an actual rock-constituent. It will be remembered, however, that von Lasaulx and other mineralogists have argued that the behaviour of the groundmass of many acid rocks with re-agents points to the existence in them of some form of opal.[2] That the opal in the rock of the Cir Mhor dyke is younger than the porphyritic crystals, and also than the hornblende-microlites of the groundmass, is perfectly clear; but at present we have no trustworthy data to show whether it separated before or after the complete consolidation of the rock.

In addition to these globules of hyalite there are in the pitchstone of the Cir Mhor dyke ordinary spherulites, showing positive double-refraction. These are somewhat sparsely scattered, and are at once distinguished by their greater opacity (see Pl. XIX. fig. 1). Thin sections viewed with high powers show that these spherulites are built up of the usual forked microlites of felspar, and that scattered among them are plates of tridymite. The nuclei of many of these spherulites are also seen with high magnifying-powers to be formed of groups of overlapping tridymite-plates, while similar plates are found scattered among the felspar-microlites.

The rocks of the Cir Mhor dyke called by the earlier authors 'hornstone' and 'claystone-porphyry' are seen, when studied under the microscope, to represent different stages in the devitrification of the 'pitchstone.' In the rock called 'hornstone' the microscope shows that the porphyritic crystals present are identical with those of the glassy variety of the rock, but that some changes have taken

[1] Prof. Rosenbusch, who has kindly examined a section, points out that the most delicate tests at his command failed to show any difference in the refractive index between these clear globules and the surrounding glass. The refractive index of obsidian is 1·48 and of hyalite 1·45, but while the refractive index of the glass would be diminished by the very large quantity of water shown in the analysis, that of the hyalite would be raised by the numerous microscopic and 'ultra-microscopic' needles of hornblende which it contains.

[2] Mr. Teall, in his 'British Petrography' (p. 309), states that some felsites of St. David's and of Arran exhibit spherulites with the appearance and optical characters of hyalite.

place in the groundmass. The feathery outgrowths of the hornblende skeleton-crystals are wanting and only the shafts remain; while, besides the ordinary spherulites, numerous centres of incipient spherulitic devitrification have been set up, and thus the hyaline character of the materials is almost completely destroyed.

In the felsites ('claystones' of the older geologists) the spherulitic structure gradually disappears, and with it the hornblende-crystals, which appear to be completely absorbed (if they were ever developed), until finally we have a cryptocrystalline mass of quartz and felspar ('felsite' or 'petrosilex' of some authors) in which the porphyritic crystals of quartz, felspar, augite, and magnetite are scattered.

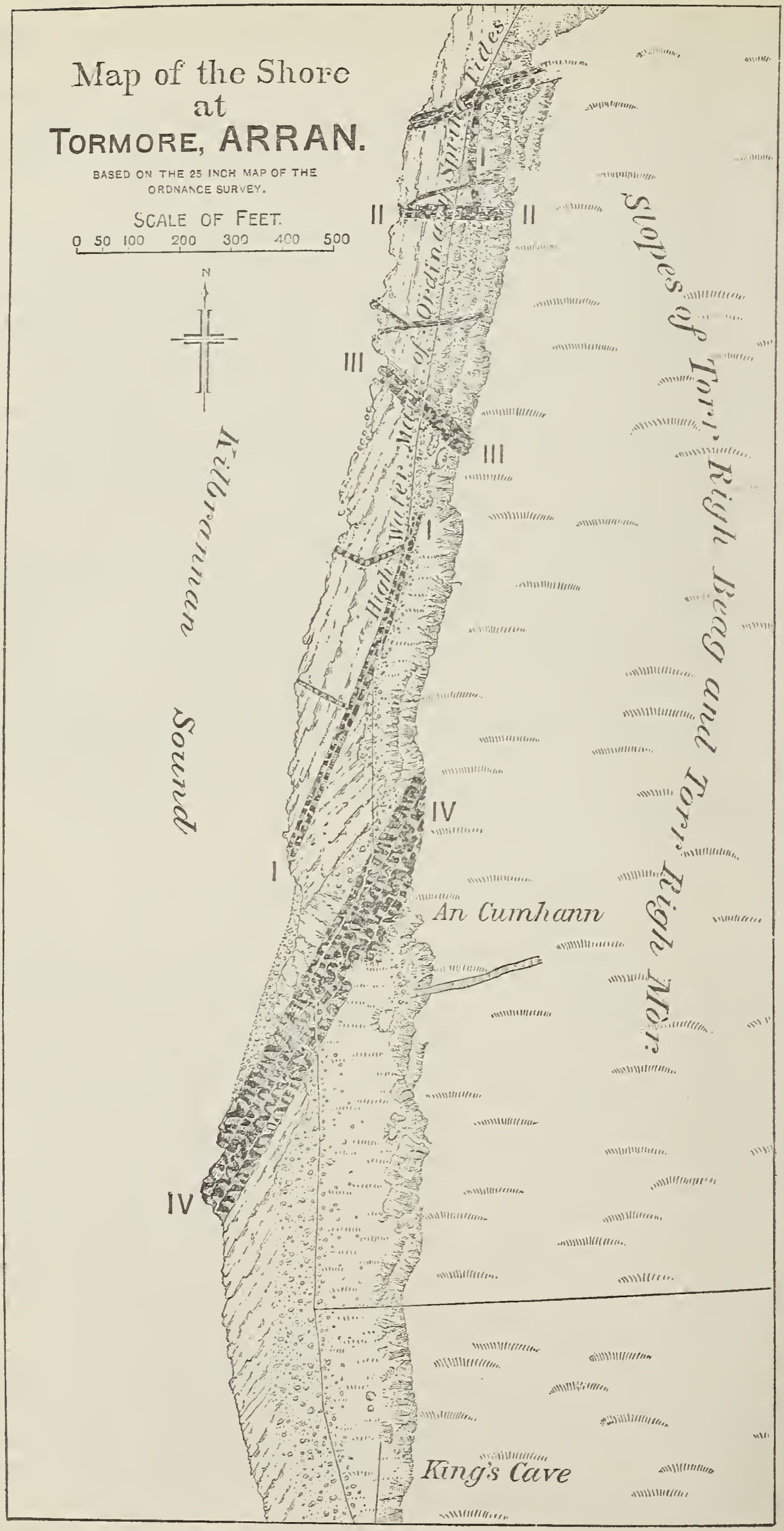
Some doubt may exist as to the period when the devitrification-process took place in this rock. Allport regards the stony rock as resulting from secondary devitrification; my own studies, however, lead me to regard it as formed by primary devitrification, taking place probably during its original consolidation.

Alike in its glassy groundmass and in the crystallized minerals it contains, the 'quartz-pantellerite' forming the centre of the Cir Mhor dyke is absolutely dissimilar from the augite-andesite forming the sides of the dyke. In the one rock the glass resembles an obsidian, in the other a tachylyte; while the free quartz, the alkali-felspars, the green augite, the enstatite, and the hornblendes of the one rock have nothing in common with the lime-felspars and the brown augite of the other. By no conceivable process of selective crystallization and liquation could these two rocks be produced from the same magma.

VII. The Tormore Plexus of Composite Dykes—Earlier Notices.

At several points in Arran, and in other parts of the Western Highlands, examples of composite dykes, presenting a greater or less similarity with that of Cir Mhor, may be found. One of the most remarkable localities at which illustrations of these phenomena can be seen is that part of the west coast of Arran stretching northward from Drumadoon Point, about two miles, to Tormore. There is reason to believe that the whole of the dykes and intrusive masses along this portion of the coast have a very close connexion one with another, and that they all stand in intimate relation to the great sheet of columnar quartz-felsite rock forming Drumadoon Point. It will be sufficient for my present purpose, however, to direct attention to the northern part of this line of coast—from a little north of the King's Cave to a point south of the village of Tormore. (See Map, p. 552.)

We have in this section of the coast, about half a mile in length, a very remarkable plexus of dykes, admirably exposed on the shore between high- and low-water marks, and also seen in the adjoining cliffs, below the hill of Torr Righ Beag; these dykes present clear evidence of the successive injection of the same fissure with rocks of different chemical composition.


Map of the Shore
at
TORMORE, ARRAN.
BASED ON THE 25 INCH MAP OF THE ORDNANCE SURVEY.
SCALE OF FEET.
0 50 100 200 300 400 500
N
Kilbrannan
Sound
High Water Mark of Ordinary Spring Tides
Slopes of Torr Righ Beag and Torr Righ Mor.
I
II
II
III
III
I
IV
I
IV
An Cumhann
King's Cave

The first author to describe this very interesting locality was Prof. Robert Jameson. In his earlier work on Arran the occurrence of a great pitchstone-vein crossed by a series of transverse dykes of basalt is mentioned.[1] In his 'Mineralogy of the Scottish Isles,' published in 1800, we find not only a very accurate description of the composition and relations of these various intrusions, but a plan of the shore on which the several dykes are indicated by letters.[2] So accurate are this plan and description that they were reproduced by Ramsay in his 'Geology of Arran,'[3] without alteration, and Bryce also quoted the same description.[4] Zirkel in 1871[5] gave a plan and description of one of the composite dykes, while Allport in the same year[6] referred to another of them.

There are slight discrepancies in the accounts of these several dykes given by different authors, owing to the fact that no two observers probably have seen the shore in quite the same condition. The tidal scour, sweeping loose blocks and shingle into hollows, at times obscures certain tracts of the shore or uncovers other portions of it. The publication of the excellent maps of the Ordnance Survey enables us to lay down the positions of the several dykes in a more accurate manner than was before possible; but the original plan and description of Jameson still constitute an admirable guide to the position and relations of these rock-masses.

In the following account of these composite dykes, I shall give the result of observations and measurements which I have made upon several different occasions, adding references to the accounts of Jameson and other geologists who have stated what they saw there in previous years.

VIII. General Structure of the Tormore Dykes.

The Tormore plexus consists of a great dyke or sheet running nearly north-and-south for a distance of about 600 yards approximately parallel to the shore, sometimes in a vertical and sometimes in an inclined position, and crossed at intervals by numerous other dykes in a transverse or more or less east-and-west direction. The principal intrusion (I in the Map) and three of the transverse masses (II, III, and IV in the Map) are beautiful examples of composite dykes, and, taken together, they illustrate in an admirable manner the main varieties of that class of phenomena with which

[1] 'Outline of the Mineralogy of the Shetland Isles and of the Island of Arran,' 1798, pp. 126–128.

[2] 'Mineralogy of the Scottish Isles,' vol. i. pp. 101–106, with plate facing p. 103. In the text of this paper I have introduced the letters employed by that author to distinguish the several dykes. It will be seen that, by an inadvertence, Jameson sometimes employs the same letter twice—but no real inconvenience has arisen from this circumstance.

[3] 'The Geology of the Island of Arran from original Survey,' 1841, p. 51.

[4] 'The Geology of Arran and the other Clyde Islands,' 4th ed. (1872) pp. 201–203.

[5] Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxiii. (1871) p. 40, pl. ii.

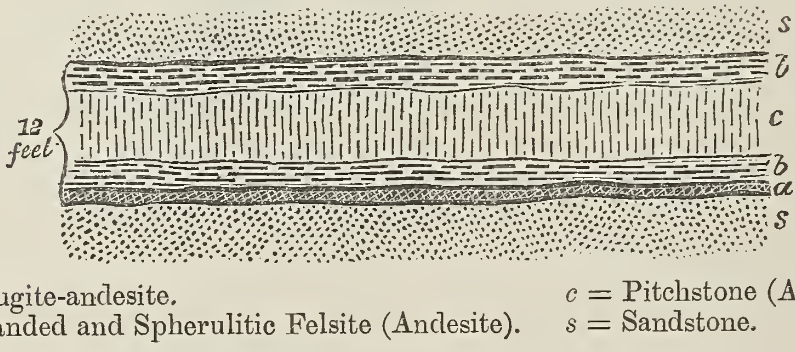
[6] Geol. Mag. for 1872, p. 5.

we are chiefly concerned in this memoir. Although the actual relation of these several dykes to each other is sometimes difficult to trace, the nature of the rock-materials in them is of such a character as to warrant the belief that they are all intimately connected, and that all the fissures have been filled from the same subterranean reservoirs. I will now proceed to describe in detail the characters of these four composite dykes.

The Great North-and-South Dyke (I in Map).—This great igneous intrusion can be traced, at intervals, where not covered by shingle, for a distance of over 600 yards. It is indicated on Jameson's plan by the letters A, B, C, D. It should perhaps be called in some places a sheet rather than a dyke, for it is occasionally almost horizontal, but the changes in its dip appear to be numerous and sometimes sudden. At the most northerly point where it can be seen rising from under the shingle, it consists entirely of a green pitchstone which, by microscopic study, is found to be a 'vitrophyric augite-enstatite-andesite,' without quartz. For a distance from north to south of about 450 yards it seems to follow pretty closely the direction of the shore; but, at its southern extremity, it bends from this direction at an angle of 40° towards the west, and runs out seawards. Here, too, the mass loses its vertical position and in places has a dip of less than 60°. The dyke, where it can be measured, appears to have a width of 10 to 12 feet, and a marked alteration of the red sandstone, forming its walls, is seen to be produced by it.

This intrusion constitutes an interesting example of a composite dyke. While at its northern extremity it consists entirely of green pitchstone, at its southern extremity the glassy rock passes near the sides into a 'lithoidite' or stony andesite; and on its western

Fig. 2.—*Diagrammatic Plan of North-and-South Composite Dyke, Tormore.*



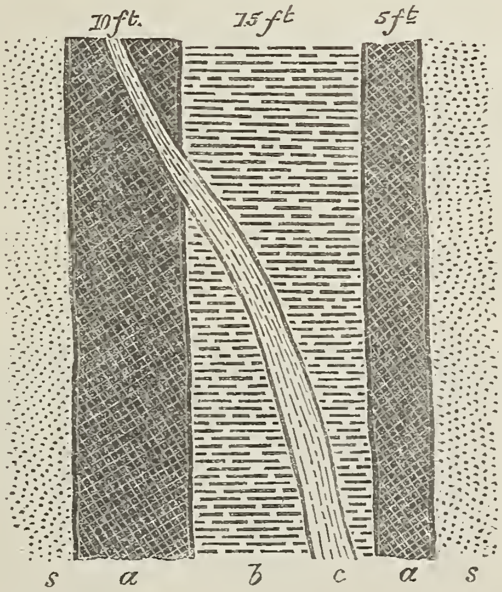
a = Augite-andesite.
b = Banded and Spherulitic Felsite (Andesite).
c = Pitchstone (Andesite).
s = Sandstone.

side it gives off a vein of hornstone-like rock (E of Jameson) which runs out seaward. On its eastern side, however, a band of dark-coloured augite-andesite, weathering into balls, is seen coming in between the more acid rock and the sandstone-walls of the dyke. This dark-coloured rock precisely resembles that forming the sides of the Cir Mhor dyke. While there may be some doubt on the subject, I think the evidence points to the conclusion that the thin band of more basic rock was injected at a later date than the more acid materials forming the mass of the dyke. (See fig. 2, p. 554.)

This great dyke is crossed by a number of transverse dykes, the most northerly of which is one composed of pitchstone (Q of Jameson), which is about 10 feet wide and runs out to sea in a S.W.-by-W. direction, but does not appear to present any special features of interest. Other composite dykes occur, however, which we will proceed to notice in order from north to south.

The Northern Transverse Composite Dyke (II in Map).—This dyke is indicated by the letters X, O, P on Jameson's plate; a plan of the vein taken on the shore near low-water mark is given by Zirkel.[1] The width of the dyke is about 30 feet; its sides are composed of an augite-andesite, which weathers into rounded balls, its centre of a quartz-felsite which in places passes into a 'pitchstone-porphyry' or 'vitrophyric' rock. The acid rock forms about one half of the width of the dyke, and the 'pitchstone-porphyry' occurs as a band varying in width from 6 inches to 2 feet, sometimes forming part of the quartz-felsite mass and at other times intersecting the adjoining masses of andesite (see fig. 3). The augite-

Fig. 3.—*Diagrammatic Plan of Northern Composite Dyke, Tormore.*



a=Augite-andesite. *c*=Pitchstone-porphyry (Dacite).
b=Quartz-felsite (Dacite). *s*=Sandstone.

andesite is sometimes coarse-grained, with intersertal structure, and at other times it is fine-grained, with much glass filling amygdaloidal hollows. The 'pitchstone-porphyry' is somewhat peculiar in character. In colour it is nearly black, and instead of the usual feathery masses of hornblende-microlites, so common in the Arran

[1] Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxiii. (1871) pl. ii.

pitchstones, it contains great numbers of stellate groups, each surrounded by its 'court of crystallization' as described by Allport.[1]

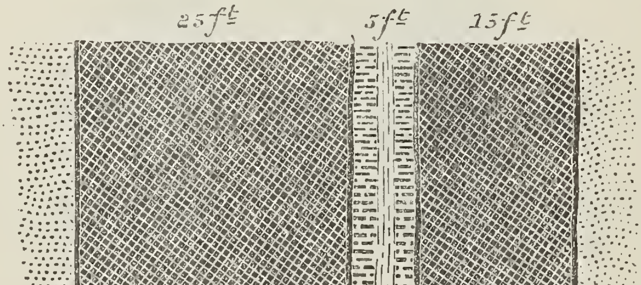
This 'pitchstone-porphyry' contains a considerable quantity of pyrites. It also exhibits a phenomenon which I have already described as occurring in the glassy rock of Chiaja di Luna in Ponza. When broken by a hammer, the mass tends to split up into spheroids with concentric structure, and each surface exposed only retains its brightness momentarily, being then covered with a whitish film. This white film is evidently formed by a molecular change following the relief from a condition of strain.[2]

As the 'pitchstone-porphyry' in this dyke is sometimes enclosed entirely in the quartz-felsite, and at other times crosses the boundaries of that rock and intersects the augite-andesite (see fig. 3, p. 555), there is reason for believing that the infilling of the dyke was accomplished at three distinct periods.

A short distance south of this northern composite dyke two dykes of augite-andesite are seen enclosing a mass of conglomerate or coarse sandstone. These two dykes, which appear to be branches of a single one, are designated by Jameson M, L, M.

The Middle Transverse Composite Dyke (III in Map) occurs about 120 yards south of the northern dyke, and is marked in Jameson's plan by the letters L, K, H, G, F. It strikes N.W.-and-S.E. and is from 40 to 50 feet wide. The dyke is mainly composed of augite-andesite, but in its midst there occurs a band of quartz-felsite 4 or 5 feet wide, passing at its centre, for a width of 2 feet, into the 'vitrophyric' form ('pitchstone-porphyry'). The band of acid rock is usually much nearer to the north-eastern than to the south-western side of the dyke, but is very variable, and, when followed up into the cliff, is found to expand to a width of 10

Fig. 4.—*Diagrammatic Plan of Middle Composite Dyke, Tormore.*



a=Augite-andesite.
b=Quartz-felsite (Dacite).
c=Pitchstone (Dacite).
s=Sandstone.

[1] Geol. Mag. for 1872, p. 5. [2] *Ibid.* 1886, pp. 245-246.

to 12 feet (see fig. 4). It here appears to send off sheets, laterally, between the sandstone-beds, and to be connected with the great north-and-south dyke which crosses it on the shore.

Some distance southward a simple dyke of augite-andesite, about 5 feet wide (P of Jameson), is found crossing the shore.

The Southern Transverse Composite Dyke (IV in Map).—This dyke is not included in Jameson's plan, but it occurs only a little south of the point where the great north-and-south dyke runs out to sea, and appears to be closely connected with the other dykes of this plexus; it is about 300 yards south of the middle composite dyke. This southern dyke is about 90 feet wide, and traverses the sandstone, which it greatly alters, in a N.N.E.-and-S.S.W. direction. The point where it runs into the cliff is called on the Ordnance map An Cumhann, and the intrusion forms a great buttress across the shore.

In places the strike of this dyke closely agrees with that of the sandstone-rocks into which it is intruded, and the mass, like the great north-and-south dyke, which is parallel to it at its southern end, may be regarded as being of the nature of a sheet rather than a dyke.

The rock forming the greater part of this dyke is a quartz-felsite, with very large porphyritic crystals, closely resembling that which constitutes the headland of Drumadoon. On the south-eastern side of the mass there is a dyke of augite-andesite, $2\frac{1}{2}$ feet wide, which has inserted itself between the quartz-felsite and the sandstone, in the latter having sent off a branch which can be seen in the cliff. On the north-western side is a second dyke of augite-andesite, which bifurcates where it rises into the cliff into two bands each 3 feet wide, including between them a 'horse' of the quartz-felsite. A third dyke of augite-andesite, 4 feet wide, traverses the middle of the great quartz-felsite dyke in a sinuous line. It is one of the andesite dykes that, weathering away easily, has formed a ravine down which the path from the top of the cliff to the shore has been formed (see fig. 5, p. 558).

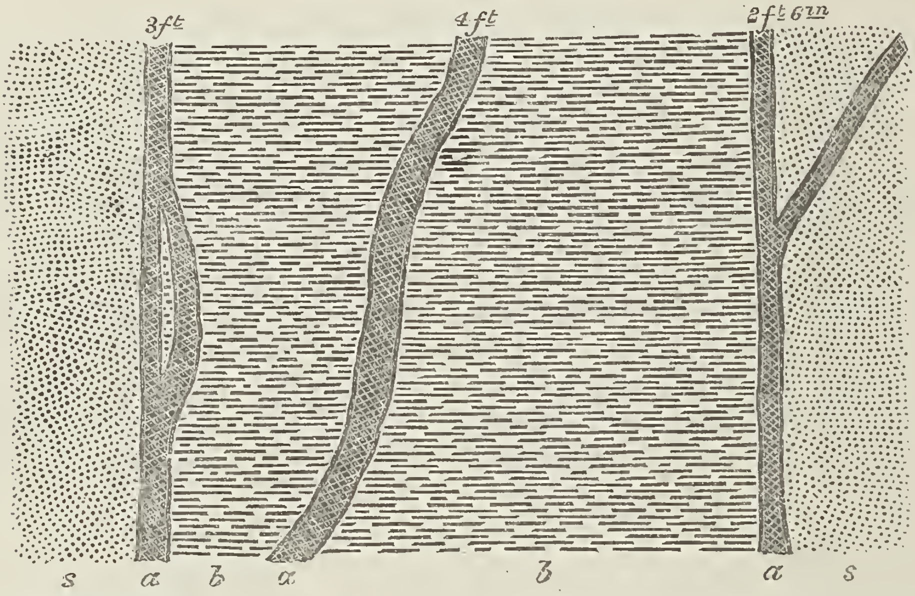
There can be no doubt that these three dykes of augite-andesite were injected at a later date than the mass of the quartz-felsite. The relations of the several rocks render this point clear, and, if any doubt existed on the subject, it would be removed by the presence of numerous crystals of quartz and felspar in the augite-andesite, which have, as I shall presently show, been derived from the quartz-felsite.

Passing southward, past the well-known King's Cave, we come to the cliff in which the masses of red and brown pitchstone and quartz-felsite described by Allport[1] occur, and a little farther on a composite dyke occurs with augite-andesite at its sides and pitchstone in its centre. Nearer Drumadoon Point many dykes of different composition are seen, one of augite-andesite having produced partial fusion in a mass of quartz-felsite, as shown by Prof. Bonney.[2] Other augite-andesites are remarkable for the number of quartz-crystals they have caught up in traversing the quartz-felsite. As, however,

[1] Geol. Mag. for 1872, pp. 538–540.
[2] *Ibid.* 1877, pp. 505–509.

the connexion of these dykes south of the King's Cave with the plexus of Tormore is more problematical, I have not included them in my account of the district.

Fig. 5.—*Diagrammatic Plan of Southern Composite Dyke, Tormore.* [Total width = 90 feet.]



s = Sandstone.
a = Augite-andesite.
b = Quartz-felsite (Rhyolite and Quartz-pantellerite).

IX. Chemical Composition of the Tormore Dykes.

Although we possess no published analyses of the augite-andesites of Tormore, there can be no doubt that their composition is fairly represented by Analysis I. in this paper (p. 545), and by the analyses of the North-of-England Dykes published by Mr. Teall.

The 'vitrophyric' augite-enstatite-andesite has been analysed by Mr. Magnus M. Tait, F.C.S., and his results are given under IV. below; it is the least acid of all the 'pitchstones' of Arran that have yet been chemically examined.

The more acid rocks of the southern composite dyke are represented in Analysis V., made by the same chemist,[1] while VI. and VII. are analyses of still more acid dykes of semi-vitreous character which occur in the cliff a short distance south of the area described in these pages.

	IV.	V.	VI.	VII.
Silica	66·03	72·50	77·99	73·84
Alumina	12·55	11·53	11·17	10·10
Oxides of iron	2·75	2·06	1·12	1·24
Oxide of manganese	......	......	0·16	......
Lime	2·80	1·79	0·93	1·17
Magnesia	2·33	2·72	trace	trace
Soda	5·02	3·37	4·93	2·65
Potash	4·13	5·24	trace	2·43
Water	4·20	0·70	3·59	8·19
	99·81	99·91	99·89	99·62

[1] Bryce, 'Geology of Arran,' 4th ed. p. 203.

IV. is an analysis of a pitchstone from Tormore; although it is not expressly stated to be from the north-and-south dyke, there can be little doubt on the subject.

V. is said to be from a 'claystone' from the same locality. It is probably the porphyritic felsite of the great southern composite dyke.

VI. and VII. are analyses made by John Arthur Phillips, and published by Mr. Allport (Geol. Mag. for 1872, p. 540). The results given are the mean of two closely concordant analyses. VI. is a red 'hornstone-like' felsite, and VII. represents the nodules contained in the same rock.

X. Microscopical Characters of the Rocks composing the Tormore Dykes.

Although there are minor differences to be recognized between the rocks of Cir Mhor and those of Tormore, their essential identity is sufficiently obvious. At both localities we find in association in the same dyke a rock of essentially basic composition (augite-andesite) and one distinctly acid, with a large amount of glassy base which may be more or less devitrified.

The augite-andesite is of the ordinary character in most of the dykes at Tormore. Rounded gas-cavities filled up with glass, now wholly or in part, converted into chlorites and other secondary products, are by no means unfrequent. In the middle transverse composite dyke the rock is of considerable thickness, and the slow cooling of such a large mass of material has led to the formation of an ophitic dolerite or diabase, which passes by insensible gradations into an intersertal rock ('tholeite'), and thence into the ordinary andesite with its felted base of felspar-microlites and its porphyritic crystals of zoned plagioclase.

The acid rocks, however, show a much greater variety in composition and character, though they always reveal clear traces of their close family relationships.

The great north-and-south dyke is an example of the most basic type of these pitchstones. It contains no quartz-crystals and only somewhat sparsely scattered plagioclase, with possibly a few crystals of anorthoclase, but no true orthoclase. Porphyritic crystals of enstatite and augite occur, the former mineral being not unfrequently enclosed in or zoned by the latter; the microlites of the groundmass are as usual, however, hornblende. The 'claystone' and 'hornstone' into which this rock passes show beautiful examples of the transition of a glassy to a stony rock, the groundmass becoming first spherulitic, and then taking the characters assigned to what is known as the 'felsitic substance.' It is very interesting to note how in this process the hornblende-microlites appear to be re-absorbed, while the glassy groundmass breaks up into an aggregate of quartz- and felspar-microlites, with or without spherulitic arrangement. This rock must be classed as an augite-enstatite-andesite with much base and few porphyritic crystals. Very careful determinations of its specific gravity by Mr. T. Barron showed that it lies between 2·343 and 2·344.

The 'felsite' and 'pitchstone' of the northern composite dyke differ from the acid rock of the north-and-south dyke in containing a considerable number of quartz-crystals in addition to the plagioclase-felspar. The rock is a quartz-augite-andesite (dacite) with a base which is sometimes glassy and at other times stony. The devitrification of the glass is seen to be produced, first by the development of spherulites around the porphyritic crystals or independent centres, and then by the breaking up of these into ordinary 'felsitic substance.'

In the middle composite dyke we have also a quartz-andesite or dacite, the great majority, if not the whole, of the felspars being plagioclastic. The glassy form of the rock can here also be traced graduating into the 'lithoidal' form, the first stage being in this case the development of spherulites either independently or surrounding the porphyritic crystals; and the rock also exhibits a beautiful banding. This rock, as well as some of the other 'pitchstones' of Tormore, exhibits globules of hyalite like that of the 'pitchstone' of the Cir Mhor dyke, but less distinctly. It is worthy of remark that the phenomenon has not escaped the notice of that acute observer Mr. Allport, who speaks of clear continuous bands surrounding quartz-crystals, and giving a black cross between crossed nicols; these he apparently considered as incipient spherulites.[1]

The rock forming the mass of the great southern composite dyke is the most acid of all these felsites. In all its main features it is identical with the rock of Drumadoon, and with the other masses of similar character which cover so considerable an area in the south of Arran. A more or less cryptocrystalline base is studded with large, but often much corroded, crystals of quartz and felspar. The latter appear to be either orthoclase or anorthoclase, the few plagioclase crystals being quite subordinate to these. According to the predominance of the orthoclase or the anorthoclase, the rock must be called, in accordance with the generally accepted terminology, either a rhyolite or a quartz-pantellerite.

One very interesting fact about all the rocks of these dykes is the prevalence in them of derived crystals. The 'felsites' and 'pitchstones' not unfrequently contain the zoned plagioclases and the brown augites of the augite-andesites, and these are usually much corroded by the acid magma in which they have been caught up. Far more frequent, however, are the cases of minerals clearly derived from the acid rocks, enclosed in the basic ones. Some of the augite-andesites are completely studded with crystals of quartz, and this is especially the case near the junctions with the pitchstones or felsites. The quartz-crystals are surrounded with zones of pyroxene, and the rock thus closely resembles the well-known basalt of the Detunata in Transylvania and also the 'quartz-basalts' of the Western Territories of North America which have been so well

[1] Geol. Mag. for 1872, p. 541.

described by Iddings and Diller. In some cases the felspars (orthoclase, anorthoclase, or plagioclase) of the acid rocks can be clearly recognized in the midst of the augite-andesites, and are then seen to be surrounded by a zone of alteration produced by the reaction of the magma on the surfaces of the crystals.

Mr. Allport records the finding of a porphyritic pitchstone-boulder in Arran which contained "a considerable proportion of fine-grained basalt included in it," as well as "small isolated fragments of the same rock . . . . and a few grains of augite."[1] It is not improbable that this pitchstone was derived from one of the numerous composite dykes of the island.

XI. Summary; and General Conclusions derived from the Study of the Composite Dykes of Arran.

Any suggestion concerning the possibly *accidental* association of the augite-andesite and 'pitchstone' in the Cir Mhor dyke is at once negatived by the study of the remarkable plexus of dykes at Tormore. No one can doubt, after the study of this latter case, that there is a real and not merely an accidental connexion between the ejection of materials of such very different composition and character: all the facts, indeed, point to the conclusion that the fissures were injected from the same subterranean reservoir, but that this reservoir contained two magmas of totally different chemical composition. In the same way, as is well known, a single volcanic vent may give rise at successive periods to two totally distinct kinds of lava.

Nor can there be any difficulty in understanding how the same fissure, while still in connexion with a reservoir of liquefied lava, may be reopened and re-injected at successive periods. The plane of weakness, along which the reopening of the dyke is effected, is sometimes, as in the Cir Mhor dyke, in its centre; in other cases, as in the great north-and-south dyke of Tormore, and also in the most southerly of the transverse dykes of the same district, planes of weakness are found along one or both of the lateral walls of the dyke, and it is here that the re-injection is effected; in yet other cases, also illustrated at Tormore, the new fracture seems to be quite irregular in position and to traverse the old dyke-material in a sinuous line. In one instance we have evidence of three separate injections into the same fissure.

In some cases the more acid rock (quartz-felsite and pitchstone) was the first ejected; but, quite as frequently, the basic material (augite-andesite) was the earliest to be intruded into the opening fissure. The relative ages of the two rocks in the dyke are shown, not only by the positions which they occupy, but by the circumstance that derived minerals from the older rock are found included in the younger one. That a very considerable interval of time must have elapsed between the two injections is shown by the fact that

[1] *Op. cit.* p. 537.

complete consolidation and crystallization of the materials of the one rock must have occurred before its invasion by the other rock: this is proved by the characters of the junctions and also by the derived crystals.

These composite dykes afford, moreover, very valuable evidence concerning the relative ages of some of the larger ejections in the area of the West of Scotland. I have shown that at the five great centres of volcanic outburst in that area—at Mull, Ardnamurchan, Rum, Skye, and St. Kilda—the order of appearance of the three kinds of igneous material was as follows:—intermediate, acid, basic. In Arran, however, the great basic eruptions, represented by olivine-gabbro and plateau-basalts, seem to have been wanting. Farther south, in Ireland, both acid and basic rocks are represented by granites and gabbros; but whether these are to be regarded as contemporaneous with the similar rocks in the Scottish area is a question which has been left unsettled by the work of the Geological Survey in that region.

That the rocks with which we are concerned in this paper are of far more recent age than the granite of Arran is evident, because at Cir Mhor we find the granite intersected by this and similar dykes. It is clear that not only was this great mass of granite already ejected, but that it must have become consolidated and acquired its present structures, before the injection into it of the andesite and 'pitchstone.'

Of still greater interest, as I have already intimated, is the light thrown by the study of these dykes upon the cause of the differentiation of lavas—a question which has frequently been discussed in the past, but which during the last few years has received new treatment at the hands of Guthrie,[1] Lagorio,[2] Teall,[3] Rosenbusch,[4] Brögger,[5] Vogt,[6] and Iddings.[7]

We may classify the explanations which have been suggested to account for the differentiation of lavas into two groups:—those which rely upon some process of selective crystallization, and those which premise some kind of separation taking place in a liquid magma prior to the commencement of crystallization and consolidation.

Differentiation during crystallization has been referred to two distinct causes. Prof. Vogt, in order to account for the deposits so rich in magnetite occurring in Scandinavia and elsewhere, has put forward the theory that the remarkable magnetic properties of the iron-spinellid may account for its segregation, and that the mutual attraction of the magnetite-particles may lead to their

[1] Phil. Mag. 5th ser. vol. xvii. (1884) pp. 462–482, vol. xviii. (1884) pp. 22–35 & 105–120.

[2] Min. u. petr. Mitth. vol. viii. (1887) pp. 421–529.

[3] 'British Petrography,' 1888, pp. 391–403; and 'Natural Science,' vol. i. (1892) pp. 288–299.

[4] Min. u. petr. Mitth. vol. xi. (1889) pp. 144–176.

[5] Zeitschr. für Krystallogr. u. Min. vol. xvi. (1890).

[6] Geol. Förening. Förhandl. vol. xiii. (1891) p. 476.

[7] Bull. Phil. Soc. Washington, vol. xi. (1890) pp. 191–220, vol. xii. (1891) pp. 89–214.

accumulation at certain points in the still fluid magma. But this ingenious suggestion omits a very important consideration. It has been shown by Prof. Rücker, F.R.S., that both metallic iron and magnetite, when heated, rapidly lose their magnetic properties, and that at a dull red heat all phenomena both of attraction and polarity disappear alike in metallic iron and in magnetite. Such being the case, it seems impossible to conceive of such a degree of heating of a magma as would permit of internal movements, and yet would not at the same time destroy the attractive properties of the magnetite.

The other suggested method by which differentiation may be brought about in a magma during the process of crystallization, is based on the fact that, as a general rule, the more basic minerals crystallize out of a molten mass before those of acid composition, and that, as a consequence of this, the matter left liquid continually tends to become more and more acid in composition. That in these masses of molten rock consisting of basic crystals diffused through an acid menstruum, a process of partial or complete liquation may occur, is shown by the phenomena which have been observed at Santorin,[1] Krakatoa,[2] Beinn Hiant,[3] Garabal Hill,[4] etc. This method of differentiation, while it affords a satisfactory mode of explanation of the first class of composite dykes—that so well described by Lawson and Vogt—is clearly inapplicable to the cases in Arran, where the porphyritic crystals and glassy basis in the two constituent rocks are so strikingly contrasted one with another.

We are thus compelled to fall back upon the view that an actual separation takes place among the materials of a molten magma *before the work of crystallization has commenced*; and I may, in conclusion, pass in review the several suggestions that have been offered to account for such action in a mixed mass of molten silicates.

Bunsen and many authors since his time have dwelt upon the fact that such molten masses of silicates are really solutions, and must obey all the laws which govern solvent action. Guthrie and Lagorio have especially insisted on this view of the subject.

Many writers on the question have been impressed by the view that the two magmas into which a mass of molten silicates may be supposed to break up must vary greatly in density; and several of these writers have suggested, in more or less distinct terms, that this difference in specific gravity may be the efficient cause of their separation. But until recently it was difficult to realize the physical principles that would cause density-differences to come into play as factors of differentiation. The researches of Gouy and Chaperon,[5] however, supply a possible explanation of the phenomenon. These authors have pointed out that, in accordance with well-recognized

[1] 'Santorin et ses Éruptions,' Fouqué, 1879.
[2] Geol. Mag. for 1888, p. 1.
[3] Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 371–381.
[4] *Ibid.* vol. xlviii. (1892) p. 104.
[5] Ann. de Chimie et de Physique, 6th ser. vol. xii. (1887) pp. 384–394.

thermodynamical principles, there should be—in a very great volume of a solution, especially if near saturation—a tendency for concentration to take place in the lower parts of the mass. Such vast masses of molten silicates as must exist in the deeper parts of the earth's crust are precisely the kind of solutions in which we may expect to find the action of this law illustrated.

There is still another physical principle which has been appealed to as affording an explanation of the differentiation which takes place in a liquefied mass of silicates. In the same year that Gouy and Chaperon demonstrated the causes that would lead to "the concentration of solutions by gravity," van't Hoff published his paper on 'The Rôle of Osmotic Pressure in the Analogy between Solutions and Gases.'[1] He argued that solutions must follow the law of gaseous tension, and that if two parts of a solution be maintained at different temperatures, concentration must take place in the cooler part. It is interesting to note that, six years before van't Hoff published his general conclusions, Soret had conducted a series of experimental researches which showed that, when two portions of a solution are maintained at different temperatures, there is always a tendency to concentration in the colder part.[2]

If, as we may assume is generally the case, the lowest portions of the great liquid reservoirs within the earth's crust are at the highest temperature, then the principles established by Gouy and Chaperon and by van't Hoff respectively would operate in contrary directions and tend to neutralize each other. It is sufficient for our present purpose, however, to call attention to the fact that there are now well-recognized physical principles, in accordance with which differentiation must necessarily be set up in the heated solutions constituted by molten masses of mixed silicates, anterior to, and independently of, the liquation that may follow selective crystallization. That differentiation does take place before, as well as during, crystallization, the phenomena exhibited by the two classes of Composite Dykes afford interesting and striking proofs.

[At the recent Meeting of the British Association at Nottingham, Mr. Alfred Harker suggested that there is another physical principle which may be appealed to as explaining the differentiation which takes place in homogeneous molten magmas. This is Berthelot's 'principle of maximum work,' or the cognate one of 'most rapid degradation.' Migration of the least soluble ingredient to the part of the liquid most easily saturated would determine crystallization, the process which would give rise to the most rapid evolution of heat.—September 30th, 1893.]

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[1] Zeitschr. f. Phys. Chemie, vol. i. (1887) p. 481.
[2] Ann. de Chimie et de Physique, 5th ser. vol. xxii. (1881) p. 293.

1.
$\times \frac{35}{2}$

1a.
$\times \frac{100}{3}$
+nic.

1b.
$\times \frac{250}{4}$

2.
$\times \frac{35}{2}$

M. P. Parker del. et lith.

Mintern Bros. imp.

PITCHSTONE AND ANDESITE OF THE CIR MHOR DYKE.

EXPLANATION OF PLATE XIX.

Fig. 1. Illustrates the ordinary characters of the glassy rock forming the centre of the Cir Mhor dyke. The groundmass shows numerous fern-like aggregates of hornblende-microlites, each surrounded by its 'court of crystallization.' In the lower part of the figure are seen two crystals of felspar, which in polarized light exhibit the characters of anorthoclase. On the right-hand side is an ordinary spherulite, composed of bifurcating felspar-microlites, surrounding a nucleus formed of plates of tridymite; this spherulite exhibits positive double refraction. Near the centre of the figure are two grains of quartz, enclosed in a double envelope of perfectly clear hyalite, with negative double refraction. The clear substance of the hyalite is penetrated by numerous radiating microlites of hornblende. Two other similar globules of hyalite are seen in the figure:—one on the left, enveloping a minute group of tridymite-crystals, and another, in the lower part, attached to an angle of the large felspar-crystal.

Fig. 1 *a* shows the group of quartz-crystals, with their globular envelopes of hyalite, as seen with a higher power, between crossed nicols.

Fig. 1 *b* is a drawing of portion of a double envelope of hyalite, as seen with a high power, in a very thin section and with suitable illumination. Between the two layers of hyalite are seen numerous plates of tridymite, and the clear substance of the former is seen to be traversed by many very fine hornblende-microlites.

Fig. 2. Augite-andesite of the sides of the Cir Mhor dyke. The rock consists of numerous felspar-microlites, crystals of brown augite, and grains of magnetite, with glass between them, and a few large and often much corroded porphyritic crystals of plagioclase. In the upper part of the figure is an irregular patch of tachylytic glass, filled with magnetite dust; glass also occupies an amygdaloidal cavity near, but here it has undergone much alteration; among the secondary minerals formed from the decomposition of the glass in this cavity, chlorites are conspicuous.

Discussion.

Prof. Bonney said that his own observations in Arran several years ago enabled him to confirm Prof. Judd's description. He had seen basalt (or augite-andesite) following quartz-felsite, and pitchstone following quartz-felsite, and so on: evidently the one rock had been solid when the other came; so the magma must have been differentiated underground. He quite agreed with Prof. Judd that sometimes differentiation took place in the intrusive mass itself, but that separation also took place below, and masses of different composition were ejected at different times.

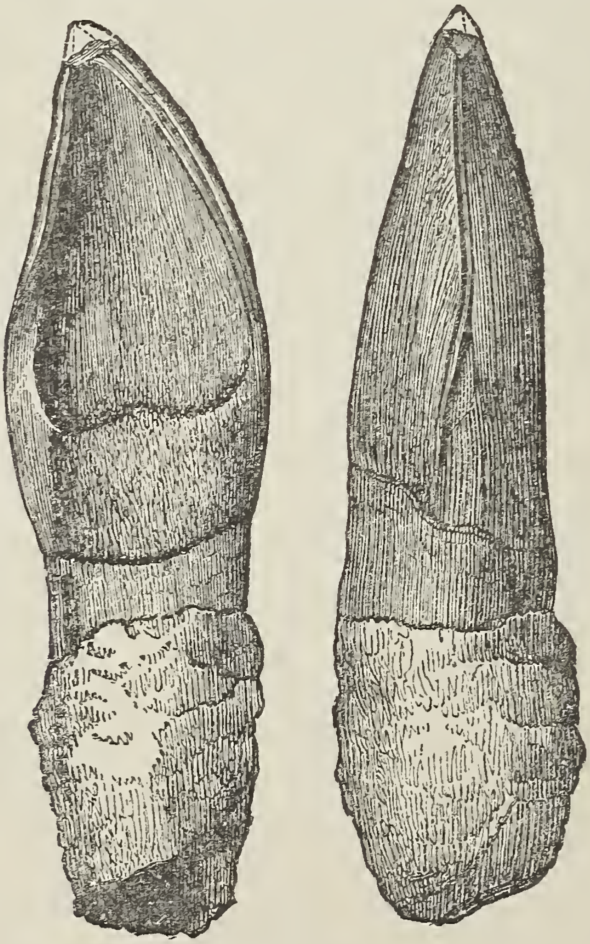
Mr. W. W. Watts, referring to the occurrence of many complex dykes in another region, the coast of the Mourne Mountains, thought that the exceptional nature of the phenomena might be explained by the fact that, although lines of weakness in and along dykes were frequent, the necessary materials for filling them were not usually so near at hand as in the Eocene period. He enumerated a series of characters which ought to be more common in igneous rocks if segregation during crystallization were of frequent occurrence in their origin.

Mr. Hulke and Mr. Teall also spoke, and the Author briefly replied.

41. *On* Two Dinosaurian Teeth *from* Aylesbury. By R. Lydekker, Esq., B.A., F.G.S. (Read June 21st, 1893.)

I have previously figured in this Journal two teeth of large Dinosaurian reptiles belonging to the Sauropodous division of the group—the one in vol. xliv. pl. iii. fig. 4, and the other in vol. xlv. p. 243, fig. 7; and I have now the pleasure of bringing to notice two other examples of such teeth, recently obtained by Mr. J. Alstone, from strata at Beagle Pit, Hartwell, near Aylesbury, believed to be of Portlandian age. Of the two specimens previously figured, the former

Fig. 1.—*Inner and Lateral Aspects of Tooth of* Hoplosaurus armatus. (*From the Wealden of the Isle of Wight.*)



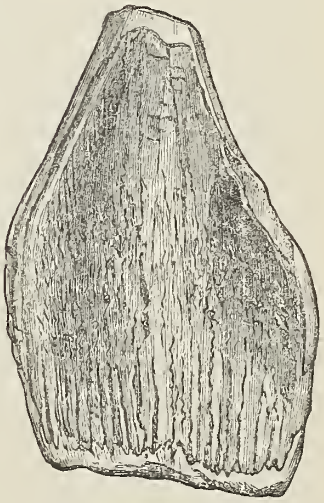
[Natural size.]

was originally described under the name of *Ornithopsis Hulkei*, a name subsequently replaced by *Hoplosaurus armatus*, as being one which had been applied by Gervais at an earlier date to this particular tooth.[1] Of this tooth two views are given in the accompanying figure. The second specimen, which, like the preceding, is from the Wealden, was at first referred provisionally

[1] See Cat. Foss. Rept. Brit. Mus. pt. iv. (1890) p. 243.

to *Ornithopsis*, but was subsequently considered to belong more probably to *Pelorosaurus Conybeari*,[1] although some of the teeth of that animal must doubtless have been of larger size. This second tooth, of which the figure is reproduced from Quart. Journ. Geol. Soc. vol. xlv. p. 243, fig. 7, differs from that of *Hoplosaurus* in being decidedly broader, and also by the smaller degree of concavity of its inner surface; although unfortunately, from its worn condition, its full height cannot be ascertained.

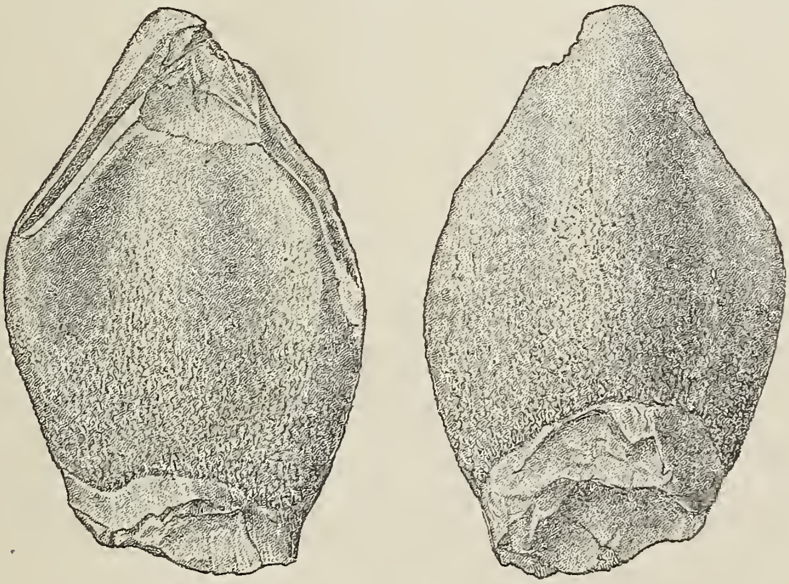
Fig. 2.—*Inner View of Crown of a Tooth of* ? Pelorosaurus Conybeari. (*From the Wealden of Kent.*)



[Natural size.]

Of the new teeth, the larger one, which is represented in fig. 3, comprises the crown and a fragment of the root, and is very similar to the specimen assigned to *Pelorosaurus Conybeari*, although of somewhat superior dimensions. It has been considerably worn, and the summit is slightly imperfect. The inner surface, on which the enamel is extremely rugose, entirely lacks the deep, spoon-like hollow of the tooth of *Hoplosaurus*, and is but slightly concave, with a broad vertical ridge traversing its median line. Externally there is a very broad

Fig. 3.—*Inner and Outer Views of Crown of Tooth of* Pelorosaurus humerocristatus. (*From the Portlandian of Aylesbury.*)



[Natural size.]

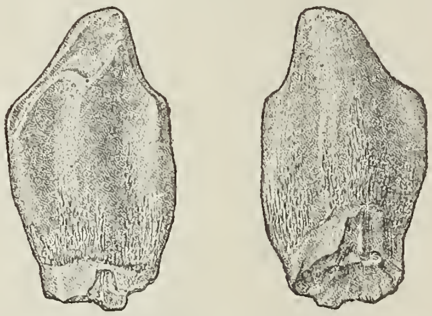
vertical ridge, somewhat curved, and placed nearer one edge than the other. On the one side this ridge is marked off by a

[1] *Op. cit.* p. 240.

distinct channel from the general surface of the crown, while on the other border it merges gradually into the same. In the tooth of *Hoplosaurus* the same aspect of the tooth is there uniformly convex. Although their summits are somewhat worn, it is now perfectly evident that the present specimen and the one represented in fig. 2 had broader and shorter crowns than the tooth of *Hoplosaurus*, from which they are evidently generically distinct. The broadest diameter of the Aylesbury specimen is 1·35 inch.

The second of the new specimens is the crown of a much smaller tooth of similar character. This small size indicates that it probably came from the hinder extremity of the jaw; while it further suggests that the larger tooth may likewise have been somewhat far back in the series, and consequently inferior in size to some of the others.

Fig. 4.—*Inner and Outer Aspects of Crown of Hinder Tooth of* Pelorosaurus humerocristatus.



[Natural size.]

Comparing the larger of the Aylesbury specimens with the tooth from the Portlandian of Boulogne figured by De La Moussaye[1] as *Neosodon*, and identified by Sauvage[2] with his *Caulodon precursor*, I find an identity of characters: the only difference being that the Boulogne specimen is somewhat the larger, having a transverse diameter of 1·46 inch. Both may accordingly be assigned to the same species.

With regard to the form to which the so-called *Neosodon* belongs, I have shown[3] that the teeth so described are probably referable either to the reptile typified by a humerus from the Kimeridgian of Weymouth, described as *Cetiosaurus humerocristatus*, or to a closely allied form. Finding that there are no characters by which the type of the species last named can be distinguished generically from *Pelorosaurus* of the Wealden, I have, however, assigned it to that genus, with the name of *P. humerocristatus*;[4] and it is to this same form that I would tentatively refer both the Boulogne and the Aylesbury teeth.

The other two teeth of large Sauropodous Dinosaurs being in the National Collection, I am glad to be able to announce that the owner of the Aylesbury specimens has generously presented them to the British Museum; and it may be hoped that in the course of time other examples of these teeth will eventually reach the same collection, and enable further comparisons to be instituted.

[1] Bull. Soc. Géol. France, sér. 3, vol. xiii. (1885) p. 51.
[2] *Ibid.* vol. xvi. (1888) p. 626.
[3] Cat. Foss. Rept. Brit. Mus. pt. iv. (1890) p. 241.
[4] *Loc. cit.*

42. Observations *on the* Affinities *of the* Genus Astrocœnia. By Robert F. Tomes, Esq., F.G.S. (Read June 21st, 1893.)

[Plate XX.]

Researches recently made relative to the structure of certain undoubted *Astrocœniæ*, having for their primary object the better understanding of the supposed species of the genus obtained from the Glamorganshire Conglomerate, have been productive of results which are to a great extent unexpected, and which will render imperative a complete modification in the classificatory position of the genus.

Before recording the examinations which have led to these results, it is desirable that I should make a brief survey of some part of the literature relating to the genus. Commencing with its definition by the original describers, MM. Milne-Edwards and Haime, which appeared in the 'Annales des Sciences Naturelles' in 1848,[1] I transcribe in full their own words:—

"Ce genre a un polypier massif, beaucoup plus dense que celui des Styloccœnies. Les cloisons sont proportionnellement épaisses, et on ne distingue jamais à l'angle des calices de tubercules columnaires. Enfin, la columelle est en général très peu saillante. Sous tous les autres rapports, les Astrocœnies ne diffèrent pas du genre précédent [*Stylocœnia*]; elles se séparent comme lui des Stylines par les calices polygonaux; des Stéphanocœnies, par l'absence de palis; des Phyllocœnies, des Dichocœnies et des Hétérocœnies par la columelle styliforme."

After a few words relative to the distribution of the several species constituting the genus, the same authors continue:—"Parmi celles que nous avons pu étudier, de manière à les caractériser suffisamment, les unes présentent des calices en polygones irréguliers et de grandeurs un peu différentes, parce qu'elles se multiplient à la fois par bourgeonnement latéral et par bourgeonnement marginal, tandis que d'autres s'accroissent seulement en surface par le premier mode de bourgeonnement, et n'offrent que des calices de même grandeur et en polygones réguliers."

Two years later, namely in 1850, the same authors published the first part of their great work on British Fossil Corals, Palæont. Soc. Monogr., at p. xxx. of which is a definition of the genus *Astrocœnia* in the following words:—

"Corallum very dense and not bearing columnar processes as in the preceding genus [*Stylocœnia*]. Calices polygonal. Columella styliform, not projecting much. No pali. Septa thick; apparently eight or ten systems, two or four of the secondary septa being as much developed as the six primary ones. Walls thick and united, as in *Stylocœnia*."

It is not a little remarkable that in the description of *Astrocœnia pulchella*,[2] which appears in the same volume (p. 33) and is of the

[1] 3ème sér. vol. x. p. 296.

[2] It seems probable that this may prove to be generically distinct from the Cretaceous species.

same date, the following paragraph, which is so contradictory, should appear:—"When the corallites are not crowded together, the calices are circular, and have a distinct though not prominent edge; they are also separated by a pseudo-cœnenchyma, the surface of which is covered with small costal ridges, that are usually denticulated so as to assume the appearance of rows of round, obtuse granulæ. When the calices approximate, they become somewhat polygonal, and their margins are separated only by a narrow furrow, or united so as to appear simple." A further definition is given by the same authorities in 1851, of which I need only observe that the walls are described as being thick and directly soldered together.[1]

The 'Histoire Naturelle des Corallaires' (Paris, 1857) of the same authors adds nothing to our knowledge of the genus, the corallites being described as prismatic, soldered together by their walls, which are thick and simple; but the somewhat contradictory remarks respecting *Astrocœnia pulchella* are repeated.

Dr. E. de Fromentel, in his 'Introduction à l'Étude des Polypiers Fossiles,' dated 1858–1861, defines the genus in the following words:—"Polypier massif composé d'individus soudés directement par les murailles, qui sont prismatiques; calices polygonaux" (p. 232).

In 1854 appeared the fine work by Reuss on the Anthozoa of the Cretaceous deposits of the Eastern Alps,[2] in which are beautiful figures of the *Astrocœniæ* from the well-known locality of Gosau. In that work the talented author made known what had not before been noticed—namely, that there are denticulations in the edges of the septa.

The late Prof. Duncan, in his 'Monograph of the British Fossil Corals, Second Series,' Palæont. Soc. 1872 (part iv. No. 1, p. 24), after accepting the description of the genus by MM. Milne-Edwards and Haime, with the modification made by Reuss, follows the former authors in their remarks on *Astrocœnia pulchella*, but states that the cœnenchyma between the corallites in that species arises "from an hypertrophied condition of the adjacent corallite-walls." This is followed by some statements relating to the nature of the gemmation in *Astrocœnia*; but it is perhaps necessary to observe that this immediately precedes the description of the supposed *Astrocœniæ* from the deposits at the bottom of the Lias in South Wales, twelve in number, in every one of which the cœnenchyma is either definitely stated to exist, or its presence alluded to.

There is a further description of the genus by the same author in his 'Revision of the Families and Genera of the Sclerodermic Zoantharia,' Journ. Linn. Soc. vol. xviii. (1884), which, as it does not appear in immediate connexion with doubtful forms, deserves a fuller mention, and is as follows:—"Colony variable in shape, massive, gibbous, lamellar, dendroid or discoid, compact, sometimes encrusting. Corallites prismatic or cylindrical, uniting by their walls, which

[1] 'Monogr. des Polyp. Foss. Terr. Paléoz.' Arch. Mus. Hist. Nat. Paris, vol. v. p. 64.

[2] 'Beitr. zur Charakt. der Kreid. i. d. Ostalpen,' Denkschr. kais. Akad. Wissensch. Wien, vol. vii. p. 73.

are thick and simple; cœnenchyma rare between them. The calices are polygonal, irregular or regular in shape and size, and their margins are ordinarily simple." After defining the columella and septa, he concludes thus:—"Gemmation marginal and lateral, or marginal and circumferential only" (p. 120).

In a paper on the so-called *Astrocœniæ* from the South Wales Conglomerate, by the same author, which was published in this Journal in 1886,[1] are many scattered remarks on the characteristics of the genus, to which reference must be made. These are the most recent observations which have come to my knowledge, but their value is unfortunately much lessened by the highly controversial nature of the paper in which they occur. The polygonal form of the corallites is strongly insisted upon, and the greater number of species are specially mentioned as having no structure whatever between the walls, which are united. The concluding remarks I transcribe *verbatim*:—"It appears that, owing to greater or less vigour of growth and to the influence of crowding, the corallites may be perfect hexagonal prisms, or irregularly polygonal in transverse section, and that the walls of corallites in the same corallum may be very thin at the calicular surface and thick lower down, or thick at the calicular surface and forming with their joined neighbours a mural or intercalicular cœnenchyma of varying width" (p. 110). Then follows a footnote in which it is stated that the cœnenchyma "resembles that of *Pocillopora* and some of the Oculinidæ, especially of the base of *Amphihelia* and the stem of *Astrohelia*," and "is totally distinct from the intermural cœnenchyma of such forms as the Stylinaceæ."

With such great discrepancies in generic definition as appear in the foregoing, there need be no surprise if a somewhat mixed assemblage of forms are found accumulated under one name, and it was with a view to clear up the confusion that the following investigations were made.

I much regret that I have been unable to examine specimens of the type species, *Astrocœnia d'Orbignyi*, but with the kind aid of my friend Mr. R. Etheridge, F.R.S., who has had sections prepared for me, and otherwise afforded me valuable assistance, I have examined the internal structure of *Astrocœnia decaphylla*, *A. reticulata*, *A. tuberculata*, *A. ramosa*, and *A. tourtiensis*, Bölsche. Only very partial success attended my efforts at first, the Gosau specimens not showing their structure very clearly. But the last-named species has proved to be in a very satisfactory state of preservation, and the details of its structure could be examined with certainty. I commence therefore with that species, and speak of the others afterwards.

ASTROCŒNIA TOURTIENSIS, Bölsche.[2]

A large piece of a specimen from Plauen, for which I am indebted to the original describer, Dr. Bölsche, was cut into thin slices and examined by transmitted light, and its details of structure were then seen most beautifully. The first thing observable is that the walls of the prismatic corallites are invariably thin, sometimes rudimentary

[1] Vol. xlii. pp. 101–111.

and without a trace of interval between them in which cœnenchyma could exist. There are neither dissepiments, tabulæ, nor pseudo-synapticules in the interseptal loculi, but the inside of the corallites is greatly reduced in diameter and rendered more or less cylindrical by the deposition of an excessive quantity of stereoplasm, which really constitutes a great deal of the bulk of the corallum, and makes it solid and strong. No such tissue, however, is added to either the septa or columella. (See Pl. XX. fig. 3.)

All the larger septa run into the columella. They are of medium thickness, straight, and without any kind of lateral ornamentation.

Astrocœnia decaphylla.

Examples of this species from the Cretaceous formation at Gosau, when well preserved, have the thickened walls and ornamental calicular surface shown in the figure by Reuss ('Beiträge, etc.,' Denkschr. kais. Akad. Wissensch. Wien, vol. vii. 1854, pl. viii.). If figs. 5 and 6 of pl. viii. in his work be examined, it will be seen that the calices are bounded by a double row of tubercles. Between them is a very narrow space, the position of the true wall. Polished sections do not, however, add much to our knowledge of the wall-structure. The rows of tubercles are really the ornamentation of the stereoplasm; the wall itself, represented by the space between them, is obviously not very thick, and indeed in one specimen now before me there is an extremely fine depressed line representing the position and thickness of the wall. Another specimen, having an approach to an elevated pyramidal form, shows satisfactorily the corallites at and near the axis, seen in section. They have thin and closely-applied walls, and there is no stereoplasm. The nearer the corallites are to the outside of the corallum, the more are they loaded by stereoplasm, and their original structure hidden.

Astrocœnia reticulata.

Of this species I have the advantage of one specimen only for examination, but it is a very instructive one. A few calices had been weathered before fossilization, and the thickened wall, standing up in bold relief, has a central thin portion which is still more prominent. This is the true wall, and is not only thin, but in some places merely rudimentary.

Astrocœnia ramosa.

Transverse sections of this species are very instructive, for, as in *A. decaphylla*, the central corallites (those which are more or less vertical and run up the centre of the corallum) have thin, well-defined walls, closely applied to each other, and not in the least obscured by any secondary deposit. The outer ones, on the contrary, are very much altered by such an addition, and the walls of the corallites are with difficulty distinguished. (See Pl. XX. fig. 5.)

Astrocœnia tuberculata, Reuss.

Of all the species which I have examined, this proves the least instructive. The corallum seems to be almost wholly made up of secondary material; but, as I have no section showing the state of the central corallites, they may probably, as in the foregoing species, be free from stereoplasm.

It is obvious that all the definitions of the genus *Astrocœnia* are defective, because the internal structure has not been studied by means of sections, and that they are superseded by the results of the foregoing investigations. Under those circumstances a new definition of the genus becomes imperative. I define it as follows, but I may observe that I do not at present include in it any species of earlier date than the Cretaceous period, having concluded that all the so-called Jurassic *Astrocœniæ* are referable to other and quite distinct genera.

Definition of the Genus Astrocœnia.

Corallum compact, spreading or dendroid, and composed of prismatic corallites intimately united by their walls, which are thin and sometimes rudimentary. Corallites greatly lessened, and rendered more or less cylindrical internally by a considerable deposit of stereoplasm. Septa straight, alternately long and short, denticulated, the longer ones blending with the columella. The sides of the septa are without growth of any kind. There are no dissepiments, but the loculi are probably filled up inferiorly by stereoplasm. Columella variable in size, but not prominent.

Of the mode of increase I am unable to speak definitely, but should suppose that gemmation must take place on the top of the greatly thickened wall.

At present I refrain from a precise opinion on the classificatory position of this very peculiar genus, but that it will be removed from the place it has hitherto held there can be no doubt. *Stylocœnia*, with which it was associated by M. Milne-Edwards, has few characters in common with it, and neither have any of the genera with which it has been associated by Dr. de Fromentel. The late Prof. Duncan made of it an 'alliance' in which he also included *Cyathocœnia*, *Stephanocœnia*, *Narcissastræa*, *Haldonia*, and *Bathycœnia*, to none of which is it at all nearly related.

In conclusion, I may offer a few remarks on the apparent discrepancies relative to the thickness of the walls enclosing the corallites. As I have shown, both M. Milne-Edwards and Prof. Duncan have made what appear to be most contradictory statements on the subject. The explanation of their apparently (but not really) inconsistent assertions is, however, perfectly simple and easy. In many calices the attenuated wall has become rudimentary, while in some it has wholly disappeared. When this is the case, the stereoplasm takes its place, though always, so far as I have been able to ascertain, with some remaining indication of its proper position, and the contracted and circular calices, being defined by it, appear to possess what MM. Milne-Edwards and Haime, and the late Prof. Duncan, respectively designated 'pseudo-cœnenchyma' and 'dense cœnenchyma.' The stereoplasm in *Astrocœnia* is not unlike dermic cœnenchyma in appearance, from which, however, it differs radically, being wholly within the walls of the corallites.

43. Description *of a* New Genus *of* Madreporaria *from the* Sutton Stone *of* South Wales. By Robert F. Tomes, Esq., F.G.S. (Read June 21st, 1893.)

[Plate XX.]

In vol. xlii. (1886) of this Journal is a critical and detailed description of a coral from the Sutton Stone of South Wales, which is there described as *Astrocœnia gibbosa*, Dunc. The paper in which it appears is, I need hardly say, by the late Prof. Duncan. But the specimen there described is not the type of the species, and, indeed, I do not know whether it had ever been specifically determined before the publication of the paper above alluded to; certainly there is no mention of it in the pages of the volume of the Palæontographical Society, in which *Astrocœnia gibbosa* was first characterized. It was collected by E. B. Tawney, is now in the Museum of the Geological Society, and after having been cut through horizontally and polished, was described by Prof. Duncan in the paper above mentioned.

A very hasty examination of the polished surface figured by Prof. Duncan sufficed to assure me that there were characters which neither he nor I had attributed to that or any other species of coral from the Glamorganshire Conglomerate. Some of the elongated or double calices presented much the appearance of fissiparous division, and I was anxious to examine them by means of thin sections and transmitted light, and at the same time to learn something of the structure of another part, the (apparently) much thickened walls. In accordance with my wish, the Society had a section made and submitted to me for examination. It consists of a slice taken horizontally from the bottom of the specimen, the upper surface, which was figured by Prof. Duncan, being left untouched. This section proves to be nearly all that could be desired, and exhibits structures which are directly at variance with all former determinations of the generic relationship. The corallites having more or less of a radiating arrangement, are cut through at all angles, and consequently give sections which are transverse, oblique, and even longitudinal.

It is always unsatisfactory to have to found a genus on a single species, however strongly marked its characters may be, on account of the difficulty of drawing the line between those which are generic and those which are merely specific; and still less satisfactory is it to do so when only a single specimen is available. I have long hesitated to make use of the only known specimen for such a purpose, but fortunately two other specimens from the same locality, that is, from the Sutton Stone of Glamorganshire, have been discovered. One of these is in the Museum of Practical Geology in Jermyn Street, and is attached to the same tablet as the specimen of *Astrocœnia gibbosa* figured by Prof. Duncan in pl. v. fig. 2 of the fourth part of his 'Supplement to the History of British Fossil Corals.' It was presented with the figured specimen, which is quite distinct from it, both generically and specifically, by the Rev. H. H. Winwood, and is the larger specimen on the tablet. One part is dark in colour, having been discoloured by exposure to the elements, while the other part appears to have been freed from the matrix by the collector, and is quite light in colour. On the dark and weathered portion there is a distinct and raised space in the triangular interval where three calices meet, on which are indications of septa, being the commencement of a calice. This is so placed between the large calices, and so much above their level, as to leave no doubt that extra-calicular gemmation took place just as in *Stylocœnia* and *Bathycœnia*. There are several other small calices on the light-coloured part of the corallum similarly placed with respect to the larger ones, which are also very striking and conclusive, and are evidently the result of gemmation. Elongated and undoubtedly fissiparous calices also appear in places on the corallum, but they do not show division actually taking place so clearly as do some similar ones in another specimen to which I shall presently refer. Nowhere on this specimen is there the faintest indication of a calicular wall, but there is obvious continuity of the septa between the calices; indeed, there is in this specimen a remarkable departure from any of the characters hitherto assigned to any of the Sutton Stone Madreporaria.

The remaining recognized specimen was taken by me from the Sutton Stone in 1883, but has remained undetermined until the present time. It is small, barely 1 inch in diameter, but, being freed from the matrix, exhibits the form of the corallum with certainty. It may be described as tuber-shaped, with some gibbosities, and was attached by a small space on one of the longer sides. Excepting that it has a great number of small round calices scattered between the larger ones, undoubtedly the consequence of budding, and that it exhibits fissiparous increase of the calices at one place, it is less instructive than the other.

I now come to the examination of the thin section, taken from the specimen in the Museum of the Geological Society, having the polished surface which was figured by Prof. Duncan. This specimen, like the other two, has small rounded calices in the intervals between the larger and more angular ones, which are highly suggestive of extra-calicular gemmation. The elongated or double calices, figured by Prof. Duncan as instances of inter-calicular gemmation and as affording evidence of Astrocœnian relationship, are undoubtedly the result of fissiparous increase. Of the apparently extremely thick walls but little could be determined until they were examined by transmitted light; neither could the nature of the ornamentation on the sides of the septa, shown by fig. 9[1] of Prof. Duncan's plate, be any better understood. When, however, these parts were seen in thin section, the nature of both became apparent.

I will now proceed to give more in detail the results of my examination of the section just mentioned, without which the real

[1] Quart. Journ. Geol. Soc. vol. xlii. (1886) pl. viii.

affinities of this curious form would have probably remained in great obscurity. The thick walls, as such, have entirely disappeared, and no wall either thick or thin is present, the septa of one calice being continuous with those of another, just as in *Thamnastræa* and *Clausastræa*. (See Pl. XX., fig. 1.)

The ornamentation of the sides of the septa is resolved into pseudo-synapticulæ, having the character of those observed in the genus *Clausastræa*.

Several elongated calices furnish unquestionable proof that fissiparity took place, the operation being clearly observable in a more or less advanced state. (See Pl. XX., fig. 2.)

There are also a few calices which, though almost full-sized, are so nearly circular, and which encroach so visibly on the others, that they can only have been caused by extra-calicular budding. (See Pl. XX., fig. 6.)

The septa and their connecting costæ consist of a single trabecule, as in *Astræomorpha*.

The septal costæ are much swollen, and, coming into contact with each other laterally, are fused together between the calices, where there would be a wall in the Astræidæ, and the swollen part of each has a central portion, which, being more dense, is opaque when seen by transmitted light, and is consequently quite dark in thin section. This lateral fusing of the septal costæ gives solidity and strength to the corallum, and in reality takes the place of a wall.

All parts of the septal apparatus, including the columella, are composed of lines of granules passing upward and outward, very much like the webs of a feather.

There are a few weak and straight dissepiments between the septa.

The pseudo-synapticulæ are numerous, have little prominence, and appear on the sides of the septa as continuous horizontal ledges, greatly resembling those of *Clausastræa*. (See Pl. XX., fig. 4.) They are formed by the continuation outward at regular intervals of the lines of granules of which the septa are formed, and were mistaken by Prof. Duncan for mere lines of ornamentation.

The columella is large and formed by lines of granules passing upward and outward; into it all the primary septa pass, and blend without any evidence of the point of union.

The full number of primary septa in a large calice is ten.

I name and define the genus of which the present species is the sole representative as follows:—

Genus Stelidioseris, gen. nov.[1]

Corallum compact, small, globose, or tuber-shaped, the corallites radiating more or less regularly from a basal point of attachment. There is no wall between the corallites, the septa being continuous between them. The septa are imperforate, each consisting of a single

[1] [I had originally selected the name *Styloseris*; but after the paper had been read, it was pointed out to me that the name was pre-occupied, and I have therefore substituted *Stelidioseris* for it.—July 15th, 1893.]

trabeculæ. They have pseudo-synapticulæ which are numerous, have little prominence, and closely resemble those of *Clausastræa*. The dissepiments are distant, straight, or oblique, and feebly developed. Columella large, and the primary septa fused into it. Increase takes place by fissiparity and by gemmation between the corallites, as in *Stylocœnia* and *Bathycœnia*.

In neither of the specimens examined are the external characters of the calices determinable. Whether the edges of the septa were denticulate, and whether the columella was prominent or the reverse, are particulars which can only be known when specimens having the external characters better preserved have been examined.

The genus will take its place near to *Clausastræa*, with which it agrees pretty closely, excepting in the very important particular of possessing a well-developed columella, and having both modes of increase, *i. e.* fissiparity and gemmation. In the latter particulars it differs from all the genera to which it is in any way related.

Although the present is obviously distinct as a species from that described as *Astrocœnia gibbosa* by the late Prof. Duncan, I retain the same specific name, and give the following definition:—

STELIDIOSERIS GIBBOSA, sp. nov.

Astrocœnia gibbosa, Duncan, Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 101, pl. viii., not *A. gibbosa* of 'Suppl. to Brit. Foss. Corals.'

The septa are rather stout, straight, from twenty to thirty in number, of which ten pass into the columella, and all the others are more or less rudimentary. The inside or openings of the corallites are more or less polygonal, but with the angles so much rounded that they are often irregularly ovoid or even circular. The lateral fusing into each other of the septal costæ in the mural region varies from one-sixth of the diameter of the remaining opening in the corallite to nearly its whole diameter.

Diameter of a large calice = $\frac{3}{32}$ inch.

Hab. The Sutton Stone of Glamorganshire.

EXPLANATION OF PLATE XX.

Fig. 1. *Stelidioseris gibbosa.* A horizontal section of some calices magnified four times, and seen by transmitted light. The dark markings between the calices in this figure and in figs. 2 & 4 are due to greater opacity, and they represent the cycles of septa, which, however, are difficult to enumerate.

Fig. 2. *Stelidioseris gibbosa.* Two contiguous corallites, cut through horizontally and seen by transmitted light. They show fissiparous increase very clearly, and are magnified eight times.

Fig. 3. *Astrocœnia tourtiensis*, Bölsche. A horizontal section of some corallites seen by transmitted light, showing the thin rudimentary wall and the great development of stereoplasm within the corallites, reducing their diameter by nearly one half, and from a polygonal to a circular form. Magnified eight times.

Fig. 4. *Stelidioseris gibbosa.* A corallite cut though very obliquely, and seen by transmitted light. In the fragments of septa on the right and left-hand of the figure the pseudo-synapticulæ appear as horizontal lines, as in the genus *Clausastræa*. The septa shown at the top and bottom

of the figure are cut though almost longitudinally, and in a manner to show their thickness and the prominence of the pseudo-synapticulæ. The columella exhibits the radiate arrangement of the lines of granules of which it is composed. The nature and frequency of the dissepiments are also shown in the figure. Magnified six times.

Fig. 5. *Astrocœnia ramosa.* A magnified representation of a section taken horizontally near the base, showing the central corallites with their well-defined and closely-attached walls, free from any intervening tissue, and showing also the addition of stereoplasm, which increases in quantity as the corallites approach the outside of the corallum. Magnified three times. A transverse section of these corallites taken near the calice would present much the same appearance as that shown by fig. 3 in pl. viii. of Reuss's fine work on Cretaceous Madreporaria.

Fig. 6. *Stelidioseris gibbosa.* A portion of the upper surface, having a small gemmiparous calice between four of ordinary size, showing the mode of increase by budding. Magnified four times.

Discussion (on the two preceding Papers).

Mr. Etheridge alluded to the difficulty attached to the better determination of the many British species of the genus *Astrocœnia.* No less than twelve forms are recognized as occurring in the Lower Lias of the Sutton Stone, near Brocastle, Glamorganshire. The affinities of the *Astrocœniæ* given in Mr. Tomes's first paper constitute an important addition to the literature of the genus and its distribution: six species are critically examined. The new genus *Styloseris* [*Stelidioseris*] proposed by Mr. Tomes, if published, would clear up certain anomalies respecting the *Astrocœniæ.* The speaker did not doubt that the critical research bestowed upon *Styloseris* [*Stelidioseris*], with its affinities and differences from *Astrocœnia*, would be accepted on close examination. The paper would facilitate the better classification and structure of this group of the Astræidæ.

Dr. G. J. Hinde appreciated the efforts of the Author to determine the real characters of the genus *Astrocœnia*, which could only be ascertained from a study of the typical species from the Cretaceous strata of Gosau. Much of the difference of opinion as to the nature and systematic position of the corals from the Lower Lias of Sutton which had been assigned by the late Prof. Duncan to *Astrocœnia*, Edwards and Haime, and subsequently by Mr. Tomes to the genus *Stylastræa*, Fromentel, arose from the fact that microscopic sections of these forms had not been made.

It was a striking commentary on the importance of microscopic sections that the Author had now selected as the type of his new genus, *Styloseris* [*Stelidioseris*], the identical specimen which had been previously chosen by Prof. Duncan to illustrate the specific characters and to justify the position in the genus *Astrocœnia* in which he had placed it.

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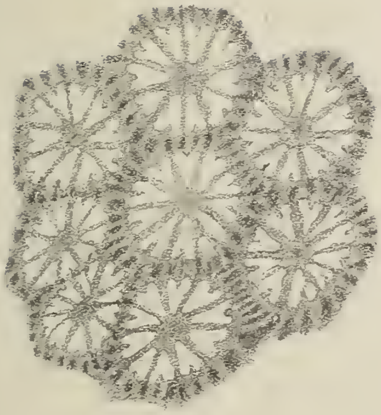

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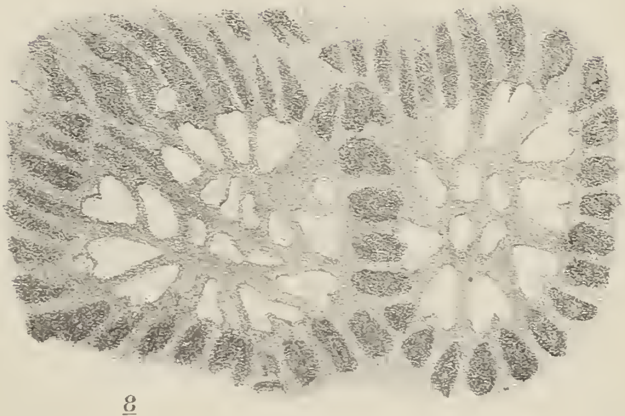

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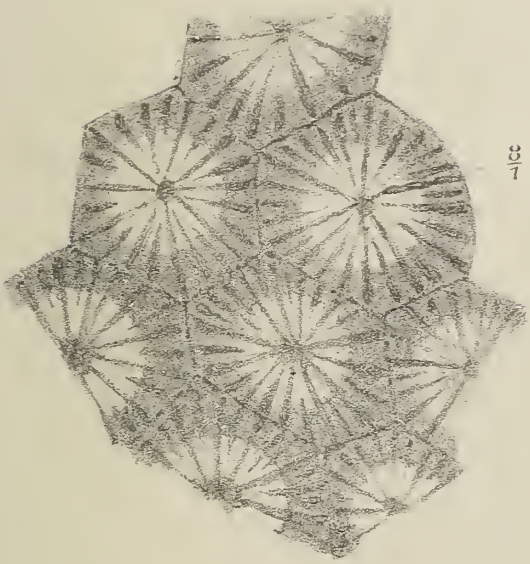

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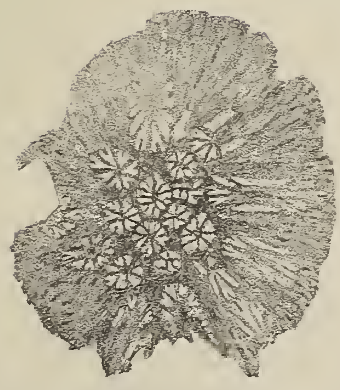

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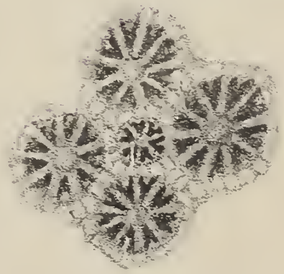

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ASTROCŒNIA AND STELIDIOSERIS.

44. *The* Rise *and* Fall *of* Lake Tanganyika. By Dr. Robert Sieger. (Communicated by the President. Read June 21st, 1893.)

Perhaps I may be permitted to offer a few remarks concerning Mr. A. Carson's interesting paper, published in vol. xlviii. of this Journal, p. 401. That author regards the rise and fall of Lake Tanganyika as a purely local phenomenon, due to alterations of its outlet, the Lukuga, which was blocked up a long time ago, but reopened between the years 1874 and 1879; and he discusses in a very careful manner the geological conditions necessary for the damming-up and the outburst of the lake. Another opinion, now very common among German geographers and maintained by myself, treats these great oscillations of the level of Lake Tanganyika as analogous to the variations reported of other African lakes and resulting simply from climatic changes. I believe that there is no absolute contradiction between these two opinions, and that it is possible to arrive at a satisfactory explanation of the phenomena in question by combining the influences of climate with those of mechanical agencies.

The meteorological explanation of lake- and river-variations has been given already in a very important paper by Prof. H. Fritz, of Zürich, published in 'Petermann's Mittheilungen,' vol. xxvi. (1880), pp. 245 *et seqq.* I regret that I was not aware of the existence of that memoir at the time of my own first essays on the variations of level in African and other lakes. Prof. Fritz held it impossible that the amount of rainfall should vary and the temperature oscillate in the same manner over the whole surface of a continent or of the globe, but he held that there is a sort of compensation between the different areas. Subsequently, Prof. Brückner, now of Bern (chiefly in his valuable work on 'Klima-Schwankungen,' Vienna, 1890), and myself, succeeded in demonstrating a surprising coincidence of the epochs of oscillation in a great many lakes, rivers, and glaciers. This can hardly be explained otherwise than by *general* oscillations of climate, indicated by meteorological observations, and proved beyond doubt by Prof. Brückner's laborious researches.

In the course of my study of the secular oscillations of lakes, I published two short papers on the lakes of the Dark Continent, copies of which I have now sent to the Geological Society's library.[1]

I have found that the culminating points of cold-and-moist periods stated by Prof. Brückner to approximately coincide with the years 1850 and 1880, and even the warm-and-dry period culminating in 1860, also coincide with the dates of the maxima and minima of level of the Central African lakes. The reader's attention is directed in this connexion to the great floods on Lake Tsad at the

[1] Jahresbericht des Vereines der Geographen an der Universität Wien vol. xiii. (1887), and 'Globus,' vol. lxii. no. 21, Brunswick, 1892.

time of Barth and Vogel's, and again of Rohlfs and Nachtigal's visit; to the variations of humidity in Southern Africa mentioned by Prof. Fritz; to the high level of Lake Nyassa about 1875, and the subsidence which followed; to the sinking of the Victoria Nyanza, inferred from Capt. Speke's narrative; to the rise of the same lake reported by Mr. Wilson in 1877 and 1878; and to the considerable decrease of all the lakes of the Upper Nile region observed from about 1880 until 1892. Moreover, I would remind the Society of the observations on the Lower Nile, dealt with by Profs. Fritz and Brückner in their respective papers. Finally, I would especially refer to so careful an observer as Dr. Franz Stuhlmann, who explains the observations and traditions concerning changes of level in the Victoria Nyanza by a "secular variation of rainfall."

The time when Lake Tanganyika was at its highest, and the Lukuga reopened its channel, being nearly coincident with the maximum level in Lakes Tsad, Nyassa, Albert and Victoria Nyanza, etc., and also with the high waters so frequent between 1870 and 1880 in European lakes and rivers, even in the Baltic Sea, I have had no hesitation in regarding the oscillations of Lake Tanganyika as also resulting chiefly from the climatic changes enumerated by Prof. Brückner.

This rise and fall of the lakes, due to meteorological influences, is, I believe, the main cause of the changes in the Lukuga; these, however, in their turn must influence and modify the amplitude and the particular mode of oscillation of level.

If the climatic conditions and the lake-level be constant or 'normal,' I am unable to account for agencies sufficient for damming up the whole efflux of the lake. The stopping-up has, indeed, been referred to a periodic upheaval of the land, to the action of earthquakes and volcanic forces (as visible in Lakes Rudolf and Stefanie), to the famous grass-bars or *sindi* and the formation of a bar at the river-entrance. These points, except the last two, being discussed in my papers, and Mr. Carson insisting especially on the blocking-up of the river by vegetation and its silting-up by sedimentation, I do not propose to speak here of the movements of the earth's crust, of Mr. Stanley's 'cataclysmal' theories, of Capt. Storms's hypothesis attributing the rise of Lake Tanganyika to an outburst of Lake Likwa, etc., but only of the two points referred to. Mr. Carson has himself seen the effects of the *sindi* on the River Shiré, and he regards them as inadequate to produce, without the help of other agencies, a rise of the lake to a height of 30 feet. I would add that at the very time when these masses of floating vegetation blocked the Shiré, Lake Nyassa continued to sink. Even the 'setts' of the Upper Nile (in connexion with which the reader will doubtless remember the disaster that overtook Gessi Pasha and his companions) had not force enough to dam up the Lakes. The observations show that the maxima of level on the Victoria and Albert Nyanzas were nearly simultaneous with the maxima on the Lower Nile.[1] Now, if the lake was rising, the water, by its pressure, would

[1] See also Lugard, Proc. Roy. Geogr. Soc. 1892, p. 827.

have very soon cleared the entrance of the Lukuga of those bars, or at least flowed beside and over the masses of vegetation which blocked its course. If, on the contrary, the lake was sinking, the diminishing current is more likely to have been too feeble to remove such a hindrance. Therefore the accumulation of *sindi* may have been a consequence of the subsidence of the lake, which prevented any considerable action being accomplished by the dwindling Lukuga.

Perhaps also the formation of a bar or bank at the entrance of the river, described by the explorers Cameron and Thomson, is a mere consequence of sinking water-level. The old embankment of 20 feet in height, described and sketched by Mr. Carson, was no doubt formed while the lake was high. But we must suppose that here there were not the same conditions for sedimentation as at the bar of the Lukuga. The sediments in question are deposited on the point where a flat valley or former bay debouches into the lake; they could be carried there by rain and small streams, and accumulated by wind, wave-action, etc., the more easily if the lake was rising, because there was no current strong enough to prevent their deposition. But how could the outlet of the lake be closed so long by such a bar, considering that it is undiminished in breadth and in volume and swiftness of current? In the struggle between sedimentation and river-erosion by a stream enlarging and deepening its bed, victory is clearly on the side of the latter. If the level of the lake rises, its outlet must all the more easily overcome the obstacle existing from former times. The formation of a new bar, however, is probable only in so far as the river-current becomes more and more enfeebled: that is, if the level of the lake be sinking. Only in this case the annual variation of rainfall and water-level may produce the effects described by Mr. Carson as a continuous struggle between the choked bed and the flood, while the filling-up of the separated mud-pool, the accumulation of *sindi*, the growth of aquatic vegetation, etc., accelerate the closure of the lake's outlet.

But it is at least an equally probable hypothesis that the formation of the bar commenced while the lake had no outlet and a comparatively small river, also called the Lukuga, discharged into the lake at the same locality (*cf.* Stanley, Storms, and others). In this case the deposition of sediments might take place just in the same way as in the locality mentioned above, and it might go on until the rising lake regained at least a temporary outlet. The small channel mentioned by Commander Cameron may be considered as the work of the current in its initial period, eroding perhaps only during the wet season. It would be very interesting to study the present condition of the bar, its increase or decrease, and its relation to the rise or fall of the lake. At all events, I believe that the dwindling of the lake, due to climatic oscillation, is the real cause of all the alterations of its outlet.

The above hypothesis agrees with the views of Herr Carl Ochsenius,[1] of Dr. Paul Reichard,[2] and others, who likewise regard

[1] Zeitschr. d. Deutsch. geol. Gesellsch. vol. xliv. (1892) p. 89.

[2] 'Deutsch. Ostafrika,' 1892, pp. 387 *et seqq.*

the oscillations of the lake as the effect of climatic variations and of the resulting changes in the current, the depth, and the volume of the Lukuga. As the climatic causes act periodically, it is probable that the blocking-up and reopening of the Lukuga are similarly periodical (although the periodicity is not that of 15 to 20 years, advocated by Ochsenius, whose suggestion hardly accords with the observed facts).

It will be a highly interesting study to watch the future fate of the Lukuga, its increase or decrease in volume, and the action of erosion on the river-bed. It would, moreover, be a work of really considerable importance to connect a system of regular observations of water-marks or level-gauges with meteorological observations, not only along the shores of Lake Tanganyika, but also along those of other African lakes, and so to eliminate the influences of seismic and other tectonic agencies, and to determine with some certainty the periodicity of meteorological epochs. Perhaps the period of subsiding level is already nearing its end in the African lakes—and in that case we may expect a simultaneous rise of Tanganyika and the Lukuga, which would furnish a striking proof of the correctness of my opinion that the change of level in Lake Tanganyika is rather a meteorological than a geological phenomenon.

The subsidence of Lake Tanganyika was still going on in September 1892, as reported by Dr. Baumann.[1] A recent decrease of its tributaries has been observed by Mr. Shaw during a residence of ten years at Urambo, but is regarded by Dr. Baumann as a mere consequence of the sinking of the lake itself, because there are no proofs of any remarkable diminution of rainfall in Urambo. Capt. Lugard[2] reports that the year 1891–92 was a wet one on the shores of the Victoria Nyanza, and the lake-level had risen 6 feet above the normal. Dr. Merensky[3] expresses some doubts concerning the diminution of Lake Nyassa reported by so many British travellers. These reports point perhaps to the first traces of a rise of level beginning in the African lakes, and so it appears the more highly desirable to continue regularly and patiently all such observations as may serve to elucidate the phenomena in question.

[1] Peterm. Mittheil. vol. xxxix. (1893) pp. 47 *et seqq.*
[2] Proc. Roy. Geogr. Soc. 1892, p. 827.
[3] Peterm. Mittheil. vol. xxxviii. (1892) p. 250.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

[The Fossils of which the names are printed in italics are figured.]

END OF VOL. XLIX.

Printed by TAYLOR AND FRANCIS, Red Lion Court, Fleet Street.

[Presd by the "Society" 30.1.93]

Vol. XLIX. FEBRUARY 1st, 1893. **No. 193.**
PART 1.

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

LONDON:

LONGMANS, GREEN, AND CO.

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(Presd by the Society 29.4.93)

Vol. XLIX. MAY 1st, 1893. No. 194.
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