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 SIXTY-SIXTH.

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PART 1.

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[With Twelve Plates and One Folding Table, illustrating Papers by Miss M. K. Heslop & Dr. J. A. Smythe, Mr. E. S. Cobbold, and Mr. S. S. Buckman.]

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

Session 1909–1910.

1910.

Wednesday, March .... 9*—23
" April .... 13*—27
" May .... 11*—25
" June 15*

[*Business will commence at Eight o'Clock precisely.*]

The dates marked with an asterisk are those on which the Council will meet.

THE

QUARTERLY JOURNAL

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Vol. LXVI.

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1. *On the* Dyke *at* Crookdene (Northumberland) *and its* Relations *to the* Collywell, Tynemouth, *and* Morpeth Dykes.

By Miss M. K. Heslop, M.Sc., and Dr. J. A. Smythe, F.C.S. (Communicated by Prof. G. A. Lebour, M.A., D.Sc., F.G.S. Read November 17th, 1909.)

[Plates I & II—Microscope-Sections.]

Contents.

Of the four dykes dealt with in this paper, only one, the Crookdene Dyke, appears not to have been investigated before, although its position is marked on the Geological Survey Map, Sheet 106 N.E. As it has many points of interest, we shall describe its mode of occurrence and properties in some detail. The other three dykes have already been investigated by Dr. Teall[1]; what observations we have to make upon them are thus only supplementary to his work, and serve chiefly to bring out the relationships which exist among these dykes in a clearer light. It should be mentioned that Teall had already come to the conclusion that the Collywell, Tynemouth, and Morpeth Dykes fall into a distinct group, and this inference we are in a position to substantiate; the Crookdene Dyke belongs also to the same group, having the strongest analogies to the Collywell Dyke. The field-relationships of the Collywell, Tynemouth,

[1] 'Petrological Notes on some North-of-England Dykes' Quart. Journ. Geol. Soc. vol. xl (1884) pp. 209–46.

and Morpeth Dykes have been clearly described by Prof. Lebour.[1] All three belong to the series which in Northumberland has a general east-and-west trend. The Crookdene Dyke also runs east and west, and for this reason, and chiefly because of its strong petrological resemblance to them, it must be classed with the dykes just mentioned.

I. The Crookdene Dyke.

About 16 miles west of Morpeth, in latitude 55° 8′ 35″ N., longitude 2° 2′ 45″ W., there occurs a small exposure of a basaltic dyke in the bed and banks of the Wansbeck, which is there a very small stream. Close by is the farm of Crookdene, a name which may serve to distinguish this dyke. The exposure is greatly obscured by talus; three patches of the rock can, however, be examined: one at the top of a steep bank about 30 feet high, another about half way down the bank, and a third at the foot of the bank and in the burn. The dyke occurs in a fault running east and west, which, from a consideration of the surrounding country, apparently throws about 25 feet to the south; it is intruded in the rocks of the Bernician Series of the Carboniferous System, which in that part consist largely of thick limestones and sandstones varied with shales. The direction of the dyke is athwart the strike of the Whin Sill, which crops out a little to the west, and across a surface-break in this formation about a mile wide. No connexion can thus be traced between the two igneous rocks, and although not greatly dissimilar to the naked eye and in chemical composition,[2] they are very different in microscopic structure.

The northern face of the dyke is fresh and unweathered, and in close contact with limestone and shale. On the southern face there is a broad breccia-filled fissure 12 feet wide, and the rock in contact with this is weathered into a brown sandy-looking rock for a depth of about 9 inches, the fresh basalt being about 1 foot 9 inches thick. The fault-fissure is filled with a soft breccia of sandstone, limestone, shale, and some fragments of much decomposed basalt. It would be difficult to imagine the intrusion of molten material through a broad breccia-filled fissure in such a way that the resulting dyke clung closely to one wall of the fissure, retained a uniform thickness, and sent no offshoots apparently into the soft breccia. We would suggest, in explanation, that fissuring took place subsequently to intrusion, and that the fragments of basalt in the breccia were torn off the dyke during the fissuring.

In the lowest (easternmost) exposure, in the burn, the dyke is seen to stop short in a bed of limestone, and the contact is highly metamorphosed, the basalt being converted into white trap. This occurrence suggests that the dyke rises steeply from below, and consequently that we are near the head of the dyke at its eastern end. The fact that the dyke is traceable west, but not east, of the burn-exposures lends some support to this view. This is a point of

[1] 'Outlines of the Geology of Northumberland & Durham,' 2nd ed. (1886) p. 86.

[2] See Dr. Teall's analysis of the Whin Sill from Borcovicus, Quart. Journ. Geol. Soc. vol. xl (1884) p. 654.

some interest in so far as this dyke, like the one at Collywell, which can be proved to come to a head, shows peculiarities which are possibly due to this circumstance.

One of the most interesting features of this dyke is the occurrence in it of patches of felspathic matter. They are best developed in the middle exposure, and are irregular in shape; in some cases the contact with the basalt is firm and unweathered, and the basalt adjoining the felspar is somewhat finer in texture than elsewhere. In the largest of these aggregates (up to 6 inches in diameter) the junction is weathered, and the surface of the basalt in contact somewhat convex. We shall now describe the chemical and petrological characters of the basalt and the felspathic aggregates.

The Basalt.

The rock was sampled and crushed, and the portion which passed through a sieve with 30 meshes to the inch, but was stopped by one with 40 meshes, was selected for analysis. It was dried at 110° C.; total iron is reckoned as ferrous oxide (Analysis I).

To facilitate comparison, the analysis of the Collywell Dyke is included in the following table (II), and also those of the Tynemouth and Morpeth Dykes (III & IV). The last two are quoted from Dr. Teall's paper,[1] and have been supplemented by a determination of titania. In the original analysis this would be weighed partly with the silica and partly with the alumina: in the table it has been deducted from the alumina.

	I.	II.	III.	IV.
SiO_2	51·31	51·10	58·30	51·20
Al_2O_3	14·55	16·75	15·39	18·89
TiO_2	1·00	0·96	0·75	1·14
FeO	9·02	8·03	4·50	—
Fe_2O_3	—	—	4·76	7·57
MnO	0·47	0·37	—	—
CaO	11·61	11·97	10·96	10·52
MgO	6·85	5·89	2·68	6·75
K_2O	0·60	0·66	0·94	0·51
Na_2O	1·79	2·02	1·74	1·71
CO_2	1·47	1·20	—	—
H_2O	1·14	1·16	—	1·70
Totals	99·81	100·11	100·02	99·99
Specific gravity	2·880	2·859	2·842	2·880

I. Crookdene Dyke. II. Collywell Dyke. III. Tynemouth Dyke (analysis by Stead). IV. Morpeth Dyke (analysis by Stead).

It is a fairly fine and even-grained rock composed of felspar, augite, and iron oxide, with some interstitial matter. The two former make up the mass of the rock, while the iron oxide occurs only in small and imperfect or skeleton crystals. The ground-mass felspars are lath-shaped, and usually show distinct binary twinning;

[1] Quart. Journ. Geol. Soc. vol. xl (1884) pp. 235, 239.

but sometimes the extinction is wavy and interrupted. The augite is curved and wrapped round the felspar-laths in a peculiar way (see Pl. II, fig. 1), and the iron oxide occupies the spaces left by the other two minerals. The general texture is shown in the figure, and particular attention may be drawn to the curving of the augites, since apparently the only other local dyke that shows this feature to the same extent is the Collywell Dyke, although it has been observed occasionally in the Tynemouth and Acklington Dykes.

The glassy base, in which the felspars are embedded, is clear and colourless, as a rule, and has little or no action on polarized light. There are, however, patches of green amorphous glass which will be more fully dealt with later. The clear glass is crowded with skeleton felspars and augites which have definite interference-colours; besides these there are innumerable black grains, which are resolved under high powers into semi-translucent spherical bodies of brownish hue, owing their apparent blackness to their deep dark borders—caused, no doubt, by their high refractive index producing considerable internal total reflection. They are usually attached to some part of an elementary augite, and may, indeed, be regarded as basic globulites. The skeleton augites in the local dykes almost invariably have nodes at which there are little accumulations of iron oxide, and in the rock here described the globulites seem to unite to form small augites, the growth of which is accompanied by the elimination of iron oxide at intervals along the axes of the elementary crystals. From this it would seem that the basic globulite contains, besides the augite ingredients, an excess of iron oxide which is liberated in the process of building up the augite crystals. A similar association can be traced in the ground-mass generation of crystals, for the augites there are very frequently studded with black cubes and grains of iron oxide. In other words, we may trace an intergrowth of augite and iron oxide from the globulitic stage upwards.

The order of crystallization is clear, both in the ground-mass crystals and in the elementary forms found in the glass. Felspars in narrow laths crystallized out first, augites in rather massive prisms followed, and iron oxide was left in the spaces formed by the separation of the first two minerals. There was apparently a certain amount of overlapping in these periods, for some felspar in rather broad large crystals appears to be later than some of the augite, and that mineral had probably not ceased to crystallize out when the iron oxide was in process of formation. There was, seemingly, very little free iron oxide, for no perfect crystals of it have been seen in any of the slides examined, and even the skeleton forms are not abundant.

Contact-sections of the basalt with the neighbouring rocks show some interesting modifications of structure. Fine, needle-like felspars are surrounded by skeleton augite bars usually set perpendicular to the felspars, in such wise that the whole has a fern-like appearance with the felspar-lath as axis. This is the common form of growth at the contacts. Often, however, the central axis is of the same material as the bars, and the whole is a skeleton crystal of augite. There is a third mode of occurrence in which the bars on each side of an axis (either of felspar or of augite) curve up on one side and down on the other, producing a set of S-shaped curves of augite united by a stem (see Pl. I, fig. 2). Similar forms have been described by Mr. E. B. Bailey,[1] though no mention is made in his paper of a felspar axis to the skeleton augites.

Fig. 1.—*Collywell Dyke rock, showing acanthus-like strands of imperfectly individualized augitic material, lying between, or curving round, the felspars.*

[Magnified 650 diameters. Grains of iron oxide are accumulated along the edges of augite strands, or in the glassy spaces around them.]

Besides these definite skeleton forms, there is a yet more elementary stage of growth. The augite seems to have segregated and adopted the curved forms characteristic of the dyke, but definite separation has not yet taken place, and thus the presence of augite is indicated only by the beautiful acanthus-like curves in the glass (fig. 1). This form of elementary crystallization is best

[1] 'On Two Spherulitic (Variolitic) Basalt Dykes in Ardmuchnish, Argyll' Trans. Geol. Soc. Edin. vol. viii (1904) p. 363.

developed in the Collywell Dyke, but it is, nevertheless, quite distinct here.

In this dyke, as in those at Collywell, Tynemouth, and Morpeth, there are calcite amygdaloids. These have usually a semi-lunar residue of glassy material in which skeleton crystals of felspar and augite and grains of iron oxide have separated out, while calcite occupies the rest of the cavity. In one or two cases, however, cavities have been observed, occupied either partly or entirely by green material. In these there is usually a gradation, from deep green at the borders, to pale green or colourless material at the centre. This is emphasized between crossed nicols, when the outer edge is seen to show distinct doubly-refracting fibres, the colours of which diminish in intensity towards the centre of the cavity, which is almost invariably isotropic in such cases. There can be no doubt that the substance occupying these cavities is glass, in which devitrification has begun around the margin and is travelling inwards. Reference will be made to a similar occurrence in the description of the Morpeth Dyke.

Weathering of the Basalt.

It has already been mentioned that the basalt in contact with the breccia of the fissure is weathered to a depth of about 9 inches into a brownish sandy-looking rock, which in the field bears little or no resemblance to the original basalt. When examined microscopically, however, the structure of the basalt is quite apparent: the felspars are clear, and evidently but little decomposed; a good deal of brownish oxide of iron has separated out; and the augite is almost entirely replaced by calcite. A small amount of rutile can also be detected. Analysis of this rock (dried at 110° C.) yielded the following results:—

SiO_2	38·06
Al_2O_3	16·38
TiO_2	0·96
Fe_2O_3	6·97
MnO	0·84
CaO	20·42
MgO	0·87
K_2O	0·56
Na_2O	1·95
CO_2	10·37
H_2O	2·31
SO_3	0·13
Total	99·82

If the carbon dioxide be taken as combined with calcium oxide, then the rock contains 25·57 per cent. of calcium carbonate, all, or nearly all, of which has come in by infiltration and replaced some constituents of the basalt. A better idea of the changes wrought by weathering may be obtained by fixing one's attention on the essential constituents (acidic and basic oxides) of the original and weathered rocks. Calculating these in percentages from the analytical data, we get:—

	Basalt (fresh).	Basalt (weathered)
SiO_2	53·51	52·18
Al_2O_3	15·18	22·45
TiO_2	1·04	1·31
Fe_2O_3	10·47	9·55
CaO	10·17	9·89
MgO	7·14	1·19
K_2O	0·62	0·76
Na_2O	1·87	2·67
Totals ...	100·00	100·00

The figures in the second column, representing the composition of the unaltered portion of the weathered rock, indicate that this is essentially a felspar allied to labradorite. Replacement of the augite by calcium carbonate has left the remainder of the rock poorer in magnesia and correspondingly richer in alumina, without seriously affecting the other constituents, whence it may be inferred that the augite is rich in magnesia and has a silica-content approaching that of the rock itself.

The Felspar Aggregates.

To prepare the felspar for analysis it was crushed so as to pass through a 30-mesh sieve, but to be stopped by one with 40 meshes to the inch; then digested with cold, very dilute hydrochloric acid, which took out some iron, calcium, magnesium, and aluminium present as readily soluble sulphates, carbonates, and silicates. After washing and drying, the powdered mineral was brought into a solution of boro-tungstic acid of specific gravity 2·69. This caused a good separation, the weathered mineral (sp. gr. = 2·671) rising to the surface and the fresher portions sinking. Further purification was effected by hand-picking.

The analysis of this mineral is tabulated below (I). Under II are the figures for the aggregates of the Collywell Dyke, and under III the analysis of the porphyritic felspar of the Tynemouth Dyke, quoted from Dr. Teall's paper (Quart. Journ. Geol. Soc. vol. xl, 1884, p. 234).

	I.	II.	III.
SiO_2	45·88	46·61	47·30
Al_2O_3	34·31	35·13	31·50
TiO_2	0·04	0·13	—
Fe_2O_3	0·83	0·25	1·85
CaO	18·28	16·74	14·88
MgO	none	none	0·93
K_2O	0·11	0·15	0·38
Na_2O	0·82	1·05	1·22
H_2O	0·14	0·22	1·80
Totals ...	100·41	100·28	99·86
Specific gravity ...	2·703	2·729	

I. Felspar aggregates of the Crookdene Dyke. II. Felspar aggregates of the Collywell Dyke. III. Porphyritic felspar of the Tynemouth Dyke (analysis by Stead).

The felspar is thus very closely allied to anorthite (calculated for CaO, Al_2O_3, $2\,SiO_2$: $SiO_2=43{\cdot}25$, $Al_2O_3=36{\cdot}66$, $CaO=20{\cdot}09$), and the differences may be in part accounted for by the slight weathering of the mineral, and by the presence of basic inclusions in the crystals.

Under the microscope these anorthite aggregates are seen to consist of large twinned crystals irregularly intergrown, without crystalline outline, and profusely studded with small inclusions of dark glass. These are generally arranged parallel to a cleavage. They are usually oval in shape, but some have the outlines of the crystal or are formed by the intersection of the principal cleavages, and may be seen in some sections to be of considerable length. Careful examination with high powers ($\frac{1}{12}$-inch objective) reveals the fact that they are not homogeneous, but contain, apparently, both augite and iron oxide. Between crossed nicols they often give definite interference-colours, and in one or two rare cases show a radial arrangement of fibres.

There are often two sets of twinning-planes in the felspars, the striæ meeting at angles varying from 90° to 40° in different sections; as a rule, one set only continues after the two have met. The more perfect crystals are traversed by irregular cracks, roughly parallel, which seem to have no constant relation to the outlines of the crystal. Some of these cracks show brilliant interference-colours—those of calcite in one or two instances.

Some of the felspars are absolutely shattered (see Pl. I, fig. 1), others broken and slightly faulted (see Pl. II, fig. 2), but in no case can it be proved that the dislocation is great—in fact, the crystals seem to have burst *in situ*. The shattered fragments are embedded in a ground-mass composed of felspar-dust, much of which has decomposed into a dark granular mass. Very occasionally threads of much altered basalt are seen penetrating a little way into this ground-mass, and there are also circular patches of glass similar to those described as occurring in the amygdaloids. Here, however, the material is colourless or faintly yellow, and shows a spherulitic arrangement between crossed nicols, though the interference colours are very faint.

Threads of basalt, containing well-defined felspar-laths, have found their way among the groups of crystals in the aggregates, and now serve to cement the pieces together. In these threads the augite has been entirely replaced by calcite, and there is but little iron oxide.

Where the felspars have come into contact with the basalt there is a distinct zone, broadest in those crystals that are situated on the outside of the aggregates; but even the penetrating basaltic threads seem to have furnished material to the felspar surfaces with which they have come into contact. These zones are often very ragged, the edge being indented and penetrated by the ground-mass crystals. No zoning is to be seen on those fragments which are embedded in the felspar-dust, and, indeed, not on any to which the basalt has not had access (*cf.* fragments marked A & B in Pl. I, fig. 1).

Consideration of all these facts leaves little doubt that the felspar aggregates are inclusions, and it seems most likely that they are inclusions of an earlier crystallization in a later. The absence of crystalline outlines in the interior of the aggregates, and the occurrence of dark inclusions of glass in the crystals, are strongly suggestive of crystallization from a fairly pure felspathic magma which had separated from a more basic one, the slight excess of basic material being eliminated during the crystallization of the felspar. That this basic material contains augite and iron oxide is further suggestive that the inclusions as a whole separated out at some early stage from the basalt with which they are associated. There is thus evidence of differentiation of the magma from which the dyke is derived, such differentiation, possibly gravitational, resulting in the production of pockets or crusts (presumably specifically lighter) of solid material approaching anorthite in composition.

If such differentiation took place prior to intrusion, then on intrusion the crusts would be broken up and floated away by the molten rock, and would tend to aggregate near the head of the dyke; possibly, too, the felspar crystals would be unstable by reason of the changed conditions, especially of pressure, and would tend to disruption by release of internal strain, somewhat after the manner of a Rupert's drop. As these felspathic inclusions are embedded in molten matter containing the constituents necessary for their growth, a certain amount of fresh felspathic material would be added to them at their contact with the basalt, producing thus the zoning which is characteristic of this contact.

II. The Collywell Dyke.

This dyke has been briefly described by Dr. Teall[1] under the name of the Hartley Dyke, but as it is always termed the Collywell Dyke locally, it seems well to retain that name. It is well exposed at present (1909) on the coast about half a mile north of Hartley, and is seen to come to a natural head. Specimens of the altered dyke at Shankhouse Pit, a few miles inland, were examined by Teall and found to contain fresh felspar, but to have the pyroxene replaced by calcite. The effect of weathering is thus the same as that which we have observed in the case of the Crookdene Dyke. Near the top of the exposure at Collywell the rock is much decomposed, and effervesces freely with hydrochloric acid; lower down, however, it is hard and fresh. Specimens of this fresh rock were analysed, with results already stated (p. 3).

In chemical composition there is the very closest resemblance between this rock and the Crookdene Dyke; and sections under the microscope show the same general structure, although the rock is, perhaps, rather finer-grained and contains a little more unindividualized iron oxide in the glass.

The felspars are long and narrow, and the augite is wrapped

[1] Quart. Journ. Geol. Soc. vol. xl (1884) p. 237.

round them in continuous strands, and thus it is often impossible to fix the limits of individual crystals. The extinction gives little help in this matter, for it creeps over the field in a most erratic way. Very often the felspar-laths serve as axes for the augite crystals; at times they seem to have been swept into their present position and kept there by an overwhelming mass of augite. In such cases the arrangement is nearly always fan-shaped, and the augite mass seems to have a point of origin from which it spreads out laterally, carrying the felspars with it.

Grains of iron oxide frequently fringe these joint masses of felspar and augite, and the glass which appears between them is darkened by the presence of that mineral in a more or less unindividualized form. Elementary growths of felspar and augite, the latter strongly predominating, are also common in the glass.

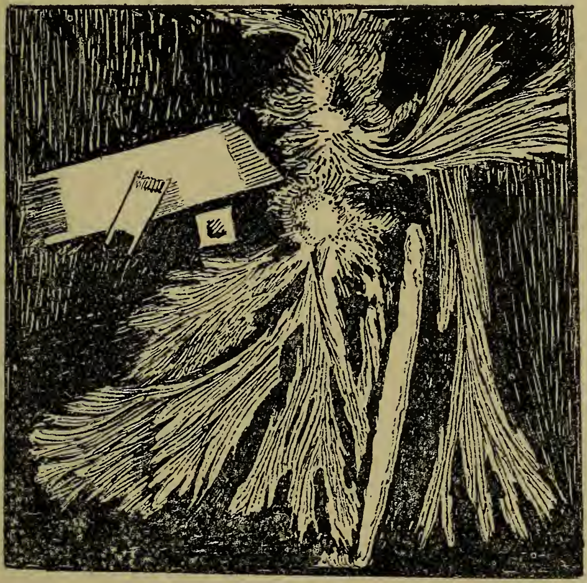
At the top of the dyke there is a comparative scarcity of felspar, the few laths that occur being embedded in an apparently almost amorphous glass in which, however, very small augites and grains of iron oxide are found. There are the usual modifications at the contacts; the felspars are clear, and the augites occur in the same beautiful skeleton forms as those found in the Crookdene Dyke. The acanthus-like twists shown in fig. 1 (p. 5) are also common in the better-crystallized parts near the contact, while the more elementary stages show felspars surrounded by light-coloured areas, mostly isotropic, except where they are penetrated from without by little bars of augite. As these have been entirely replaced by calcite, they show brilliant interference-colours between crossed nicols, and are readily distinguished from the somewhat turbid ground-mass in which they are embedded. The felspars are quite fresh; the pale areas surrounding them are usually colourless, but sometimes stained yellow, and, though it seems probable that they consist of felspathic material, there is little positive evidence in support of this view, except the concentration of skeleton augites and basic globulites in the narrow spaces between the pale areas. These may, perhaps, be conveniently termed *felspar aureoles*.

The modification described above is very rare, but it is perhaps worthy of mention as showing the influence of physical conditions on the mode of crystallization: for, if we compare this case with any from the more central portions of the dyke, we see that the augite is concentrated near and wrapped round the felspars in the latter; while, in the former, the basic constituents seem to be repelled from the felspar laths. The order of crystallization is the same in both cases, and it seems highly probable that the felspars were formed before the basalt reached its present position, so that, being the only solid bodies present, they acted as nuclei for later crystallizations. It would be difficult to say exactly why in one case they seem to have attracted, and in the other case to have repelled the basic elements, but it is probable that the repulsion of these from the felspars at the contacts is a *viscosity effect*. It is hoped that future investigations may throw some light on this subject.

Like the Crookdene Dyke, this one contains calcite amygdaloids. In the semi-lunar sections of the glassy residues there are curving forms of felspar and augite and grains of iron oxide. In one case the gas-cavities are partly filled with green isotropic glass, very like the material which occupies amygdaloids and forms irregular patches in the Morpeth Dyke. It is less devitrified, however, being strikingly uniform in colour and texture, and isotropic except for an occasional faint doubly refracting band at the margins.

Several small aggregates of felspar, more or less spherical in shape, were found in this dyke. They were prepared for analysis in the

Fig. 2.—*Collywell Dyke rock, showing elementary crystallization in contact with felspar aggregate.*



[Magnified about 544 diameters. The felspars are clear, though somewhat incomplete, and the augite is in a tufty condition, while the iron oxide is unindividualized in the glass.]

same manner as those of the Crookdene Dyke. Comparison of the analytical results with those for the Crookdene aggregate (p. 7) shows that the two minerals are practically identical in composition.

The crystals composing these aggregates (see Pl. I, fig. 1) are exactly like those of Crookdene under the microscope, though in the hand-specimens they are a little finer in texture. They show the same twinning, interference-colours, cleavages, and inclusions; they are irregularly intergrown, some are shattered and others traversed by broad cracks, which are filled with small fragments of felspar embedded in a ground-mass of decomposed felspar dust. This dust forms the base in which all the crystals are embedded and by which they are bound together; it is occasionally penetrated by threads of greenish glass. In one case, some of the larger cracks in the felspar are invaded by tongues of basalt containing small felspars and augites. The basalt in contact with this segregation is, apparently, slightly chilled, the ground-mass crystals at the junction being much smaller than usual (fig. 2, p. 11). The change is perfectly abrupt; there is no concentration of felspar in the basalt near the aggregate; and this, together with the penetration of basalt along the cracks, shows that these felspar masses are inclusions older than the ground-mass generation.

The close resemblance between the dykes at Collywell and Crookdene in chemical composition and in the structure of the rocks and their anorthite inclusions—a resemblance which almost amounts to complete identity—suggests the possibility of their being different exposures of the same intrusion. Both dykes run west by north to east by south; the distance between them is 24 miles. The line joining the two passes through what are usually regarded as exposures of the Collywell Dyke in Holywell Dene, close to Collywell, and Shankhouse Pit, a few miles inland. A little farther west, at Middle Duddoe, it passes near to a small exposure of a dyke, marked on the Survey maps but now no longer visible. It seems likely, then, in view of these facts, that these five exposures of basalt all belong to the same intrusion. It may be mentioned that the faults in the neighbourhood run chiefly east and west, and so would not be likely to shift the outcrop of this dyke. A great part of the country through which the dyke cuts is covered with drift; there are, nevertheless, frequent opportunities for the dyke to come to light, and that it does so but rarely may perhaps be ascribed to the fact that, as at Collywell and probably just east of Crookdene, it fails to reach the surface.

III. The Tynemouth Dyke.

This dyke has been fully described by Dr. Teall,[1] and therefore a brief description of it will suffice in this place.

On reference to the analysis (p. 3) it will be noted that this rock is somewhat more acidic than the other dykes. Microscopic examination shows that it contains also more residual glass than these. It seems possible that these facts are interdependent.[2]

It is a fairly even-grained rock, composed of felspar, augite, and some crystals of iron oxide. The felspars are in well-defined laths which show binary twinning, and not infrequently a stellate arrange-

[1] Quart. Journ. Geol. Soc. vol. xl (1884) pp. 233–36; also Geol. Mag. dec. iii, vol. vi (1889) pp. 481–83.

[2] See J. J. H. Teall, 'British Petrography' 1888, pp. 42, 43.

ment in groups of four or five. Augite, either in large crystals or in granular aggregates, is gathered round the felspar. Both these minerals are embedded in a glassy base which is rendered almost opaque by the presence of granular iron oxide and skeleton augite in great abundance. It would seem that the bulk of the iron oxide is in a globulitic condition: for, although small square sections and skeleton crystals of it are common, they are not numerous.

The rock is characterized by the presence of many large porphyritic felspars and amygdaloids of calcite. The latter vary considerably in size, and show semi-lunar residues consisting of dark glass in which some devitrification has usually taken place; while some are entirely filled by ground-paste with skeleton crystals. There are green patches, probably pseudomorphs after olivine, but these are rare; and pockets of green glass, such as characterize the Morpeth Dyke, are practically unknown.

The porphyritic felspars are large, and are mostly intergrown in groups of two or three, single individuals being rare. There is invariably a zone of later felspar material which surrounds the group as a whole, but is not carried between the individuals which comprise it. This point was noticed and emphasized by Dr. Teall, and he also observed (Quart. Journ. Geol. Soc. vol. xl, 1884, p. 233) that

'the internal boundaries of the crystalline particles do not show definite faces, although the external boundaries usually do.'

That is, the proper faces of the crystals are furnished by the later additions of felspar material. These porphyritic felspars are usually traversed by roughly parallel cracks, which do not appear to bear any definite relation to the crystal outlines—they are not the usual cleavages. In some cases the cracks have been filled by calcite, but in the freshest crystals they consist of felspar material, and are only distinguishable between crossed nicols as bands of brilliant colour.

These bands correspond to the large cracks which occur in the felspars of the aggregates in the other dykes, and possibly represent directions of weakness which might, in other circumstances, have become cracks. The interference-colours are chiefly of the rainbow type, such as are produced by thin films of strained material.

These porphyritic crystals were isolated and analysed by Mr. G. E. Stead (p. 7), and proved to be 'closely allied to anorthite.' In all respects—in composition, in twinning, in arrangement and character of inclusions, and in optical properties, they are identical with the felspars of the aggregates in the other dykes; and Dr. Teall's summary of their most salient characteristics may be applied to the felspar aggregates of the Crookdene and Collywell Dykes:

'The internal relations of the individuals forming a group are those of plutonic rocks (*e. g.* gabbro), whereas the external relations of the same individuals are those of volcanic rocks.' (Geol. Mag. dec. iii, vol. vi, 1889, p. 481.)

Compared with the dykes previously described, the one at Tynemouth differs chiefly in having more dark glass and less augite (and no twisted crystals of the latter). The augites, indeed, have the appearance of having separated out in a perfectly mobile medium, which cooled very slowly and allowed time for the development of the crystals, and the broad zones around the porphyritic felspars bear witness to the same conditions.

IV. The Morpeth Dyke.

This dyke has been investigated by Dr. Teall and analysed by Mr. Stead (see p. 3).

It resembles very closely in composition those of Collywell and Crookdene. Silica, titania, magnesia, and alkalies are practically the same; alumina is somewhat higher in the Morpeth Dyke, at the expense chiefly of the iron. It is remarkable in these circumstances that this dyke should be rich in olivine, while the others are free from it; and this would seem to point to differences of physical conditions (pressure and temperature?), rather than to difference of chemical composition, as the determining cause of variation in mineral development.

In general appearance, it is remarkably like the Tynemouth rock—perhaps a little coarser in texture. The presence of abundant olivine, however, as mentioned above, establishes a difference, as this mineral is only represented by some rare and somewhat doubtful serpentinous pseudomorphs in the Tynemouth Dyke. Again, the porphyritic felspars are smaller and less abundant, though similar in appearance and general arrangement to those in the Tynemouth rock.

There are numerous green patches of irregular shape in the dyke, consisting probably of partly devitrified glass. The same substance occupies the gas-cavities either wholly or partly, thus taking the place of the calcite amygdaloids in the other three dykes.

Most of the olivines are decomposed, but many fresh specimens occur; they are colourless and are traversed by deep, dark green grooves roughly at right angles, and by occasional curved cracks. The interference-colours are brilliant. When decomposed, the whole crystal becomes replaced by green pleochroic material, arranged apparently in bundles parallel to the cracks in the original crystal. It is not easy to fix the relative age of the olivine. The fresh pieces never have good outlines, and most of the decomposed pieces present the rounded appearance suggestive of magmatic corrosion. Several sections have been observed included in augite, and therefore, if they belong to the ground-mass generation, they are certainly older than augite. There is very little evidence bearing on the ages of the felspar and the olivine relatively to each other; the olivines may be porphyritic elements of the same generation as the porphyritic felspars, but it seems on the whole more probable that they belong to the earliest period of the ground-mass generation.

The porphyritic felspars are much smaller than those of the Tynemouth Dyke, and they occur in groups of two or three intergrown or in single crystals. They are always surrounded by a zone which, as a rule, furnishes the crystal faces.

The green patches are very peculiar, and imitate on a small scale the unique structure found in the dyke at St. Oswald's Chapel, near Hexham. There is no gradation from the normal clear glass with its innumerable microlites, to the green, almost amorphous type; but patches of the latter are embedded, like any crystal, in the normal glass. They are singularly free from skeleton forms and globulites, but frequently enclose felspar laths and grains of augite. In some cases they are almost rounded, and have circular cracks.

The amygdaloids are usually darker at the circumference than at the centre, and between crossed nicols the latter remains isotropic, or is only faintly illuminated, while the circumference shows bright interference-colours and a spherulitic arrangement of fibres. The same gradation of colour is found in the irregular patches as in the amygdaloids.

A curious variation of texture occurs in this rock for no apparent reason. There is no evidence of chilling, but the groundmass suddenly changes to a minute intergrowth of felspar, augite and iron oxide, with apparently no glassy base. Crystals of felspar and augite are embedded in this crystalline base, in which also there are rounded grains and small crystals of olivine. Here, as elsewhere, the gas-cavities are filled with green glass, and are surrounded tangentially by the very small felspar laths which characterize this part of the dyke. In one case, small laths penetrating a sphere of glass are all directed towards the centre at almost equal distances, forming felspar radii in a glassy sphere.

This close-grained variety of rock seems to be characterized by the predominance of small, well-defined crystals of iron oxide, of the same order of magnitude as the small felspars and augites. This local variation is remarkable, as the bulk of the iron oxide is still in the globulitic stage; but, for some reason, the conditions seem to have been so modified in this locality that all the minerals had equal facilities for crystallizing out. There is a distinct wavy line of junction between this and the ordinary type of basalt, and the transition from one to the other is perfectly abrupt. The occurrence is strongly suggestive of the patches of a micropegmatitic intergrowth of felspar and augite found in the Cleveland Dyke. These patches are very small and usually rounded; they are embedded in the normal basalt, and the transition from one form to the other is abrupt as in the case just described, but on a very much smaller scale. It seems probable that the phenomenon is due to the local prevalence of conditions favourable to the formation of an eutectic, with the resulting simultaneous crystallization of all the constituents.

No equivalent structures have been found in any of the other dykes dealt with in this paper.

V. Comparison of the Dykes.

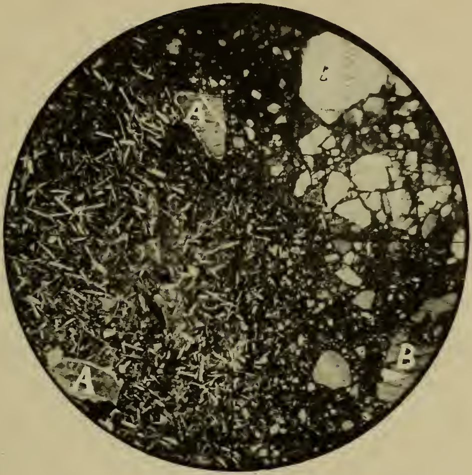
The results of the examination of the four dykes may be summed up conveniently in tabular form. As the differences between the Collywell and Crookdene Dykes are very slight and unimportant, those two may be taken together :—

I. Collywell and Crookdene.	II. Tynemouth.	III. Morpeth.
Fine, even-grained basalt composed of felspar, augite and iron oxide crystallized in the order stated.	As in I, but coarser-grained and with some pseudomorphs after olivine.	Coarser-grained than II; minerals as in I, with the addition of olivine.
Felspars occur in narrow laths, around which augite is wrapped in curved strands.	Felspars larger than in I; augite gathered in around them in grains or in clear straight crystals.	Minerals as in II, with straight-edged augites.
Iron oxide in small skeleton forms, not very plentiful.	Iron oxide mostly in unindividualized form darkening the glass.	Iron oxide as in II.
Large inclusions of anorthite occur.	Porphyritic inclusions of anorthite in groups of two or three, or in single crystals.	Rare groups and single individuals of porphyritic felspars (probably anorthite).
Felspars of the inclusions faintly zoned in contact with the basalt only. Individual crystals irregularly intergrown, and rarely showing good crystalline faces.	Porphyritic felspars strongly zoned, but a zone is never carried between intergrown crystals. Outer faces always furnished by the zone, and when the crystals are intergrown the boundary is irregular.	Porphyritic felspars zoned as in II.
Felspars of the inclusions cracked, faulted, and shattered, and the basalt in contact slightly modified (chilled).	Porphyritic felspars crossed by strain-bands giving brilliant interference-colours. There is no modification of the basalt in contact with them.	Porphyritic felspars show no special characters, and the basalt in contact is not modified.
Basalt contains amygdaloids of calcite, with dark residues.	Basalt contains amygdaloids of calcite and some of green glass, both with crystalline residues.	Basalt contains amygdaloids of green glass with dark residues and no calcite.

VI. Conclusions.

Some conclusions suggested by the study of these dykes have already been touched upon. We have seen reason, for instance, for supposing that the Collywell and Crookdene Dykes are in reality one, and that their felspathic aggregates are the result of magmatic differentiation under plutonic conditions. What applies to these aggregates applies also to the porphyritic felspars of the Tynemouth and Morpeth Dykes. This, and the many other points

FIG. 1.



x 196

FIG. 2.

x 15

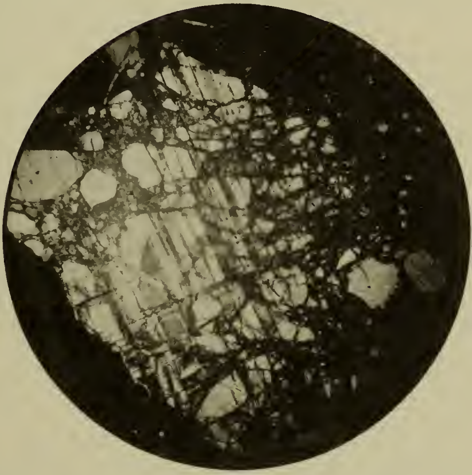
J. A. S., Photogr. *Bemrose Ltd., Collo., Derby.*

CROOKDENE DYKE ROCKS.

Fig. 1.

× 80

Fig. 2.



× 15

J. A. S., Photogr. *Bemrose Ltd., Collo., Derby.*

CROOKDENE DYKE ROCKS.

which all the dykes have in common, suggests that they have been derived either from the same source, or from pockets of molten matter similar in composition and existing under similar conditions. If the first hypothesis (as the simpler) be provisionally accepted, then the observed differences among the dykes and the association of phenomena may throw some light upon their history. Among the most suggestive facts bearing on the subject we may note that those dykes which in the field can be shown to come to a head are characterized by curved augites, large inclusions of feebly-zoned anorthite, and chilled basalt in contact with these inclusions. On the other hand, those dykes, the present exposures of which are clearly below the natural top or head, are distinguished by sharp-edged definite crystals, and scattered, corroded, and deeply-zoned felspathic inclusions. Again, the most coarsely-grained rock contains much olivine, few porphyritic felspars, and has its gas-cavities completely filled by glass.

These facts point to variation in physical conditions as the main cause of the differences in rocks which have had, possibly, a common origin. The peculiarities of the Collywell and Crookdene rocks would seem to be explicable as the results of the rapid fall of temperature consequent on their position at the top of the dyke. Opportunity was not afforded for the complete development of the ground-mass crystals owing to rapid cooling ; possibly, too, diffusion was checked by the great viscosity of the medium, and the molten rock enveloping the felspar inclusions could furnish but little material for their growth before consolidation set in. The results are the stunting and distortion of the crystals of the ground-mass and the feeble zoning of the felspar inclusions.

The Morpeth and Tynemouth rocks would seem to have consolidated lower down in the dykes where cooling was slower, the magma more fluid, and thus the conditions more favourable for the growth of the ground-mass crystals. The felspathic inclusions (smaller and more scattered in proportion to their distance from the top of the dyke) had time to enable them to add considerably to their substance, so that zoning is well developed. Increased pressure, too, may have been a factor of importance, favouring the formation of a different mineral species, olivine, from a magma which, in other circumstances, would only develop augite. Again, when crystallization had reached an advanced stage, and cooling had proceeded so far that the gaseous matter in the rock had lost its elasticity, the crystallization-residues were evidently still fluid enough in many cases to fill completely the now vacuous gas-cavities.

Viewed in this light, the observations point to the present exposure of the Morpeth Dyke having been the lowest, that is, the farthest removed from the head of the dyke, at the time of consolidation ; next, in ascending order, comes the Tynemouth Dyke ; and, lastly, the dykes of Collywell and Crookdene.

EXPLANATION OF PLATES I & II.

Rocks of the Crookdene Dyke.

Plate I.

Fig. 1. Junction between the basalt and the shattered portion of the felspar aggregate. The nicols are crossed, and the zoning of particles embedded in the basalt is shown (A), as also the absence of zoning in felspars embedded in felspar-dust (B). Magnified 15 diameters.

2. Specimen showing elementary forms of crystallization (*cf.* E. B. Bailey, Trans. Geol. Soc. Edin. vol. viii, 1904, p. 363). Branches of elementary augite (A) curve up on one side and down on the other of a felspar lath (F). The augite has been entirely replaced by calcite. Crossed nicols. Magnified 196 diameters.

[On the Plate itself the statements of magnification have been accidentally interverted, as between figs. 1 and 2.]

Plate II.

Fig. 1. Specimen showing curved augites (A) and felspar (F). Crossed nicols. Magnified 80 diameters.

2. Felspar aggregate shattered and slightly faulted. Magnified 15 diameters.

2. *On some small* Trilobites *from the* Cambrian Rocks *of* Comley (Shropshire). By Edgar Sterling Cobbold, F.G.S. (Read December 1st, 1909.)

[Plates III–VIII.]

The trilobites described in this paper were mainly collected during the progress of the excavations at Comley, which formed one of the subjects of the Report[1] of the Geological Excavations Committee of the British Association, read at the Dublin Meeting, 1908.

The majority of the specimens were derived from the preliminary excavation in the fields, some 200 yards south of the well-known Comley Quarry. This excavation cuts transversely through the same set of beds as those that are worked in the quarry, and, though of only a very shallow depth, it exhibits the most complete section as yet exposed of the local junction between the *Olenellus* and *Paradoxides* divisions of the Cambrian. Between the *Olenellus* Limestone, which in the quarry yields *Olenellus (Holmia) callavei*, Lapw., and the Conglomeratic Grit, which in the same quarry yields *Paradoxides groomii*, Lapw.,[2] there is intercalated some 4 feet of grey limestone. Provisionally, I divide this into the following bands, in descending order (see text-fig., p. 20):—

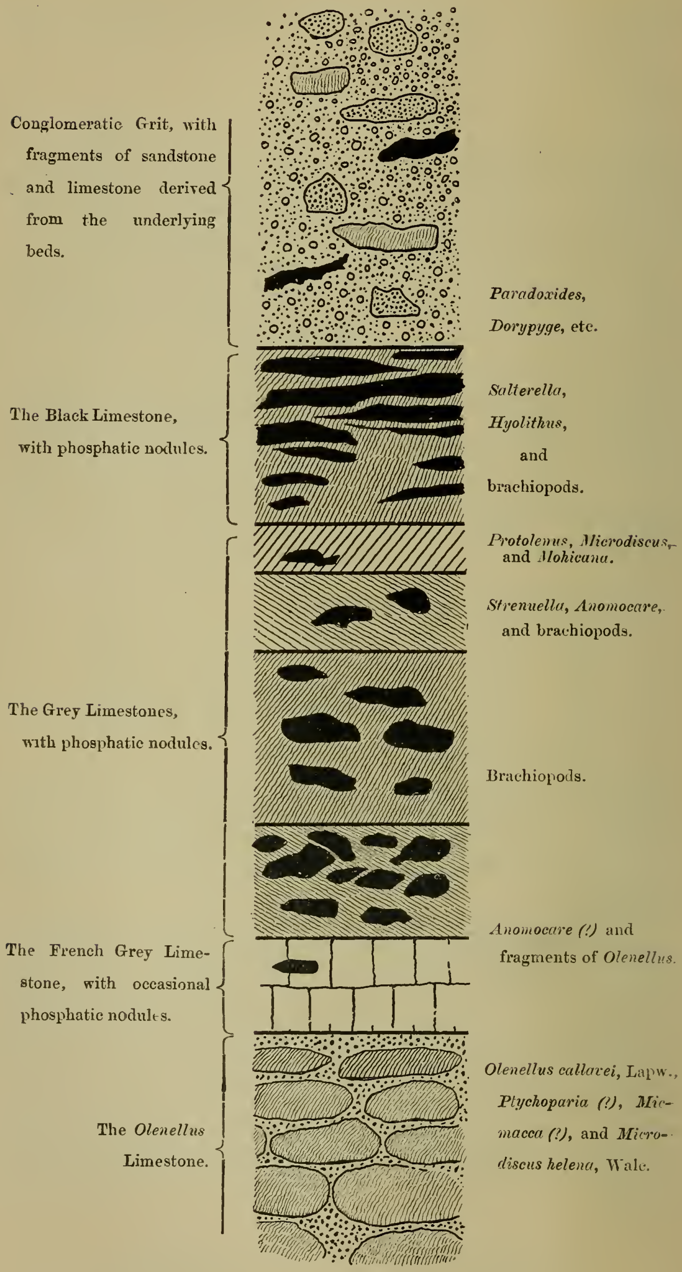
			Thickness in inches.
Conglomeratic Grit (*Paradoxides*).			
Black Limestone			12
Grey	do.	Uppermost part	3
Do.	do.	Upper part	6
Do.	do.	Middle part (reddish purple)	12
Do.	do.	Lower part (greenish grey)	9
French Grey Limestone			6
Olenellus Limestone. *Olenellus (Holmia).*			

I hesitate to assign any definite numbers or letters to these beds, until more is known as to their faunal characteristics, which will throw light on their natural grouping. All these limestones above the *Olenellus* Limestone contain black nodules of, probably, phosphatic matter.

The trilobites occur as aggregations of many parts or fragments of parts, indiscriminately mixed three or four species together, and usually preserve their original form and convexity. In most cases the test has also been preserved, either wholly or in part; and where this has been the case I have often been enabled to correlate free cheeks, pleuræ, etc. with the cranidia, in a way that would have been quite impossible if the surface characters had not been retained and propinquity only had to be relied upon. In the descriptions I have set forth the evidence upon which I have relied in making my correlations, so that future workers may be able to distinguish between what is actual fact and what is only matter of inference.

[1] Rep. Brit. Assoc. 1908 (Dublin) 1909, pp. 231–42.
[2] Geol. Mag. dec. iii, vol. viii (1891) p. 532 & footnote.

Vertical section 200 yards south of the Comley Quarry, on the scale of, approximately, 1 inch to 1 foot.



Microdiscus.

MICRODISCUS COMLEYENSIS, sp. nov. (Pl. III, figs. 1–4.)

E. S. Cobbold, *Microdiscus* sp., Rep. Brit. Assoc. 1908 (Dublin) p. 236 (1909).

This species is founded upon the examination of over seventy head-shields and pygidia, the thoracic segments being unknown.

CEPHALON: Size—moderate; length = from 3 to 4 millimetres.

General form.—Semi-elliptical; proportion of length to width about 3 to 4; evenly rounded at front and sides, and having a sinuous posterior border; postero-lateral angle gently rounded.

General convexity.[1]—Considerable, about $\frac{1}{4}$.

Glabella.—About seven-eighths of the total length and a third of the width of the shield; subconical, widest at the posterior end, which is also somewhat swollen and campanulate; anterior end semicircularly rounded, and reaching to the flattened marginal rim; posterior end, with which the occipital ring is entirely confluent, rounded elliptically, and projecting considerably beyond the posterior margin of the shield; no transverse furrows.

Axial furrows.—Sharply impressed; wider in the internal cast than on the exterior.

Cheeks.—Gently and evenly convex; greatest elevation, about half the height of the glabella at a point rather in advance of the middle of their length; the exterior boundary is nearly a quadrant of a circle, which is tangential to the apex of the glabella.

Postero-lateral border.—A somewhat sinuous rim, raised (? geniculate) at a point about three-fourths of the width outwards. At the posterior angle there is a little depression crossing the margin, and separating the side marginal rim from the postero-lateral border.

Marginal rim.—Standing out horizontally from the cheeks, and then bent downwards; rather narrow at the sides; widening to about an eighth of the length of the head-shield in front of the glabella; without tubercles[2]; having no groove in its rear.

PYGIDIUM: General form.—Approximating very closely to that of the head-shield, but rather more convex.

Axis.—Tapering regularly backwards and extending the full length of the shield; anterior end projecting a little beyond the general line of the margin with a narrow articulating rim (rarely preserved); posterior end rounded, and having the appearance of being pressed down into the confluent swollen side-lobes; divided into about seven annulations, hardly discernible on the exterior, but sometimes seen in the cast of the interior [508][3] (Pl. III, fig. 4).

[1] The fractions used under this heading, in this and the following descriptions, to express the convexity, indicate the proportion borne by the greatest height of the head-shield to its transverse width.

[2] When viewed sideways, some of the specimens exhibit a very slight irregularity in the horizontal surface of the marginal rim towards the sides of the head-shield, suggestive of incipient (or decadent) tubercles. They are so badly defined, that they can neither be counted nor shown on the figures.

[3] The numbers in square brackets are those attached to the specimens themselves.

Axial furrow.—Narrow and sharply impressed on the exterior, wider on the internal cast.

Side-lobe.—Evenly convex; curving down from the axial furrows; confluent round the tip of the axis, where also it frequently overhangs the marginal rim; it has one well-marked groove close to the anterior border, which is a little raised at its edge.

Marginal rim.—Narrow all round, and bent downwards rather more decidedly than in the head-shield.

Test.—Relatively to other trilobites from the same rock, thick and firm and resistant to weathering; marked by numerous impressed punctæ set at fairly even distances and represented on the interior by raised spots, which are reproduced as punctæ on the internal cast.

The variations are very slight, chiefly consisting in the amount of inflation of the swollen parts.

This species appears to be somewhat intermediate between *M. speciosus*, Ford, and *M. punctatus*, Salter: with both it agrees in having a punctate test, and a simple form of pygidium; but, whereas the present species has about seven annulations of the axis, *M. punctatus* is described as having nine, and *M. speciosus* eleven.

The enlarged occipital ring, coalescent with the glabella, may be paralleled in *M. punctatus*, but is not produced in the form of a spine. From both these species it differs in having a plain marginal rim to the head, and in the proportionate length of the glabella.

In the plain marginal rim and punctate test it may be paralleled with *M. lenaicus*, von Toll[1]; but it differs from that species, in having a longer glabella and more convex axis to both cephalon and pygidium.

Locality and horizon.—The grey limestone of Comley, from the uppermost band (3 inches thick) at the excavation 200 yards south of the quarry.

Microdiscus lobatus (Hall). (Pl. III, figs. 17 & 18.)

J. Hall, 'Pal. N. York' vol. i (1847) p. 258 & pl. lxvii, figs. 5 *a*–5 *f*.
C. D. Walcott, U.S. Geol. Surv. Bull. 30 (1886) p. 156 & pl. xvi, figs. 1, 1 *a*, 1 *b*; and 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) p. 632 & pl. lxxxi, figs. 4, 4 *a*, 4 *b*.
P. Lake, 'British Cambrian Trilobites' Monogr. Palæont. Soc. vol. lxi (1907) pt. ii, p. 32 & pl. iii, figs. 4–6.

Head-shields of this species from the same locality and bed as *M. comleyensis*, sp. nov., have been figured by Mr. Philip Lake in his monograph. Since that portion of his work was published, several pygidia referable to *M. lobatus* have been found, one of which [445], together with a very well-preserved head-shield [453], is figured on Pl. III.

Locality and horizon.—Comley, from the uppermost band of grey limestone, and from the next lower band, at the excavation 200 yards south of the quarry. It is plentiful there.

[1] 'Beitr. z. Kenntn. d. Sibirischen Cambrium' Mem. Acad. Imp. Sci. St. Petersb. ser. 8, vol. viii, no. 10 (1898) p. 23 & pl. i, figs. 6–8, 10, 11, 14–17, 24.

MICRODISCUS HELENA, Walcott. (Pl. III, figs. 14–16.)

C. D. Walcott, Proc. U.S. Nat. Mus. vol. xii (1889) p. 40; and 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) p. 632 & pl. lxxxi, figs. 1–1 *a*.
P. Lake, *Microdiscus* sp., 'British Cambrian Trilobites' Monogr. Palæont. Soc. vol. lxi (1907) pt. ii, p. 34 & pl. iii, fig. 8.
E. S. Cobbold, *Microdiscus* sp., cf. *helena*, Walc. Rep. Brit. Assoc. 1908 (Dublin) 1909, p. 235, & *Microdiscus* sp., *ibid.* p. 237.

Since Mr. Lake figured the single pygidium from the *Olenellus* Limestone of the Comley Quarry, additional and better-preserved specimens have been found from the same horizon at the excavation 200 yards to the south. He has kindly examined these, and tells me that he regards them as quite confirming his opinion that Dr. Walcott's species is represented at Comley.

Three pygidia [385, 386, 387], in which the test and original convexity are preserved, are figured on Pl. III. These show four or five annulations of the axis, in addition to the articulating surface in front and a terminal posterior portion: the side-lobes are confluent beyond the end of the axis, and are marked by four impressed lines, which are less strongly shown on the exterior than on the interior. The margin is narrow and convex. The convexity of the shield seems to vary from about $\frac{1}{4}$ to $\frac{1}{5}$, and the surface of the test appears to be smooth. The length is from 2 to $2\frac{1}{2}$ millimetres.

Locality and horizon.—Comley, from the *Olenellus* Limestone of the quarry; from the excavation 200 yards south thereof; and from the same horizon at an excavation at the northern end of Dairy Hill, 200 yards to the south-east.

MICRODISCUS SPECIOSUS, Ford.

S. W. Ford, Am. Journ. Sci. ser. 3, vol. vi (1873) p. 137 & figs. 2 *a*–2 *b*; and vol. xiii (1877) p. 141.
C. D. Walcott, U.S. Geol. Surv. Bull. 30 (1886) p. 154 & pl. xvi, figs. 3, 3 *a–c*; and 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) p. 632 & pl. lxxxi, figs. 5, 5 *a–c*.
P. Lake, 'British Cambrian Trilobites' Monogr. Palæont. Soc. vol. lxi (1907) pt. ii, p. 33 & pl. iii, fig. 7.

A good head-shield from my collection has been figured by Mr. Lake in his monograph.

With the exception of two imperfect and rather doubtful pygidia, no further remains of this species have come to light.

Locality and horizon.—Comley, from the upper part of the grey limestone, at the excavation 200 yards south of the quarry.

Ptychoparia, Corda.

PTYCHOPARIA (?) ATTLEBORENSIS, Sh. & F. (Pl. III, figs. 11–13.)

N. S. Shaler & A. N. Foerste, Bull. Mus. Comp. Zool. vol. xvi (1888) p. 39 & pl. ii, fig. 14.
C. D. Walcott, 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) p. 649 & pl. xcv, fig. 2.

In my collection there are some fifteen or more specimens of a minute cranidium which answers very closely to Dr. Walcott's figures and to his quotation of the original description of this species.

There is but one point that I have not identified. Shaler & Foerste say that 'the most marked feature of the fixed cheeks is the existence of a depression on their postero-lateral outline.' Unless this be a reference to the wide postero-lateral groove, which expands outwards, this feature is not present in the Comley specimens.

The most marked feature about these fixed cheeks is their triangular aspect, as viewed from above. The two cheeks, taken together, form a square elevated area set diagonally upon the somewhat quadrate cranidium; this feature comes out almost too strongly in my figures.

The specimens figured [405, 406, 576] do not show another feature mentioned by the authors of the species. After referring to the expanded 'anterior border,' they say that 'near the lateral margins of the border, or rather near the facial suture, there are sometimes two or three low tubercles visible.' One of the Comley specimens (a very friable internal cast) exhibited similar tubercles when first found, and was mistaken for a head-shield of *Microdiscus helena*, Walc., until the eye-lobe was exposed by removal of the soft matrix. The enlarged base of the combined glabella and occipital ring lent colour to the illusion.

The Comley specimens are about 2 millimetres long; in the original description the head is said to be 'small, often minute, in the largest specimen 4 mm. long, usually 2·6 mm.'

Locality and horizon.—Comley, from the *Olenellus* Limestone, at the excavation 200 yards south of the quarry, and also in the Dairy Hill excavation. It is plentiful.

Ptychoparia (?) annio, sp. nov. (Pl. III, figs. 5–8.)

Four incomplete head-shields [401, 402, 403, 404] form the only material available for description, but the features are so well marked that the specimens seem worthy of specific designation. The generic reference is quite provisional.

Cranidium: Size—minute; length = about $2\frac{1}{2}$ millimetres.

General form.—Irregularly pentagonal; proportion of length to width = 3 : 4.

General convexity.—While the features are all in themselves very convex, the general level of the head-shield is nearly horizontal, but the sides appear to be much depressed.

Glabella.—Strongly convex; distinct from the occipital ring; parabolic; almost pyriform in the cast, see specimen [401] (Pl. III, fig. 7); most elevated near the posterior end; very depressed anteriorly, as though it had been pressed down into the head-shield; without furrows; about three-fifths of the total length of the head-shield.

Occipital furrow.—Entire; strongly impressed at the sides, less so in the middle.

Occipital ring.—Equal in width to the glabella; bearing (the base of) a strong spine or large tubercle [401] (Pl. III, fig. 7).

Axial furrow.—Very deep and wide.

Fixed cheeks.—Anterior limit marked by a curve of rather long radius, convex forwards and passing just clear of the apex of the glabella. In transverse section the cheeks rise steeply out of the axial furrows, then become horizontal, and finally rise to the rather wide and elevated eye-lobe (Pl. III, figs. 5 & 6); the posterior angle is much depressed; the posterior margin of each cheek is furnished with two curious little circular mounds [401, 402] (Pl. III, figs. 5, 6 & 8).

Ocular ridge.—Well defined on the internal cast (Pl. III, fig. 7); arising on the outer side of the axial furrow a little below the apex of the glabella, and passing almost directly across the cheek to the eye-lobe; not always visible on the exterior.

Eye-lobe.—About a third of the length of the glabella, and situated far out and rather forward; the anterior end of the eye-lobe is distinctly higher than the posterior.

Posterior margin.—Unknown.

Frontal limb.—Swollen up to a great height in the middle, as high as, or higher than, the maximum elevation of the glabella, from which it is separated by a deep hollow; the prominence decreases in width and falls away in height to right and left, but continues to be well marked and is separated from the cheeks by the continuation of the deep hollow already mentioned.

Facial suture.—Somewhat doubtful; anterior branch (Pl. III, fig. 6) short and direct to the margin; posterior branch, so far as can be made out from the specimen (fig. 5), taking a sigmoidal curve outwards to cut the posterior margin in line with the outer edge of the eye-lobe.

Test.—Finely granular, as seen under a strong lens.

The prominent front and elevated eye-lobes, together with the depressed apex of the glabella, suggested when first seen the coiffure of a clown, hence the proposed specific name. A restoration of the complete cranidium, based upon the three specimens figured, is given in Pl. III, fig. 8.

Locality and horizon.—The *Olenellus* Limestone of Comley, from the excavation 200 yards south of the quarry.

This species is very closely allied to the Siberian form *Ptychoparia czekanowskii*, von Toll.[1] It differs (i) in the shape of the glabella; (ii) in the front outline of the cranidium; (iii) in the strength of the nuchal spine, which in the Siberian species is described as entirely replacing the occipital ring. In E. von Toll's figures there is an uncertain indication of an upturned marginal rim, in advance of the swollen frontal limb; no trace of this is to be detected in the Comley form.

[1] 'Beiträge zur Kenntniss des Sibirischen Cambrium' Mem. Acad. Imp. Sci. St. Petersb. ser. 8, vol. viii, no. 10 (1898) p. 21 & pl. i, fig. 1.

Nearly allied also is the same author's second Siberian species, *Ptychoparia meglitzkii*,[1] which, however, has weak glabellar furrows and differently formed fixed cheeks.

Pt. (?) prospectensis, Walcott,[2] has a circular swelling in front of the glabella of equal elevation with it, and a fixed cheek extending forwards, with prominent eye-lobes on the outer margin. This form would seem to be a more distant ally of our species, but it has an anterior border to the frontal limb.

Pt. (?) linnarssoni,[3] Walcott (not the *Pt. linnarssoni*, Brögger), is another species with a swelling on the frontal limb in front of the glabella, and elevated fixed cheeks extending forwards with a rather prominent eye-lobe, but the general shape of the cranidium and the widely diverging posterior branches of the facial suture give a very different aspect to the head-shield. It, too, has an anterior border to the frontal limb.

A still more divergent form has been described by Dr. Walcott as *Pt. (?) pernasutus*,[4] in which the glabella has much the same general shape as the Comley species; but in this case there is an extravagantly enlarged frontal limb, which runs out forwards into a point and is only slightly convex. It is somewhat reminiscent of *Anomocare acuminatum*, Ang.

In all these forms, which have been doubtfully referred to *Ptychoparia*, there seems to be a relic of an aboriginal trilobation of the anterior portion of the head-shield.

Micmacca, Matthew.

Under this name Mr. G. F. Matthew describes

> 'A group of trilobites with large, rather prominent, cylindrical glabella, which extends almost to the front of the shield; and with continuous eye-lobes and a short, direct posterior extension of the dorsal suture.' (Trans. N.Y. Acad. Sci. vol. xiv, 1895, p. 141.)

There are several forms derived from the *Olenellus* Limestone of Comley which I provisionally refer to this genus, although they are almost as closely allied to *Ellipsocephalus*, Zenker, and again have affinities with some forms of *Anomocare*, Angelin, and with Mr. Matthew's suggested subgenus (*Strenuella*) of *Agraulos*, Corda.

The true generic position of these Comley fossils can hardly be ascertained, until the thoracic segments and pygidia are forthcoming.

For the present, I divide them into two species: one a very minute form, and thereby differing strongly from Mr. Matthew's type species; the other of moderate size, and presenting several variations, so that it is possible that a third or even a fourth species may be represented.

Their occurrence in the same bed of rock with *Olenellus* (*Holmia*)

[1] Mem. Acad. Imp. Sci. St. Petersb. ser. 8, vol. viii, no. 10 (1898) p. 22 & pl. i. fig. 2.

[2] 'Palæontology of the Eureka District' U.S. Geol. Surv. Monogr. viii, (1884) p. 46 & pl. ix, fig. 20.

[3] *Ibid.* p. 47 & pl. ix, figs. 18, 18 *a*.

[4] *Ibid.* p. 49 & pl. x, figs. 8, 8 *a*, 8 *b*.

would seem to indicate that they come from a relatively earlier horizon than the Acadian forms, and their alliances with other genera suggest an earlier stage in development.

MICMACCA (?) ELLIPSOCEPHALOIDES, sp. nov. (Pl. VII, figs. 8 & 9 & Pl. VIII, fig. 1.)

This species is founded upon five specimens in my own collection, and upon a similar number from the British Museum (Natural History) collection at South Kensington; and I would here wish to acknowledge my indebtedness to the Keeper of the Geological Department for the loan of the latter specimens.

I take as the type-specimens [413] of my own collection and [J 12905] from the British Museum, and to this typical form specimens [955, 200, & 201] are also referred.

The remainder of the British Museum specimens [J 12900, J 12901, J 12902, J 12904] and one of my own [414] will be noticed later as varieties.

Nos. 413 and 955 have the test in excellent preservation. In J 12901 it is slightly decomposed and of a beautiful chalky white, like so many of the fossils from the *Olenellus* Limestone of the Comley Quarry. The other specimens have the test more or less decomposed, or actually removed.

CRANIDIUM: Size—rather small; length = 5 to 7 millimetres.

General form.—Trapezoidal, widest behind; widely rounded in front; proportion of length to width = 3 : 4.

General convexity.—Considerable; apparently about $\frac{1}{4}$; with features in strong relief.

Glabella.—Without the occipital ring, about two-thirds of the length of the head-shield; wide; very convex transversely and also longitudinally; highest in the middle of the length; parallel-sided, with semicircularly rounded apex; marked at the sides by three pairs of furrows, of which the posterior is strongly curved backwards, the next is similarly directed but not so strongly, and the third is only sometimes discernible.

Occipital furrow.—Shallow and wide; entire; somewhat curved backwards, and weak in the middle of its length.

Occipital ring.—As wide as the glabella; expanded in the middle to a rounded angle; and bearing a tubercle or incipient spine directed backwards.

Axial furrow.—Wide; slightly hollowed and not marked by any impressed line; not traceable round the apex of the glabella.

Fixed cheeks.—Suggestive of spherical triangles; flatly convex, rising a very little from the axial furrow, almost flat transversely to it, curving over towards a groove (deepest posteriorly) in rear of the eye-lobe; anteriorly they fall away in elevation, and merge into the frontal limb beyond the ocular ridge; posteriorly they are limited by a steep curve down to the postero-lateral limb.

Eye-lobe.—One-third the total length of the head; the posterior end, which is a little enlarged, does not quite reach the postero-lateral limb; from this point the surface of the lobe, which is always raised above the depressed side of the cheek, rises distinctly to the forward end, where it drops away abruptly to the place of the ocular ridge.

Ocular ridge.—Arising from the outer side of the axial furrow a little in advance of the point where the side of the glabella begins to curve round to the apex; very slightly elevated, and sometimes only marked by a slight hollow or furrow behind it which connects with the hollow in rear of the eye-lobe.

Postero-lateral limb.—A triangular area, consisting of a hollow which widens outwards, and a slightly raised margin which is strongly geniculated just within the distance outward of the eye-lobe, the geniculation being almost a tubercle. Beyond this point the surface of the limb falls rapidly down to the facial suture.

Frontal limb.—Narrow, not more than an eighth of the length of the head; subequally divided into a flat area (or a shallow hollow) and a slightly convex marginal rim; both these features can be followed in one of the specimens to right and left as far as the facial suture.

Facial suture.—Anterior branch nearly straight forwards and parallel with the axis of the head; posterior branch a little curved outwards, and extending as far out as the extreme limit of the eye-lobe.

Test.—Apparently thick and strong, sometimes almost polished on the surface of the glabella; having a finely granular aspect on the fixed cheeks, and a few short raised lines on the front margin.

Two detached pleuræ occur on the same little piece of rock with the cranidium [413]. These are smooth, widely furrowed, and strongly geniculated, but the ends are not visible. I cannot with confidence assign them to this species, because at least two other trilobites are represented by fragments on the same little block of limestone.

This form of the species seems to me to be intermediate between *Micmacca* and *Ellipsocephalus*. From the type species of the former it differs in the somewhat extended frontal limb, and in the rather wider postero-lateral limb with the consequent lengthening of the posterior branch of the facial suture. From the latter genus it differs in the fact that the glabella is not expanded in front, nor is it pentagonal in outline, nor is the frontal limb strongly bent downwards in front.

The species seems nearest to *Micmacca recurva*, Matthew, but the eye-lobe of that species, as represented in his figure, extends farther back, the postero-lateral limb is narrower, and the ocular ridge seems to be differently developed; there is no 'obscure tubercle' on the side of the glabella in the Comley form, which also is smaller.

Micmacca ellipsocephaloides, var. spinosa. (Pl. VIII, fig. 5.)

Specimens [414 & J 12900] show the tubercle on the occipital ring developed into a short spine directed backwards; the axial furrow is more distinctly hollowed, and traceable almost to the apex of the glabella; the fixed cheeks appear to be rather narrower; the hollow parallel with the eye-lobe and the ocular ridge is more distinct; the frontal limb is thickened and curved downwards to the front margin, with an extension forwards equal to one-third of the length of the glabella, and, though flattened in front of this latter feature, does not show any decided hollow or marginal rim.

MICMACCA ELLIPSOCEPHALOIDES, var. STRENUELLOIDES. (Pl. VIII, figs. 3 & 6.)

Two cranidia [J 12904 & J 12902] are somewhat wider across the base and narrower in front between the sutures than is the case in the type-specimens, and in this respect bear a resemblance to *Agraulos* (*Strenuella*). The frontal limb stands out horizontally to a greater distance, and has the form of the toe of a slipper when seen from the side; and in one specimen [J 12902] the glabella is narrower in front than behind. In both cases the occipital ring is incomplete, so that it is impossible to say whether it bore a spine or a tubercle. This last specimen also shows traces of at least seven thoracic segments in place: these are so much damaged, that it can only be said that the number is incomplete; that they have a very convex axis; that the pleuræ stand out horizontally for a distance equal to about two-thirds of the width of the axis, and are there bent downwards at a steep angle to their terminations, which are also bent backwards and probably ended in sharp points. The traces of these points in the rock are concave throughout, implying the existence of an extended doublure.

On the same piece of rock there is a well-preserved fixed cheek, showing the sutures, and approaching more nearly to the type (Pl. VIII, fig. 4).

MICMACCA ELLIPSOCEPHALOIDES, var. SENIOR. (Pl. VIII, fig. 2.)

A cranidium of larger dimensions (length = 13 mm.) is represented in the specimen [J 12901] shown in fig. 2. There is a robustness about it which suggests that it is an older individual. It departs from the type, principally in the greater proportionate width across the posterior branches of the facial sutures; in the occipital furrow being quite lost in the middle of its length, but wide and deep at the sides; and in the very thick but shortened frontal limb, with a decided hollow between it and the glabella. The occipital ring seems to have been devoid of spine or tubercle.

The divergences between these four forms are, when considered together, too slight to warrant a separation into diverse species, and I am doubtful whether they have any permanent varietal importance. It seems more probable that the species was in a state of flux and that it was not until later, if at all, that it crystallized out into forms with well-marked permanent differences.

Locality and horizon.—Comley, from the *Olenellus* Limestone of the quarry and of the excavation 200 yards south of it.

MICMACCA (?) PARVULA, sp. nov. (Pl. III, figs. 9 & 10.)

One imperfect internal cast of the cranidium [412] and one fragment with the test preserved [411], and showing the glabella and fixed cheek, form the only material at present available for description.

CRANIDIUM: Size—minute; 2 to $2\frac{1}{2}$ millimetres long.

General form.—Subquadrangular, with rounded front.

General convexity.—Rather flat; curving down somewhat at the front, and perhaps at the sides.

Glabella.—Moderately convex; touching the front margin; widening forwards beyond the ocular ridge; with four pairs of incomplete furrows, which are slightly impressed at the sides and very evenly distributed in the length.

Occipital furrow.—Wide and shallow; traceable all across.

Occipital ring.—Narrower than the glabella, and produced backwards to a point or short spine.

Axial furrow.—Wide and very slightly impressed; increasing in strength forward of the ocular ridge.

Fixed cheeks.—Subquadrangular; as wide as the glabella and nearly flat; falling a little to a hollow behind the eye-lobe; limited anteriorly by the ocular ridge, and posteriorly by a steep descent to the postero-lateral groove.

Ocular ridge.—Arising from the outer side of the axial furrow a little posterior to the anterior glabellar furrow; passing outwards at right angles to the glabella to join the eye-lobe by a bold curve.

Eye-lobe.—Fully half the length of the head; rising rather steeply from the depressed edge of the fixed cheek; reaching backwards nearly to the posterior marginal groove.

Postero-lateral limb.—A groove margined by a slightly raised and rounded ridge, which is geniculated almost as far out as the eye-lobe.

Frontal limb.—Not wholly known; apparently it consists of a narrow upturned fillet touching the glabella, and separated from it by a distinctly impressed line. This fillet is produced on each side to form the anterior curve of the shield; between this and the ocular ridge there seems to be a comparatively wide flat area.

Facial suture.—Anterior branch unknown; posterior branch apparently short and direct to the posterior margin immediately behind the eye-lobe.

TEST.—Very finely granular.

This little species differs from Mr. G. F. Matthew's type for the genus (*M. matthewi*) in its minute size; and, but for the width of the glabella, it might well be a larval form of this genus. The long and distant eye-lobe and the glabella reaching the front margin are both (*fide* Matthew)[1] embryonic features in allied genera.

Locality and horizon.—Comley, from the *Olenellus* Limestone of the quarry, and of the excavation 200 yards south thereof.

[1] Trans. Roy. Soc. Can. vol. v, sect. iv (1887) pp. 123 *et seqq.*

Agraulos, Corda.

Subgenus **Strenuella**, Matthew.

In 1886 Mr. Matthew[1] called attention to the divergence of *A. strenuus*, Bill., from the type of Corda's genus, and proposed the name of *Strenuella* for a subgenus, of which Billings's species would form the type; and in 1887[2] he referred (but with a note of doubt) his species *A. (Strenuella?) halliana* to the same subgenus.

A form occurs at Comley which seems closely related to *A. strenuus*, var. *nasutus*, Walcott, and should come under the same subgenus. It has some points of resemblance with *Anomocare*, Angelin, but would seem to have a wider head-shield than the type of the genus, and a small pygidium very different from the rounded pygidia described and figured by Angelin. It appears to me that *Strenuella* might well be adopted as the name for a genus intermediate between *Agraulos* and *Anomocare*; but without access to specimens of *Agraulos strenuus*, Bill. (which should form the type species), I cannot sketch out a generic diagnosis.

AGRAULOS (STRENUELLA) SALOPIENSIS, sp. nov. (Pl. IV, figs. 1–9.)

E. S. Cobbold, *Anomocare*, cf. *Agraulos strenuus*, var. *nasutus*, Walc., Rep. Brit. Assoc. 1908 (Dublin) 1909, p. 236.

Fragments of this species occur in abundance in one band of the grey limestone of Comley; but they are difficult of extraction, owing to the strong relief of the features.

I have portions of twelve or more individual cranidia in my collection, the most complete, though not the largest, of which [161] is figured.

The fragments of this species are intimately mixed in the rock with those of another of about the same size, and the correlations made below, of pygidium, thoracic segments, and free cheeks with these cranidia, are necessarily matters of inference.

CRANIDIUM: Size.—Length (exclusive of the nuchal spine) = from 7 to 10 millimetres; the width across the eye-lobes is about half as much again.

General form.—Broadly subquadrangular, with a very widely curved front and a somewhat sinuous posterior border, from which the long nuchal spine projects backwards.

Convexity.—The glabella is strongly convex, the fixed cheeks are more or less horizontal, and the sides of the head-shield dip steeply down. The convexity works out at about $\frac{1}{4}$.

Glabella.—Almost semicircular in convexity; somewhat parabolic in outline; width, about a third of that of the cranidium; length, about three quarters of that of the shield without the nuchal

[1] Trans. Roy. Soc. Can. vol. iv, sect. iv, pp. 151, 154.
[2] *Ibid.* vol. v, sect. iv, p. 132.

spine; three pairs of furrows directed strongly backwards are sometimes visible at the sides, but they are frequently almost obsolete.

Occipital furrow.—Sometimes traceable all across, sometimes only represented by impressions at the sides.

Occipital ring.—Merged into the base of a very strong nuchal spine, which projects backwards over several thoracic segments.

Axial furrow.—The change in vertical curvature all round the glabella indicates its limits very definitely, but there is no impressed line or hollow.

Fixed cheek.—Subquadrangular; as wide as the glabella; almost horizontal for about half its width, rising a little in the third quarter, and falling steeply to a hollow or groove, the outer margin of which rises to form the eye-lobe; posteriorly the surface of the cheek falls steeply to the postero-lateral groove; anteriorly it slopes gently and evenly down to the frontal limb, extending a very little beyond the ocular ridge.

Eye-lobe.—A little less than a third of the length of the head-shield (without the spine); rather nearer to the posterior than to the anterior margin; elevated at its interior end above the ocular ridge, and having its upper surface distinctly inclined backwards as seen from the side.

Ocular ridge.—Almost obliterated at its commencement near the glabella, but gaining in definiteness, by reason of the slight depression behind it, as it crosses the front slope of the cheek towards the eye-lobe.

Frontal limb.—Extending for a quarter of the length of the head-shield in front of the glabella; composed of a deep and wide rounded hollow and a very convex marginal rim: the hollow and rim lose intensity to right and left, and are hardly discernible at the line of the facial suture.

Postero-lateral limb.—Consisting of a groove widening considerably towards the facial suture, and a well-marked but rather narrow raised rim. At a distance from the glabella equal to the width of its base there is a strong geniculation, sometimes rising so much that it might be called a tubercle; beyond this the surface of the limb slopes down steeply to the facial suture, and the groove and raised rim gradually fade away.

Facial suture.—Not well seen from above, owing to the curving over of the sides of the cranidium; the anterior branch is short, subparallel to the axial line of the shield, and curves very slightly outwards; the posterior branch is somewhat sigmoidal, but also short, and meets the posterior border behind the eye-lobe.

Test.—The test in this species seems very thick and strong, and all the minor features, such as the glabellar grooves, or ocular ridge, are softened or almost obliterated from this cause. I have not seen any internal casts. The actual surface is smooth, but not polished, and under a strong magnifier appears to be of extremely fine grain.

As a rule, no surface-marks are visible on the upper surface; but on one nuchal spine attached to a glabella [158] there are some faint and very slightly raised lines, running longitudinally, and on one front border [945] there are similar marks almost on the under surface.

Free cheeks.—Among the innumerable fragments associated with these cranidia and with other similar fragments belonging to the next species to be described, there are several free cheeks which I feel confident may be assigned to this species.

One of the most perfect [170] is figured in four aspects (Pl. IV, figs. 6 *a*–6 *d*): fig. 6 *a* is a representation of the cheek as it lies flat in the rock; fig. 6 *b* is the view presented as seen from the side of the complete organism; fig. 6 *c* is the view presented as seen from above (as nearly as I can judge); fig. 6 *d* is an enlargement of the spine, to show the surface-markings. These markings correspond very closely with those on the spine and front border above mentioned, but they are more pronounced. They consist of raised, inosculating, flattened lines, looking like tiny ribbons of gossamer, irregularly arranged subparallel with the margin. The rest of the surface is of exactly the same texture as the associated cranidia.

The transverse curvature of the cheek-margin agrees with that of the cranidium, and the lower branch of the facial suture on the cheek would (with allowances for differences in size and individual) fit fairly well to the suture shown on the head-shield.

The flat area of the cheek is very small; the rise to the eye is steep and pronounced; the marginal fold is produced at the genal angle into a stout spine, somewhat oval in section, and this projects (to judge by fig. 6 *c*) but slightly from the general outline of the thorax.

The associated thoracic segments that may be referred to this species are represented in Pl. IV, figs. 2–4 and 7–9. They are characterized by a very convex axis usually, if not invariably, more than a semicircle; and by a pleural lobe which is horizontal for half its length, and has a strong geniculation at a distance out subequal to the transverse diameter of the axis, the tip being bent down at an angle of 60° to 65°. In some axis-rings there is a very small central tubercle; others are provided with the base of a stout spine directed vertically upwards, and seen, in one instance [176] (fig. 4), to rise fully three-quarters of the height of the ring without change of direction. The extremities of the pleuræ are rarely easy to observe: in [162] fig. 3 the whole tip is corroded and indefinite; in [164] fig. 2, which was carefully excavated with a needle, the tip appears to be distinctly rounded; in [180] fig. 7 a distinct but somewhat incipient hook is observed; in [944] fig. 8 the hook is more pronounced; and in [948] fig. 9 a much stronger hook is seen. The last two are detached tips unconnected with any axis-ring, but showing an angle of geniculation of about 60°.

Summarizing from the above-quoted specimens, the characters of the thorax may be described as follows:—

Thorax.—Number of segments unknown.

A x i s.—Very convex; anterior segments plain, or provided with a central tubercle; median and posterior segments all (?) provided with strong cylindrical spines, directed vertically upwards; articulating surface marked off from the body of the ring by a decided transverse hollow. At each side of the axis there is a small cushion-shaped thickening, perhaps serving to strengthen the attachment to the pleura.

Pleura.—Standing out nearly at right angles to the axial line; horizontal for a distance subequal to the transverse diameter of the axis; then suddenly geniculated and bent downwards at an angle of 60° to 65°; the bent portion is subequal in length to the horizontal portion, and slightly convex outwards; the extremities are rounded or armed with incipient hooks, which, possibly, become more pronounced posteriorly. The surface of each pleura is provided with a front and a back rib, with a furrow between them: the back rib is marginal throughout; the front rib is marginal to the geniculation, from which point it bends a little backwards, leaving a narrow facet in front of it, and causing the furrow to contract in width, until it disappears at a distance from the extremity equal to about the width of the pleura; where a hook is present, it is formed of a continuation of this front rib carried backwards.

Surface.—Smooth or very finely granular, with a slightly coarser granulation at the extremities.

A fragment [274] of a pygidium (Pl. IV, fig. 5) may be referred to this species with a high degree of probability. The surface characters agree with those above described; the sides and posterior margin are bent down at a steep angle; the general form is very like that of the pygidium figured by Walcott[1] as associated with the head-shields which he refers to *Agraulos strenuus*, var. *nasutus*. The one doubtful point is the flattened upper surface of the axis, which does not exhibit the high convexity of the glabella and thoracic segments.

Pygidium.—The following is the description of the associated pygidium referred with very little hesitation to this species.

General form.—Trapezoidal; wider behind than in front.

Axis.—Convex; somewhat flattened in the middle; reaching the posterior end of the shield; with no divisions except that marking off the articulating surface, which projects a little beyond the general line of the anterior border.

Side-lobes.—Subtriangular; not confluent behind the axis; front border standing out at right angles to the axis for one-third of its length and then bent suddenly backwards and slightly downwards to meet the posterior margin at a rounded angle; posterior margin almost straight and bent down vertically. In the view from behind, this hanging portion is seen to arch suddenly upwards as it approaches the axial line.

The surface of the side-lobe slopes almost uniformly backwards and outwards from the inner anterior angle, and is marked by

[1] 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) p. 653 & pl. xcvii, figs. 1, 1 *a–c*.

one short depression near the same angle, representing a marginal groove. There is no trace of any spine or tubercle.

This pygidium differs from that figured by Walcott in the absence of any division of the axis, and in the fact that the side-lobes are not connected together behind the axis.

The cranidia which I have referred to this species differ in several particulars from the characters shown in Dr. Walcott's figures[1] of his variety of *Agraulos strenuus*, Bill.

	Agraulos strenuus, var. *nasutus*, from Walcott's figures.	*Agraulos (Strenuella) salopiensis.*
Width at anterior facial suture	considerably less than width across eye-lobes.	slightly less than width across eye-lobes.
Width at posterior facial suture	considerably more than width across eye-lobes.	not exceeding width across eye-lobes.
Nuchal spine	broad and stout.	strong, but elongate and slender.
Glabellar furrows......	distinct.	almost obliterated.
Occipital furrow	distinct.	almost obliterated.
Axial furrow	distinct.	obsolete.
Eye-lobe	nearly half the length of the head-shield, omitting the spine.	about one-third the length of the head-shield, omitting the spine.

From *Agraulos (Strenuella?) halliana*, Matthew, the differences of the Shropshire species are more marked. *A. (Str.) halliana* has the cheek-lobes 'connected in front of the glabella,' the frontal margin is only a little raised, the fixed cheeks have a steep slope to the axial furrow,[2] the 'tubercular process' (geniculation) of the postero-lateral margin appears to be at a less distance out from the glabella, and the eye-lobe is 'short and not prominent.'

From *Anomocare*, as figured by Angelin,[3] there are numerous differences. In all the seven species the fixed cheeks are decidedly narrow. *A. læve*, Ang., is perhaps nearest to the Shropshire species in the convexity of the axis and course of the facial suture, but the glabella, front margin, occipital ring, and free cheeks are all very different.

Locality and horizon.—Comley, from the upper part of the grey limestone of the excavation, 200 yards south of the quarry.

[1] 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) pl. xcvii, figs. 2, 2*a–c*.
[2] Mr. Matthew's figures appear to have been drawn from internal casts.
[3] 'Palæont. Scan.' 1854, pl. xviii.

Anomocare, Angelin.

Mr. Philip Lake, who very kindly examined many of my specimens from Comley, suggested to me that certain of the forms belonged to Angelin's genus.

The evidence supplied by the fragments next to be described is too scanty to enable me to be certain whether they should be placed in this genus or with the preceding *Agraulos (Strenuella)*. The fragmentary pygidium [173] (Pl. V, fig. 6) is so much mutilated that it is impossible to say whether it had or had not an extended flat border similar to those figured by K. A. Grönwall as belonging to *A. excavatum*, Ang., and *A. læve*, Ang.[1]

Anomocare platycephalum, sp. nov. (Pl. V & ? Pl. IV, fig. 10.)

E. S. Cobbold, *Anomocare*, sp. 1 & sp. 2, Rep. Brit. Assoc. 1908 (Dublin) 1909, p. 236.

This species is associated in the same rock with *Agraulos (Strenuella) salopiensis*, and appears to be equally plentiful; but, owing to the greater flatness of the head-shields, it is perhaps more easily collected, and I have about twelve nearly complete cranidia, as well as a large number of fragments.

This comparative flatness of the heads has suggested the specific name.

Cranidium: Size.—Length varying from 4 to 8 millimetres.

General form.—Subquadrangular, with broadly rounded front.

General convexity.—About $\frac{1}{5}$; while the convexity is not inconsiderable, there is an absence of relief in the separate features which gives an idea of flat-headedness to this species.

Glabella.—Convex; almost parallel-sided; apex rounded semicircularly; strongly impressed at the sides by three pairs of glabellar furrows which are wide and ill-defined. The posterior furrows are always, the median frequently and the anterior sometimes, inclined backwards, and they all penetrate into the glabella for a third or more of its width, and in so doing constrict the median portion, giving it a somewhat carinate appearance. The inner ends of the posterior pairs are often wider than the outer, as though the furrow had been impressed first in one direction and then in another. In one specimen [142] the furrows are much widened, and their outlines blurred (Pl. V, fig. 2).

Occipital furrow.—Strongly impressed at the sides, but hardly traceable across the median third, where it seems partly invaded by a thickening of the occipital ring.

Occipital ring.—Expanded in the middle, both forwards and backwards; the surface is but slightly convex longitudinally and inclined backwards; in some instances, there is a slight depression across the centre parallel to the lower border. Occasionally, a very minute tubercle is visible (with a strong lens) on the axial line.

[1] 'Bornholms *Paradoxides*lag og deres Fauna' Danmarks Geol. Undersög. ser. 2, no. 13 (1902) pp. 140, 141 & pl. iv, figs. 6, 8, 9.

Axial furrow.—Practically obsolete. The glabella is well-defined from the cheeks by the change of vertical curvature, but is less distinctly marked off from the frontal limb.

Fixed cheek.—Highest near the glabella; sloping down in a uniform curve to the eye-lobes and to the front; extending anteriorly beyond the ocular ridge and merging into the frontal limb; posterior limit marked by a rather steep downward curve.

Eye-lobe.—From a quarter to a third of the length of the head-shield; situated opposite the middle of the length of the glabella and occipital segment combined; distance from the glabella equal to the diameter of the latter; not raised at the outer edge.

Ocular ridge.—Beginning near the glabella in advance of the anterior glabellar furrow, and curving outwards and backwards to the eye-lobe.

Frontal limb.—Sloping at a very gentle curve downwards all the way; having usually (but not always) a wide, slightly thickened marginal rim, the surface of which has a slightly increased slope downwards and a delicately raised inner border.

Postero-lateral limb.—Consisting of a groove, widening outwards; and a raised border, with a geniculation at a distance outwards rather less than half the width of the glabella.

Facial suture.—Owing to the bending down of the sides of the cranidium, it is a little difficult to make out the exact form and position of the suture as viewed from above.

The anterior branch runs more or less directly forward from the eye, curves round rapidly inwards to meet the front margin, and is never farther out than the eye-lobe.

The posterior branch seems to vary slightly; it follows a sigmoidal course from the eye-lobe to the posterior angle of the cranidium, which is well rounded and usually rather farther out than the eye-lobe itself.

Test.—To the unaided eye the surface is almost smooth, but under a strong lens it proves to be finely granular, and, in one instance at least [144], a number of minute tubercles are to be seen. On the extreme front edge of the same specimen, the granular surface is seen to merge into one of fine raised lines subparallel to the border.

Owing to the mixture in the rock of the free cheeks and fragments of thoracic segments of this species with those of *Agraulos (Strenuella) salopiensis*, the correlations given below are somewhat inferential.

Free cheek.—There are several examples in my collection of the remarkable free cheek represented in Pl. V, fig. 8. The facial suture in the specimen [163] seems to be partly preserved, but the eye, which was considerably elevated above the plane area, is broken away.

The plane area is small, and the genal angle is produced into a very long and delicate spine of oval section, and stands out away from the head-shield at an angle of 30° to 40° with the axis.

The plane area exhibits a finely granular surface, comparable with that of the cranidia; this character continues into the base of the spine, and then merges into a series of irregular raised lines, much like those on the front margin of the cranidium [144]. I have attempted to express these characters in the enlargements (Pl. V, fig. 8).

A second form of free cheek [169] (Pl. IV, fig. 10) from the same rock exhibits a modification, which may indicate a different species: in this the spine is circular in section and much stronger; but I have other specimens somewhat intermediate between the two, and, so far as the evidence goes, it would seem that the setting of the spine and its sectional form are liable to variation.

Although the free cheek of this species remains somewhat doubtful, I have little hesitation in assigning the pleuræ, etc. [specimens 180 *a*, 178, 915] to it.

The keys to the discrimination between the thoracic segments of the *Strenuella* and the *Anomocare* are:—(i) the nature of the surface; (ii) the position and angle of the geniculation; and (iii) the curvature of the convexity of the axis.

Thorax.—Number of segments unknown.

Axis.—Transverse convexity less than a semicircle; articulating surface marked off from the body of the ring by a distinct transverse hollow or groove; body of the ring somewhat narrowed in the middle, by the advance of the groove from the front, and by a sinuosity of the posterior margin: there is a slight cushion-like thickening on each side at the point of attachment of the pleuræ.

Pleura.—Somewhat wider in the middle than at the axis; nearly square with the axial line throughout; horizontal for a distance about equal to half the diameter of the axis, then strongly geniculate and bent down at an angle of about 45°; the bent portion somewhat curved, convex outwards, and about a quarter as long again as the horizontal part; front rib low near the axis, marginal to the geniculation, whence it bends backward towards and beyond the centre of the pleura, leaving a wide facet in front of it; back rib low and wide near the axis, and remaining marginal throughout.

The groove between the ribs is wide and shallow near the axis, deepest at the geniculation, narrowing rapidly beyond it to die out near the extremity, which is broadly rounded.

Surface.—Finely granular.

Pygidium.—I have one fragment of a pygidium [173], with a finely granular surface, that appears to belong to this species.

Axis.—Wide; consisting of an articulating surface, two annulations and a longer terminal portion; the upper surfaces of the annulations are broken away in a manner suggestive of their having borne wide-based spines directed backwards.

Side-lobe.—Consisting of a horizontal extension with a width equal to about a quarter of that of the axis; beyond this the form is entirely lost, but there are two depressions on the broken edge, which have the appearance of being the bases of two marginal spines or processes directed backwards.

Pygidial spines (?).—Two specimens of spines [178, 873] (Pl. V, figs. 7 & 9) may possibly belong to the pygidium of this species, although they are somewhat too large to fit the individual pygidium figured.

Each consists of an elongate cylindrical spine with a swollen bisymmetrical base, which is rounded above but flattened or perhaps even hollowed below. Beyond the base there is a constriction or furrow separating it from an annulation, which looks like an articulating surface, but the front edge is, in both specimens, broken and shows no margin. The surface-characters are identical with those of the free cheek [163] previously described (see Pl. V, fig. 8), being finely granular on the base, in this respect matching the pygidium figured (Pl. V, fig. 6), and graduating to a system of raised lines on the spine itself. They would appear to have projected upwards and backwards, and to have been bent more decidedly backwards at a little distance above the axis.

Associated as they are with fragments of both the *Strenuella* and the *Anomocare*, it is possible that they might belong to either genus; but the swollen base and constriction are very different from the bases of both the nuchal and the thoracic spines of the former, and the surface-characters point strongly to a reference to the same species as the free cheek [163], the characters of which again match with those of the cranidium [144] (not figured) that is referred to the *Anomocare*.

The general form of these spines is very like that of the detached 'horizontal spines' figured by the late Dr. F. Schmidt as belonging to his *Olenellus (Mesonacis) mickwitzi*.[1]

Locality and horizon.—Comley, from the upper part of the grey limestone of the excavation, 200 yards south of the quarry.

ANOMOCARE PARVUM, sp. nov. (Pl. IV, figs. 11–14.)

E. S. Cobbold, *Anomocare* sp. 3, Rep. Brit. Assoc. 1908 (Dublin) 1909, p. 236.

A minute form nearly related to *A. platycephalum*, but which seems to be specifically distinct, is found in considerable numbers in the same rock.

In general form, in convexity, and in surface-characters these cranidia have so strong a likeness to *A. platycephalum*, that it is unnecessary here to do more than indicate the differences.

The glabella is, proportionately, rather more strongly convex and somewhat less wide. The frontal limb has no thickened rim; it stands out almost horizontally from the end of the glabella, and its anterior edge is slightly upturned.

The glabellar furrows are more distinctly impressed, narrower and more uniformly transverse; and, in some instances, a

[1] 'Ueber eine neuentdeckte Untercambrische Fauna in Estland' Mem. Acad. Imp. Sci. St. Petersb. ser. 7, vol. xxxvi (1888) no. 2, pl. i, figs. 23 & 24.

fourth pair is indicated at the sides of the glabella in advance of the ocular ridge (see Pl. IV, fig. 11). The geniculation of the posterior border is proportionately farther out.

Forms referable to *A. platycephalum* have been recognized, ranging down to 4 millimetres in length of head-shield; those of *A. parvum* vary from 2·3 to 4 millimetres, but have not been found larger. It would therefore appear to be a much smaller species. Narrow and wide forms [143 & 275] of this species are illustrated by the two figures (Pl. IV, figs. 11 & 12).

The thoracic segment [172] (fig. 14) and fragmentary free cheek [177] (fig. 13) may possibly belong to this species.

Locality and horizon.—The same as in the case of *Anomocare platycephalum*.

Anomocare (?) pustulatum, sp. nov. (Pl. VI, figs. 1, 2, & 3.)

E. S. Cobbold, *Anomocare* vel *Agraulos* sp., Rep. Brit. Assoc. 1908 (Dublin) 1909, p. 237.

Portions of six or seven head-shields and some thoracic fragments from various exposures in the Quarry Ridge, Comley, indicate a species with a very pustulate test. Of these, two of the larger cranidia [186, 188] and one axis ring [196] are selected for illustration.

Cranidium: Size—moderate,[1] 11 to 12 millimetres in length.

General form.—Subquadrangular, with rounded front; proportion of length to width = 3 : 4; widest across the eyes.

General convexity.—Considerable, about $\frac{1}{5}$; the features are in very strong relief.

Glabella.—Convex; parallel-sided; truncately rounded at the apex; having four pairs of furrows well marked at the sides, but not continuous across; the posterior pair inclined backwards, the others transverse; the anterior pair only just visible at the sides.

Occipital furrow.—Wide and deep; continuous across.

Occipital ring.—Strong; subequal in the middle to the length of the glabellar lobes, but shorter at the sides; projecting backwards beyond the general posterior margin of the shield; without spine or tubercle.

Axial furrow.—Wide and deep; not continuous round the apex of the glabella, where its place is taken by the hollow part of the frontal limb.

Fixed cheek.—Nearly equal in width to the glabella; somewhat quadrangular in outline; most elevated at about three-quarters of its width out from the glabella; in transverse section the surface rises slightly from the axial furrow, is then nearly horizontal to the highest point, from which it falls steeply down to a wide hollow parallel with the eye-lobe; this hollow is partly filled up by a buttress between the eye-lobe and the tumidity of the cheek (this is indicated by a change in intensity of the shading in the figures of both the internal and the external casts); the cheek

[1] Since the above description was written, specimens referred to this species have been found, ranging from 3 to 16 millimetres in length.

is limited posteriorly by the steep fall of the surface to the postero-lateral limb, and anteriorly the surface falls gradually, in advance of the ocular ridge, into the hollow part of the frontal limb.

Eye-lobe.—One-third of the length of the head; the posterior end reaching to the postero-lateral limb; the anterior end marked by a rather sudden falling-away in altitude where it joins the ocular ridge; distinctly elevated throughout above the hollow in its rear, but not so high as the fixed cheek.

Ocular ridge.—A ridge, rounded rather than flat; arising from the axial furrow nearly as far forward as the little impressions representing the anterior pair of glabellar furrows; passing across the cheek in a bold curve to the eye-lobe, and having a slight hollow (not an impressed line or furrow) behind it.

Postero-lateral limb.—Marked by a wide groove passing directly outwards, and a convex marginal rim, which is strongly geniculate at a distance out nearly equal to the width of the glabella; beyond the geniculation the surface of the limb falls steeply down to the facial suture.

Frontal limb.—About a fifth of the total length of the head-shield; consisting of a deep hollow and an equally wide and very convex rostral margin. These features lose intensity to right and left, and at the same time the limb curves downwards considerably.

Facial suture.—Hardly visible from above, owing to the curving over of the sides of the cranidium; anterior branch short and subparallel to the axial line; posterior branch a short curve, convex outwards; both branches less far out than the eye-lobe.

Test.—Probably rather thick and firm, but usually found weathered to a snowy-white powdery substance. The external cast [188] (Pl. VI, fig. 2) shows that it was covered nearly all over with closely set pustules or pustular spinelets (I have been unable to make a clear wax impression of these, but the holes in the cast appear to be pointed). These pustules have no corresponding impressions on the interior, and the internal cast [186] is consequently quite smooth (Pl. VI, fig. 1). The marginal modification is unknown.

Thorax.—Associated with these cranidia are a number of fragments of thoracic segments, some of which exhibit very similar surface-characters. One of these, an axis ring [196], is represented in Pl. VI, fig. 3, and is, with reserve, referred to the species under description. The crust is partly weathered away, but enough is left to show the bases of the pustules which covered the convex body of the axis; the front articulating portion is quite smooth, and in the groove the pustules are smaller.

A beautiful little upright spine stands on the centre of the ring; when found it was complete, now the point is unfortunately gone: it was quite smooth.

The pleuræ have not been sufficiently studied for description.

Locality and horizon.—Comley, from the French grey and lower part of the grey limestones of the excavation, 200 yards south of the quarry, and from the quarry itself; also from blocks of limestone found in the overlying conglomeratic bed. It is always associated with fragments showing the reticulate pattern characteristic of *Olenellus*, but has not yet been found in the red, *Olenellus* Limestone.

There is a general similarity between the cranidium of this species from Comley, as seen from above, with that of Dr. Walcott's *Solenopleura (?) howleyi*, as figured by him.[1] He describes the surface as being 'strongly granular or pustulose'; but, unfortunately, he gives no indication of the longitudinal curvature of the glabella, and the comparison cannot be carried further without seeing the specimens themselves. Mr. Matthew claims *S. (?) howleyi* as a *Protolenus*.[2] With these facts before me, I think it well to make the generic reference of the Comley form with reserve.

Protolenus, Matthew.

G. F. Matthew, Bull. Nat. Hist. Soc. New Brunswick, no. 10 (1892) p. 34; Trans. Roy. Soc. Can. vol. xi, sect. iv (1893) p. 100; and Trans. N.Y. Acad. Sci. vol. xiv (1895) p. 144.

Protolenus latouchei, sp. nov. (Pl. VII, figs. 1–6.)

E. S. Cobbold, *Protolenus* sp., Rep. Brit. Assoc. 1908 (Dublin) 1909, p. 236.

This species is founded upon fragments of more than thirty head-shields derived from a few pounds' weight of the uppermost band of the grey limestone of Comley. The specific name is given in remembrance of the late Rev. J. D. La Touche, of Stokesay, whose friendship and kindly help were so long enjoyed by all students of Shropshire geology, and not least by myself.

Cranidium: Size—moderate; length = from 7 to 8 millimetres.

General form.—Semielliptical: proportion of length to width = about 5 : 6.

Convexity.—Well marked; about $\frac{1}{6}$.

Glabella.—Strongly convex; distinct from the occipital ring; tapering somewhat forwards to the well-rounded extremity; about three-quarters of the total length of the head-shield; furnished with three pairs of furrows, the anterior pair very short, the two posterior pairs of medium length, directed somewhat backwards and occasionally traceable, on the cast of the interior, quite across; greatest elevation equally at the anterior and posterior lobes.

Occipital furrow.—Entire; somewhat sinuous; sharply impressed, especially on the internal cast.

Occipital ring.—Exceeding in length the posterior lobe of the glabella in the middle, but less than half of this length at the sides.

Axial furrows.—Wide and deep between the fixed cheeks and the glabella, but not marked by any impressed line.

[1] 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) p. 657 & pl. xcvii, figs. 7–7 *a*. In the explanation of this plate the names *howleyi* and *harveyi* have been transposed.

[2] Trans. Roy. Soc. Can. vol. xi, sect. iv (1893) p. 102.

Fixed cheeks.—About equal in width to the glabella; nearly flat for half their width, but curving steeply down to a wide furrow, from which the surface rises again to the prominent eye-lobe.

Eye-lobe.—Moderate in size (about half as long again as a glabellar lobe); situated opposite the posterior pair of glabellar furrows; almost reaching to the posterior border.

Ocular ridge.—Commencing by a somewhat prominent rounded boss (almost a tubercle) situated close to the axial furrow and a little forward of the anterior glabellar lobe; curving outwards and backwards, the ridge rapidly loses prominence, and is only just traceable across the forward swelling of the cheek to the eye-lobe.

Postero-lateral limb.—Rather narrow; consisting of a wide furrow and a somewhat sinuous raised rim, geniculated at about three-quarters of the way out; bending down steeply to the facial suture.

Frontal limb.—Distinct from the glabella, but continuous with the cheeks; falling away with a gentle convex curvature to the marginal rim; bent down decidedly towards the sides; faint indications of radiate markings on the internal cast. The marginal rim is somewhat convex, but not recurved, and of uniform width from suture to suture.

Facial suture [524] (Pl. VII, fig. 5).—Anterior branch short and direct from the eye-lobe to the depressed border; posterior branch curving outwards and backwards to cut the posterior margin behind the eye-lobe.

Test.—Covered with closely set tubercles, which are larger on the elevated parts and sometimes hardly discernible in the hollows of the shield. On the glabella they are specially large, and more or less confluent. On the interior the tubercles are represented by little pits, which on the internal cast show as tubercles rather smaller in size than on the exterior. On the marginal rim the tubercles are replaced by elongated narrow ridges, arranged in a reticulate manner (Pl. VII, fig. 6 *b*).

Two detached free cheeks [438, 549] have been found intimately associated with the fragments of these cranidia. One of these has a portion of the test preserved, which shows characters similar to those above described. Both specimens also resemble the head-shields in the special method of preservation of the test, and I have no hesitation in assigning them to this species.

Free Cheek.—Narrow and small, with a deep pit behind the eye; the genal angle is extended backwards into a strong spine of circular section and of great comparative length.

Thorax and Pygidium unknown.

A few thoracic segments are preserved in the same rock, but are not sufficiently good to warrant description.

Locality and horizon.—Comley; from the uppermost band of the grey limestone at the excavation, 200 yards south of the quarry.

PROTOLENUS MORPHEUS, sp. nov. (Pl. VII, fig. 7.)

A distinct species, but closely allied to the one previously described, appears to be indicated by a nearly complete head-shield [566] and several fragments, from the same bed of rock. It differs principally in the glabella, but there are minor points which combine to give a decidedly different aspect to the head-shield.

CRANIDIUM: Size.—Rather smaller than the average of *Protolenus latouchei*; length = about 5 millimetres.

General form.—Semi-elliptical, but less elongate than *Pr. latouchei*; proportion of length to width = about 4 : 6.

General convexity.—About $\frac{1}{6}$.

Glabella.—Strongly convex; parallel-sided, with a well-rounded extremity; less distinctly marked off from the frontal limb than in *Pr. latouchei*, but having a similar greatest elevation in the anterior and posterior lobes; furrows deeply impressed at the sides and continuous across, straight and not inclined backwards.

Occipital furrow and ring.—Unknown.

Axial furrow.—Distinct, but less wide than in *Pr. latouchei*; sinking deeply (almost to a pit) forward of the ocular ridge.

Fixed cheek.—As in *Pr. latouchei*, but rather more tumid.

Ocular ridge.—Rather more strongly marked than in *Pr. latouchei*, and giving, in conjunction with the swollen ('puffy') cheeks, a somnolent expression to the head.

Postero-lateral limb.—Unknown.

Frontal limb and facial suture.—Apparently similar to *Protolenus latouchei*.

Marginal rim and eye-lobe.—Unknown.

The test of this species has the same superficial characters as that of *Pr. latouchei*; but possibly it was stronger, for, so far as known, it is always in a better state of preservation. In this respect it recalls the test of *Microdiscus comleyensis*, sp. nov., from the same bed of rock, notwithstanding that this latter is punctate instead of tuberculous.

Locality and horizon.—The same as those of *Pr. latouchei.*

I am indebted to Mr. Lake for pointing out to me that these species belong to Mr. Matthew's genus. They differ considerably from his three described species; the Comley forms seem to have comparatively short eye-lobes, the free cheeks figured have a relatively smaller area and a much longer spine, and the frontal limb is more extended.

Mohicana, gen. nov.

Intimately associated with the specimens of *Protolenus* and *Microdiscus comleyensis*, and apparently confined to the same 3-inch bed of grey limestone, fragments of rather larger trilobites occur, having characters very similar to those of *Micmacca (?) plana*, Matthew, which species Mr. G. F. Matthew only referred provisionally [1] to his genus.

[1] Trans. N.Y. Acad. Sci. vol. xiv (1895) p. 143 & pl. xi, figs. 2 *a*–2 *b*.

The evidence available for description is meagre, and the following is necessarily an incomplete diagnosis.

Cephalon.—Semi-oval, moderately convex, features in slight relief. Glabella, proportionately long and wide, outlined by a decided but not deep axial furrow. Glabellar furrows slightly impressed or wanting. Occipital furrow complete, wide and shallow. Occipital ring plain, or produced to a spine. Fixed cheeks wide, gently and evenly convex, continuous with the frontal limb. Eye-lobe long, distant from the glabella, low in elevation, not raised at the edge. Ocular ridge slight or wanting. Postero-lateral limb geniculated about half way out. Facial suture short and direct, both forwards and backwards. Anterior margin with narrow indistinct fold, or none. Free cheek small, pointed, or spined.

Thorax and pygidium.—Unknown.

Mohicana lata, sp. nov. (Pl. VI, fig. 4.)

Only one specimen [578] is confidently referred to this form at the present time.

Cranidium: Size—moderate; length = about 13 millimetres.

General form.—Semi-elliptical, approaching semicircular; proportion of length to width = about 4 : 5.

General convexity.—Moderate; but, owing to the very slight relief of the features, there is an appearance of flatness. Speaking generally, there is one uninterrupted sweeping curve from the front and sides to the top of the glabella.

Glabella.—Wide and flattened; parallel-sided, with rounded apex; distinct from the occipital ring; no transverse furrows seen.

Occipital furrows.—Wide, shallow, and entire.

Occipital ring.—A plain band with curved margin; as wide as the glabella; no spine or tubercle.

Axial furrow.—Wide and shallow; continuous round the apex of the glabella.

Fixed cheeks.—Narrower than the glabella; gently convex; most elevated close to the glabella; continuous with the frontal limb; falling rather steeply to the eye-lobe, which stands away from it horizontally.

Eye-lobe.—Half as long as the glabella; almost reaching the postero-lateral furrow; situated at a low level on the head-shield; horizontal in transverse section. The specimen figured [578] has now lost the eye-lobe, but it is still to be seen in the external cast, from which, and from an earlier drawing, it has been reproduced in the enlargement.

Ocular ridge.—None seen.

Posterior border.—A more or less triangular area with a wide groove next the cheek, and a raised and rounded rim at the margin, geniculated about half way out.

Frontal limb.—Gently convex downwards; no marginal rim is preserved in the specimen.

Facial suture.—Not actually seen; there is no room, however, for anything but a fairly direct and short branch forwards, and the posterior branch would seem to have been likewise short and direct.

Test.—A small portion of the test is still visible in the right-hand corner of the specimen; it is almost smooth (? worn), with very slight indications of punctæ.

Locality and horizon.—Comley; from the uppermost band of the grey limestone at the excavation, 200 yards south of the quarry.

Mohicana clavata, sp. nov. (Pl. VI, figs. 5–9.)

Several fragments of this allied species have been found; the most complete of these [586, 582, 584] are figured in Pl. VI.

Cranidium: Size—moderate; length = from 8 to 12 millimetres.

General form.—Doubtful.

General convexity.—Moderate; about the same as in *Mohicana lata*, but with more relief of the features.

Glabella.—Moderately convex; slightly clavate; length, about three-fifths of the head-shield; width doubtful; distinct from the occipital ring; slight indications of two transverse furrows on the posterior half of the glabella, not visible at the sides; apex rounded; greatest elevation a little behind the middle of the length.

Occipital furrow.—Entire; wide and shallow.

Occipital ring.—A plain band, slightly wider than the base of the glabella.

Axial furrows.—Shallow, but sharply impressed; slightly sinuous; well marked round the apex of the glabella.

Fixed cheeks.—Wide (?); gently and evenly convex; most elevated close to the glabella, and falling away in a fairly even convex curve to the frontal limb and to the eye-lobe which stands away horizontally.

Eye-lobe.—Fairly large, distant from the glabella, not reaching the posterior border; situated opposite the middle of the head-shield; slightly rounded transversely; with an impressed line inside it; not raised at its outer edge.

Ocular ridge.—Just visible as a raised fillet across the cheek; continuous from the eye-lobe to the axial furrow.

Postero-lateral limb.—Marked by a wide furrow; somewhat curved, with the curvature convex backwards, and margined by a raised rounded rim, which is strongly geniculated about half way out.

Frontal limb.—Gently convex; continuous with the cheeks; marginal rim not seen in any of the specimens.

Facial suture.—Not seen.

Test.—Under a strong lens the surface is seen to be beautifully marked all over by closely-set minute punctæ or pits, which have no corresponding processes on the interior. It is estimated that there are as many as 150 to 200 to the square millimetre, and that the interspaces are about one and a half times as wide as the diameters of the punctæ. These interspaces have a continuous level surface, and answer to Dr. Walcott's description and figure of the corresponding feature in his *Avalonia manuelensis*—'inosculating raised lines giving the appearance of pits'.[1]

Free cheek.—One fragment [584] of a free cheek presenting the same surface-characters has been noticed. It may be described as spherically triangular; small; and having the genal angle produced to a short spine, which is oval in cross-section. I have attempted to show in Pl. VI, fig. 8 the modification of the surface-characters as they approach the outer margin. The meshes of the network become squeezed out and elongated, until little is to be seen but a set of irregular raised lines.

Locality and horizon.—Comley; from the uppermost band of the grey limestone, at the excavation 200 yards south of the quarry.

These two species have many points of resemblance with *Micmacca (?) plana*, Matthew.[2] The large glabella 'descending gradually at the front, and bordered by a distinct, but faintly impressed dorsal furrow,' the faint occipital and glabellar furrows, the slight convexity of the cheeks, and the proportions between their width and that of the glabella, are all points in common. It seems evident that the three species are congeneric.

With *Avalonia manuelensis*, Walc., there is a striking resemblance in the characters of the test of *Mohicana clavata*; and with *Avalonia acadica*, Matthew,[3] there is a general resemblance in the view from above, but the peculiar grooves on the line of the ocular ridge are absent, and the frontal limb is more extended.

Concluding Remarks.

It would be premature to discuss at length the exact age of the beds which have yielded the trilobites here described, until the remainder of the fauna has been more fully worked out. I would, however, call attention to the fact that the specimens of *Protolenus* occur at Comley a little above the horizon of *Olenellus (Holmia) callavei*, Lapw., and below the lowest local representative of the genus *Paradoxides*. This is in entire agreement with the position assigned to the genus by Mr. G. F. Matthew, at his type locality at Hanford Brook.

It also seems of interest to note that several of the Comley forms from the *Olenellus* and the grey limestones, namely, *Microdiscus helena*, Walc., *M. speciosus*, Ford, *M. lobatus*, Hall, and *Ptychoparia (?) attleborensis*, Sh. & F. (as also *Agraulos strenuus*, Bill., which seems closely related to the Shropshire *Strenuella*), are found in America low down in the *Olenellus* Zone, the last two being quoted by Dr. Walcott[4] from the base of the *Olenellus* Zone at Manuel's Brook (Newfoundland).

[1] Proc. U.S. Nat. Mus. vol. xii (1889) p. 44; and 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) p. 646 & pl. xcv, figs. 3, 3 *a*.
[2] Trans. N.Y. Acad. Sci. vol. xiv (1895) p. 143 & pl. xi, figs. 2 *a*–2 *b*.
[3] *Ibid.* p. 140 & pl. ix, fig. 5.
[4] 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) pp. 650, 654.

I would take this opportunity of very gratefully acknowledging my indebtedness to Mr. Philip Lake, who kindly examined a great number of my specimens and advised me as to their relationships.

I am also indebted to Mr. W. Rupert Jones for very kindly supplying me with most of the references in this paper, in addition to his trouble in looking out and sending me works of reference from the Library of the Society.

EXPLANATION OF PLATES III–VIII.

[The numbers in square brackets are those attached to the individual specimens. Unless otherwise stated, all the specimens are in my collection for the Geological Excavations Committee of the British Association.]

Plate III.

[The minute figures are of the natural size, the enlargements are to 5 diameters.]

Microdiscus comleyensis, sp. nov.—Uppermost band of the grey limestones, Comley. (See p. 21.)

Figs. 1 & 2. Cephala [479, 478], exteriors.
Fig. 3. Pygidium [507], exterior.
4. Pygidium [508], showing internal cast of axis.

Ptychoparia (?) annio, sp. nov.—*Olenellus* Limestone, Comley. (See p. 24.)

Figs. 5 & 6. Cranidia [402, 403], exteriors.
Fig. 7. Cranidium [401], internal cast.
8. Cranidium; restored outline; the parts shown by broken lines are hypothetical.

Micmacca (?) parvula, sp. nov.—*Olenellus* Limestone, Comley. (See p. 30.)

Fig. 9. Cranidium [412], internal cast.
10. Cranidium [411], exterior.

Ptychoparia (?) attleborensis, Sh. & F.—*Olenellus* Limestone, Comley. (See p. 23.)

Figs. 11 & 12. Cranidia [406, 405], exteriors.
Fig. 13. Cranidium [576], internal cast.

Figs. 14, 15, & 16. *Microdiscus helena*, Walcott.—*Olenellus* Limestone, Comley. (See p. 23.)

Pygidia [385, 386, 387], test partly preserved.

Microdiscus lobatus, Hall.—Uppermost band of the grey limestone, Comley. (See p. 22.)

Fig. 17. Cephalon [453], exterior.
18. Pygidium [445], exterior.

Plate IV.

Agraulos (Strenuella) salopiensis, sp. nov. (See p. 31.)

Fig. 1. Cranidium [161]; from above, from behind, and from the right × 3, and natural size from above.
2. An anterior thoracic segment [164]; from above, from behind, and from the right × 3, and natural size from behind.
3. A median thoracic segment [162], showing base of spine; from above, from behind, and from the right × 3, and natural size from behind.
4. A smaller and, possibly, more posterior thoracic segment [176]; from behind and from the right × 3, and natural size from behind.
5. Pygidium [274], probably belonging to this species; from above, from behind, and from the right × 3, and natural size from above.

Fig. 6. Free cheek [170]: *a*, as seen flatways in the rock; *b*, as seen from the side; *c*, approximately as seen from above, when attached to the cranidium, × 3; *d*, part of spine, enlarged to 6 diameters to show surface-characters.

7. Extremity of a right pleura [180] × 3, to show the incipient hook.

8. Extremity of a left pleura [944] × 3, to show the hook more pronounced.

9. Extremity of a left pleura [948] × 3, to show the hook still more pronounced.

Fig. 10. *Anomocare* sp. (See p. 38.)

Free cheek [169], × 3; indicating either a variety of *A. platycephalum*, sp. nov. (see Pl. V), or a distinct species.

Anomocare parvum, sp. nov. (See pp. 39–40.)

Figs. 11 & 12. Cranidia [143, 275], from above, from behind, and from the right × 3; and of the natural size from above.

Fig. 13. Free cheek [177] × 3, possibly belonging to this species.

14. Thoracic segment [172], possibly belonging to this species: from above and from behind × 3; and of the natural size from behind.

[All these specimens are from the upper part of the grey limestone, Comley, immediately below the narrow band with *Protolenus*, etc.]

Plate V.

Anomocare platycephalum, sp. nov. (See pp. 36–39.)

Figs. 1, 2, & 3. Cranidia [160, 142, 911], showing variation in the inclination and distinctness of the glabellar furrows: from above, from behind, and from the right × 3; and of the natural size from above.

4 & 5. Thoracic segments [915, 180]: from above, from behind, and from the left × 3; and of the natural size from behind.

Fig. 6. Incomplete pygidium [173], referred with reserve to this species: from above, from behind, and from the left × 3; and of the natural size from above.

7. Pygidial? spine [178], referred with reserve to this species: from above and from the left × 3, and natural size from above. (The side view is, unfortunately, shaded as if lighted from the right.)

8. Free cheek [163] referred to this species: from above and from the right × 3, with enlargements to show surface-characters.

9. Pygidial? spine [873], showing bisymmetrical base: from above and from the right × 3, with enlargement of part of the spine to show the surface-characters.

[All these specimens are from the upper part of the grey limestone, Comley, immediately below the narrow band with *Protolenus*, etc.]

Plate VI.

Anomocare (?) pustulatum, sp. nov.—The French grey limestone, Comley. (See pp. 40–42.)

Fig. 1. Cranidium [186], internal cast, from a detached block in Comley Quarry: from above, from behind, and from the right × 3; and of the natural size from above.

2. Part of cranidium [188], external cast, showing casts of the pustules, × 3; from a block embedded in the *Paradoxides*-bearing conglomeratic grit, Comley.

3. Thoracic segment, axis only [196]: from behind and from above × 3, and of the natural size from behind; from the limestone *in situ*, Comley.

Mohicana lata, gen. et sp. nov.—Uppermost band of the grey limestone, Comley. (See pp. 45–46.)

Fig. 4. Cranidium [578]: from above, from behind, and from the right × 3; and of the natural size from above.

Mohicana clavata, gen. et sp. nov.—Uppermost band of the grey limestone, Comley. (See pp. 46–47.)

Fig. 5. Glabella and fixed cheek [586]: from above, from the left, and in section across the middle of the head × 3; and of the natural size from above.

6. Surface of the test of the same specimen [586], enlarged to about 10 diameters.

7. Free cheek [584] × 3 and of the natural size.

8. Surface of the test of the same specimen [584], enlarged to about 10 diameters.

9. Fixed cheek and eye-lobe [582], doubtfully referred to this species, × 3 and of the natural size.

PLATE VII.

Protolenus latouchei, sp. nov.—Uppermost band of the grey limestone, Comley. (See pp. 42–43.)

Fig. 1. Part of left free cheek and genal spine [549]; × 3 and of the natural size.

2. Cranidium [524]: from above, from behind, and from the right × 3; and of the natural size from above.

3. Right free cheek [438]; × 3 and of the natural size.

4. Part of cranidium [525], showing frontal limb: from above and from the right × 3; and of the natural size from above.

5. Right fixed cheek [524], showing eye-lobe and facial suture: from above × 3 and of the natural size.

6. Glabella, occipital ring, and frontal limb [533]: from above × 3 and of the natural size; with enlargements (*a*) of front border, and (*b*) of a glabellar lobe, to show the surface-characters.

Protolenus morpheus, sp. nov.—Uppermost band of the grey limestone, Comley. (See p. 44.)

Fig. 7. Cranidium [566]: from above, from behind, and from the right × 3; and of the natural size from above.

Micmacca (?) ellipsocephaloides, sp. nov. (see also Pl. VIII).—*Olenellus* Limestone, Comley. (See pp. 27–28.)

Fig. 8. Cranidium [413], test well preserved: from above, from behind, and from the right × 3; and of the natural size from above.

9. Cranidium [J 12905, Brit. Mus. (Nat. Hist.) Coll.], test a little weathered, and presenting a beautiful white egg-shell appearance: from above, from behind, and from the right × 3.

PLATE VIII.

Micmacca ellipsocephaloides, sp. nov. and varieties. (See pp. 27 *et seqq.*)

Fig. 1. The type form [200], test partly destroyed: from above, from behind, and from the right × 3; and of the natural size from above.

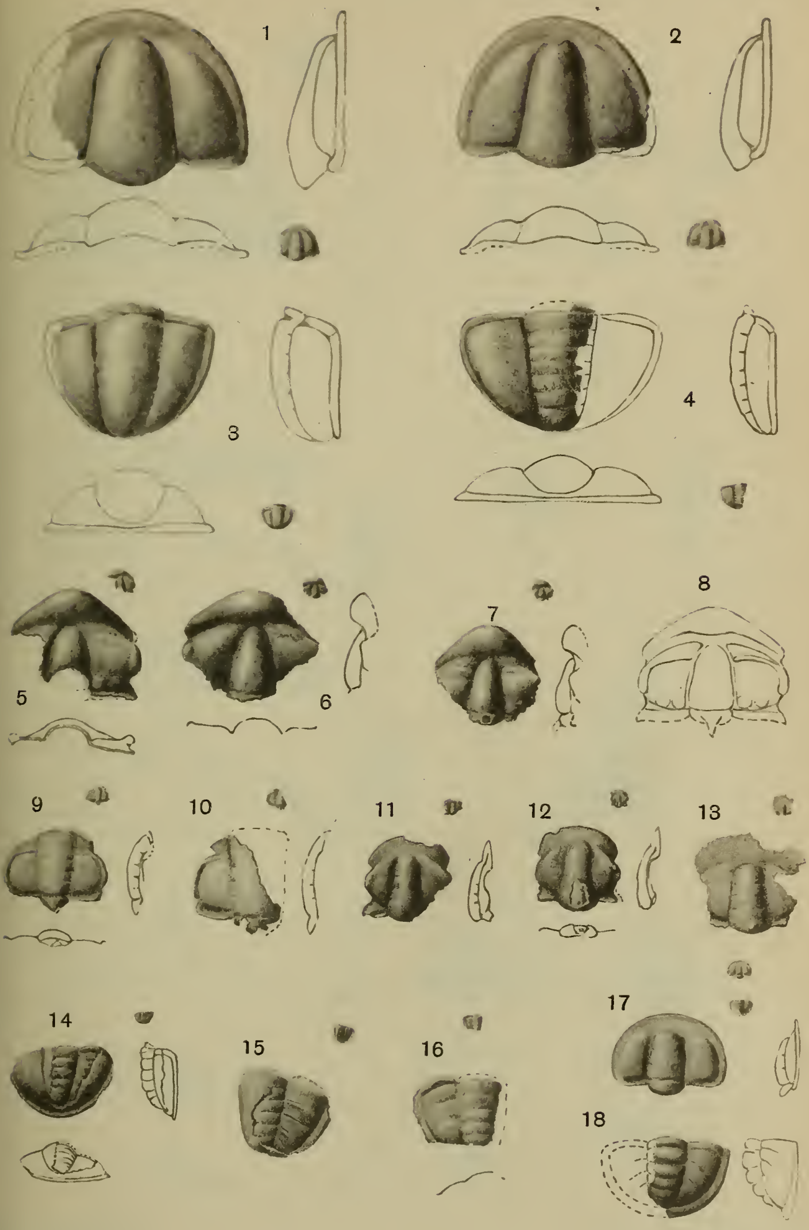
2. Var. *senior*, nov. [J 12901, Brit. Mus. Coll.], all features much thickened, facial sutures convergent forwards, divergent backwards: from above, from behind, and from the right × 3. (See p. 29.)

3. Var. *strenuelloides*, nov. [J 12902, Brit. Mus. Coll.]; frontal limb produced, facial sutures more convergent forwards and divergent backwards: from above, from behind, and from the right × 3.

4. Fixed cheek [J 12902, Brit. Mus. Coll.]: facial suture intermediate between the type and fig. 3; × 3. (See p. 29.)

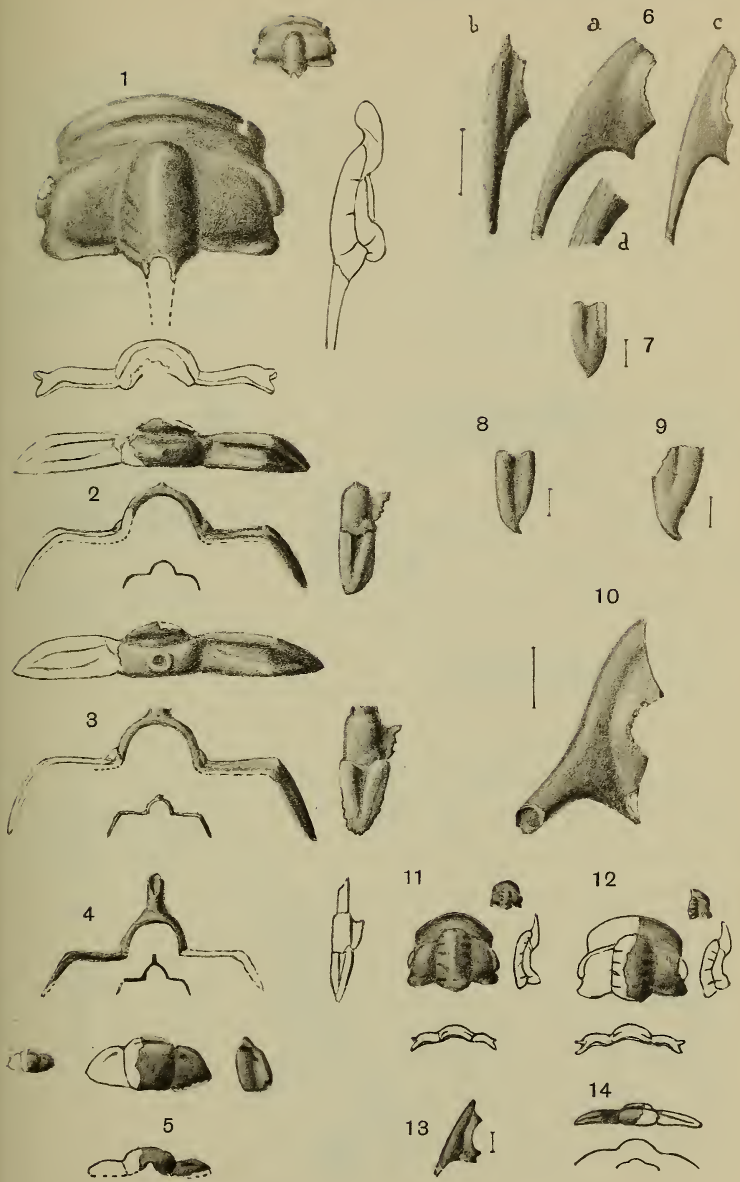
5. Var. *spinosa*, nov. [J 12900, Brit. Mus. Coll.]: frontal limb short, occipital ring produced to a short spine; × 3. (See pp. 28–29.)

6. Var. *strenuelloides*, nov. [J 12904, Brit. Mus. Coll.]: cranidium and traces of seven thoracic segments; facial sutures somewhat convergent forwards, glabella somewhat conical; from above, from the back of the head, and from the right × 3. (See p. 29.)



E. S. Cobbold, del. *Bemrose Ltd., Collo., Derby.*

CAMBRIAN TRILOBITES FROM COMLEY.



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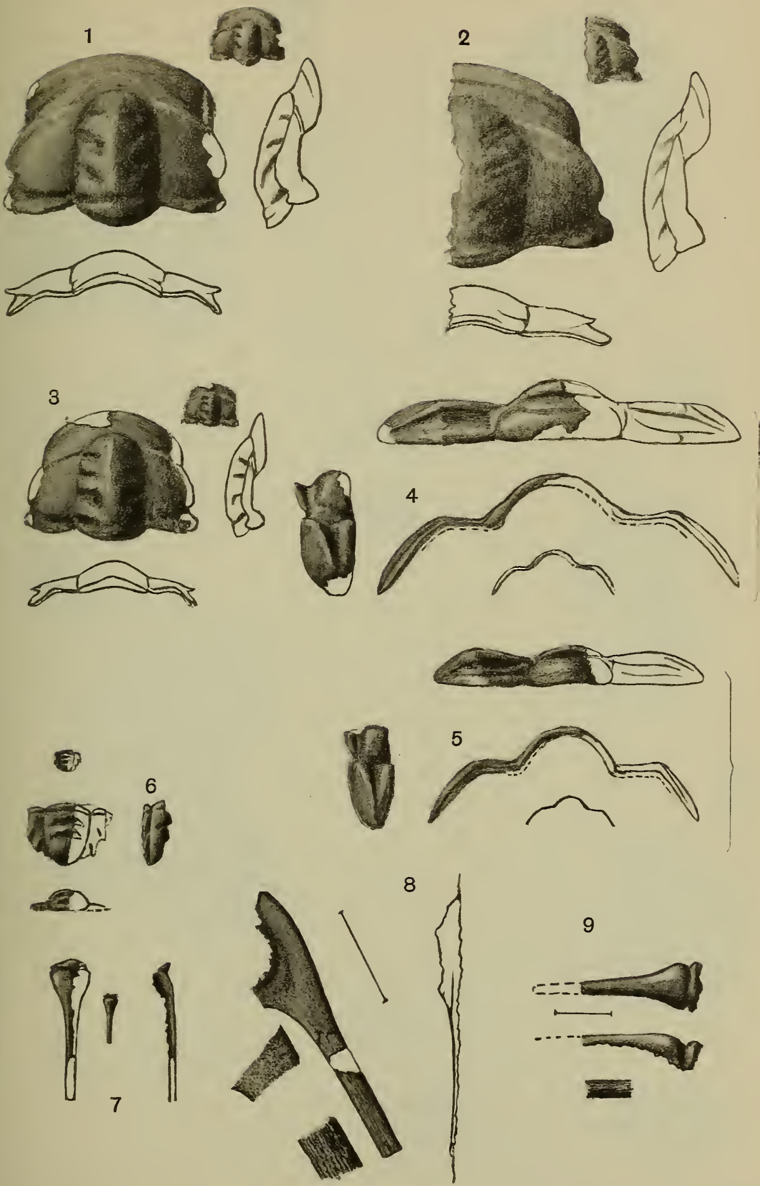
CAMBRIAN TRILOBITES FROM COMLEY.

QUART. JOURN. GEOL. SOC. VOL. LXVI, PL. V.



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Bemrose Ltd., Collo., Derby.

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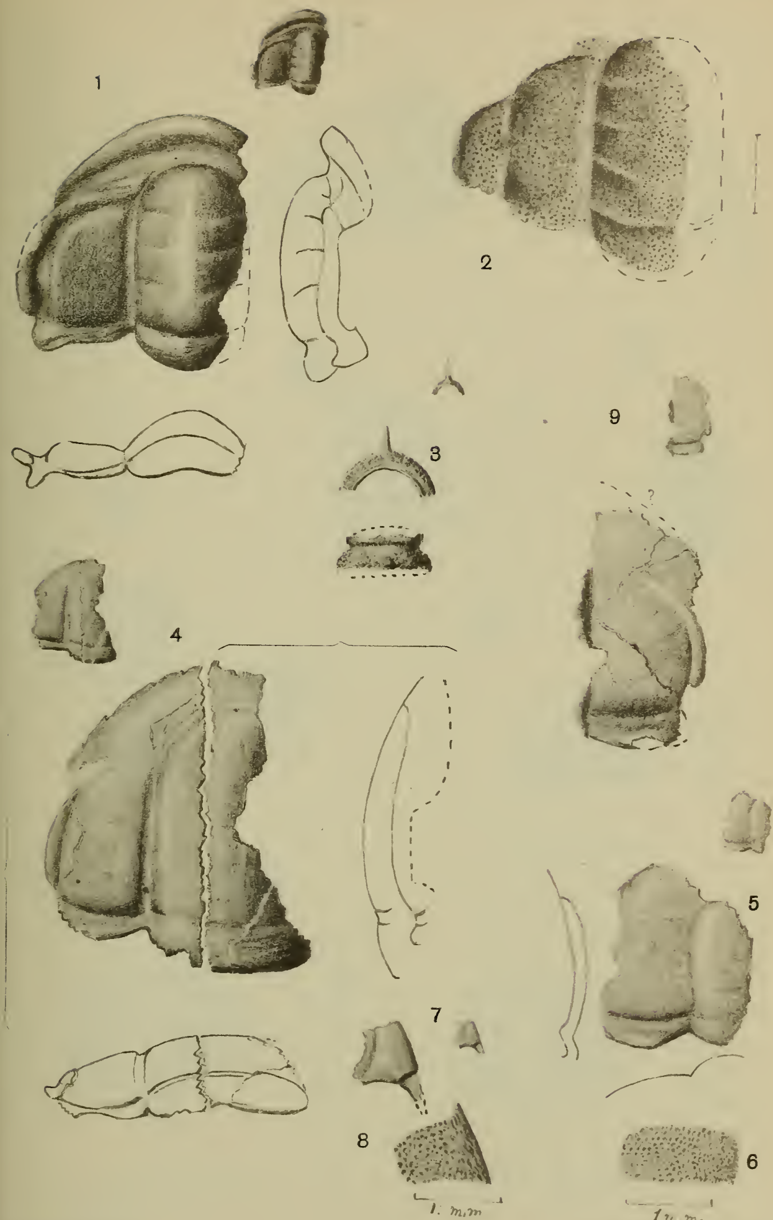

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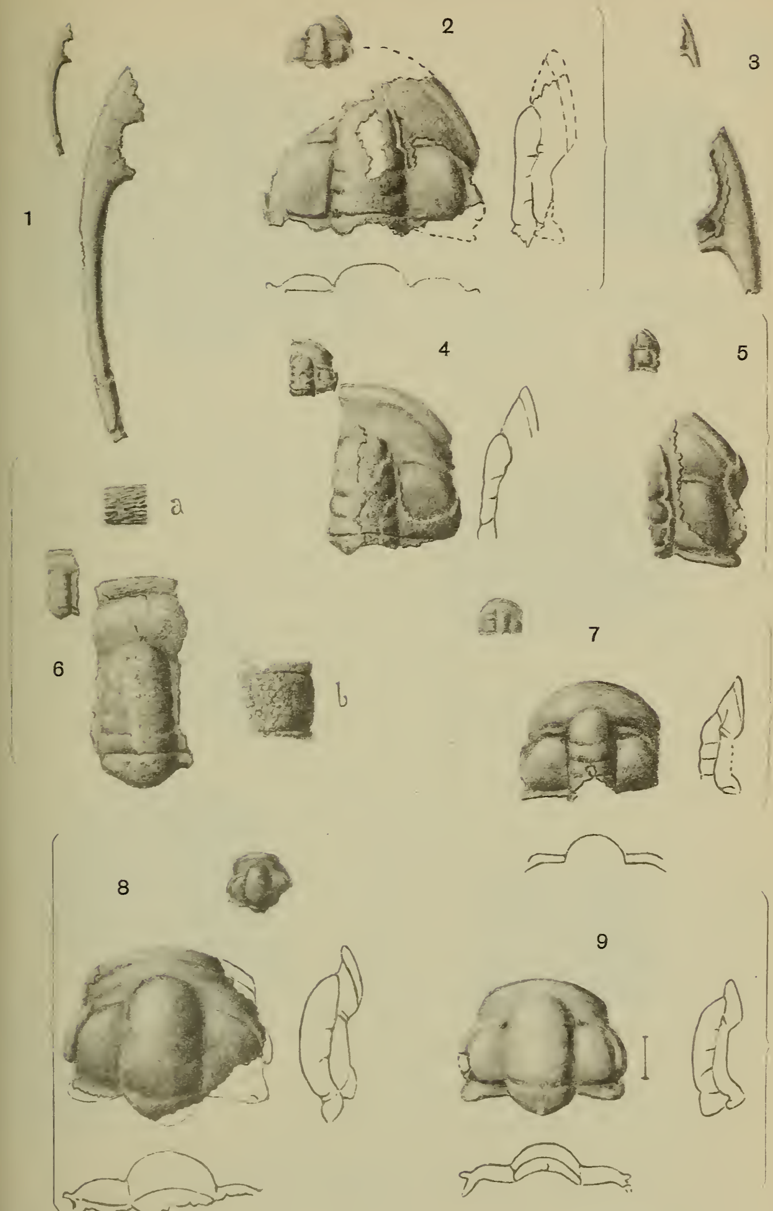

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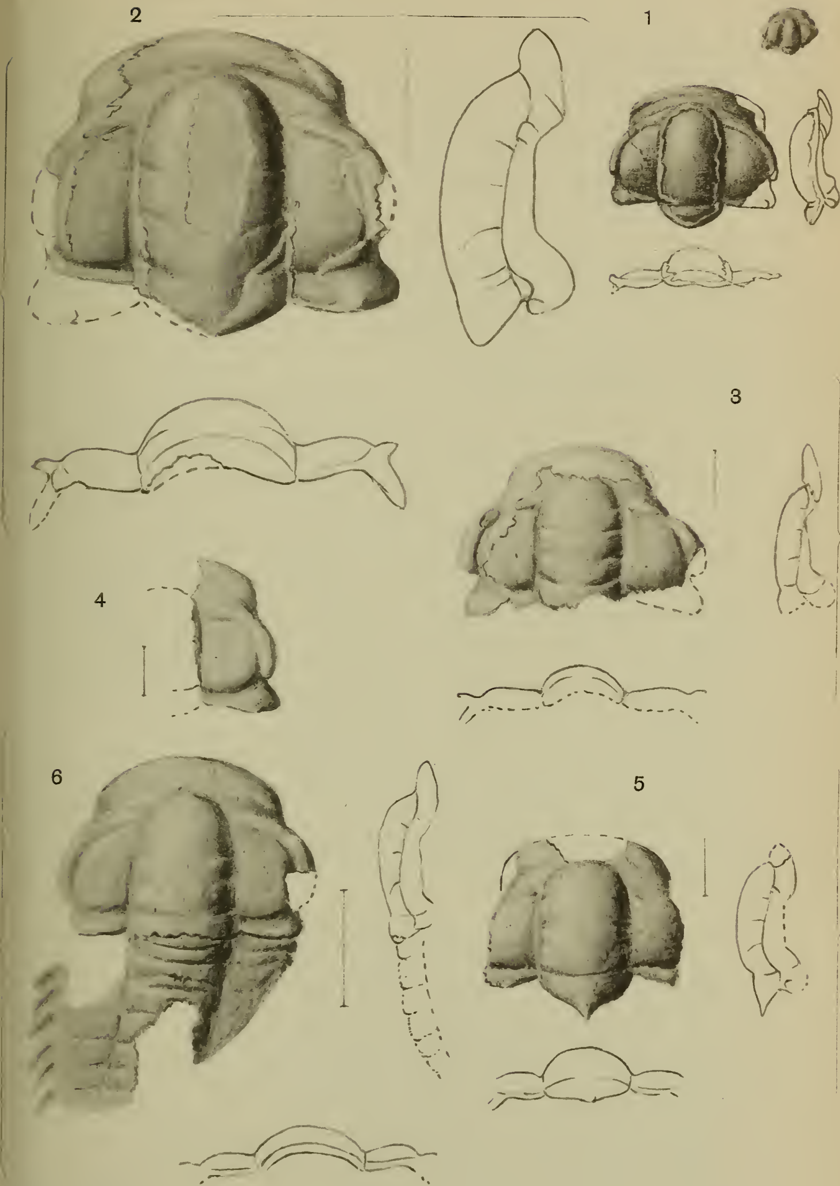

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Discussion.

The President (Prof. W. J. Sollas) welcomed this important contribution to our knowledge of the Lower Cambrian faunas; it was no small triumph to have established a standard succession by work in so restricted an area as Comley Quarry. The material was fragmentary, and to have elicited so much sound information from it reflected the greatest credit on the Author's skill and insight. The determination of the true horizon of the *Protolenus* Fauna was in itself a noteworthy achievement.

Dr. Marr congratulated the Author on having discovered the relative positions of the *Olenellus*, *Protolenus*, and *Paradoxides* Faunas in the British Cambrian sequence. In the quarry at Comley, which he had visited with Prof. Lapworth, were white and pink crystalline limestones containing *Olenellus*. These limestones were similar to others in various regions exhibiting what Mr. Tiddeman called 'reef-knoll' structure, although in this case the structure was on a very small scale.

Prof. Watts said he was glad that the Author had obtained such splendid results from his excavations in Shropshire. It was most interesting to find a representative of the *Protolenus* Fauna coming between the *Olenellus* and *Paradoxides* Faunas.

Mr. Fearnsides, as secretary to the 'Excavation of Critical Sections' Committee of the British Association, wished to congratulate the Author on the great success of his trench-digging operations. The discovery of three distinct faunas within a thickness of 6 feet of coarse-textured sediment was of great interest. It drew attention to the sharp contrast between the Lower Cambrian rocks of Shropshire and of Merionethshire, and showed that the Comley rocks were much more like the contemporaneous rocks of the Baltic area. The erosion-partings, the minute unconformities between successive beds, the limestone pellets associated with phosphatic nodules and glauconitic grains, could all be matched exactly among the Cambrian rocks of Northern Öland, and were there interpreted as distinctive of a period of recurrent alternating deposition and erosion in shallow water of the sea-bed.

The Author briefly thanked the Fellows for their appreciative reception of his paper, and in reply to Dr. Marr said that the position of the genus *Protolenus* at Comley was exactly parallel with that assigned to it by Mr. Matthew in Acadia. He also explained that the paper was only concerned with one preliminary excavation at Comley, and that the further excavations, made under the grant from the Committee for Geological Excavations of the British Association, had yielded results extending to other horizons in the Shropshire Cambrian. To a suggestion made by Mr. Fearnsides, he replied that he regarded the grey limestones as shallow-water deposits, possibly laid down in lagoon-like relics of the *Olenellus* sea, the bottom of which was gradually raised above sea-level, to be subsequently eroded by the advance of the *Paradoxides* waters.

3. *Certain* Jurassic (Lias-Oolite) Strata *of* South Dorset; *and their* Correlation. By S. S. Buckman, F.G.S. (Read November 3rd, 1909.)

Contents.

I. Introduction.

The object of the present communication is to show the development and sequence of certain Jurassic strata on the Dorset coast, and to make some comparisons with strata elsewhere. The range of strata dealt with is from the top of the Middle Lias (Pliensbachian) to the lower part of the Fullers' Earth (Bathonian, Vesulian) inclusive.

The communication is laid before the Society for several reasons: it was promised many years ago; it forms a sequence to the papers on North Dorset and the Cotteswolds; it aims to give a detailed account of certain fossiliferous strata of South Dorset, to be used as a foundation for the dating of the fossils; and it offers suggestions in the matter of correlation and subdivision as a basis for the work of other investigators. With this stratigraphical paper there is also offered a palæontological paper, to describe some of the new species mentioned, and to figure some other species which are new and illustrative of strata of the same dates. That communication will be alluded to as 'the palæontological paper.'

The investigations for this paper, which will probably be my last, so far as active field-geology is concerned, were complete in the main several years ago; it was announced in 1893 as nearly ready for publication. Since then changes of residence have involved packing of specimens, and many have not been unpacked again. As a consequence the identification of species must often be given in general terms, as they were set out in the notes: to wait until the specimens were brought together, freed of matrix, and exactly identified, would lead to indefinite postponement.

However, identification in general terms is sufficient at present, because one does not ascertain the dates of the deposit so much by the actual species, as by the general facies, in the case of Ammonites. Coarse-ribbed *Dumortieriæ*, fine-ribbed *Dumortieriæ*, Ammonites of *aalensis* pattern, Opalinoids, show the dates as well as more exact identifications; because the successive Ammonites of different genera assume certain developmental facies. Examples of how this may be a guidance will be given later. In some cases there may be difficulty, and more exact identification is necessary: especially in detailed division; for instance, there are three or four successive series of Opalinoids which are not easy to distinguish in the rough, even in a general way, but their particular features are noted in Table I (p. 55).

(*a*) Bibliography of some of the Author's similar communications.

This paper is part of a series of communications made upon similar subjects, mainly to this Society, but also to other scientific bodies, so that a list of such prior communications is desirable.

(1) 1889. 'On the Cotteswold, Midford, & Yeovil Sands, & the Division between Lias & Oolite' Quart. Journ. Geol. Soc. vol. xlv, pp. 440–73.

(2) 1890. 'On the so-called "Upper Lias" Clay of Down Cliffs' Quart. Journ. Geol. Soc. vol. xlvi, pp. 518–21.

(3) 1890. 'On the *Jurense* Zone' Journ. Northants. Nat. Hist. Soc. vol. vi, pp. 76–80.

(4) 1891. 'The Ammonite Zones of Dorset & Somerset' Rep. Brit. Assoc. (Cardiff) pp. 655–56; & Geol. Mag. dec. 3, vol. viii, pp. 502–04.

(5) 1893. 'The Bajocian of the Sherborne District; its Relation to Subjacent & Superjacent Strata' Quart. Journ. Geol. Soc. vol. xlix, pp. 479–521.

(6) 1895. 'The Bajocian of the Mid-Cotteswolds' Quart. Journ. Geol. Soc. vol. li, pp. 388–462, & pl. xiv.

(7) 1896. 'Dundry Hill: its Upper Portion, or the Beds marked as Inferior Oolite (*g* 5) in the Maps of the Geological Survey' Quart. Journ. Geol. Soc. vol. lii, pp. 669–720. (In collaboration with the late Edward Wilson.)

(8) 1897. 'Deposits of the Bajocian Age in the Northern Cotteswolds: the Cleeve Hill Plateau' Quart. Journ. Geol. Soc. vol. liii, pp. 607–29 & pl. xlvi.

(9) 1898. 'On the Grouping of some Divisions of so-called "Jurassic" Time Quart. Journ. Geol. Soc. vol. liv, pp. 442–62.

(10) 1901. 'Homœomorphy among Jurassic Brachiopoda' Proc. Cotteswold Nat. F.-C. vol. xiii, pp. 231–90 & pls. xii–xiii.

(11) 1903. 'The Toarcian of Bredon Hill, & a Comparison with Deposits elsewhere' Quart. Journ. Geol. Soc. vol. lix, pp. 445–58.

(12) 1906–7. Monogr. Inf. Ool. Amm., Suppl. (Pal. Soc.) pp. cciv–ccix.

(13) 1898. The Author (& others). 'Excursion to Bridport, &c.' Proc. Geol. Assoc. vol. xv, p. 293.

(*b*) Chronology.

In the various communications enumerated in the foregoing Bibliography, I have shown how it is possible to date the Jurassic strata with very great precision, and I have given various tables of chronology. The plan of more numerous chronological or zonal divisions has been adopted by various geologists, both in this country and on the Continent: even further refinements than I had made, though not always than I had anticipated, have been proposed and used.

The Table of Chronology, which it is proposed to employ in the present paper for dating purposes, is given below. A partly similar table has appeared already [1]; but, as modifications of nomenclature have been introduced by other workers, and are now suggested by myself, republication seems desirable. Further, opportunity is taken to add what may be described as the prominent Ammonite facies of each date, employing for the purpose terms as concisely descriptive as possible. This addition may not only be a guide for field-workers, but it may illustrate what a fine museum exhibit could be made of the stratigraphical-zoological sequence of the different Ammonite facies; because not only is such a sequence proved in the main for Europe, but there is good reason to suppose that it obtains on the other side of the Atlantic and in Japan.

Of the hemeral names tabulated here, three are new: one, *Shirbuirnia*, is due to refinement in generic nomenclature, and two, *schlœnbachi* and *Ancolioceras*, arise from greater precision in chronology; they will be discussed later.

How with opportunity for the examination of thick deposits of strata the want of great refinement in stratigraphical or chronological nomenclature makes itself felt, is shown in a recent paper by Dr. Mascke. Where I have made one division he has made nearly four.[2] A copy of his interesting table is appended (Table II, p. 56), where he compares his divisions with mine. The difference is explained by the fact that in North Germany Mascke has something over 140 feet to study, whereas in this country we have in the most favoured localities less than 5 feet, and at most localities a few inches or nothing. All the same, the possibility

[1] 'On the Grouping of some Divisions of so-called "Jurassic" Time' Quart. Journ. Geol. Soc. vol. liv (1898) table i, facing p. 450.

[2] Just as I am about to present this paper, Mr. Beeby Thompson very kindly sends me some MS. showing that he is doing the same for the Upper Lias. This matter is dealt with later (p. 85).

Table I.—Chronology.

Hemeræ.	Distinctive Fossil.	General Ammonite Facies.
fuscæ	*Oppelia fusca* (Quenst.)	Oxynote Oppelids.
zigzag	*Zigzagiceras zigzag* (d'Orb.)	Zigzag Stepheoceratids; rounded whorled *Parkinsoniæ*; trigonal whorled *Parkinsoniæ*.
schlœnbachi	*Parkinsonia schlœnbachi*, Schlippe.	Stout-whorled, crassicostate *Parkinsoniæ*.
truellii	*Strigoceras truellii* (d'Orb.)	Compressed *Parkinsoniæ*; hollow-keeled, lineate Oppelids *(Strigoceras)*.
garantianæ	*Garantiana garantiana* (d'Orb.)	Evolute *Parkinsoniæ*. Ammonites with ribs opposite but well broken on periphery *(Garantiana)*.
niortensis	*Strenoceras niortense* (d'Orb.)	Bispinous Ammonites *(Strenoceras)*. Fine-ribbed craterumbilicates *(Cadomites)*. Very evolute *Parkinsoniæ*.
blagdeni[1]	*Teloceras blagdeni*	Crassornate craterumbilicates *(Teloceras)*. Stout *humphriesianum* types; spheroidal Stepheoceratids.
sauzei	*Otoites sauzei*	Compressed *humphriesianum* types *(Skirroceras)*. Auriculate, spinous spheroids *(Otoites)*. Mammillate *Sonniniæ*; alticarinate *Sonniniæ*.
Witchelliæ	*Witchellia* sp.	Septicarinati-subsulcate platygyrals *(Witchellia)*. Club-bearing spheroids & subspheroids *(Emileia)*.
Shirbuirniæ (olim *Sonniniæ*)	*Shirbuirnia trigonalis*, sp. nov.	Trigonal whorled Sonninians *(Shirbuirnia)*. Ornatilobate, subcarinate & carinate Sonninians.
post-*discitæ*	*Oppelia* of *præradiata* type	Oppelids with convex periphery.
discitæ	*Hyperlioceras discites* (Waagen)	Carinatitabulate Hildoceratids. Quadrate-whorled subcrenulaticarinates *(Haplopleuroceras)*.
concavæ	*Ludwigella concava* (J. Sow.)	Concavumbilicate Hildoceratids. Dwarf Ludwigoids *(Ludwigella)*.
bradfordensis	*Brasilia bradfordensis* (S. Buckman).	Fine-ribbed, gradumbilicate Ludwigoids. Smooth gradumbilicates.
murchisonæ	*Ludwigia murchisonæ* (J. de C. Sow.)	Crassornate Ludwigoids.
Ancolioceras	*Ancolioceras* sp.	Carinate, rostrate Opalinoids *(Ancolioceras)*.
scissi	*Tmetoceras scissum* (Benecke)	Subcarinate, subrostrate Opalinoids *(Lioceras)*. Annular ribbed, peripherally broken, Dumortierians *(Tmetoceras)*; crassornate Hammatoceratids, *Burtonia*.
opaliniformis	*Cypholioceras opaliniforme*, S. Buckman.	Subcarinate rostrate Opalinoids *(Cypholioceras)*.
aalensis	*Pleydellia aalensis* (Zieten)	Jugate-ribbed Grammocerates. Paucicostate Grammocerates *(Cotteswoldia)*.
moorei	*Dumortieria moorei* (Lycett)	Fine-ribbed *Dumortieriæ*. Flexiradiate *Dumortieriæ*.
Dumortieriæ	*Dumortieria* spp.	Coarse-ribbed *Dumortieriæ*; multicostate & periodically constricted Dumortierians *(Catulloceras)*. Smooth Oxynotes *(Hudlestonia)*.
dispansi	*Phlyseogrammoceras dispansum* (Lycett).	Nodate Grammocerates; solid-keeled Hammatoceratids.
struckmanni	*Pseudogrammoceras struckmanni*, (Denckmann).	Hollow-carinate Grammocerates.
striatuli	*Grammoceras striatulum*	Solid-keeled (non-septicarinate) Grammocerates; non-nodate *Haugiæ*.
variabilis	*Haugia variabilis* (d'Orb.)	Parvinodate *Haugiæ*.
lilli	*Lillia lilli*	Crassinodate Haugians (*Lillia*, etc. = podagrosi). Nearly smooth *bifrons* types.
[2] *bifrontis*	*Hildoceras bifrons* (Bruguière)	Ribbed *bifrons* types. Fibulate Dactyloids *(Peronoceras)*.
[2] *falciferi*	*Harpoceras falciferum*	Hollow-keeled *falciferi* (*Harpoceras* s. str.), genuine sickle-bearers.
[2] *tenuicostati*	*Dactylioceras tenuicostatum* (Young & Bird).	Annulate Dactyloids *(Dactylioceras)*.
[2] *acuti*	*Seguenziceras acutum* (Tate)	Annulate Dactyloids (compressed).
spinati	*Paltopleuroceras spinatum*	Quadrate-whorled crenulaticarinates *(Paltopleuroceras)*.

[1] This term is used in the body of the paper; but Mascke has made further subdivision here; and his terms should be inserted to make a complete sequence, see p. 56.
[2] These terms are used in the body of the paper, but other terms are necessary. See footnote 2, p. 54.

TABLE II.—CORRELATION.

Part of Table by Dr. Erich Mascke.[1]

S. BUCKMAN.	E. MASCKE, North Germany.
Strigoceras truellii.	*Parkinsonia*-zone.
Park. garantiana.	*Garantiana*-zone.
Strenoc. niortense.	oben *Strenoc. niortense*, d'Orb. *Teloceras*-zone.
	Stepheoceras-zone mit *Dorsetensia complanata*, Buckm.
Cœloceras blagdeni.	*Stephanoceras*-zone.
	Stemmatoceras-zone mit *Witchellia edouardi*, Sow.
Sphæroc. (?) sauzei.	*Otoites*-zone. *Witchelliæ* f.
Witchelliæ sp.	*Emileia*-zone. *Witchelliæ* f.
Sonninia sp.	*Sonninia*-zone. *Witchelliæ* f.

of these divisions was noted in my Sherborne paper. On p. 501 it is said:

'Bed 5 [of Frogden], with the numerous large specimens of *Stephanoceras Banksi*...seems to be a separable, third portion of the Ironshot'; [and on p. 517:] 'I think it possible that this [division] is an horizon which has escaped notice in our own country. ...... The biological characters [of certain ammonites] suggest that they may have lived in a hemera between that of *Sauzei* and *Humphriesianum*.' (Quart. Journ. Geol. Soc. vol. xlix, 1893.)

Thus the sequence expected in our thin beds was:

Niortensis,
Banksi,
Humphriesiani
inter *Humphriesiani-Sauzei*,
Sauzei;

and this is the stratal sequence which Dr. Mascke has been able to prove in the thick deposits of North Germany. It has not seemed necessary to adopt his divisions in the present paper, because the deposits of those dates are so indistinct in South Dorset; but any future investigator in the Sherborne District should find them very useful.

[1] 'Die *Stephanoceras*-Verwandten in den Coronatenschichten von Nord-Deutschland' Inaugural-Dissertation, Göttingen, 1907, p. 16.

II. Description of the Strata.

(*a*) Chideock.

There is a very interesting and fairly continuous section from the top of Chideock Quarry Hill to the cliffs by the seaside. The sequence on the hill is difficult to follow, because there are only shallow workings and most of these are closed; so, in my former paper, the extent of the beds on the Chideock Quarry Hill was understated, owing to the difficulty of seeing junctions properly.[1] The same cause may affect the section now tabulated; but more details have been obtained, and the method of dating the beds is more exact and elaborate than was in use at that time.

In the same paper was given a section of part of Down Cliffs—the cliffs to the south of Chideock on the sea-coast. Here there was an omission. It was noted in the paper (p. 519) that there was no evidence of the *dispansum*, *striatulum*, and *variabilis* beds, and it was stated that they ought to come in at the base of the Blue Clay, there numbered Bed 9, or at the top of the Junction Bed, there numbered Bed 10. Subsequent discovery verified that surmise; for, in certain places, at the top of the Junction Bed there is a thin layer (2 inches) of a light-coloured stone containing ammonites of the *Grammoceras-striatulum*[2] series. But in many places, even where the Junction Bed is investigated *in situ* in the cliffs, this layer is absent. However, it has also been found in the fields on the west side of Chideock Quarry Hill. Then, in a road-cutting at Symondsbury, there was found further evidence of deposit of this date—a specimen of *Haugia fascigera* encrusted with irony matter.

At about the same time that I had noted the occurrence of *Grammoceras-striatulum* forms near Chideock, the late Mr. J. F. Walker had made the same discovery near Bridport, where he quotes '*Am. (Harpoceras) striatulum*' and '*Am. (Grammoceras) thouarcense*'.[3] He had, however, announced a further discovery—that of *Ammonites germa[i]ni*, d'Orbigny, in a higher layer.[4] With his usual kindness he gave me examples; and, though I have not seen the rocks *in situ* myself, I consider that *Am. germaini* indicates the presence of some portion of the *dispansum* zone: at any rate, a layer lower than the Blue Clay of Down Cliffs. This layer has not been found in the coast-sections.

The top bed of Chideock Quarry Hill consists of several feet of blue clay of the Fullers' Earth. Below this are some 14 feet of limestones—actual limestones which can be burnt for lime. No evidence was found of the upper or *zigzag* layer, and nothing was seen of any evidence for the lower or *truellii* layer; hence it is presumed that all these limestones belong to the intervening layer which may

[1] 'On the so-called "Upper Lias" Clay of Down Cliffs' Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 519.

[2] To find the author's name, etc., of Ammonites thus mentioned, consult Index, 'Monogr. Inf. Ool. Amm.' (Palæont. Soc.) 1907.

[3] Geol. Mag. dec. 3, vol. ix (1892) pp. 440, 442.

[4] *Ibid.* p. 442.

be dated as hemera *schlœnbachi*: the section of Burton Bradstock (p. 72) will show what this means.

Below these limestones are red earthy stone-beds, much iron-shot, the grains becoming coarser and coarser in the lower part. Rather more than 6 feet of these was noted, and their fossil evidence in part is abundant. A few inches of the top yield Ammonites indicative of the *sauzei* zone; and about 2 feet down there is evidence of the fauna of the *Witchelliæ* hemera. The date of the lower part is not certain: the only evidence was an Ammonite which could be said to be a coronate, and either *Emileia* or a *Stepheoceras*-like form; its condition did not allow of any more exact determination, but it suggests hemera *Shirbuirniæ* (*Sonniniæ*). Below this there seems to be a break in the sequence—nothing of *discitæ* or *concavi* date was noted,[1] though the discovery is possible. The next bed seen is what the quarrymen call the Wild Bed, with its planed-off top, by which they say it can be recognized all over the hill. In some places the top of the Wild Bed shows pockets containing Ammonites of the *Brasilia-bradfordensis* style, in a matrix different from that of the Wild Bed proper. The Wild Bed itself is remarkable for the number of finely preserved examples of the *Ludwigia-murchisonæ* style, many of which from this locality have been figured in my Monograph.

At the bottom of the Wild Bed, attached, is a different matrix containing a big Lytoceratoid, near to *Pachylytoceras aalenianum*.[2] The *Lytoceras wrighti* cited in the former paper[3] is, perhaps, this species, for *L. wrighti* strictly defined is a noticeable fossil of the strata of *aalensis* hemera, a good bit lower down.

This basal part of the Wild Bed it is desirable to date as something earlier than *murchisonæ* hemera and later than *scissi*: it may be dated as *Ancolioceras* hemera; and it will be discussed later.

Below the Wild Bed is the first bed of the Bridport Sands—a hard sandy limestone—the *scissum* bed—with *Tmetoceras scissum* and *Lioceras*, that is, the true *opalinum* group (see Burton Bradstock section, p. 74). Below is marl and stone with badly preserved Opalinoids. Some 6 feet lower is found a noticeable little globose *Rhynchonella* in some abundance (*Rhynchonella pentaptycta*, sp. nov., see the palæontological paper, p. 103).

Associated with it are fine-ribbed Ammonites of *Canavarina-steinmanni* type. About 2 feet lower are many Ammonites of the *aalensis* pattern (for instance, *Canavarina*, *Cotteswoldia*, etc.), on the whole coarser in the character of their ornament than those above; they are good, but difficult to extract. For about 25 feet down there are more or less indications of Ammonites of the *aalensis* pattern. Then there is a break of some 15 feet, which

[1] *Sonninia dominans*, 'Monogr. Inf. Ool. Amm.' p. 324, from Chideock would indicate the presence of *discitæ* deposit. A little to the east, at Mappercombe near Powerstock, evidence of *discitæ* deposit was found by the roadside:—*Terebratula eudesiana*, *Rhynchonella forbesi*, and a Sonninian.

[2] Quart. Journ. Geol. Soc. vol. lxi (1905) pl. xv, figs. 3 & 4.

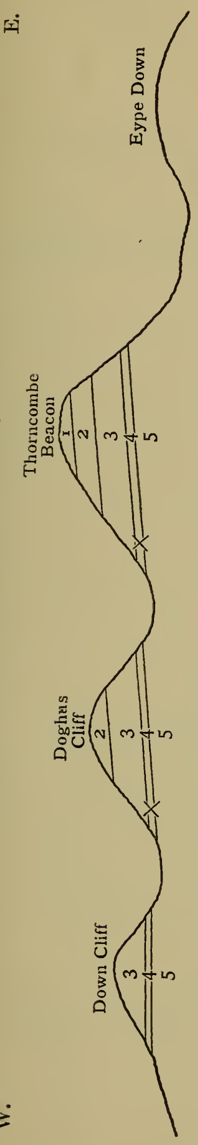
[3] *Ibid.* vol. xlvi (1890) p. 519, Bed 4.

gave no result, and then was found a block with many specimens of fine-ribbed *Dumortieriæ*, indicative of *moorei* hemera.

The important point about this part of the section is that there are more than 40 feet of strata deposited during the hemeræ *aalensis* and *moorei*. In the Cotteswolds the amount of deposit during these dates was only a few inches—so insignificant that separation of the distinctive deposits is not easy. Here there is no doubt about the sequence; and, further, change even in the character of the Ammonites of the *aalensis* pattern (*Canavarina*) can be noted: the finer-ribbed forms are later than the coarser-ribbed, as is right in a catagenetic series.

Below the *moorei* bed is a series of yellow sands and sandstones, made out roughly by the level to be about 100 feet thick, down to the spring of water in the road near the top of the hill east of Chideock. This water is held up by the clay-bed which forms the top of Down Cliffs.

Fig. 1.—*Section from Down Cliff to Eype Down.*



[Scales: horizontal, 4 inches = approximately 1 mile; vertical, 1 inch = approximately 750 feet.]

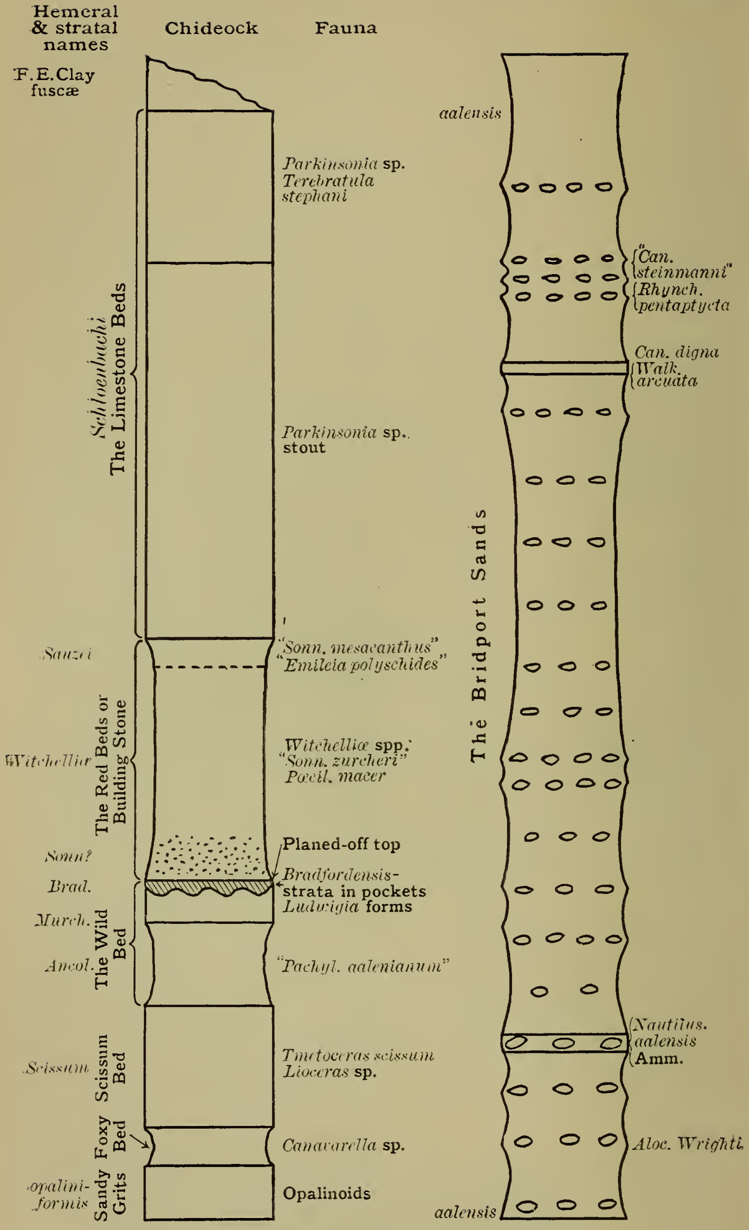
1 = Greensand; 2 = Bridport Sands; 3 = Clay above 4, the Junction Bed; 5 = Upper part of the Middle Lias.

The × shows where the Junction Bed is accessible *in situ*.

The beds have now to be studied on the sea-coast. Here, between Seatown and Eype, are four prominences of the cliffs with hollows between: fig. 1 represents a rough sketch of them. Some local informants stated that the prominences are called from west to east as shown in the appended sketch; others that the term Down Cliffs covered the two prominences west of Thorncombe Beacon. The former is the most suitable for distinctive purposes. Down Cliff is not capped by Bridport Sands, but Doghus Cliff is the first one from Seatown which is so capped. Thorncombe Beacon shows Bridport Sands capped by Greensand; while Eype Down is below the Junction Bed.

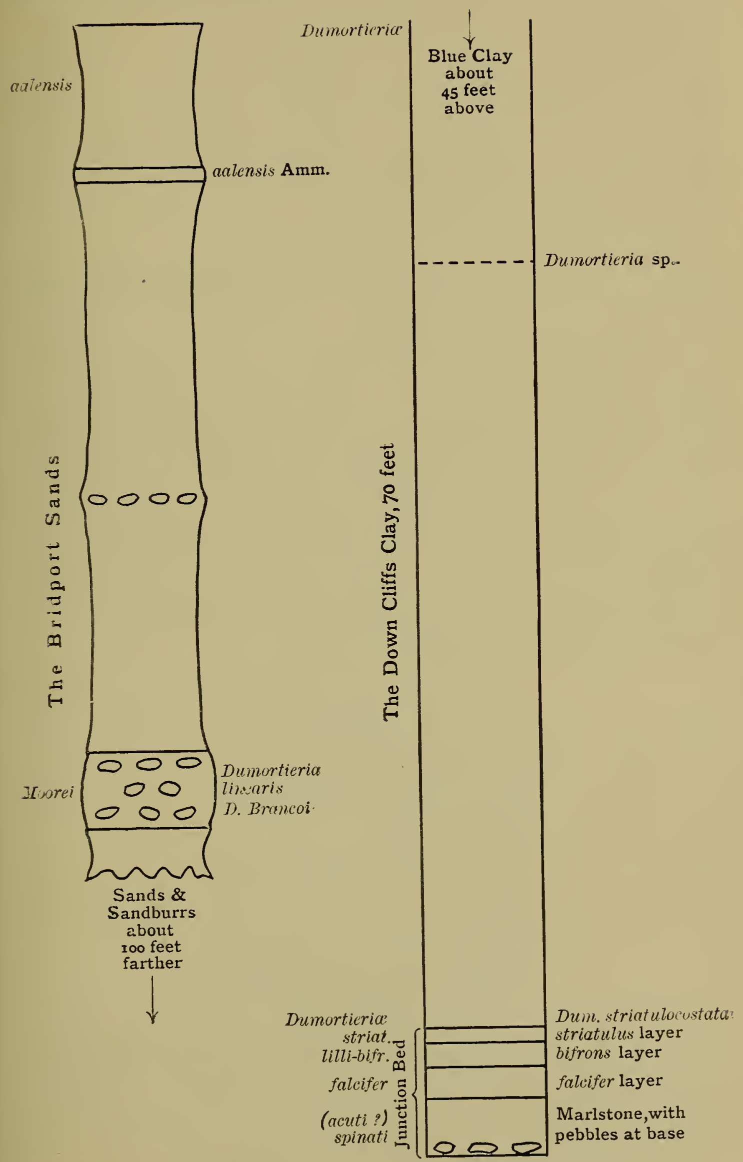
It may be noted that the cliffs are very fairly accessible even for ladies, with a little practice, though they look formidable.

Fig. 2.—*Vertical section of Chideock*



Scale. 1 inch = 5 feet. 1 : 60
10 millimetres = 2 feet.

Quarry Hill and the coast.



Scale. 1 inch = 5 feet. 1 : 60
10 millimetres = 2 feet.

In the Blue Clay of Doghus[1] Cliff below the Bridport Sands, species of *Dumortieria* were obtained at 12, 40, 50 feet down and right on top of the Junction Bed.[2] The names were noted many years ago, and the specimens were fragmentary; but a reference to my Monograph on Inf. Oolite Ammonites (Palæont. Soc.) pt. v (1890) will indicate the approximate forms. The really important point is that they are more or less coarse-ribbed *Dumortieriæ*, and that the 70 feet of blue clay can be dated as belonging to the hemera *Dumortieriæ*: it is of later date than the Midford Sands of Bath, and still later than the Cotteswold Sands of Gloucestershire, yet it is earlier than the Bridport Sands of Dorset.

Inland, in the lane-cutting from Symondsbury leading up to Chideock Quarry Hill, this blue clay is not found on the top of the representative of the Junction Bed: it has either passed laterally into yellow sands, or it is absent.

The Junction Bed lies below the clay. In its more complete form it consists of five different layers of matrix, which occur in regular order and can be easily separated one from another by the chisel. The strata are those of *striatulus*, a *bifrons* bed, a *falcifer* bed, and two layers of marlstone down to *spinatus*: so that this bed of about 2½ feet at the best, represents the lower part of the Toarcian joined to Upper Pliensbachian. However, it is seldom complete—the top, or the bottom, or a middle layer will be wanting. The characters and contents of this bed demand separate treatment later.

The following is a detailed section of Chideock Quarry Hill and the cliffs (see also fig. 2, pp. 60–61):—

Section I.—Chideock Quarry Hill and the Coast.[3]

				Thickness in feet	inches.
fuscæ	(1) Blue clay, capping the limestone .			10–12	0
	(2) 'The Limestone Beds.'[4]				
schlœnbachi ...	(*a*) Grey crystalline limestone, with bands of clayey marl in the lower part. *Parkinsonia* sp., stout form; *Terebratula stephani*	4	0		
	(*b*) Similar limestone. *Parkinsoniæ* same as those in 2nd Bed of Burton Bradstock	0	6		
	(*c*) Earthy parting	0	2		
	(*d*) Greyish limestone.....................	1	3		
	(*e*) Grey crystalline limestone, the lower part in massive blocks, about	8	0	13	11

[1] Doghus is the name of the cliff and of the farm in the valley behind it. The name is printed as pronounced. A Yorkshireman might think that the name referred to the sandburrs in the cliff which he would call 'doggers.' A south countryman, with as little reason, supposes it to be a corruption of 'doghouse'; but a Welshman might perhaps have more right to claim the name as a corruption of a Celtic term.

[2] See also Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 519.

[3] It is sometimes called Chideock Hill, but this term is given by the natives to the hill up the road to the west. Quarry (Qwor) Hill is the native term for this eminence on the east.

[4] Quarrymen's term. 'These are the only beds of stone fit for lime, the other stone, if burnt, will not slake.'—Quarrymen's information.

				Thickness in feet	inches.
	(3) 'The Red Beds or the Building-Stone.' (Quarrymen's terms.)				
sauzei, *Witchelliæ.*	(*a*) Dark brown, fairly ironshot, sandy, easily worked stone .... about In the upper few inches alticarinate *Sonniniæ* of the *S. mesacanthus* type, and large *Emileia* cf. *polyschides*, Waagen. About 2 feet down, *Sonniniæ* of the *S.-zurcheri* type, *Sonninia buckmani*, Haug, *Pæcilomorphus macer*, numerous *Witchelliæ*, *Stepheoceras*, *Otoites* cf. *contracta* (Sow.).			6	0
	(*b*) Brown ironstone with coarse grains, more irony than bed above.			0	4
Sonniniæ or *discitæ* (?)	Bluish-brown, coarsely ironshot oolite; more coarsely grained than bed above. *Stepheoceras* or *Emileia*.			0	3
	(4) 'The Wild Bed.'				
bradfordensis...	(*a*) Ironshot sandy stone, with Ammonites of the *Ludwigia-gradata* type, often in a perished condition, found in irregular hollows of (*b*). *Cosmogyria subtabulata*, *Apedogyria platychora*, *A. subcornuta*.[1]				
murchisonæ ...	(*b*) Light yellow, finely ironshot stone, sometimes bluish yellow. *Zeilleria anglica* (Oppel) at base. *Welschia obtusiformis*, *Crickia reflua*, *Hyattia pustulifera*, *H. wilsoni*, *Apedogyria patellaria*, *Strophogyria cosmia*, *Kiliania armipotens*, *K. laciniosa*, *Pseudographoceras literatum* (see Monograph)			1	0
Ancolioceras ...	(*c*) Light yellow, softer and less ironshot than above. Large Lytoceratid, cf. *Pachylytoceras aalenianum* .... about			2	0
scissi	(5) Grey sandy limestone. *Tmetoceras scissum* and *Liocerata*			3	0
opaliniformis.	(6 *a*) Brown ironshot, marly stone, with Opalinoid Ammonites, cf. *Canavarella*..	1	0		
	(*b*) Sandstone with Opalinoid Ammonites, cf. *Walkeria subglabra*, *Rhynchonella stephensi* (*cynocephala*) ...	1	8		
	(*c*) Sands and sandburrs. *Rhynchonella* of *cynocephala* pattern, Opalinoid Ammonites	3	8	6	4

[1] See Monograph. These Ammonites were entered as 'from base of red beds'; but it was afterwards found that this particular red bed was in hollows of the Wild Bed.

			Thickness in feet	inches.	feet	inches.
aalensis	(7 *a*)	Sand and sandburrs. Fine-ribbed *aalensis*-like Ammonites (the *Canavarina-steinmanni* pattern)... *Rhynchonella pentaptycta*, sp. nov. at about 2 to 2½ feet down.	2	9		
	(*b*)	Yellow sands	1	0		
	(*c*)	Sand-rock, with coarse-ribbed *aalensis*-like Ammonites (*Canavarina digna*; *Walkeria arcuata*, *W.* cf. *lotharingica*)	0	4		
	(*d*)	Sands and sandburrs. Fragment of large *Nautilus*, and coarse-ribbed Ammonites of *aalensis* pattern at the base	17	0		
	(*e*)	Sands and sandburrs. *Alocolytoceras wrighti* at the base	2	4		
	(*f*)	Sands and sandburrs, fragments of Ammonites of *aalensis* pattern at the base.............................	6	3	29	8
moorei	(8)	Sands and sandburrs: in the lower 2 feet striate *Dumorticriæ* of the *D. moorei* pattern (for instance, *D. linearis*) and of the *D. subundulata* series (for instance, *D. brancoi*) occur			17	0
moorei and *Dumortieriæ*.	(9 *a*)	Sands and sandburrs, down to spring by roadside, ... about			100	0
		Sea-coast cliffs:—				
	(*b*)	The blue clay of Down Cliffs. At 12 feet down *Dumortieria* cf. *striatulocostata*, *D.* cf. *radians*, *D.* cf. *pseudoradiosa*; at 40 feet down fragments of *Dumortieria*; at 50 feet *D.* cf. *costula*; and at the base *D.* cf. *striatulocostata*			70	0
	(10)	JUNCTION BED, generalized:—				
	(*a*)	Irony scale.				
striatuli	(*b*)	Yellowish-grey, earthy, slightly ironshot stone, with a somewhat soapy feel. *Grammoceras striatulum* and allied forms..............	0	2		
lilli (?).........	(*c*)	Grey earthy stone. *Hildocerata* of the *bifrons* type (angustumbilicate forms), some much eroded and iron-covered, some quite sharp. A small specimen of the Podagrosi (*Lillia-Haugia* series) occurs; it has large ribs, cf. *Lillia* or *Denckmannia*	0	2		
bifrontis	(*d*)	Yellowish-pink earthy stone, with derived lumps of pink stone. '*Hildoceras bifrons*' small, eroded, iron-coated. Lower down pink stone predominant, '*H. bifrons*' larger and less iron-coated; *Harpocerata* derived (in irony nodules)	0	6		
	(*e*)	Irony scale.				
	(*f*)	Pink stone with red streaks.........	0	2		
	(*g*)	Yellowish-pink stone	0	4		

		Thickness in	*feet*	*inches.*
falciferi	(*h*) Attached to yellowish-blue, somewhat sandy stone. *Harpoceras falciferum* and *H.* cf. *strangwaysi*.	0	8	
acuti or *tenuicostati* (?) (*serrata*-bed)	(*i*) Marlstone brown, finely ironshot. In two beds. In the upper bed: *Rhynchonella serrata*; large, hollow-keeled Harpoceratoid Ammonites and *Thysanoceras*.			
spinati......... (*Rh. media* bed).	(*j*) In the lower bed *Rhynchonella media* (that is, the rotunde *tetrahedra* form), *Rh. acuta*, *Spiriferina*.	1	3	
			3	3

(The thickness of the Junction Bed is thus 3 feet 3 inches, but it is never found complete; about 2 feet, with beds missing, is the rule.)

Having come so far down the cliff in detail, it may not be uninteresting to reproduce, with modern interpretations, the section published by E. C. H. Day, which embraces the whole of it (see fig. 3, p. 66).

(*b*) Burton Bradstock.[1]

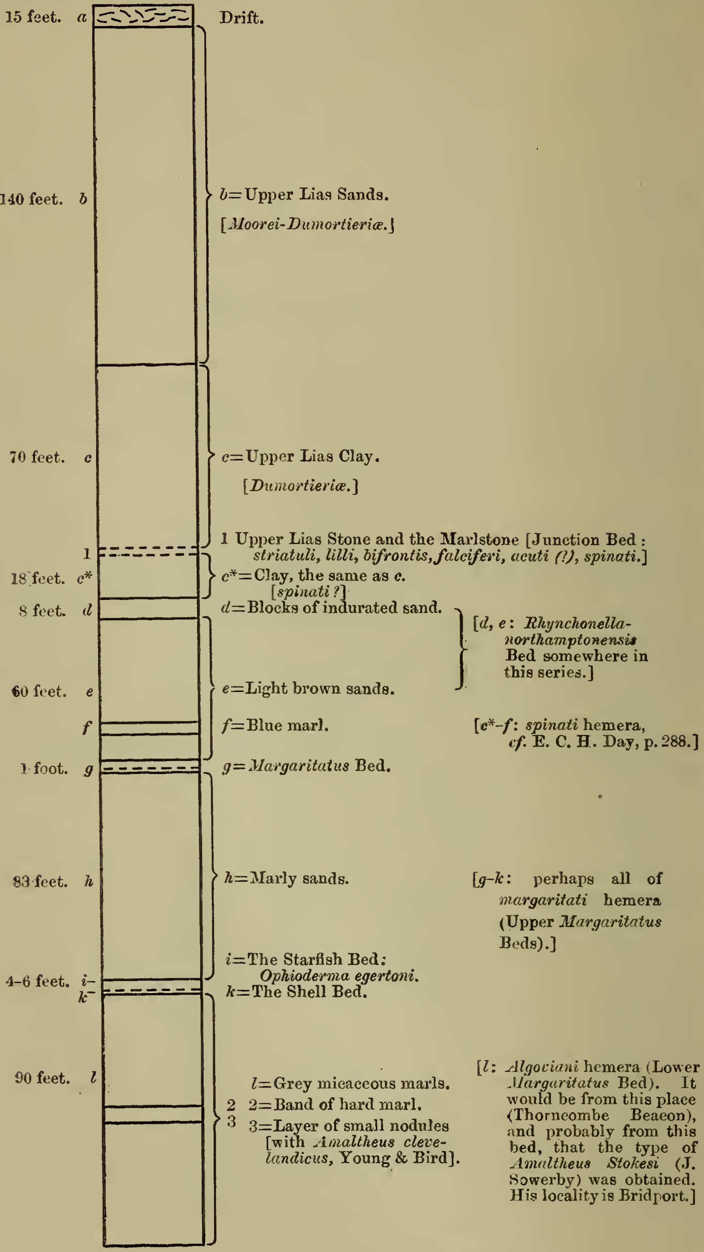
Eastward along the coast the cliffs east of West Bay up to Burton Bradstock afford fine sections of Bridport Sands, capped in places with Inferior Oolite: the latter, especially at Burton Bradstock noted for its abundant fauna, can also be studied in quarries about the village. The details of the stone beds—the Inferior Oolite—differ greatly in a short distance; and therefore only a generalized account of the succession is necessary.

The Fullers' Earth Clay rests on a bed known to the workmen as The Scroff—a thin irony layer yielding *Oppelia fusca* and allied species. Like the *striatulus* layer on the top of the Junction Bed, it is often missing.

The *zigzag* bed comes below the Scroff—it is confined to about the top 6 inches of what the workmen call the 1st Bed, and is recognizable by its bluish colour. The rest of this bed is a different matrix: it is somewhat deficient in fossils; but lithically and faunally it seems to be the continuation of the bed below, which the workmen call the 2nd Bed. Its yellowish colour, with earthy partings, and its stout forms of often poorly preserved *Parkinsoniæ* distinguish it. This 2nd Bed and the lower part of the first, containing a fauna distinct from that of the *zigzag* bed above or the *truellii* bed below, may be dated as hemera of *Parkinsonia schlœnbachi*, Schlippe. The 3rd Bed of the workmen contains two

[1] For other accounts of the strata of this locality, the reader is referred to W. H. Hudleston, 'Monogr. Brit. Jurass. Gasteropoda' (Palæont. Soc.), 1887, pt. i, p. 31; H. B. Woodward, 'Jurassic Rocks of Britain: vol. iv—The Lower Oolitic Rocks of England' Mem. Geol. Surv. 1894, pp. 55 *et seqq.*; also S. S. Buckman, Quart. Journ. Geol. Soc. vol. xlv (1889) p. 451, and Proc. Geol. Assoc. vol. xv (1898) p. 296.

Fig. 3.—*Vertical section of the Middle and Upper Lias at Down Cliffs and Thorncombe Beacon; adapted, with additions, from E. C. H. Day, Quart. Journ. Geol. Soc. vol. xix (1863) p. 285.*



[Additions are enclosed in square brackets.]

distinct beds for the geologist. The upper or *Terebratula* Bed may be recognized by its whitish colour, the masses of *Terebratula* '*sphæroidalis*,' and the excellent preservation of its numerous bluish-coloured *Parkinsoniæ*: this is the *truellii* zone. At the base are some few inches of an ironshot layer, the *Astarte* Bed, so called from the abundance of *Astarte* (now *Crassinella*) *obliqua*; though the species, or something very similar, also occurs in the bed above.

This *Astarte* Bed, or ironshot marly bed, contains fine specimens of *Garantiana*, of *Parkinsonia rarecostata*, and of forms intermediate between that and *P. parkinsoni*. It is Hudleston's P.1, and can be dated exactly as *Garantiana* Beds. It is of the age of the Rubbly Beds and Building-Stone of Sherborne in North Dorset.[1]

Below the *Astarte* Bed is a massive bed, known to the workmen as the 4th Bed, or the Red Bed. It is so massive that, even with the help of a quarryman wielding a sledge-hammer, little impression can be made on the very large blocks lying on the sea-shore. For this reason, and because it is not richly fossiliferous like the other beds, it has not been possible to obtain information as to the exact sequence of fossils in the bed. All the available evidence points to the bed being a conglomerate, containing the fossils of various dates mixed in more or less confusion. The latest date, indicated by a *Perisphinctes*, is the *niortensis* hemera: hence it may be surmised that the deposition of the bed, or of the greater part of it, was finished in that hemera; but right at the top are found Stepheocerata of the *blagdeni* and *sauzei* hemeræ, with a matrix agreeing more with the middle part of the bed.

In the bottom 9 inches of the bed are large limonitic concretions, sometimes measuring as much as 4 inches in length by about 3 inches across. They are arranged roughly in two layers, and are known to the workmen by the expressive name of Snuff-boxes. These snuff-boxes are also found about 3 miles to the north, inland, in quarries near the high road about 2 miles east of Bridport.

The matrix associated with the snuff-boxes at Burton is coarsely ironshot, different in character from the rest of the bed above. From the workmen and from scattered blocks have been obtained specimens showing somewhat this character of matrix—*Witchelliæ* and alticarinate *Sonniniæ* of the *S. propinquans* type—species of the *Witchelliæ* and *sauzei* hemeræ.

The conclusions that may be drawn concerning the date or dates of the deposition of the Red Bed—including the snuff-box layers—are:—that the bed was begun in the *Witchelliæ* or *sauzei* hemera, was continued during the *blagdeni* hemera, and was much disturbed, broken up, and greatly re-arranged during the *niortensis* hemera.

This Red Bed affords a good instance of the difference between zones and hemeræ. It cannot be said to belong to any definite zone or zones: rather is it a mix-up of several zones; but it is

[1] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 507.

possible to say that species known to have existed during the various dates *Witchelliæ* to *niortensis* hemeræ are found in this bed.

The bed below is another example of the same phenomenon—it is a yellow marly conglomerate of very irregular thickness—generally no more than a couple of inches; and it is cemented on to a sandstone-bed below, though portions of it are sometimes found striking to the base of inverted blocks of the snuff-box bed.

This 'Yellow Conglomerate Bed,' as it may be called, is really no more than a parting between the snuff-box bed and the sandstone (*scissum*) bed. But it contains a rich assemblage of mostly small fossils of many different dates. Its latest fossils are of the date of *discitæ* hemera; and so it may be supposed that the bed was formed during that date, deriving materials from the destruction of earlier deposits.

The characteristic fossils of the *discitæ* hemera are carinatitabulate Hildoceratids of the *Reynesella*, *Darellia*, etc. pattern[1]; small gastropoda characteristic of the *discitæ* bed of Bradford Abbas; Belemnites of the *blainvillei* type, and so forth. Indications of *concavi* hemera are various small *Ludwigellæ*. Fragments of fine-ribbed gradumbilicate Hildoceratids indicate derivation from strata of *bradfordensis* date; while such a species as *Cirrus nodosus* points to strata of *murchisonæ*, or perhaps earlier, *Ancolioceras* hemera. Then there are derived fragments of the *scissum* bed included.

Below the Yellow Conglomerate Bed is the *scissum* bed—a sandstone, or sandy limestone, of a bluish-grey colour. This bed yielded the series of *Liocerata* described in my Monogr. Suppl. pp. xxxvi *et seqq.* It also furnished *Tmetoceras scissum* (from which it takes its name) and *Tm. circulare*, besides yielding species of a rather remarkable series of Hammatoceratidæ. For these a new generic name *Burtonia* is proposed[2]; and they are remarkable for their likeness to what used to be known in a wide sense as *Ammonites murchisonæ obtusus*; the likeness has not improbably led to confusion in regard to zonal identification; at any rate it would be desirable to be sceptical about any records of *A. murchisonæ* from Burton or the neighbourhood to the north.

Below the *scissum* bed is a brown marly layer, whence has come *Zeilleria* (or *Ornithella*) *oppeli.*[3] In it, too, are various more or less poorly preserved Opalinoid Ammonites, differing from the *Liocerata* in having a much larger umbilicus in proportion to their tenuity. They are near to *Canavarella sceleta*[4]; but that species, though its horizon is not exactly known, probably came from the sand-rock immediately below.

This sand-rock yields poorly preserved Opalinoids, of the *Walkeria-subglabra* pattern; but the collection of identifiable specimens *in situ* is difficult.

1 'Monogr. Inf. Ool. Amm.' Suppl. (1906–07) pp. cv *et seqq.*
2 See the palæontological paper, p. 97.
3 Quart. Journ. Geol. Soc. vol. lii (1896) p. 702.
4 'Monogr. Inf. Ool. Amm.' Suppl. (1906–07) p. cxxix & pl. xxii, figs. 19–21.

Some $6\frac{1}{2}$ feet below the top of the *scissum* bed are found sand-burrs and sand-rock, yielding Ammonites of the *aalensis* pattern; they are good but not very easy to extract, and the sandy matrix is removable with difficulty.

Scattered blocks yielding Ammonites of the *aalensis* pattern may be presumed to belong to this horizon: they have yielded *Canavarina*, *Walkeria*, *Cotteswoldia*, and various examples of *Alocolytoceras wrighti*: one, which broke up while a workman was extracting it, was 20 inches in diameter; there is also a *Nautilus* near to *N. multiseptatus*, Foord & Crick.[1]

It may be presumed that it was from this horizon that *Canavarina digna* (Monogr. p. cxlii) and *Walkeria burtonensis* (p. cxxxix) were obtained, while possibly *W. delicata* (p. cxl) and *Canavarina steinmanni* (p. cxlii) were just a few inches higher, by analogy with Chideock.

In a little knoll north of Freshwater, the name for the place where the River Bredy enters the sea, west of Burton, there is a section in sands—a few feet. It gave evidence for *aalensis* beds at the top, and for *moorei* beds some few feet lower down; but the condition of the Ammonites allowed merely of a general determination of their facies.

The *Catulloceras dumortieri*[2] was from a fallen block: it can only be said that it belongs to a group indicative of an earlier date than *moorei* hemera. The lower part of the sands in the cliff, where they are accessible, seems to be particularly barren: so far as Ammonites are concerned, nothing can be recorded; there are Belemnites.

The thickness of Bridport Sands shown in the Burton cliffs would somewhat exceed 100 feet, and at intervals of every few feet there are lines of sandburrs, or sometimes more continuous sand-rock (see fig. 4, p. 70). As the sands (or sand-rock) become blue in the lower layers, which are exposed occasionally after exceptional tides, it may be presumed that these sands rest upon a blue clay like that at Down Cliffs.

The White Bed or *Nautilus* Bed.—In the foregoing account of the strata of Burton the bed which is of special interest, because it is a new discovery, has not been mentioned, for the reason that it is not found in the main cliff, nor in any of the quarries. It only occurs in a more or less tumbled condition in the bank at the beach opposite the villas, where the roadway comes to the shore (see fig. 4, p. 70). It is particularly exposed on the sort of pathway leading from the road to the beach, and just to the right hand as one reaches the beach.

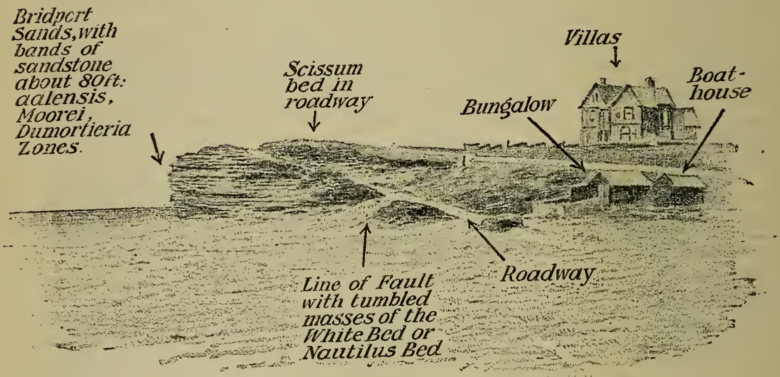
The place where this bed is exposed is in the line of fault, a downthrow to the east of 200 feet or more, which has brought Bradford Clay and Forest Marble (Bathonian) of the East Cliff of

[1] The specimen is now in the Museum of Practical Geology, Jermyn Street.
[2] 'Monogr. Inf. Ool. Amm.' p. 277 & pl. xxxix, figs. 6–9.

Burton to a level with the Bridport Sands (Toarcian) of the West Cliff. It is singular, however, that the white bed with its attached sandstone was found alone—not associated with other Inferior Oolite beds, although the *scissum* bed crops out in the road above (see fig. 4), near the top of the hill.

The characters of the White Bed are:—That it is a conglomerate

Fig. 4.—*View of the cliff-exposure at Burton Bradstock.*



of various sorts of white, and sometimes brownish, matrix; there is a fine-grained white matrix looking like a lithographic stone, and very similar to the White Jura of Würtemberg, or the *diphya*-kalk of Tyrol—it has a smooth soapy feeling: there is a less fine-grained white matrix which feels rough, and seems to be somewhat sandy. These two sorts of stone are in fragments irregularly compacted together, sometimes in larger masses, sometimes more or less in layers; and with them occurs some brownish stone. Of this bed there would seem to be some 3 or 4 feet; and attached, presumably to the base,[1] is a layer of about $1\frac{1}{2}$ to 2 feet of a brown sandy rock.

As to the position of this bed or beds,—in the Red Bed, about the middle, there is a small amount of a brown sandy matrix. In the upper part of the Red Bed there are pieces of rock similar to the less fine-grained stone enclosed in the redder matrix; but there is no trace of the rock resembling lithographic stone in any other exposures than this one at the roadway.

The evidence from fossils is poor. The help of a man with a sledge-hammer was obtained, and the blocks on the beach were broken. The yield was several specimens of a *Nautilus*,[2] a *Rhynchonella* like *Rh. parvula*, a *Garantiana* (difficult to identify on account of condition), and a piece of a *Garantiana* sp. nov. with

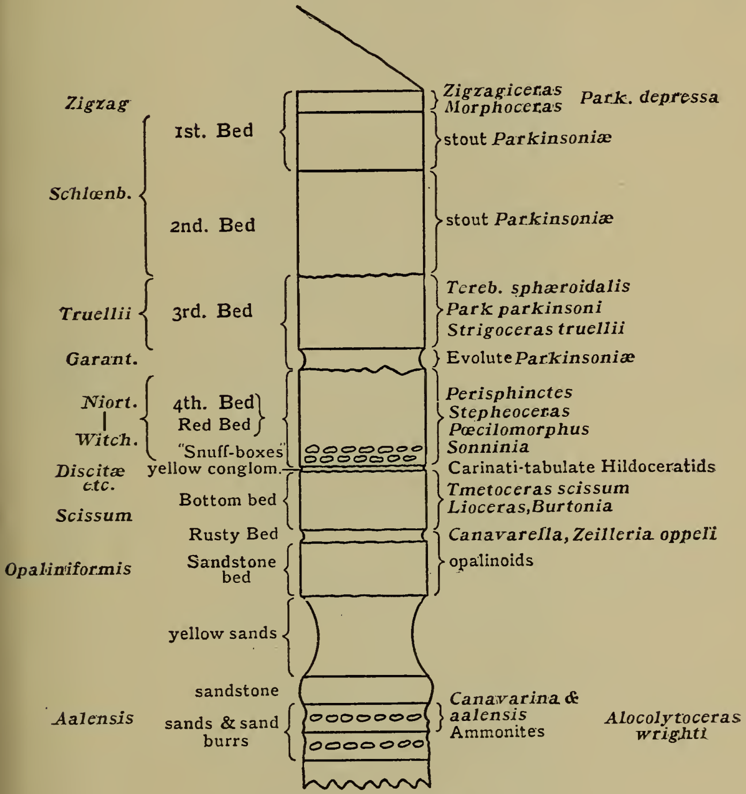
[1] The tumbled condition prevents any opinion as to top or bottom.

[2] Probably new. It is something like *Nautilus rotundus*, Crick, has a rapidly increasing whorl, a small (almost closed) umbilicus, and a periphery becoming flattened.

a latesulcate periphery, known as a species from the *niortensis* beds of Louse Hill near Sherborne.

This evidence then, although not satisfactory, would date the deposit as *niortensis*, or as late *niortensis* early *Garantianæ* hemera: it would make the deposit of the same date as the upper part of the Red Bed, and earlier than the *Astarte* Bed; but how it happens

Fig. 5.—*Vertical section of the beds exposed at Burton Bradstock. (See pp. 72 et seqq.)*



Scale: 1 inch = 5 feet.
5 millimetres = 1 foot.

that so distinct a deposit should have been formed at the same time as the Red Bed at this one place, and not at the others, is certainly a puzzle. There is one section a quarter of a mile north (Larkfield Quarry), another section a quarter of a mile north-west (road-cutting to Burton village), and the cliff-section a quarter to half a mile westward of this exposure of the White Bed; and yet in these short distances there is practically no sign of any deposit of a thick white bed of the character of the one that has just been described.

Section II.—Burton Bradstock.

[The section is generalized: it is based mainly on information obtained from the blocks under the cliff: but there is some variation in the thicknesses of these from different parts. Information as to fossil contents is also embodied from other places, the cliff between West Bay and Freshwater, Larkfield Quarry, the road-cutting, the quarry north of Bredy River, and even from the walls. The lithic differences of the beds are so distinctive and are so soon recognized, that fossils from isolated blocks can be placed without difficulty. The quarrymen know them quite well.]

Zone	Bed	Description	Thickness in feet	inches	feet	inches
fuscæ		Lower Fullers' Earth Clay. At Larkfield Quarry, Burton Bradstock, many Belemnites can be obtained from this. At Eype Cliff it has produced *Oppelia fusca* and *Perisphinctes*.				
		The Scroff. At the base of the clay and at the very top of the stone-beds there is a brown, more or less indurated marl, sometimes considerably iron-stained. It is 3 to 4 inches thick, and contains *Oppelia fusca* and *Perisphinctes*. Canaliculate Belemnites of the *B.-parallelus* type and *Zigzagiceras* cf. *subprocerum* are in it, partly attached to the bed below.				
zigzag	(1)	The 1st Bed.—The top 6 inches of this bed (Hudleston's P. 3) are a somewhat hard, bluish, earthy limestone. *Zigzagiceras zigzag*, *Z. subprocerum*, and others; *Morphoceras polymorphum*, *M. pseudo-anceps*; *Parkinsoniæ* of the *P. depressa* and *P.-lævis* type; *Oppelia* sp.; *Collyrites ovalis*			0	6
schlœnbachi...	(2 *a*)	Rest of bed bluish yellow to yellowish, fossils sparingly found; but there are *Parkinsoniæ* like those of the bed below	2	1		
	(2 *b*)	The 2nd Bed.—Mostly a yellowish limestone with much brown, earthy matter, the Ammonites often in rotten condition. *Parkinsoniæ* which have squared inflated whorls, coarse ribs, and conspicuous peripheral interruption like *P. schlœnbachi*, Schlippe; *Terebratula phillipsi*, *T. sphæroidalis*, *Rhynchonella parvula*, *Acanthothyris spinosa*, *A. panacanthina*, *Aulacothyris carinata*; *Collyrites ringens*, *C. ovalis*, *Holectypus hemisphæricus*, *Stomechinus bigranularis*	2	6	4	7
truellii	(3)	The 3rd Bed of the quarrymen, with their Shell Bed at the base. To be divided:—Main part *Terebratula* Bed or *truellii* bed. Fairly hard grey limestone, softer towards the				

		Thickness in feet	*inches.*
	bottom, sometimes almost white with greenish grains. Masses of rather small *Terebratula sphæroidalis* just above the bottom. Large *Parkinsonia dorsetensis*, *P. parkinsoni*, etc., in excellent condition, *Strigoceras truellii*, *Nautilus* spp., and *Crassinella* [*Astarte*] *obliqua*. These are the most noticeable fossils. Others are: *Morphoceras dimorphum*, *M. defrancii*, *Cadomoceras cadomense*, *Cadomites daubenyi* (Gemm.); *Polyplectites* spp. var., *Lissoceras psilodiscum* (Schlœnb.), *L. monachum* (Gemm).; *Acanthothyris panacanthina*	1	10
Garantianæ...	(4) At base of 3rd Bed is the Shell Bed or *Astarte* Bed, Hudleston's P.1 in part—a soft brownish ironshot. Contains numerous *Crassinella obliqua* and flat evolute *Parkinsoniæ*, *Perisphinctes* of the *P.-martinsi* type; *Ancyloceras*; *Garantiana* spp.; occasional *T.* '*sphæroidalis*.' Derived fossils like *Stepheoceras umbilicus*	0	4
niortensis, ... *blagdeni*, *sauzei*, *Witchelliæ*.	(5) The 4th Bed, or Pink Bed, or Red Bed of the quarrymen. A hard, fine-grained, ironshot, somewhat crystalline limestone, particularly massive. The top is very irregular, and portions of the shell-bed lie in hollows. The fossils represent various dates: they are mostly derived, and covered with limonitic layers. In the lower 9 inches there is more coarse ironshot, irregular; it is coarser towards the bottom. Mixed with it are large limonitic concretions called by the workmen snuff-boxes, with much-bored pieces of *Myoconcha*, *Ctenostreon*, etc., and bits of stone as nuclei. Fossils of the Red Bed, at the top, were *Perisphinctes* sp., of *niortensis* date; *Stepheoceras umbilicus*, of *blagdeni* date; *Skirroceras* cf. *macrum*, *sauzei* date	2	10

Other species from this bed are:—

Blagdeni date: *Pœcilomorphus cycloides*.

Sauzei date: *Stepheoceras freycineti*, *St. bayleanum*, *Sonninia* cf. *patella*; *Acanthothyris paucispina*.

Witchelliæ date: *Witchellia* sp.

There is a rare, but very characteristic, rather large *Terebratula burtonensis*, sp. nov. (see the palæontological paper, p. 99), which is probably of *sauzei* date.

					Thickness in feet	inches.
discitæ, ... *concavi*, *bradfordensis*, *murchisonæ*.	(6)	Yellow Conglomerate Bed.—A thin yellowish marl, containing in irony coatings and often worn condition small fossils of various dates: those of *discitæ* date perhaps most numerous. The bed may generally be seen attached to upturned masses of the Pink Bed......................				
		Discitæ date: Carinatitabulate Hildoceratidæ, *Toxolioceras incisum*, *Braunsina elegantula*; *Haplopleuroceras subspinatum*; *Belemnites blainvillei*; *Nautilus bradfordensis*, *N. exiguus*; *Cœlastarte excavata*.				
		Concavi date: *Ludwigella*.				
		Bradfordensis date: Broken fragments of *Brasilia-bradfordensis* pattern.				
		Murchisonæ (or *Ancolioceras*) date: *Cirrus nodosus*, *Onustus*.				
		Scissi date: *Burtonia* sp., and rock-fragments derived from the				
scissi	(7)	*Scissum* bed. Grey sand-rock with *Tmetoceras scissum*, *Tm. circulare*; *Lioceras* spp. var. See 'Monogr. Inf. Ool. Amm.' Suppl. *Burtonia*; and large *Lima* of the *etheridgi* type			1	6
scissi-opaliniformis.	(8 *a*)	Foxy Bed, Rusty Bed, ironstained sandy marl. *Canavarella* spp.; small Hammatoceratids, *Zeilleria oppeli*, *Rhynchonella stephensi*			0	2
opaliniformis...	(*b*)	Brown sands and sandburrs, with Opalinoid Ammonites in poor condition			1	6
	(*c*)	Sands			2	0
aalensis	(9 *a*)	Sandstone	0	8 }	1	6
	(*b*)	Sands with Ammonites of the *aalensis* pattern in occasional sandburrs	0	10 }		
	(*c*)	Sand and sandburrs continued downwards.				

NOTE:—The sands are known to the natives as 'Fox-mould.' There is a notice in Burton village about the removal of fox-mould and sand, where 'sand' presumably means a sharp grit for building-purposes.

III. Comparison of the Strata.

(*a*) Comparison of the Sections at Burton and Chideock.

Working upwards, from the bottom of the sands to the top of the *scissum* bed, the strata of these two localities seem to be the counterpart one of another, so far as the evidence goes. After the *scissum* bed, changes begin—due to penecontemporaneous erosions. The Wild Bed of Chideock (*Ancolioceras* to *bradfordensis*) is not represented by deposit at Burton; the *discitæ* bed of Burton has not been definitely found at Chideock. The Red Bed of Burton and the Red Beds or Building-Stone of Chideock are only partly on the same horizon, while they differ in lithic character very considerably. The beds yielding fossils of *Witchelliæ* and *sauzei* date are well developed at Chideock, and are rich in specimens; they are poorly developed at Burton. At Chideock, however, there are no strata yielding species of *blagdeni-niortensis* dates. The *Astarte* Bed (*Garantianæ*) is not found at Chideock. In regard to the Top Beds, neither the *truellii* bed nor the *zigzag* bed have been noted at Chideock, where the mass of limestone seems to belong to the position of the 2nd Bed and the lower part of the 1st Bed of Burton (*schlœnbachi*).

(*b*) Other South Dorset Sections.

The general type of the Burton Bradstock Inferior Oolite will be found reproduced with variation of detail in quarries inland, bordering the main road from Bridport to Dorchester. One of these quarries, Vetney (or Vinney) Cross, shows the *Astarte* Bed thicker, and an excellent repository of well-preserved fossils. Farther inland, around Beaminster, the 'Top Beds' are found resting on deposits of different dates—on those of *concavi*, or *bradfordensis*, or *murchisonæ*, according to the quarry. At Broad Windsor the Top Beds rest on strata of *murchisonæ* date in the road-cutting, where the sequence into the sands might be profitably investigated with regard to modern divisions: old notes are not sufficiently detailed.

The Grange quarry at Broad Windsor has produced a remarkable series of fossils, mostly from the *zigzag* and *schlœnbachi* horizons; but the strata of *truellii* date are to be seen.

Between Broad Windsor and Beaminster, however, is a locality which shows a very much more complete sequence than any other in South Dorset, so far as Bajocian-Aalenian beds are concerned. It is Stoke Knap, and deserves some notice.

(*c*) Whaddon Hill, or Stoke Knap.

About 6 miles north of Bridport, and about 7 miles to the northward of Down Cliff, is the locality marked on the Ordnance Survey map as Stoke Knap, known to the natives as Whaddon Hill. It is about midway between Beaminster and Broad Windsor, and is of interest for the development of strata of *bradfordensis* to *discitæ* hemera, which yield a profusion of specimens in excellent condition. The bed in which they occur is known as the Building-Stone; and some years ago, when I was visiting the locality, the workmen took off the bed for me layer by layer, so that it was possible to collect each species *in situ*, and note the change of fauna in one bed.

Mr. H. B. Woodward, F.R.S., has published a section of Stoke Knap.[1] Though it is not detailed enough for my purpose, and he has not numbered his beds, it may usefully be compared with the workmen's divisions and with my dating system.

[1] 'Jurassic Rocks of Britain: vol. iv—The Lower Oolitic Rocks of England' Mem. Geol. Surv. 1894, p. 63.

Section III.—Stoke Knap.

Hemeræ.	H. B. Woodward. Numbers supplied.	Workmen's Terms. Fossils inserted. (S. S. B.)	Thickness in feet	inches.
		'Clay.'		
schlœnbachi	1	'Ragstone'	7	0
	2	[*Terebratula stephani*, *Collyrites ringens*, *Parkinsonia*.]		
	3	'Best Limestone'	4	2
Shirbuirniæ	4	'Roadstone'	1	4
		[Top planed off and covered with oysters. *Sonninia* cf. *adicra* (Waagen). *S.* cf. *fissilobata* (Waagen).]		
		'Waste'	0	5
		[Clay, limestone, and marl in three beds, irregular.]		
post-*discitæ*, *discitæ*, *concavi*, *bradfordensis*, *murchisonæ*, *Ancolioceras* (pars)	5	'Building-Stone.'		
		[See p. 77 for details.]		
		'Bottom Bed.'		
		[To which some Building-Stone may be attached. *Ludwigia lævigata*, *Ancolioceras substriatum*.]		

Hemeræ.	Numbers		Thickness. (H. B. W.)
Ancolioceras (pars) and *scissi* (?).	6	[The Sandy Grits with Brachiopod Beds in the middle. Not economically worked.] (S. S. B.)	4 to 5
	....	....	
	7	....	about 8
scissi-opaliniformis .	8	....	10 to 14
	9	....	6 to 8
	10	....	2 to $2\frac{1}{2}$
	11	....	about 3

The Beds 6–11 (Woodward) may, for distinction's sake, be called the Sandy Grits, with Brachiopod Beds (8 & 10) in the middle. The chief Brachiopods are—*Terebratula whaddonensis* [= '*T. infra-oolithica*'], *Zeilleria whaddonensis*, *Aulacothyris* '*blakei*,' and *Rhynchonella stephensi* (see the palæontological paper, pp. 101 *et seqq.*). Of Ammonites which have been recorded from these Sandy Grits, without precise horizon, are—*Lioceras uncinatum* and *Canavarella belophora* (type): there are many Ammonites in poor condition.

These Sandy Grits are later than *aalensis* hemera, so far as my collecting goes. They may be dated approximately as *Ancolioceras-scissi-opaliniformis*; but they have not been studied sufficiently for present detailed work. The ferruginous clayey seam [9] of Woodward suggests correlation with the Rusty Bed of Burton Bradstock; possibly then the Brachiopod Beds (8 & 10) are a thickened development of the Rusty Bed, and should really be dated as pre-*scissi*–post-*opaliniformis*.

Section III *a*.—Stoke Knap Building-Stone (detailed).

(In square brackets are names of species known to be from the Building-Stone, but their exact layer was not ascertained: it is here suggested.)

		Thickness in feet	inches.
post-*discitæ*...	1st Bed.—Top bed of Building-Stone. Brown iron-shot limestone. *Stepheoceras*, and *Oppelia* of the *præradiata* pattern[1]	0	4
	2nd Bed.—Bluish-grey ironshot limestone. No fossils except at the bottom, where there were impressions of those in the bed below	0	5
discitæ	3rd Bed.—Yellowish ironshot limestone with (on top) numerous carinatitabulate Hildoceratids. *Darellina dorsetensis*, *Reynesella piodes*, *Lopadoceras arcuatum*, *L. euides*; *Rhynchonella forbesi*, *Terebratula eudesi*; *Stepheoceras*. *Graphoceras* sp. at the bottom	0	7
	[*Sonninia inæqua*, *S. lævigata*; *Depaoceras fallax*, *Platygraphoceras latum*, *Pl. apertum*, *Reynesia laxa*, *Œdania lepta*, *Reynesella juncta*, *R. inops*, *Lopadoceras furcatum*, *Darellia polita*, *Dissoroceras subornatum*, *Stokeia marmorea*.]		
	4th Bed.—Greyish-yellow, hard, ironshot limestone; the iron grains being numerous, and of fair size. *Megalytoceras confusum*, *Graphoceras* spp.	0	5
concavi	5th Bed.—Similar to 4, but harder. *Graphoceras* spp. *Ludwigella casta*	0	7
	[*Ludwigella concava*, *L. tenuis*, *Lucya marginata*, *Graphoceras v-scriptum*.]		
bradfordensis .	6th Bed.—Similar ironshot. Ammonites of *Brasilia-bradfordensis* pattern, *Graphoceras* sp.; *Rhynchonella ringens*; *Ludwigella arcuata*, *L. carinata*, *Pseudographoceras limatum*	0	6
	Then there is attached to the top of the bottom bed, which is whitish limestone, some of this ironshot bed with *Brasilia* spp.	0	6
	[*Wiltshireia gigantea*, *Brasilina tutcheri*, *Ludwigella flexilis*, *L. rugosa*, *L. nodata*, *Vacekia stephensi*, *Zurcheria pugnax*, *Welschia rustica*, *Apedogyria platychora*.]		
		3	4

(*d*) South and North Dorset.

Since the present communication is supplementary to that on the 'Bajocian of the Sherborne District' and in part to that 'On the Cotteswold, Midford, & Yeovil Sands,' it may be desirable to show the comparison of the strata on the Dorset Coast with those found in North Dorset; and it will be interesting to see how the chronological arrangement introduced for the North Dorset strata several years ago can be followed out in those of the coast.

Table III, facing p. 78, shows the comparison: some illustrative remarks are also appended.

[1] *Sonninia densicostata* (Monogr. p. 376), labelled 'Beaminster,' was probably from Stoke Knap from the 1st or 2nd Bed; its character is of later pattern than that of the *discitæ* species. Going from Stoke Knap to Beaminster, in each quarry more and more of the Building-Stone is found to be denuded and removed until it quite disappears; so Stoke Knap is the likely place.

IV. Remarks on Hemeral Terms.

Schlœnbachi.—This term was suggested by me in some MS. notes to a paper by Munier-Chalmas [1] whence it was inadvertently copied by Mr. Richardson.[2] It is a term for dating the strata which had been hitherto called inter-*truellii-zigzag*.[3]

Whereas at the top of the 'Top Beds' of Burton Bradstock there is a distinct Ammonite fauna, *Zigzagiceras* spp., *Morphoceras* spp., and *Parkinsoniæ* of the *depressa* type with rounded whorls, and of the *P. lævis* (Quenstedt) pattern with involute trigonal whorls; and in the lower part of the 'Top Beds' there is a fauna with *Strigoceras truellii*, and *Parkinsoniæ* of the *P.-parkinsoni* type with flattened whorls: there is in the 2nd Bed of Burton Bradstock and in the lower part of the 1st Bed a series of *Parkinsoniæ* different in character from those above or below—they are massive forms with stout, somewhat squared whorls.

Thus, on the evidence of Burton and other Dorset localities, there is need to recognize a date of deposition later than *truellii* and earlier than *zigzag* hemera. But Mr. Richardson's investigations in Somerset have shown that this refinement was most necessary; for between strata of *zigzag* date (there basal Fullers' Earth) and strata of *truellii* date (Upper Coral Bed) he finds three noticeable deposits—Rubbly Beds, *Anabacia* Limestones, and Doulting Stone (*loc. cit.*); and, as regards the Cotteswolds, he would put the *Clypeus* Grit (sometimes over 30 feet thick) as belonging to this date.[4]

Shirbuirniæ.—The deposit of this date was formerly known as hemera *Sonniniæ*, but a generic rearrangement of the numerous forms of *Sonninia* will have to be undertaken. The true *Sonniniæ*, the platyleptogyral, angustumbilicate, alticarinate species of the *Sonninia-propinquans* type, are found only in a deposit of *sauzei* date.

The type-species of the genus *Shirbuirnia* will be described in the palæontological paper (pp. 92 *et seqq.*).

The deposit of *Shirbuirniæ* hemera is noticeable, because it is of the date of the celebrated deposits of Gingen (Würtemberg), the Ammonites from which were described by Dr. W. Waagen.

In this country a deposit of *Shirbuirniæ* date is only found in perfection at one quarry, Sandford Lane near Sherborne (Dorset), where it forms the bottom part of the fossil-bed. Here it has produced an extraordinary abundance of remarkable Ammonites, most of which are new: they have waited over 40 years to be figured and described. And in this country the channels for palæontological publication are becoming more and more unable to keep pace with the new discoveries of geologists.

[1] C. R. Soc. Géol. France, 1892, no. 14, pp. 164–67.
[2] Proc. Cotteswold Nat. F.-C. vol. xvi, pt. 2 (1908) p. 188.
[3] L. Richardson, Quart. Journ. Geol. Soc. vol. lxiii (1907) p. 423.
[4] Proc. Cotteswold Nat. F.-C. vol. xvi, pt. 2 (1908) p. 187.

›ORNE DISTRICT: CORRELATION OF CERTAIN
TE DEPOSITS.

›erborne District.	Remarks.	
3. Limestone (Top Beds) of Bradford Abbas and Halfway House.	Basal Fullers' Earth of Midford District.	
Sandy Stone, Bradford Abbas and Stoford.	Rubbly Beds (R.). *Anabacia* Limestones of Doulting District (R.).	*Clypeus* Grit of Mid and North Cotteswolds.
'ossil Bed of Halfway House.	Doulting Stone (R.). Upper Coral-Bed.	
›ubbly Bed of Sherborne.	Dundry Freestone.	

(R.) = L. Richardson's divisions.

Table III.—Dorset Coast and Sherborne District: Correlation of certain Lias-Oolite Deposits.

Hemeræ.	Dorset Coast, etc.	Sherborne District.	Remarks.
A. *fuscæ*	Lower Fullers' Earth clay and the Scroff.	A, B. Limestone (Top Beds) of Bradford Abbas and Halfway House.	
B. *zigzag*	Top of Stone Bed. Top of 1st Bed.		Basal Fullers' Earth of Midford District.
C. *schlœnbachi*	Lower part of 1st Bed and all 2nd Bed of Burton.	? C. Sandy Stone, Bradford Abbas and Stoford.	Rubbly Beds (R.). *Anabacia* Limestones of Doulting District (R.). Doulting Stone (R.). (all three:) *Clypeus* Grit of Mid and North Cotteswolds.
D. *truellii*	*Terebratula* Bed of Burton.	D. Fossil Bed of Halfway House.	Upper Coral-Bed.
E. *Garantianæ*	Shell Bed of Burton. (E–F)	E. Rubbly Bed of Sherborne.	Dundry Freestone.
F. Do.		F. Building-Stone of Sherborne.	Upper *Trigonia* Grit.
G. *niortensis*	Fossils mixed in Pink Bed of Burton. (G–K¹) ? White Jura Bed of Burton.	G., H. Roadstone of Frogden.	*Teloceras* Zone. Mascke in North Germany. (*Teloceras* to *Sonninia* Zones)
H. *blagdeni*			*Stepheoceras* Zone. *Stephanoceras* Zone. *Stemmatoceras* Zone.
J. *sauzei*	Red Beds. Building-Stone of Chideock. (J–K¹)	J. Upper; Portions of Fossil Bed of Sandford Lane. (J–K)	*Otoites* Zone.
K¹. *Witchelliæ*		K. Middle	*Emileia* Zone.
K². *Shirbuirniæ*	? Base of Building-Stone of Chideock. Roadstone of Stoke Knap.	K. Lower	*Sonninia* Zone.
L¹. post-*discitæ*	Layers 1, 2 of the Building-Stone of Stoke Knap. (L¹–N)	L. L.s of Sandford Lane.	*Terebratula-buckmani* Grit of the Cotteswolds.
L². *discitæ*	Layers 3, 4	L. Upper part of Fossil Bed of Bradford Abbas.	Lower *Trigonia* Grit of the Cotteswolds.
M. *concavi*	Layer 5	Lower part of Fossil Bed of Bradford Abbas.	Divided into five distinct deposits in the North Cotteswolds.
N. *bradfordensis*	Layer 6	N. *Rhynchonella-ringens* beds of various localities.	
O. *murchisonæ*	Bottom Bed of Stoke Knap. Upper part of Wild Bed, Chideock.	O. Paving-Bed of Bradford Abbas.	Horizon of *Zeilleria anglica*.
P. *Ancolioceras*	Lower part of Wild Bed, Chideock. Base of Stone Bed of Mapperton, Misterton, Haselbury, etc.	P. of various localities.	Lower Limestone of the Cotteswolds.
Q. *scissi*	Sandy limestone, base of Stone Beds, Chideock and Burton.	P. (*pars ?*) of Marston Road + Q.	Sandy ferruginous beds of the Cotteswolds.
Q¹. *opaliniformis*	Foxy Bed, Burton, with subjacent sands and sand-rock.	Not found.	Hard capping of the Cephalopod Bed of the Cotteswolds.
Q². *aalensis*	From about 6 feet down to about 40 feet of Bridport Sands at Chideock.	Not found.	First marly layer of the Cephalopod Bed of the Cotteswolds.
R. *moorei*	About 50 feet down in sands at Chideock.	R. Dew (Dhu) Bed of Bradford Abbas and underlying Sands. = Ham Hill Building-Stone.	*Rhynchonella-cynica* horizon.

(R.) = L. Richardson's divisions.

This Sandford Lane bed was only worked once, for economic purposes, about 1875. It was opened up again specially for the purpose of the paper on the 'Bajocian of the Sherborne District'.[1] It is evident that the collecting that can have been done from this deposit must be a mere scratch of the surface; yet the results are remarkable, and the beautiful preservation of the Ammonites is extraordinary.

At a few other localities evidence of a deposit of *Shirbuirnia* date can be detected by a few ill-preserved Ammonites: for instance, at Dundry (Somerset), and in the Gryphite Grit of the Cotteswolds; but, for all practical purposes, the quarry of Sandford Lane is the one place in the kingdom, known at present, where the deposit could be studied, and that place has been closed these 40 years.

Ancolioceras.—The finding of Opalinoid Ammonites in the base of the *murchisonæ* bed has before now led to the supposition that there was a certain mixture of forms of *murchisonæ* and *opalinum* (*scissum*) zones. The explanation would appear to be that what has been regarded as the base of *murchisonæ* is really of an earlier date.

At Chideock Quarry Hill the lower part of the Wild Bed is of different matrix from the upper part: it yields a Lytoceratoid, but does not furnish any Ammonites of the *murchisonæ* pattern. In the neighbourhood of Beaminster, strata at the base of *murchisonæ* yield *Ancolioceras cariniferum* and similar forms; but they were not associated with Ammonites of the *murchisonæ* types. Around Crewkerne (Somerset) there are several species more or less allied to *Ancolioceras costatum*, and they seem to be somewhat peculiar to that district ('Monogr. Inf. Ool. Amm.' Suppl. 1899, p. xlix).

At Misterton, which is near Crewkerne, the strata hitherto regarded as early *murchisonæ* yield Lytoceratoids of the style of *Pachylytoceras aalenianum*. At Chideock the bed yielding the Lytoceratoid is in position above the *scissum* bed and below the *murchisonæ* bed; and is distinct from both by its matrix. Presumably then the Misterton strata are on the same horizon.

At Chideock in the *murchisonæ* part of the Wild Bed is a characteristic brachiopod, *Zeilleria* [*Waldheimia*] *anglica*. This is a noticeable species, which may be followed a long way.

At Chideock the strata dated *Ancolioceras* are below the *anglica* horizon. At Haselbury Mr. Hudleston recorded a thickness of 2 feet 5 inches between the *anglica* horizon and the 'Base Bed'[2] (presumably *scissum*).

In my descriptions of strata of the Sherborne District[3] the *anglica* horizon is marked as O; and a lower level (P), 2 and 3 feet thick, was noted for Halfway House and Louse Hill. But the P noted for Marston Road (*op. cit.* p. 490) is apparently wholly or in part *scissum*.

[1] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 479.
[2] 'Monogr. Brit. Jurass. Gasteropoda' (Palæont. Soc.) 1887, p. 41.
[3] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 489.

However, in Dorset-Somerset the strata which it is suggested should be dated as *Ancolioceras* are those above *scissum* and below the *anglica* horizon.

In the Cotteswolds, there is between the Sandy Ferruginous Bed (*scissum*) and the Pea Grit (*murchisonæ*) a considerable development known as the Lower Limestone: it is suggested that this should be dated *Ancolioceras*.

Various species of Ammonites of which the horizon has been given 'near base of limestone-beds,' and the date as *murchisonæ* or doubtful between *murchisonæ* and *scissi*, are presumably more correctly to be dated as *Ancolioceras* hemera: for instance, the following species:—*Ancolioceras cariniferum*, *A. substriatum*, possibly *A. costatum*, *Geyeria fasciata*, and *G. evertens*. Investigation will probably reveal others, which in former days were recorded under the too comprehensive term *Ludwigia murchisonæ*.

Moorei, *Dumortieriæ*.—The strata of these dates make a fine showing in the cliffs of the Dorset coast as the Bridport Sands[1] and Down Cliff Clay: they attain a thickness of nearly 200 feet.[2] The Bridport Sands and the subjacent clay are represented around Yeovil in Somerset by the Yeovil Sands, which are also of considerable thickness and have yielded many species of *Dumortieriæ*, as at Yeovil Junction, Furzy Knaps near Yeovil, Bradford Abbas, etc. The Ham Hill Stone is a local development of calcareous beds of *moorei* date.

The Yeovil Sands have suffered denudation, because around Yeovil they end with the Dew (Dhu) Bed, which contains *Dumortieriæ* like those in the *moorei* bed of Chideock Quarry Hill. Somewhere between Crewkerne and Yeovil the failure of the *aalensis-scissi* beds begins.

In the neighbourhood of Ilminster, Barrington, and Shepton Beauchamp, the Yeovil Sands rest upon clay of *dispansi* date: in these places the strata of *variabilis* date are a thin development of clayey limestones very well charged with Ammonites.[3]

Around Yeovil the sands become bluish and clayey in their lower part: this may be of *dispansi* date. But the argillaceous limestones of the Upper Lias on which this blue part rests gives no certain evidence for later date than *striatulus*; the principal strata are *falcifer*, *bifrons*, *striatulus*, all thin, without *variabilis*. The same beds are found at Glastonbury Tor; there is no sign of *variabilis* forms among the fossils lying about in the fields.

The deposit of sands between Yeovil and the Mendips presents a field not yet investigated. When the Somerset & Dorset Railway was made, a cutting in the sands at Cole Station near Bruton (Somerset) yielded some fine specimens of *Hammatoceras* and Lytoceratoids. I obtained a few of these, many years afterwards, by

[1] Excepting the upper 40 feet which are *aalensis* to *scissi*. See fig. 4, p. 70, showing the Bridport Sands of Burton Bradstock.

[2] 210 feet, *teste* E. C. H. Day, possibly including the upper 40 feet.

[3] See Monogr., *Haugia-Lillia* series.

accident, from a man who had been employed as a mason on the line; and, in a collection of Ammonites sent to me for determination from Yale University, New Haven (Conn.), U.S.A., there was a fine *Hammatoceras* without further localization than England: there is no doubt that it came from Cole, on account of its condition and matrix. These Hammatocerata mark the Yeovil Sands of Cole as belonging to the *dispansi* hemera in date; but I have never had the opportunity of inspecting the deposit in this neighbourhood.

To return to the *moorei-Dumortieria* beds. In North Somerset, at Dundry, the *Dumortieria* Beds appear as a thick clay-deposit. In the Cotteswolds, they and the *moorei* beds are found as a thin deposit of ironshot marl or marly stone, in the middle of the so-called 'Cephalopod Bed'; but they are not recorded in the Cotteswolds north of Haresfield. There is some indication of the beds at Bredon Hill,[1] but in the rest of the Lias outcrop they are not known until they are met with as '[the Yellow and] Grey Sands below the Dogger' of the Yorkshire Coast.[2]

The 'Grey Sands' are also divided as the *Lingula* Bed, and the *Serpula* Bed above it.[3]

Hudlestonia sinon (Mon. Amm. p. 227) is from the Grey Sands. *H. affinis* (*ibid.* p. 229) was sent as from the 'Yellow and Grey Sands'; but presumably it is from the Grey Sands: these species indicate *Dumortieria* date. *Dumortieria munieri* (Mon. pl. xxxvii, figs. 14 & 15), evidently from Blea Wyke (Yorkshire), ought to be from the same beds. On this evidence the 'Grey, but not the Yellow, Sands' are of *Dumortieria* date; but whether it is the *Lingula* Bed or the *Serpula* Bed, or both, that are of this date is uncertain.

The identification of Ammonites quoted from these beds cannot be trusted, unfortunately. A specimen in the Museum of Practical Geology (Jermyn Street), 4423, labelled '*Am. aalensis* var. *Moorei*, bottom bed,' cited by Mr. C. Fox Strangways[4] and by Mr. R. H. Rastall[5] as from the *Serpula* Bed, is really an unidentifiable fragment of a body-whorl $1\frac{1}{2}$ inches long. It shows remains of a small distinct carina, which makes its agreement with any *aalensis* form (Fam. Hildoceratidæ) or any *moorei* form (Fam. Polymorphidæ) almost impossible. It shows a Hildoceratid radial line, agreeing with fig. 155, Monogr. Suppl. p. clxvii, which happens to be *Phlyseogrammoceras orbignyi*, a species sent to me by Hudleston from the *striatulus* beds (Mon. p. 188) but suggestive of *dispansum* date. This, therefore, should not occur above the *Lingula* Bed (*Dumortieria*) except by derivation; the evidence of a fragment like this, even if determined with some certainty, is not of any value.

Since the above was written, Mr. L. Richardson has shown me specimens of Ammonites collected by him 4 feet from the top of the *Lingula* Bed: they are *Hudlestonia* sp. (*affinis* form) and

[1] Quart. Journ. Geol. Soc. vol. lix (1903) p. 447.
[2] 'Monogr. Inf. Ool. Amm.' (Palæont. Soc.) p. 168.
[3] W. H. Hudleston, Proc. Geol. Assoc. vol. iii (1874) p. 296.
[4] 'Jurassic Rocks of Yorkshire' vol. i, Mem. Geol. Surv. 1892, p. 153.
[5] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 444.

Phlyseogrammoceras cf. *dispansum*. They date the *Lingula* Bed as *Dumortieriæ-dispansi* hemera, and make it exactly contemporaneous with the middle part of the Gloucestershire Cephalopod Bed, and with the lower 100 feet of the Yeovil Sands near Yeovil.

Striatuli-spinati (The Junction Bed).—There are two situations in which the Junction Bed of the coast can be studied *in situ*: in the cliffs and on the beach in the fallen blocks. In the cliffs is the best place to find the *striatulus* layer; and, after scraping away some of the overlying clay, portions of this layer can be detached with a chisel, and then broken up for examination. One of the best places for this purpose is on the west side of Doghus Cliffs; but curiously enough, even in the cliffs, the *striatulus* layer is often missing. It is always missing, so far as my knowledge goes, from the Junction Bed at Thorncombe Beacon, and it is rarely found in the blocks on the shore: small portions of it may sometimes be found loose on the shore.

For general examination of the Junction Bed, the shore is the best place; but, as the blocks are often upside down, care is required in collecting. A heavy hammer and good chisels are also necessary.

The complete series of the Junction Bed is seldom, perhaps never found. While the *striatulus* layer, if it be met with, is only found under Down and Doghus Cliffs, the basal Marlstone layer is not present until one is well under Thorncombe Beacon. Even then the upper layer of Marlstone—Day's *Pleurotomaria* Bed[1] presumably—is often absent.

Sometimes the greenish rock—the *falciferum* layer—is absent; sometimes it is 10 inches thick, at other times 3 inches. The most persistent rock is the pink rock—the *bifrons* layer; there seems to be no failure of this. Its colour reminds one of the colour of *bifrons*-yielding beds of the Toarcian of Lombardy. The pink bed is generally separated from the *falciferum* layer by an ironstone band 1 to 2 inches thick.

With a little practice it is quite easy to distinguish the different layers when they are lying detached from blocks: roughly there are—the white (*striatulus*), the pink (*bifrons*), the greenish (*falciferum*), and the brown (Marlstone).

J. F. Blake's suggestion that the Junction Bed was an aggregate deposit formed at one time by the sweepings of various zones[2] fails to meet the facts of the case: there are not only the layers of distinct matrices, but they contain their distinctive fossils, in definite sequence. It is true that there has been erosion and redeposition nearly all the time: thus the Marlstone is conglomeratic, and contains sometimes Blue Lias pebbles (? *algoviani*, or lower); the *bifrons* bed sometimes holds broken and worn specimens of *Harpocerata*, which really belong to the bed below; while the

[1] Quart. Journ. Geol. Soc. vol. xix (1863) p. 284.
[2] 'Excursion to Bridport, &c.' Proc. Geol. Assoc. vol. xv (1898) p. 295.

specimens that properly belong to the *bifrons* bed are often worn, iron-coated, and deposited on edge.[1]

The *striatulus* layer appears to be quite a regular deposit; but then there is a big gap between the *striatulus* layer and the *bifrons* bed—a time during which about 250 feet of strata were laid down in the Cotteswolds.

With regard to Day's *Pleurotomaria* Bed—the top layer of the Marlstone[2]—I do not feel certain of having met with it, unless it be the *serrata* bed mentioned above (p. 65). But, considering how often certain beds are locally missing from the Junction Bed, it is quite possible that it may be a layer just above the *serrata* bed, only developed occasionally. In the Jermyn Street Museum there are the following Ammonites from Upper Lias of Chideock [=Junction Bed of Down Cliffs]—R. No. 22475, *Dactylioceras* cf. *tenuicostatum* (Young & Bird), and 22514, *Dactylioceras crassiusculosum* (Simpson). The first of these is a species from the *annulatus* zone of Yorkshire, and Martin Simpson records the second from the Jet Rock, which is higher. It may be interesting, therefore, to compare the Dorset and Yorkshire Toarcian.

V. Pre-*striatulus* Toarcian.

(*a*) Dorset and Yorkshire Coasts compared.

The difference in development is remarkable. On the Dorset coast the pre-*striatulus* Toarcian beds are packed into a seam of calcareous stone about 2 feet thick. On the Yorkshire coast, according to a useful section given by Martin Simpson,[3] they occupy nearly 200 feet. An epitome of Simpson's section and divisions of the Yorkshire Toarcian is given on p. 84 (Table IV), with the dates, according to my interpretation, at the side. Tate & Blake's rendering is also given, correlated with Simpson; the correlation is fairly obvious, except with regard to Beds 1–10, where they have a far greater thickness. Alongside is the development of the Dorset strata of the same dates.

Simpson's Division 1, by the species recorded and known to come from there, was deposited during five hemeræ—*dispansi–bifrontis*. The bulk of the strata of the division probably belong to the date of *bifrons*; but there is good evidence for the others. For *dispansi* hemera, *Phlyseogrammoceras orbignyi*, S. Buckman (Monogr. p. 188) and *Ammonites gubernator*, Simpson—a Lytoceratoid, probably *Alocolytoceras* near to *perlæve*, Denckmann. For *striatulus* date the evidence is abundant—the term '*striatulus* shales' is in use; and species of this facies are plentiful at the Peak. For *variabilis–lilli*, the latter perhaps dubious, there is evidence, in the Whitby Museum collection of types, of a rich Ammonite fauna:—*A. obliquatus*,

[1] The Red Bed and the Yellow Conglomerate Bed of Burton Bradstock would conform much more to Blake's requirements for an aggregate deposit; they are made up of sweepings from deposits of various dates.

[2] Quart. Journ. Geol. Soc. vol. xix (1863) p. 288.

[3] 'Fossils of the Yorkshire Lias' 2nd ed. (1884) pp. ix–xiv.

TABLE IV.—COMPARISON OF YORKSHIRE AND DORSET TOARCIAN.

Tate & Blake. 1876.		Simpson. 1884.		Thickness in feet
Zone of *A. jurensis*, p. 190.	Beds 1–10.	Alum Shale.	Division 1	34
Zone of *A. communis*, p. 182.	Beds 11, 12.	Alum Shale.	Division 2	18
	Beds 13, 14.	Alum Shale.	Division 3	18
	Bed 15.	Alum Shale.	Division 4 *A.* '*ovatus*.'	18
	Bed 16.	Hard Shale.	Division 5 *a*	10
Zone of *A. serpentinus*, p. 174.	Beds 1, 2.	Hard Shale.	Division 5 *b* *A. mulgravius*.	12
	Beds 3, 4.	Hard Shale.	Division 6 *A. mulgravius*.	24
	Bed 5.	Jet Rock.	Division 7 *A. exaratus*.	20
Zone of *A. annulatus*, p. 168.		Grey Shales.	Division 8 *A. annulatus* [= *A. tenuicostatus*].	40
			Total	191

Dorset Coast.

	inches.	
striatulum	2	Upper Lias of the Junction Bed.
lilli	2	
bifrons	10	
falciferum	8	
[1] Total	1′ 10″	

[1] The stratum at Down Cliffs which yielded *Dactylioceras* cf. *tenuicostatum* and *D. crassiusculosum* (see above, p. 83) shows that the Grey Shales and Jet Rock are represented in Dorset. Perhaps this stratum is the *Pleurotomaria* Bed, base of *falciferum* or top of Marlstone.

Young & Bird, *A. fabalis*, *A. beani*, *A. phillipsi*, *A. rudis*, Simpson, are species of the *Lillia-Haugia* series, indicative of deposits of *lilli-variabilis* dates: they are fine specimens too. There is also *Haugia patelliformis*[1] = *Ammonites obliquatus*, Simpson, *pars*, *non* Young, indicative of *variabilis* beds.

I have not yet seen the type of *Hildoceras hildense* (Young & Bird); but, from their figure, it appears to be a species of the *lilli* beds, from its likeness to my *H. semipolitum* which is so characteristic. The *Ammonites hildensis*, Simpson, is another species; it occurs in the Jet Rock, and has no likeness to Young & Bird's figure.

In Divisions 2 & 3 Simpson records no Ammonites: Tate & Blake appear to have *Ammonites bifrons* from about this level.

In Division 4 there is evidence of a deposit made during a period of time of which there is not evidence in the south—a hemera of *ovatus*. However, this is not the true *Ammonites ovatus* of Young & Bird's first edition, though it is of their second: they had a happy knack of changing names.

The Hard Shale and the Jet Rock give nearly 70 feet of deposit during the *falciferi* hemera; unless, as seems possible, this can and ought to be subdivided into an earlier and a later period.[2]

Interest now centres in the Grey Shales, or *annulatus* beds of Tate & Blake. First, the *Ammonites annulatus* is wrongly named: it is *A. tenuicostatus*, Young & Bird: with it occurs *A. semicelatus*, Simpson, and both belong to *Dactylioceras*. It is best to call this the deposit of *tenuicostati* hemera.

The point that now remains for consideration is this:—What relation does the stratum of *tenuicostatus* bear to the stratum of *Seguenziceras acutum* (Tate)—the Transition Bed of the Midlands? Is it of the same date, or earlier, or later? The question is difficult to answer, because it is impossible to trust the identifications of the *Dactylioceras* Ammonites. To answer this question, it may be advisable to consider the relationship of the Yorkshire and Midland Toarcian strata; and this, through the kindness of Mr. Beeby Thompson, I am able to do in greater detail than when the preceding paragraphs were first penned.

(*b*) Yorkshire and other Districts compared.

Since this paper was written, Mr. Thompson, in answer to certain queries which I addressed to him with regard to the correlation of the Northamptonshire and Yorkshire Upper Lias, placed in my hands some MS. of a paper just printed off by the Geologists' Association. This MS. is valuable, for it shows that Mr. Thompson, from his study of the Northamptonshire Upper Lias, finds it necessary to increase the number of zones, a process that I was contemplating for this paper from a consideration of the records of the Yorkshire strata.

[1] 'Monogr. Inf. Ool. Amm.' Suppl. pl. iii, figs. 1–3.

[2] Mr. Thompson has done this since these words were penned, see later in this page.

The following Table shows Mr. Thompson's results, summarized and compared with details of Yorkshire and Gloucestershire strata, while at the side is placed the zonal classification which appears to be necessary for future work:—

TABLE V.—COMPARISON OF TOARCIAN DEPOSITS.

Gloucestershire generalized.	Northamptonshire, from Mr. Beeby Thompson's MS., summarized.		Yorkshire, based on Simpson (& see Table IV, p. 84).	Zonal or hemeral terms.
Lilli beds, or lower part of Cotteswold Sands.		Upper *Leda-ovum* or *lilli* beds.	The lower part only of Simpson's Division 1.	*lilli.*
The *bifrons* or *communis* beds.		Oyster Bed.		
	braunianum zone.	Middle *Leda-ovum* Beds.		*braunianum.*
		Lower *Leda-ovum* Beds.		
		Unfossiliferous beds or *fibulatum* zone.		*fibulatum.*
	Upper Cephalopod Bed.	*Communis* bed or *subcarinatum* zone.		*subcarinatum.*
			Division 2.	'*ovatum.*'
			Division 3.	
			Division 4 with *A.* '*ovatus.*'	
The *falcifer*, or *serpentinus*, or fish-and-insect beds.	Lower Ceph. Bed.	*falcifer* beds.	Divisions 5 & 6. *A. mulgravius.*	*falciferum.*
		Fish-beds or *latescens* zone.	Division 7 with *A. exaratus.*	*exaratum.*
The *Leptæna* Beds.		Paper Shale.	Division 8 with *A. tenuicostatus.*	*tenuicostatum.*
acutum layer on top of Marlstone.		*acutum* zone.	? Top of Ironstone Series, if present.	*acutum.*

From the foregoing Table it will be seen that Mr. Thompson finds the greatest development (in the way of faunal change) of Upper Lias, in Northamptonshire, to be in the strata once called *bifrons* or *communis* beds. Here he makes five divisions, and names three zones—*braunianum, fibulatum, subcarinatum.* There is good reason to suppose that all these zones could be detected in Yorkshire; only that they are more obscure from paucity of sediment. But in Yorkshire Simpson's Divisions 2, 3, & 4 (some 50 feet of strata) appear to be a development not found in Northamptonshire; for this series I was proposing a zonal name, and *Ammonites* '*ovatus*' will have to do duty temporarily, though the identification is incorrect (see above, p. 85).

Below the '*ovatus*' bed of Yorkshire is the *mulgravius* bed, and below this again the Jet Rock series with *A. exaratus*, etc. It is evident from the Yorkshire strata that there are two zones, and I was preparing to name them in this paper. I find that Mr. Thompson, from his study of the Northamptonshire strata, has reached the same conclusion independently, and has named the lower zone *latescens* zone. I hesitate to adopt this: a study of Yorkshire types throws much doubt on identifications of *Ammonites latescens*, and on its horizon; while of *A. exaratus* the type is definitely known, and so too its bed.

Below the *exaratum* zone (Jet Rock) of Yorkshire is the deposit known as the 'Grey Shales', or *annulatus* zone of Tate & Blake. As the species is not *A. annulatus*, but is *A. tenuicostatus*, Young & Bird, a change of name is desirable. Below the *latescens* zone of Northamptonshire is a small deposit of paper-shale; and below the equivalent of the *exaratum* zone of Gloucestershire is the deposit called the *Leptæna* Beds, which are certainly above the *acutum* layer. The suggestion may, then, be made that the *Leptæna* Beds of Gloucestershire and the South-West of England are of about the same date as the *tenuicostatum* zone of Yorkshire, and that this zone is later in date than the *acutum* zone or Transition Bed of the Midlands. It may be admitted that this is at present only a suggestion based on stratigraphical evidence, and that the faunal evidence is mainly negative—that is to say, that the fossils of the *acutum* zone and of the *tenuicostatum* zone are different, implying that the zones are sequential, not contemporaneous. So here is a working hypothesis: to prove or disprove it further evidence is required.

(*c*) Migration of Areas of Maximum Deposit.

The migration from north to south of the area of maximum development of the Toarcian strata in England is an interesting phenomenon. It seems to be a regular progress from earliest beds in the north to latest beds in the south; but, no doubt, further knowledge will show some irregularity. Present results are given in the accompanying Table (VI, p. 88):—

Table VI.—Migration of Areas of Development in the Toarcian.

	Zones.	Localities.	Approximate development. Feet.
Yeovilian.	*moorei* .... *Dumortieria* .	South Dorset	200
	dispansum ... *struckmanni* .	Mid and North Somerset	100[1]
	striatulus ...	South Cotteswolds	240
Whitbian.	*variabilis* ... *lilli*		
	braunianum . *fibulatum* ...... *subcarinatum*.	Northamptonshire	150[2]
	ovatum .... *falciferum* ... *exaratum* ...... *tenuicostatum*.	Yorkshire	160
		Total	850

Owing to this migration of area of maximum deposit, it happens that the strata of the Toarcian in any one English locality do not exceed much over 250 feet in thickness, and are often far less; yet the amount of work done in deposition during that time is equal to 850 feet or more.

Though the Toarcian is now divided into fourteen zones, these zones can hardly be called minute divisions, when some of them develop thicknesses of 100 or more feet each and maintain these for many miles.

Since the Toarcian thus contains so many zones, it is often necessary to speak of the earlier of these zones as distinct from the later, or *vice versa*, and as the circumlocutory phrases pre-*striatulus* Toarcian, *striatulus* and post-*striatulus* Toarcian are very awkward, it is now suggested that the former be called Whitbian and the latter Yeovilian. The Whitbian would contain the zones *tenuicostatum* to *variabilis* inclusive, all of which are more or less finely developed on the Yorkshire coast in the neighbourhood of Whitby; while the Yeovilian would contain the zones *striatulum* to *moorei* inclusive, and certain of these are remarkably developed in the Somerset-Dorset district.

The special faunal feature of the Whitbian is the development of the Lias *planulati* (Dactylioidæ, Hyatt) which are very numerous in most of the zones; while the feature of the Yeovilian is the absence of all Dactylioidæ, but the development of Grammoceratinæ, of Hammatoceratidæ, and of *Dumortieria*.

The names would mark another distinction—the difference between the Cotteswold and other sands in date. Thus, the Cotteswold Sands being pre-striatulan would be Whitbian; but the

[1] Estimate, data uncertain.

[2] Average thickness according to Mr. Beeby Thompson.

Yeovil Sands, the main mass of the Bridport Sands, and the Midford Sands in a strict sense, being post-striatulan would be, therefore, Yeovilian. Owing to a non-sequence in the Yeovil district, the finish of the Yeovil Sands coincides with the end of the Yeovilian, which makes the name appropriate; but, there being a due sequence in the Bridport area, the upper part of the Bridport Sands is later than Yeovilian: it is Aalenian.

VI. Summary.

(1) Descriptions are given of certain strata (Lower Bathonian to Pliensbachian) on the Dorset coast—Chideock and Burton Bradstock.

(2) Comparison is made with similar strata inland—with a summary of beds at Stoke Knap; with certain North Dorset strata; and with Toarcian beds of Yorkshire and Northamptonshire.

(3) The strata described are classified according to what may be called the multizonal or polyhemeral system—in the main, according to the scheme introduced for these strata in 1893[1]; but further divisions due to other investigators and to myself are dealt with.

(4) The strata described are arranged among thirty-six zonal (hemeral) divisions—a greater number of divisions than Oppel used in 1856 for all the Jurassic rocks, of which these beds form but a small part.

(5) The Upper Lias part of the Junction Bed of Down Cliffs, Chideock (Lower or pre-*striatulus* Toarcian), is a very condensed, imperfect epitome in 20 inches of about 180 feet of strata on the Yorkshire coast, and of very much more when allowing for gaps.

(6) Between the *bifrons* layer and the *striatulus* layer of the Junction Bed there is occasionally a 2-inch layer which is all that represents some 250 feet of deposit in the Cotteswolds—so that about 2 feet of Junction Bed was formed while a thickness of some 550 feet was being deposited elsewhere.

(7) The Upper Toarcian (*moorei-Dumortieriæ* hemeræ) makes a great showing at Burton Bradstock and Down Cliffs as the Down Cliffs Clay and Bridport Sands (*pars*), the greatest thickness of rocks of these dates in the kingdom.

(8) The sequence of *aalensis* strata above *moorei* beds is demonstrated at Chideock Quarry Hill, in the upper part of the Bridport Sands.

(9) The Inferior Oolite (Aalenian, Bajocian, Bathonian, *pars*) strata of Burton and Chideock are not counterparts of one another: they supplement each other to a certain extent: both are incomplete and much epitomized representations of thicker deposits elsewhere.

(10) Mr. Beeby Thompson's zonal scheme for the Upper Lias is considered, and a table of Upper Lias zones for future work is presented.

[For the Discussion, see p. 109.]

[1] Quart. Journ. Geol. Soc. vol. xlix, p. 481.

4. *Certain* Jurassic (' Inferior Oolite ') Species *of* Ammonites *and* Brachiopoda. By S. S. Buckman, F.G.S. (Read November 3rd, 1909.)

[Plates IX–XII.]

Contents.

I. Introduction.

The species described or mentioned in the following pages have a more or less definite connexion with the Jurassic strata of the Dorset coast described in the foregoing paper[1]; but, although this communication is offered as an Appendix to that one, it may perhaps more rightly be regarded as an Appendix to that and the other communications on similar strata mentioned on p. 53.

The Inferior Oolite rocks are so remarkably prolific in species of Mollusca and Molluscoids—there is so great a number of species yet awaiting description—that there seems to be an idea among those who have not studied the rocks in the field, that they receive a kind of preferential treatment in this respect. Another explanation may be suggested—that our judgment as to the time occupied in the forming of the so-called 'Inferior Oolite' strata is warped owing to their tenuity—that they represent a time during which destruction of strata was particularly active, therefore the remaining deposits are only the fragmentary representatives of a whole.

This is particularly the case in Dorset. A schoolboy once defined a net as a series of holes strung together, and the Dorset Inferior Oolite might be defined as a series of gaps united by thin bands of deposit. And one reason for the prolificness of the deposits is that the amount of deposit can be no indication of the amount of time, as shown by the changes in successive faunas; and also that the deposits are so local—the deposits of one place correspond to the gaps of another. Therefore many localities have to be placed together to produce the full tale of the Inferior Oolite. The very local distribution of Inferior Oolite species often means that strata of particular dates have only been preserved in a few favoured localities.

The beds of the 'Inferior Oolite,' in a restricted sense, have now been divided as deposits of about twenty-two successive dates or hemeræ.[2] The total for the whole of the Jurassic would not be more than about eighty-five, or perhaps, on an extended scale, a

[1] Alluded to as 'the stratigraphical paper.'
[2] See the stratigraphical paper, p. 55.

hundred hemeræ. Therefore, according to this reckoning, the few feet of Inferior Oolite represent from about a quarter to a fifth of the total time occupied in the deposition of the entire Jurassic System.

One can hardly view the few feet of Inferior Oolite limestone at Burton Bradstock, about 15 to 20 feet say, and imagine that it represents an interval of time equal to a quarter or a fifth of the whole Jurassic Period—a time during which thousands of feet of strata were laid down. But this is because we do not allow sufficiently for the gaps.

If anything like this supposition be correct, then the Inferior Oolite prolificness is understandable: it should represent in species as many as would form from a quarter to a fifth of the total for the Jurassic System. At that rate, its tale is nothing like complete yet; which all workers in its rocks know to be the case.

For most of the photographs of Ammonites which illustrate this paper, and for all the photographs of Brachiopods, I desire to express my best thanks to my enthusiastic friend, Mr. J. W. Tutcher, whose excellent work I have acknowledged on other occasions; but all such acknowledgments and thanks fall very far short of the measure of my indebtedness to him.

In the descriptions of some of the following species of Brachiopoda, the consequences of a former lack of zonal divisions of strata will be noticed. Because the top beds of the Inferior Oolite—from *Garantiana* to *fusca* in some cases, from *truellii* to *zigzag* in others—were called simply *parkinsoni* zone, the dates of some species are uncertain within these limits: that is to say, which species are truly contemporary and which are successive, was not properly noted at the time of collecting, because the strata were grouped too comprehensively.

II. Descriptions of Ammonites.

Family **Amaltheidæ** (subfamily **Sonnininæ**).

Genus Shirbuirnia,[1] nov.

Definition.—Whorls stout, trigonal, with considerable inclusion. Ornament coarse, but showing rapid decline to levigate stage. Carina distinct, not large, hollow. Suture-line not complex; superior lateral lobe broad-stemmed, short. Lobules short, inequipoised; terminal lobule endobrachysceles; inner lobes not dependent.

Distinction.—From *Sonninia* (*S. propinquans* series), the stout whorls, the rather small carina, the not complex suture-line, the broad-stemmed superior lateral lobe. From *Dorsetensia*, of which

[1] Sherborne (Dorset), where the species of the genus are found; but I would also like to associate with the name my kind friend, Mr. C. Davies Sherborn, as a small expression of thanks for his invaluable bibliographic assistance on many occasions.

the suture-line has somewhat this pattern, but is less lobulate, the stout whorls, the coarse ornament, and the smallish carina, are distinctions.

In *Sonninia* the whorls are much compressed; the carina is very strong—it is distinctly an alticarinate genus; the suture-line is very complex; the lobes are long; the superior lateral lobe is narrow-stemmed. In *Dorsetensia* (*D. liostraca* series) the whorls are much compressed and the carina is very strong; but the suture-line is of a type much simpler than in *Shirbuirnia*. From the '*Sonniniæ* of the *concavum* zone' there is no need to consider the various distinctions, because they ought to be separated from *Sonninia*. From *Dorsetensia edouardiana*, which is the type of the genus *Dorsetensia*, there is also little need to consider distinctions; the regular costate stage and the absence, except on inner whorls, of a tuberculate stage, show the different line of development in that case.

SHIRBUIRNIA TRIGONALIS, sp. nov. (Pl. X, figs. 2 & 3.)

Description.—Gradumbilicate; ornament-stages irregularly tuberculate-costate, declining to levigate.

Remarks.—The inner whorls show various small costæ, with occasional irregular, inner marginal nodi. Later these ornaments decline into complete smoothness.

The trigonal shape of the whorl gives a pronounced wall to the umbilicus. Specimens of this species have lain in my cabinet, with the description now given, for some dozen or more years awaiting description. The species is interesting, because its fellows are found in Würtemberg[1]; and because the fauna which they typify is only found in perfection in one place in England, namely, at Sandford Lane Quarry, Sherborne (Dorset).

Locality and stratum.—Dorset, Sherborne, at Sandford Lane Quarry, in the bottom part of the Fossil Bed; Bajocian.

Date of existence.—*Sonniniæ* hemera. This should now be altered to hemera of *Shirbuirnia trigonalis*; for *Sonninia* sensu stricto belongs only to the *sauzei* hemera.

The holotype of this species is a large adult specimen, which could not be adequately figured in these pages. It is about 325 mm. in diameter, showing little else than a smooth catagenetic stage. The umbilicus expands in the last turn, attaining a breadth of 120 mm. The whorl-section becomes more and more trigonal or galeatiform with age, the breadth of the whorl just about the inner margin being about 98 mm., making allowance for the thick test which borders the umbilicus. The umbilical bordering wall becomes very conspicuous.

The paratype specimen, of which figures are given (side view ×0·86 and front view ×0·61), shows the nodaticostate stage of the inner whorls (the nodi being somewhat irregular swellings on the inner margin) passing into the levigate stage.

[1] See the *Ammonites sowerbyi* fauna figured by Quenstedt, 'Amm. Schwäb. Jura' 1886, pls. lxi & lxii. *A. sowerbyi gracililobatus* is possibly a *Shirbuirnia*.

Another species of this genus is

Shirbuirnia stephani (S. Buckman).

1882. *Amaltheus (?) stephani*, S. Buckman, 'New Species of Ammonites' Proc. Dorset N. H. & A. F.-C. vol. iv, p. 138 & pl. i, fig. 1.

This species is angustumbilicate, the whorls being occluded almost to the inner margin; but the slopes of the inner margins being convex, it cannot be described as concavumbilicate. The species is wholly levigate, and shows nothing of the tuberculate stage. It differs therefore in umbilication and in ornament from *Sh. trigonalis*; but it differs really because it has inherited at an earlier date the senile characters of that species. It shows the same characteristic suture-line, and the trigonal whorl-section is fairly marked. The type specimen has the complete mouth-border, quite plain, with a slight peripheral projection.

This species comes from the same beds and the same place as *Shirbuirnia trigonalis*.

Genus **Sonninia**, Bayle.

Sonninia subtrigonata, S. Buckman. (Pl. XI, figs. 4–6.)

This species was described in 'Descent of *Sonninia* & *Hammatoceras*' Quart. Journ. Geol. Soc. vol. xlv (1889) p. 659; but it was not figured, as it was supposed that it would soon be illustrated in my Monograph of the Inferior Oolite Ammonites. As that supposition has not been realized and is not likely to be accomplished, and as Mr. Tutcher has kindly made photographs of the type, it seems desirable to give the illustrations now, to show what an alticarinate *Sonninia* (a true *Sonninia*) is like, such as is mentioned in the stratigraphical paper, p. 55.

Locality and stratum.—[Sandford Lane] Sherborne (Dorset) [from the *sauzei* zone by matrix]; see Quart. Journ. Geol. Soc. vol. xlix (1893) p. 492, Bed J *a*.

Family **Oppelidæ**.

Genus Bradfordia,[1] nov.

Type Bradfordia liomphala, sp. nov.

Definition.—Compressed, involute, keelless; inner area more or less sunken to a shallow sulcus, bordered by a more or less raised rim at the edge of the concave inner margin. Radii wide-angled, v-script, without peripheral projection, passing on to the periphery and more or less distinctly over it.

Distinction.—The absence of the carina distinguishes the genus from *Oppelia*; and the concave inner margin with its rim bordering a depressed zone distinguishes it from *Lissoceras*, which also shows a different run of radial line—sigmoid with peripheral projection.

[1] Bradford Abbas.

BRADFORDIA LIOMPHALA, sp. nov. (Pl. X, figs. 4 & 5.)

Description.—Whorls much compressed, especially around the umbilicus, which is smooth and gradate with an ill-defined rim. Ornament not strong: costæ on outer two-thirds of whorl, inner third almost smooth.

Remarks.—This species has lain in my cabinet for some twenty years, with the trivial name *liomphala* attached. It first attracted attention on account of its remarkable likeness to some of the concavumbilicate, or rather subconcavumbilicate Ammonites—species of the type of *Ludwigella concava* (Sow.), *Graphoceras v-scriptum*, S. Buckm., etc., which were all once known as *Ammonites concavus*, Sowerby. These are all keeled species of the family Hildoceratidæ; but when this species lay in the rock with its keelless periphery hidden, it was doubtless often passed over as 'only a common *A. concavus*.' This perhaps accounts partly for its rarity; but when the keelless condition was noted, and search was made for the species, no more than some twenty specimens were the reward of much collecting, though the *concavus*-like ammonites were obtainable by hundreds.

To *Platygraphoceras apertum*, S. Buckm., *Graphoceras limitatum*, S. Buckm., and especially to *Pseudographoceras compressum*, this species bears very great resemblance. In fact, in relation to the latter it is almost a case of isochronous homœomorphy. The distinction in all those species is a keel and a costate umbilicus.

From *Oppelia subplicatella*, Vacek,[1] pl. xi, figs. 2 & 3 (which seem not to be the same species as his pl. xi, fig. 1), the different direction of the ribs is sufficient distinction. With *O. subplicatella* (fig. 1) the different size of umbilicus and the different thickness of whorls prevent any comparison.

Locality and stratum.—Bradford Abbas (Dorset), from the Fossil Bed: and certainly by matrix from the upper part; Stoford (Somerset), from a similar bed.

Date.—*Discitæ* hemera.

BRADFORDIA COSTATA, sp. nov. (Pl. X, fig. 6 & Pl. XI, fig. 1.)

Description.—Whorls comparatively stout (for a species of this genus); ribs somewhat coarse; umbilical rim small, but distinct.

Distinction.—From *Bradfordia liomphala*, stouter whorls and coarser ornament.

Locality and stratum.—Bradford Abbas (Dorset), in the upper part of the Fossil Bed. Zone of *Hyperlioceras discites* (Bajocian).

BRADFORDIA INCLUSA, sp. nov. (Pl. IX, figs. 2 & 3.)

Description.—Compressed, much included; umbilicus small; depression on the inner area of the whorl distinct, making the umbilical rim distinct.

[1] 'Ueber die Fauna der Oolithe von Cap San Vigilio' Abhandl. k.k. Geol. Reichsanst. vol. xii (1886) p. 82.

Distinction.—From *Bradfordia liomphala* or *Br. costata*, the smaller and deeper umbilicus, which gives to the central area a quite distinct appearance. The whorl is stouter than that of *Br. liomphala*, but almost as stout as that of *Br. costata*; the degree of costation, however, agrees with that of the former.

Locality and stratum.—Stoke Knap (Dorset), from the Building-Stone. It is most likely from the top layer, and so it may be of the date of the post-*discitæ* hemera.

Note.—*Oppelia preradiata*, Douvillé,[1] is not a *Bradfordia*, though there is much likeness to *Br. inclusa*; for Douvillé describes the ribs of his species as being slightly turned forwards, and ending abruptly on the edge of the periphery. These are not characters of *Bradfordia*: and in *Br. inclusa* especially the ribs meet about the central line of the periphery, but they are alternate, not opposite.

BRADFORDIA ETHERIDGII (S. Buckman).

1882. *Haploceras etheridgii*, S. Buckman, 'New Species of Ammonites' Proc. Dorset N. H. & Ant. F.-C. vol. iv, p. 143; *Œcotraustes* (misprinted *Occotranstes*), pl. iii, fig. 3.

Remarks.—This species may be regarded as a *Bradfordia*. It has the umbilical rim and general appearance of the other species; but its whorls are stouter and more involute.

Localities and strata.—Bradford Abbas (Dorset), from the Fossil Bed, and presumably the upper part. Dundry (Somerset), apparently, by matrix, from the Limestone and Marl beds.

Date.—Presumably *discitæ* hemera.

Genus Œcotraustes, Waagen.

ŒCOTRAUSTES SPINIGER, sp. nov. (Pl. XI, fig. 7.)

Description.—A much compressed, rather widely umbilicate, and almost smooth Oppelid, with a flattish uncarinate periphery. The only ornament is some obscure falcate parvicostæ, and on each edge of the periphery, for a part of the outer whorl, a row of small tubercles. The mouth-border shows the base of a lateral linguiform projection.

Distinction.—This species is something like *Œcotraustes serriger* (Waagen)[2]; but is thinner, with a narrower and more definite periphery, has a large umbilicus, and a different arrangement of tubercles. Our species has a superficial resemblance to some of the *Bonarelliæ* of the Oxfordian; but the ribbing is different.

This species has much likeness to *Oppelia echizenica*, Yokoyama[3]; but that has larger and more distant peripheral tubercles, possesses a keel, and a different whorl-section. And as it is very different in date, being Oxfordian or post-Oxfordian, the resemblance probably is only accidental.

[1] Bull. Soc. Géol. France, ser. 3, vol. xiii (1884–85) p. 33.

[2] 'Die Formenreihe des *Amm. subradiatus*' Geogn. Pal. Beitr. vol. ii, pt. ii (1869) p. 230 & pl. xx, fig. 8. His fig. 7 appears to be quite another species.

[3] Journ. Coll. Sci. Tokyo, vol. xix (1904) art. 20, p. 8 & pl. i, fig. 7.

Remarks.—This species is interesting, as being about one of the earliest of the Oppelids to develop periphero-lateral tubercles: there are apparently successive independent developments of such 'spinigerous' forms as *Œcotraustes*, *Oppelia*, *Hecticoceras*, *Bonarellia*, and *Taramelliceras*. The actual earliest form is probably *Oppelia (Œkotraustes)* sp. nov. indet., figured by Vacek from the Oolite of Cap San Vigilio.[1] That Oolite is evidently, judging from the Ammonites, of varied dates, extending from *aalensis* to *discites*: the latter, probably, is the date of Vacek's unnamed form.

Locality, etc.—Frogden Quarry, Oborne (Dorset), in the Marl Bed with green grains; Dundry (Somerset), in the Ironshot Oolite. Its date is therefore *sauzei* hemera (Bajocian). It is rare. It might be expected in the Red Beds of Chideock Quarry Hill; and perhaps at Burton.

Family Hildoceratidæ.

Genus Darellia, S. Buckman.

For description of the genus and species, see 'Monogr. Inf. Ool. Amm.' (Palæont. Soc.) Suppl. 1904, p. cxii.

Darellia alta, sp. nov. (Pl. XI, figs. 2 & 3.)

Description.— One of the carinatitabulate Hildoceratids, much compressed, with a small narrow-stepped umbilicus, and ornament passing from obscuricostate to levigate.

Distinction.—From *Darellia polita*, the smaller umbilicus, the narrower periphery, and the more elevated carina.

Remarks.—This is one of the rare and interesting Cotteswold species which serve to show that the Lower *Trigonia* Grit of the Cotteswolds is contemporaneous with certain strata in Dorset.

Localities and strata.—Frith Quarry, near Painswick, Gloucestershire (Cotteswolds), Lower *Trigonia* Grit; Dundry (Somerset), Limestone and Marl Beds; Stoke Knap (Dorset), in the Building-Stone: all these would be strata of the zone of *discites*. Mr. Charles Upton possesses a specimen from Rodborough, Gloucestershire (Cotteswolds), presumably from Lower *Trigonia* Grit, which is abnormal on one side, apparently a reversion, due to injury, to the style of *Darellia semicostata*.

Genus Œdania, S. Buckman.

For description of the genus and species, see 'Monogr. Inf. Ool. Amm.' (Palæont. Soc.) Suppl. 1904, p. cvii.

Œdania obscura, sp. nov. (Pl. IX, figs. 4 & 5.)

Description.—This is one of the carinatitabulate Hildoceratids; but the keel is small. It is a thin form, though the body-chamber shows a tendency to thicken; the umbilicus is small, step-form; the ornament consists only of obscure falcate ribs.

[1] Abhandl. k.k. Geol. Reichsanst. vol. xii (1886) pl. ix, fig. 13.

Note.—In the side view the umbilicus is imperfect, and so appears too large: the dots show the true position of the inner margin of the last part of the whorl, giving an inclusion of about half a whorl.

Distinction.—It is separable from any other species of the genus, by the deficiency and paucity of its costation, as well as by other characters.

Locality and stratum.—Bradford Abbas (Dorset), from the Fossil Bed; three specimens, whereof the one figured is the largest. It is evidently from the *discites* zone, and there is reason to think that it occurs in the Yellow Conglomerate Bed of Burton Bradstock.

Family Hammatoceratidæ.

Genus Burtonia, nov.

Whorls stout, inclusion considerable; ornament when present coarse; carina small, solid; suture-line not ornate; superior lateral lobe somewhat long, broad-stemmed, trifid; inner lobes much retracted (dependent)—running back and pointing across the whorl.

Fig. 1.—*Skeleton outline of the lobes of* Shirbuirnia.

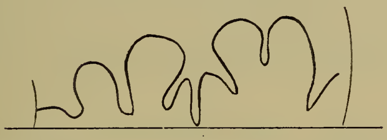
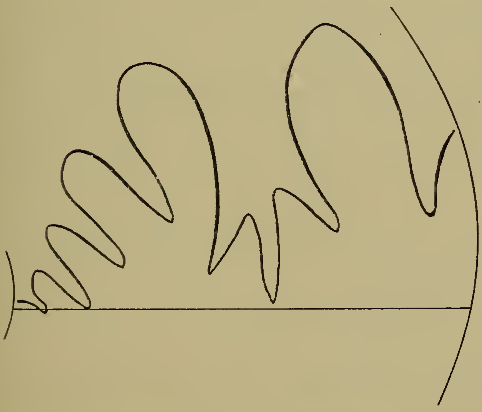


Fig. 2.—*Skeleton outline of the lobes of* Burtonia.



Distinction.—From its ally, *Hammatoceras*, the coarse ornament and the much less complex suture-line; from any of the Hildoceratidæ, to some genera of which it has superficial resemblance—to *Kiliania* for instance,—the retracted or dependent inner portion of the suture-line.

This genus belongs to a series entirely different from *Shirbuirnia*. The essential character is the retracted or dependent inner portion of the suture-line. Instead of the lobes appearing like so many protrusions from a straight line, as in fact the lobes of *Shirbuirnia* do, the inner portion of the suture-line in *Burtonia* looks as if that part hung from a line which had fallen down at one end. Thus a line connecting the tops of the saddles in *Shirbuirnia* runs from the periphery nearly straight to the centre, while the lobes are almost at right angles to it and parallel to one another. But a similar line in *Burtonia* runs in an oblique curve; and, instead of the axes of the inner lobes being parallel with that of the superior lateral, they would, if produced, cut across the axis of this lobe and strike the periphery (see figs. 1 & 2, p. 97).

This retracted character of suture-line is found in the genera *Hammatoceras* and *Erycites*, to which *Burtonia* is most nearly allied. The first is a carinate genus like *Burtonia*; the second is not carinate. The character is found in the large uncarinate families Deroceratidæ and Stepheoceratidæ; and it may be concluded that the *Hammatoceras* series is akin to them,—is probably an offshoot of the Deroceratidæ. The character is not observed in the great carinate groups, the Sonnininæ and the Hildoceratidæ. In general appearance *Burtonia* is very like examples of these groups; and its possession of a carina makes the resemblance closer; but the lobe-character is the distinction.

Species of this genus characterize the strata of the *scissi* hemera. Most of the specimens have been found in the beds of this date at Burton Bradstock; and they may be readily recognized when seen protruding from the massive fallen blocks on the shore.

Burtonia crassornata, sp. nov. (Pl. IX, fig. 1 & Pl. X, fig. 1.)

Description.—Gradumbilicate; crassornate—inner marginal bullæ and coarse costæ; periphery concavifastigate, parvicarinate.

Remarks.—The inner whorls, as seen in the umbilicus, show a succession of very strong, closely-set tubercles (bullæ); on the outer whorl these have declined to coarse, not prominent primary costæ, whence proceed the coarse secondary costæ. All the ornament gradually declines, and there is a tendency to levigation.

Distinction.—The species nearest to this—of those yet figured—is *Hammatoceras feuguerollense*, Brasil[1]; but the species now described has a larger umbilicus, coarser ornament, and much stouter whorls.

Another species, with somewhat generally similar appearance, is *Ammonites alleoni*, Dumortier[2]; but his species is flexicostate, and its ornament is much less stout.

Locality and stratum.—Dorset, Burton Bradstock (Aalenian). [In the bed containing *Liocerata* and *Tmetoceras scissum*.] The figured specimen has no record of its bed: it belonged to my father's collection, and was probably purchased; but matrix and condition are good guides.

[1] 'Niveau à *Ammonites opalinus*' Bull. Soc. Géol. Normandie, vol. xv (1893–94) p. 39 & pl. v, figs. 1–2.

[2] 'Ét. pal. Dép. jurass. Bassin du Rhône' pt. iv (1874) p. 259 & pl. lii, figs. 3 & 4.

Note.—*Hammatoceras feuguerollense* may certainly be placed in the genus *Burtonia*; and *Ammonites alleoni* would be more correctly placed there than in *Hammatoceras*; yet the different character of its ribbing may probably lead to separation even from *Burtonia*, when the species of these genera are better known.

III. Descriptions of Brachiopoda.

Terebratula burtonensis, sp. nov. (Pl. XII, figs. 11 & 12.)

Description.—A much inequivalved, incipiently biplicate Terebratulid. Dorsal valve rather flattened, ventral valve very gibbous. Lateral margin with curve projected dorsally in the anterior region; anterior margin with dorsally elevated, broad, median plication, which is only slightly sulcate—incipient biplication. Beak curved over, small, with small foramen hiding deltidial plates.

Distinction.—Is like *T. siderica*, S. Buckman,[1] but is a larger and more massive shell, more inequivalve and less biplicate.

Remarks.—Is apparently one of the *T. ventricosa*-*T. buckmani* series, which has attained to uniplication of the raised (dorsal) linguiform pattern, and is beginning to become biplicate.

Locality, etc.—From the Red Beds of Burton Bradstock (Dorset); about *sauzei* date or perhaps later. Several more or less complete examples have been obtained.

Terebratula lowensis,[2] nom. nov. (Pl. XII, figs. 9 & 10.)

1882. *Terebratula buckmani*, var. *buckmaniana*, S. Buckman (*non* Walker), Proc. Dorset Nat. Hist. & A. F.-C. vol. iv, p. 13.
1893. '*Terebratula buckmaniana*' Quart. Journ. Geol. Soc. vol. xlix, p. 489.

Description.—An obovoid, nearly equigibbous, incipiently biplicate Terebratulid. Ventral valve but little more tumid than dorsal, lateral margin almost straight, anterior margin only slightly and broadly M shaped, without dorsal linguiform projection. Beak short, not curving over the dorsal umbo, obliquely truncated by a small foramen.

Distinction.—*T. buckmaniana*, Walker[3] (in Davidson) is a longer, narrower, and more cylindrical shell. *T. perovalis*, Rothpletz,[4] is comparable, but is certainly not Sowerby's species.

Remarks.—Though the late Mr. J. F. Walker often spoke of this shell as *T. buckmaniana*, he generally qualified it as the Dorset form. Other students have done the same, and hence a distinctive name is desirable. The shell is certainly a development of the

[1] Proc. Cotteswold Nat. F.-C. vol. xiii (1901) p. 248 & pl. xiii, fig. 11.

[2] Louse Hill. Louse is due to folk etymology and the west-country habit of adding the sign of the genitive to place-names; it is not connected with a louse, but is low (Anglo-Saxon hláw, a hill), the same as in Ludlow, Bledlow. So it seems convenient to adopt the form *lowensis* for Low Hill.

[3] 'Brit. Jurassic Brach.' (Palæont. Soc.) Suppl. 1878, pl. xix, figs. 15, 17 only.

[4] 'Geol.-pal. Monogr. Vilser Alpen' Palæontographica, vol. xxxiii (1886) p. 100 & pl. ii, figs. 15–16 only.

Terebratula-buckmani series which is commencing biplication, and has proceeded very little with it. Its more equivalve shape and want of projection of the fold separate it from *T. burtonensis.*

Locality, etc.—The Irony Bed of Louse Hill (near Sherborne, Dorset), and of other quarries around, has produced this species in some abundance. It is of *blagdeni* date (Bajocian).

TEREBRATULA STIBARA,[1] sp. nov. (Pl. XII, figs. 5 & 6.)

Description.—A tumid, biplicate Terebratulid, with well-developed folds. Ventral valve rather more gibbous than dorsal. Lateral margin a good deal curved; anterior margin of a well-developed M shape. Folds and furrows reaching about half way up the valve, except the median ventral fold, which is more or less a continuous carina up to the beak. Beak short, stout, hardly overhanging the umbo, obliquely truncated by a medium-sized foramen.

Distinction.—*T. stephani*, Davidson, of which the type is figured in Proc. Dorset Nat. Hist. & Ant. F.-C. vol. i, pl. i, fig. 3 (1877), is a thinner, longer, and more biplicate shell, showing none of the tumid habit of this species.

Remarks.—This species is evidently a tumid development of the *T.-stephani* series, though hardly of that species itself. Its 'fatness' and rotundity make it a very distinct form.

Locality, etc.—Crewkerne Station (Somerset), Broad Windsor and Burton Bradstock (Dorset), have yielded various specimens in Mr. J. W. D. Marshall's collection and my own. They come from the 'top beds of the Inferior Oolite'; and have not been more accurately dated, for want of subdivisional names for these beds. The species is of about *schlœnbachi* date, perhaps *zigzag*, perhaps both.

TEREBRATULA VINNEYENSIS,[2] J. F. Walker, MS. (Pl. XII, figs. 7 & 8.)

Terebratula sphæroidalis, auctt. (pars).

Description.—A small, flattened, spheroidal Terebratulid with uniplication, the margin curved to form an inconspicuous though broad, dorsally projected, flattened fold. Beak somewhat large; foramen small; deltidial plates hidden.

Distinction.—*T. sphæroidalis*, J. de C. Sowerby, though so often quoted, is a species about which very little is known; and the specimens called by that name seldom agree with his figure. That species differs from the form now described by being more spheroidal, having 'the edges of its valves even' (Sowerby), a more dumpy beak, and valves not so flattened anteriorly (tapering, side view). *T. subsphæroidalis*, Upton,[3] is more in character with the present species, but that is more globose and has a small ∩ fold: the fold of Walker's species may be described as a flattened π fold.

Remarks.—The late Mr. J. F. Walker separated this form some

[1] *στιβαρός*, stout.

[2] Vinney Cross is the native name of what is called Vetney Cross, about 2 miles east of Bridport (Dorset).

[3] Proc. Cotteswold Nat. Hist. F.-C. vol. xiii (1899) p. 124 & pl. iii, figs. 5–7.

years ago, and with his usual kindness distributed specimens among his friends under this MS name, to which I have pleasure in giving effect as a small tribute to a generous friend. The figured specimen belongs to Mr. J. W. D. Marshall's collection, being one of a series of the species presented to him.

Locality, etc.—This small species occurs in some abundance in the top beds of the Inferior Oolite of Vinney (Vetney) Cross, of Burton Bradstock, and of other localities near Bridport (Dorset); it is also found at Broad Windsor, Bradford Abbas, Louse Hill, and many other places in Dorset and South Somerset. Its date is approximately *schlœnbachi*.

Terebratula whaddonensis,[1] nom. nov. (Pl. XII, figs. 15 & 16.)

1882. *Terebratula infra-oolithica*, S. Buckman (*non* E. Deslongchamps), Proc. Dorset Nat. Hist. & Ant. F.-C. vol. iv, p. 15.

Description.—A nearly circular, somewhat tumid, biplicate Terebratulid. Side-margin curved, and anterior margin forming a distinct M fold. Beak short, with distinct beak-ridges; it barely overhangs the dorsal umbo, and is well separated from it, showing rather wide deltidial plates; foramen small.

Distinction.—When compared with Deslongchamps's type-figure of *T. infra-oolithica*[2] and with specimens from Condé-sur-Sarthe, one of Deslongchamps's special localities, the English examples show several slight but noticeable differences. They are more circular, being less acuminate posteriorly, the beak and beak-area being broader, shorter and blunter; they are more tumid, especially the area of the dorsal umbo; they have a more curved side-margin and more distinct folds; while the beak has more distinct beak-ridges. But there is a further difference, that of punctation, although too little attention has been paid to this matter yet, and its significance is not understood. However, in *T. infra-oolithica* the punctæ are arranged in very close, slightly waving lines, the spaces between the lines being very narrow. In *T. whaddonensis* the punctæ are arranged in irregular waving lines, which are distinctly separated by plain spaces.

Locality, etc.—The species is fairly common in the sandy grit of Stoke Knap (Whaddon Hill) near Broad Windsor (Dorset), and at Little Silver near Haselbury (Somerset). It has occasionally been found at Chideock Quarry Hill and at Burton Bradstock, in the strata below the *scissum* bed. The date of the beds which yield *T. whaddonensis* has not been determined with the accuracy required for modern work, but *scissum-opaliniformis* expresses it approximately: they are apparently about on the line between the beds of these two dates. As *T. infra-oolithica* is said to come from *opalinus* beds by Deslongchamps, but from *murchisonæ* beds by Dr. Brasil (label with specimens), its date may really be *Ancolioceras*, and so there may be some difference in date between it and *T. whaddonensis*.

[1] Whaddon Hill is the native name for the eminence known as Stoke Knap.
[2] In A. d'Orbigny's 'Terr. Jur.: Brachiopodes' (Pal. franç.) pl. lvii, fig. 7.

TEREBRATULA ARENARIA, sp. nov. (Pl. XII, figs. 17 & 18.)

Description.—An obovate, inequigibbous, biplicate Terebratulid. Dorsal valve flattish, ventral valve gibbous, less so anteriorly. Side-margin curved, and anterior margin producing a distinct M fold. Beak short, stout, with indistinct beak-ridges; foramen somewhat small, with a labiate extension almost touching the umbo and hiding the deltidial plates.

Distinction.—When compared with *T. whaddonensis*, it is seen to differ in shape and proportions in many respects. *T. varicans*, Rothpletz [1] is a smaller, narrower, and for its age more plicate species; other figures differ still more.

Locality, etc.—In the same beds and localities as *T. whaddonensis*; but scarce.

AULACOTHYRIS CUCULLATA, nom. nov. (Pl. XII, figs. 1 & 2.)

1882. Shells like *Waldheimia meriani*, S. Buckman, Proc. Dorset Nat. Hist. & Ant. F.-C. vol. iv, p. 34.

Description.—A broad, short naviculoid, with a deep sulcus in the dorsal valve, and an elevated carina in the ventral. Beak curved over like a monk's cowl, strong beak-ridges, and a small foramen.

Distinction.—Resembles a dwarf *Aulacothyris meriani* (Oppel), but is much more sulcate for its size. Is a larger and more sulcate shell than *A. doultingensis*, Richardson, its possible ancestor.

Locality, etc.—In brown clay on the top of the *zigzag* bed of Grange Quarry, Broad Windsor (Dorset); not uncommon. Its date is therefore early *fuscæ* hemera, and it should be found in the Scroff or overlying Fullers' Earth Clay at Burton Bradstock.

ZEILLERIA WHADDONENSIS, sp. nov. (Pl. XII, figs. 13 & 14.)

Description.—An elliptical, tumid, smooth Dallinine, with an almost even margin, a tumid ventral valve posteriorly, a stout curved-over beak with strong ridges, a small incomplete foramen, and narrow deltidial plates.

Distinction.—*Zeilleria oppeli*, S. Buckman,[2] is a more circular and flatter shell, lacking the elongate character: that form agrees more with the young stage of the present shell.

Locality, etc.—Stoke Knap (Whaddon Hill) and Chideock Quarry Hill (Dorset), in the sandy grits with *T. whaddonensis*. *Z. oppeli* characterizes the Rusty Bed of Burton (see section, p. 74). The species now described might be expected in the same place or just below.

[1] 'Geol.-pal. Monogr. Vilser Alpen' Palæontographica, vol. xxxiii (1886) p. 97 & pl. iv, fig. 3 only.
[2] Quart. Journ. Geol. Soc. vol. lii (1896) p. 702.

Zeilleria lingulata, sp. nov. (Pl. XII, figs. 3 & 4.)

Description.—A subdiamond-shaped, somewhat flattened Dallinine, with the pointed anterior margin slightly projected dorsally like a little tongue. Both valves somewhat gibbous, the ventral more so than the dorsal. Growth-halts conspicuous at intervals. Beak-areas pronounced, flattened, broad; beak-ridges well defined. Foramen rather large, incomplete.

Distinction.—This shell is something like *Waldheimia emarginata*, Szajnocha[1]; but that does not resemble Sowerby's species. Prof. Szajnocha's shell has the same little 'turn up in front' (as it is generally called) as the species now described, whence the name *lingulata*; but that is not a character of Sowerby's shell.

Macandrewia disculus, Waagen,[2] is a rounder shell, with a less acuminate beak, a straight side-margin, and showing no sign of the anterior lingulate character.

Locality, etc.—Not uncommon in the top beds of the Inferior Oolite at Grange Quarry (Broad Windsor, Dorset). Scarce in the 'Top Beds' of Bradford Abbas (Dorset); and I have a note of a specimen similar to this species being found in the Coralline (Upper Coral) Bed (*truellii* zone) of Dundry, Somerset. The date of the species may be stated approximately as *schlœnbachi-truellii* hemeræ. It may confidently be looked for in the Top Beds of Burton Bradstock.

Note.—The growth-halts which impart to the shell a banded appearance, are very noticeable in some specimens, and seem to constitute a distinctive feature in combination with its other characters. They remind one of the growth-halts of the recent *Bouchardia*.

Rhynchonella pentaptycta, sp. nov. (Pl. XII, figs. 19 & 20.)

Description.—A small, subglobular, tripartite costate Rhynchonellid, ornamented normally with about eleven well-marked ribs, of which three are on each lateral area and five are on the median area. The median fold of the dorsal valve projects above the lateral areas, anteriorly, so that the line of valve-junction uniting lateral and median areas is about twice as long on each side of the median area as it is between any rib and furrow. The sinus on the ventral valve is much sunken: lengthwise it forms a regular gibbous curve. The ribs are prominent, with deep furrows, and so the line of junction is strongly indented. The beak is small and short, the foramen small, hypothyrid, and touching the dorsal umbo: it is bounded laterally by small deltidial plates.

Distinction.—The deeply sinuated line of valve-junction is the most characteristic feature. There is nothing figured by Davidson like this shell: *Rh. moorei*[3] has quite different proportions,

[1] 'Die Brachiopoden-Fauna der Oolithe von Balin' Denkschr. k. Akad. Wissensch. Wien, vol. xli, pt. ii (1879) p. 214 & pl. iv, fig. 18 only.

[2] 'Zone des *Am. Sowerbyi*' Geogn.-Pal. Beiträge, vol. i, pt. 3 (1867) p. 638 & pl. xxxi, fig. 8; fig. 9 is more elliptical.

[3] 'Monogr. Brit. Jur. Brach.' (Palæont. Soc.) 1876, pl. xv, fig. 11.

and lacks the characteristic valve-junction. Nor is there any one among the small *Rhynchonellæ* figured from strata of about the date of our species by Botto-Micca[1] or Meneghini[2] that is comparable. *Rh. frontalis*, E. Deslongchamps,[3] is also about a contemporary, but it has a feeble likeness to the Dorset species: it has only ribs around the margin, differs in proportions, lacks the very sinuous valve-junction, and so on; nevertheless it forms its mesial fold in somewhat the manner of the Dorset form.

Remarks.—I discovered this interesting little species in the *aalensis* beds of the Bridport Sands of Chideock Quarry Hill in the year 1893, and have distributed specimens under the present name (or something similar) to various Brachiopodists, who, like the late Mr. J. F. Walker and Mr. Charles Upton, have since been able to confirm the horizon of the species.

Although the name *pentaptycta* is given for the five plaits on the dorsal fold, there is, of course, variability in this respect. Of 88 specimens collected during the first visit there were the following forms:—

Character.	*Number.*	*Per cent.*
With four plaits	15	17·5
five do.	29	33
six do.	27	30·5
seven do.	17	19

Locality, etc.—Chideock Quarry Hill, near Bridport (Dorset), in the upper part of the Bridport Sands, with fine-ribbed *aalensis*-like Ammonites (see section, stratigraphical paper, p. 60). Its date is, therefore, *aalensis* hemera (Aalenian). It occurs at various places round the hill where its bed is exposed; and would no doubt be found at Burton Bradstock, if the sands were accessible.

A few notes on certain species may be appended to these descriptions.

There are certain species of Brachiopods that are almost peculiar to the Irony Bed (*blagdeni* zone, Bajocian) of Louse Hill, near Sherborne (Dorset), and are hardly known anywhere else in this country, which are met with in the Untere Dogger vom Rothen Stein of the Vilser Alpen. They are as follows:—

GLOSSOTHYRIS BIFIDA (Rothpletz). The author gives the name *Terebratula bifida*[4] to a form which he distinguishes from *T. curviconcha*, Oppel. Prof. Rothpletz's species is probably what we have been calling *Glossothyris curviconcha* = *T. curviconcha*, Davidson, App. to Suppl. (1884) pl. xviii, fig. 15.

[1] 'Foss. d. Strati à *L. opalinum*' Boll. Soc. Geol. Ital. vol. xii (1893) pp. 185 *et seqq.* & pl. i.

[2] 'Foss. ool. d. Mte. Pastello' Atti Sci. Tosc. Sc. Nat. vol. iv (1879) pl. xxii.

[3] 'Ét. crit. Brach. nouv.' Bull. Soc. Linn. Norm. vol. vii (1862) pl. v, p. 30 & figs. 7–8.

[4] 'Geol.-pal. Monogr. Vilser Alpen' Palæontographica, vol. xxxiii (1886) p. 114 & pl. v, figs. 17–19 (only).

WALDHEIMIA ANGUSTIPECTUS, Rothpletz.[1] Forms agreeing with his figs. 6, 7, 15, & 16 (pl. vii) have been found in the Irony Bed (*blagdeni* zone, Bajocian) of Louse Hill near Sherborne (Dorset). His fig. 12 of pl. vii appears to be similar to the *Waldheimia haasi*, S. Buckman (in Davidson, 'Mon. Brach.' App. to Suppl. 1884, pl. xix, fig. 11), also from the same place. Certainly *W. angustipectus* is a development of *W. haasi*, Davidson, pl. xix, fig. 12, through pl. xix, fig. 11, in the direction of losing the dorsal sulcation.

The *Waldheimia waltoni*, Rothpletz (*op. cit.* p. 123 & pl. vii, fig. 31), is not Davidson's species, but is very near to *Zeilleria ferruginea*, S. Buckman, 1901.[2] This is also from the Irony Bed of Louse Hill. To these apparently must be added *Terebratula lowensis*, described above (p. 99).

Another English species of the Vilser Alpen Dogger is characteristic in this country of a zone a little way lower down—the *discites* zone, see Table I (stratigraphical paper, p. 55). This species is

NORELLA LIOSTRACA (S. Buckman) = *Rhynchonella bilobata*, S. Buckman 1882, and Davidson 1884, which was, on account of the prior use of *bilobata*, named *Rhynchonella liostraca* by me, in Geol. Mag. dec. 3, vol. iii (1886) p. 217 (May). The same species was named by Prof. Rothpletz *Rh. securiformis* in December 1886.[3]

As it is a reversed Rhynchonellid—dorsally instead of ventrally sulcate, it is more suitably placed as *Norella* than as *Rhynchonella*. It is a most singular species, belonging to the *discites* zone (Bajocian); and is very rare in this country. It does not seem to be common in the Vilser Alpen.

Prof. Rothpletz's work shows the necessity for the following change of name:—

RHYNCHONELLA CYMATOPHORINA, nom. nov. This name is to replace *Rh. cymatophora*, S. Buckman,[4] as *Rh. cymatophora* is preoccupied by Rothpletz, 1886.

In connexion with the species from the Irony Bed of Louse Hill, it may be noted that *Waldheimia böhmi*, Böse (in Parona),[5] has the most remarkable likeness to *Waldheimea brodiei*, S. Buckman (in Davidson),[6] which is a species from the Irony Bed (*blagdeni* zone).

The thin Irony Bed of Louse Hill, 2 to 3 inches thick, is one of the most remarkable repositories of Brachiopod species in

[1] *Op. jam cit.* p. 131.

[2] Proc. Cotteswold Nat. Hist. F.-C. vol. xiii (1901) p. 260 & pl. xiii, fig. 4.

[3] *Op. supra cit.* pl. ix, figs. 58 & 59.

[4] 'Bajocian of the Mid-Cotteswolds' Quart. Journ. Geol. Soc. vol. li (1895) p. 447.

[5] 'Fauna & Età degli Strati con *Posidonomya* Alpina' Pal. Ital. vol. i (1895) p. 31 & pl. ii, figs. 21–23.

[6] 'Monogr. Brit. Jur. Brach.' App. to Suppl. (Palæont. Soc.) 1884, p. 266 & pl. xix, figs. 14–15.

this country. They are, many of them, such distinctive and peculiar species, and in this country so geographically restricted. There are more to be described at some future opportunity. For details of Louse Hill and the Irony Bed, see Quart. Journ. Geol. Soc. vol. xlix (1893) p. 488.

[Addendum.—The biplicate *Rhynchonella* characteristic of the Sandy Grits of Stoke Knap (see stratigraphical paper, p. 76), which is figured as *Rh. stephensi*, Davidson = ? *cynocephala*, Richard (Quart. Journ. Geol. Soc. vol. li, 1895, pl. xiv, fig. 1), may possibly be *Rh. fidia*, d'Orbigny, Prodrome, 1849 [1850] p. 258.—*February 16th, 1910.*]

IV. Summary.

The following genera and species have been described or discussed in this paper:—

Ammonites.

New names in **heavy type**.

Bradfordia.
Bradfordia **costata.**
Bradfordia etheridgii.
Bradfordia **inclusa.**
Bradfordia **liomphala.**
Burtonia.
Burtonia **crassornata.**
Darellia **alta.**
Œcotraustes **spiniger.**
Œdania **obscura.**
Shirbuirnia.
Shirbuirnia stephani.
Shirbuirnia **trigonalis.**
Sonninia subtrigonata.

Brachiopoda.

The following species are described: new names in **heavy type**.

Aulacothyris **cucullata.**
Rhynchonella **pentaptycta.**
Terebratula **arenaria.**
Terebratula **burtonensis.**
Terebratula **lowensis.**
Terebratula **stibara.**
Terebratula **vinneyensis.**
Terebratula **whaddonensis.**
Zeilleria **lingulata.**
Zeilleria **whaddonensis.**

The following new name is given:—

Rhynchonella **cymatophorina.**

The following species are noted:—

Glossothyris bifida (Rothpletz).
Norella liostraca (S. Buckman).
Rhynchonella fidia, d'Orbigny.
Waldheimia angustipectus, Rothpletz.
Waldheimia böhmi, Böse.
Waldheimia waltoni, Rothpletz.

EXPLANATION OF PLATES IX-XII.

Plate IX.

Aalenian: *scissum* zone.

Fig. 1. *Burtonia crassornata*, sp. nov. (Holotype.) See p. 98. Side view × 0·7. [*scissum* bed], Burton Bradstock (Dorset). From my father's collection. Photogr. J. W. Tutcher. (See also Pl. X, fig. 1.)

Bajocian: post-*discites* zone.

Figs. 2 & 3. *Bradfordia inclusa*, sp. nov. (Holotype.) See p. 94.—Fig. 2: Side view, natural size. Fig. 3: Front view. From the Building-Stone, presumably the top layer, Stoke Knap (Dorset).

Bajocian: *discites* zone.

Figs. 4 & 5. *Œdania obscura*, sp. nov. (Holotype.) See p. 96. Photogr. Author. Fig 4: Side view, natural size. Fig. 5: Front view (outline). From the upper part, judging by the matrix, of the Fossil Bed of Bradford Abbas (Dorset).

Plate X.

Aalenian: *scissum* zone.

Fig. 1. *Burtonia crassornata*, sp. nov. (See p. 98.) Front view × 0·7. See also Pl. IX, fig. 1.

Bajocian: *Shirbuirnia* Zone.

Figs. 2 & 3. *Shirbuirnia trigonalis*, sp. nov. (Paratype.) See p. 92.—Fig. 2: Side view (portion) × 0·86. Fig. 3: Front view × 0·61. From the lower part of the Fossil Bed of Sandford Lane, Sherborne (Dorset). Photogr. Miss Buckman.

Bajocian: *discites* zone.

Figs. 4 & 5. *Bradfordia liomphala*, sp. nov. (Holotype.) See p. 94.—Fig. 4: Side view, natural size. Fig. 5: Front view. From the upper part of the Fossil Bed of Bradford Abbas (Dorset). Photogr. Miss Buckman.

Fig. 6. *Bradfordia costata*, sp. nov. (See p. 94.) Peripheral view. See also Pl. XI, fig. 1.

Plate XI.

Bajocian: *discites* zone.

Fig. 1. *Bradfordia costata*, sp. nov. (Holotype.) See p. 94. Side view, natural size. From the upper part of the Fossil Bed of Bradford Abbas (Dorset). Photogr. Miss Buckman. (See also Pl. X, fig. 6.)

Figs. 2 & 3. *Darellia alta*, sp. nov. (Holotype.) See p. 96.—Fig. 2: Side view, natural size, photogr. Author. Fig. 3: Outline section. From the Lower *Trigonia* Grit, Frith Quarry, Painswick (Gloucestershire).

Bajocian: *sauzei* zone.

Figs. 4–6. *Sonninia subtrigonata*, S. Buckman. (Holotype.) See p. 93.—Fig. 4: Side view, natural size. Fig. 5: Front view. Fig. 6: Portion of peripheral view, to show alticarina:—all photogr. J. W. Tutcher. From the upper part of the Fossil Bed, Sandford Lane, Sherborne (Dorset).

Fig. 7. *Œcotraustes spiniger*, sp. nov. (Holotype.) See p. 95. Side view. From the Marl Bed with green grains, Frogden Quarry, Oborne (Dorset). Photogr. Miss Buckman.

Plate XII.

[All the figures in this Plate are reproduced from photographs by Mr. J. W. Tutcher, and are of the natural size.]

Bathonian: *fusca* zone.

Figs. 1 & 2. *Aulacothyris cucullata*, sp. nov. (See p. 102.) Holotype, from the clay (Fullers' Earth) immediately above the Inferior Oolite limestone (*zigzag*), Grange Quarry, Broad Windsor (Dorset).

Bathonian: circa *schlœnbachi* zone.

Figs. 3 & 4. *Zeilleria lingulata*, sp. nov. (See p. 103.) Holotype, from the 'Top Beds,' Broad Windsor (Dorset).

Figs. 5 & 6. *Terebratula stibara*, sp. nov. (See p. 100.) Holotype, from the 'Top Beds' of Crewkerne Station (Somerset).

Figs. 7 & 8. *Terebratula vinneyensis*, Walker MS. (See p. 100.) Lectotype, one of his syntypes, from the 'Top Beds,' *schlœnbachi* or *truellii* zone, Vetney (Vinney) Cross, near Bridport (Dorset). Collection of Mr. J. W. D. Marshall.

Bajocian: *blagdeni* zone.

Figs. 9 & 10. *Terebratula lowensis*, nom. nov. (See p. 99.) Holotype, from the Irony Bed of Louse Hill, near Sherborne (Dorset).

Bajocian: circa *sauzei* zone.

Figs. 11 & 12. *Terebratula burtonensis*, sp. nov. (See p. 99.) Holotype, from the Red Beds of Burton Bradstock.

Aalenian: *scissum-opaliniforme* zone.

Figs. 13 & 14. *Zeilleria whaddonensis*, sp. nov. (See p. 102.) Holotype, from the Sandy Grits of the roadside ascent of Stoke Knap (Whaddon Hill), Broad Windsor (Dorset).

Figs. 15 & 16. *Terebratula whaddonensis*, nom. nov. (See p. 101.) Holotype from the same strata and locality.

Figs. 17 & 18. *Terebratula arenaria*, sp. nov. (See p. 102.) Holotype from the same strata and locality.

Aalenian: *aalensis* zone.

Figs. 19 & 20. *Rhynchonella pentaptycta*, sp. nov. (See p. 103.) Holotype, from the Bridport Sands with *Canavarina*. See section I, p. 64. Ascent of Chideock Quarry Hill, Bridport (Dorset).

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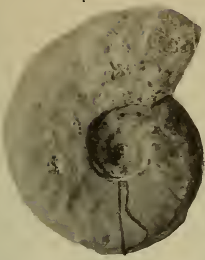

ŒDANIA OBSCURA

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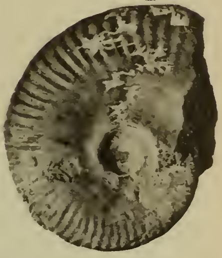

BRADFORDIA INCLUSA

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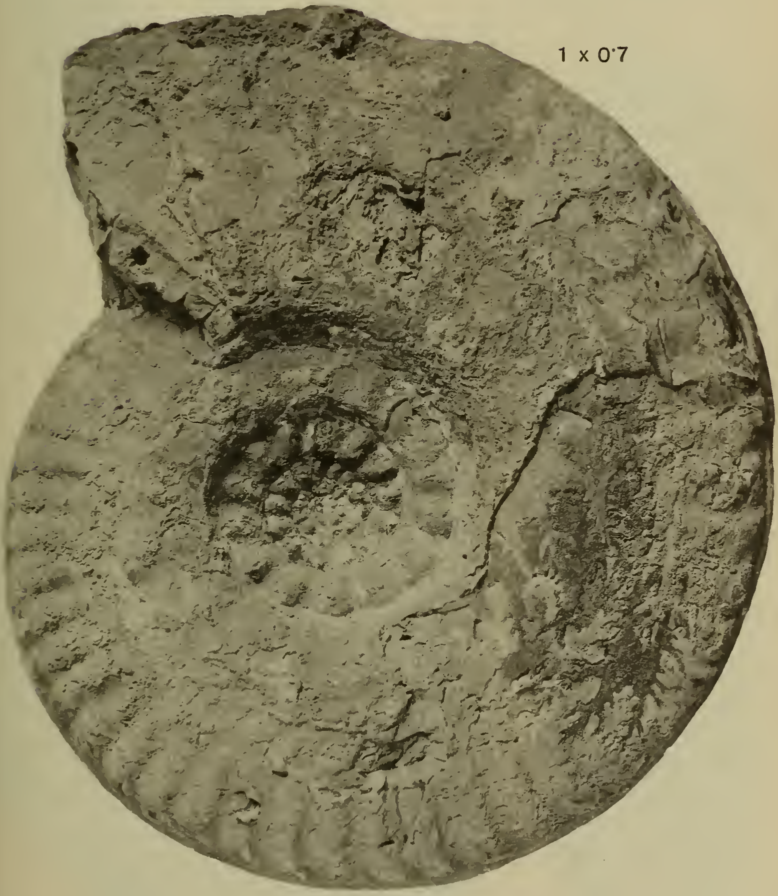

BURTONIA CRASSORNATA

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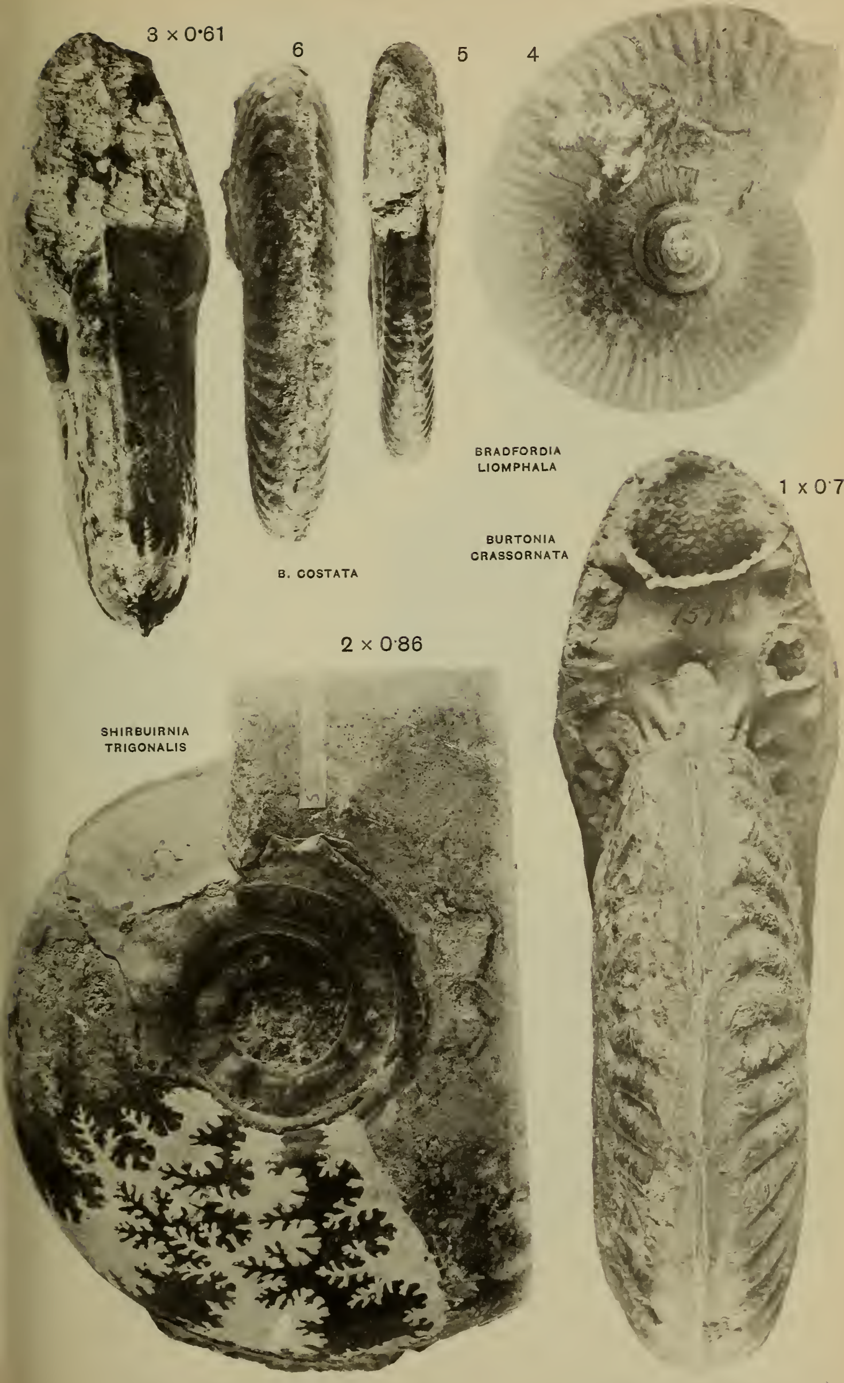
BURTONIA, BRADFORDIA, AND ŒDANIA



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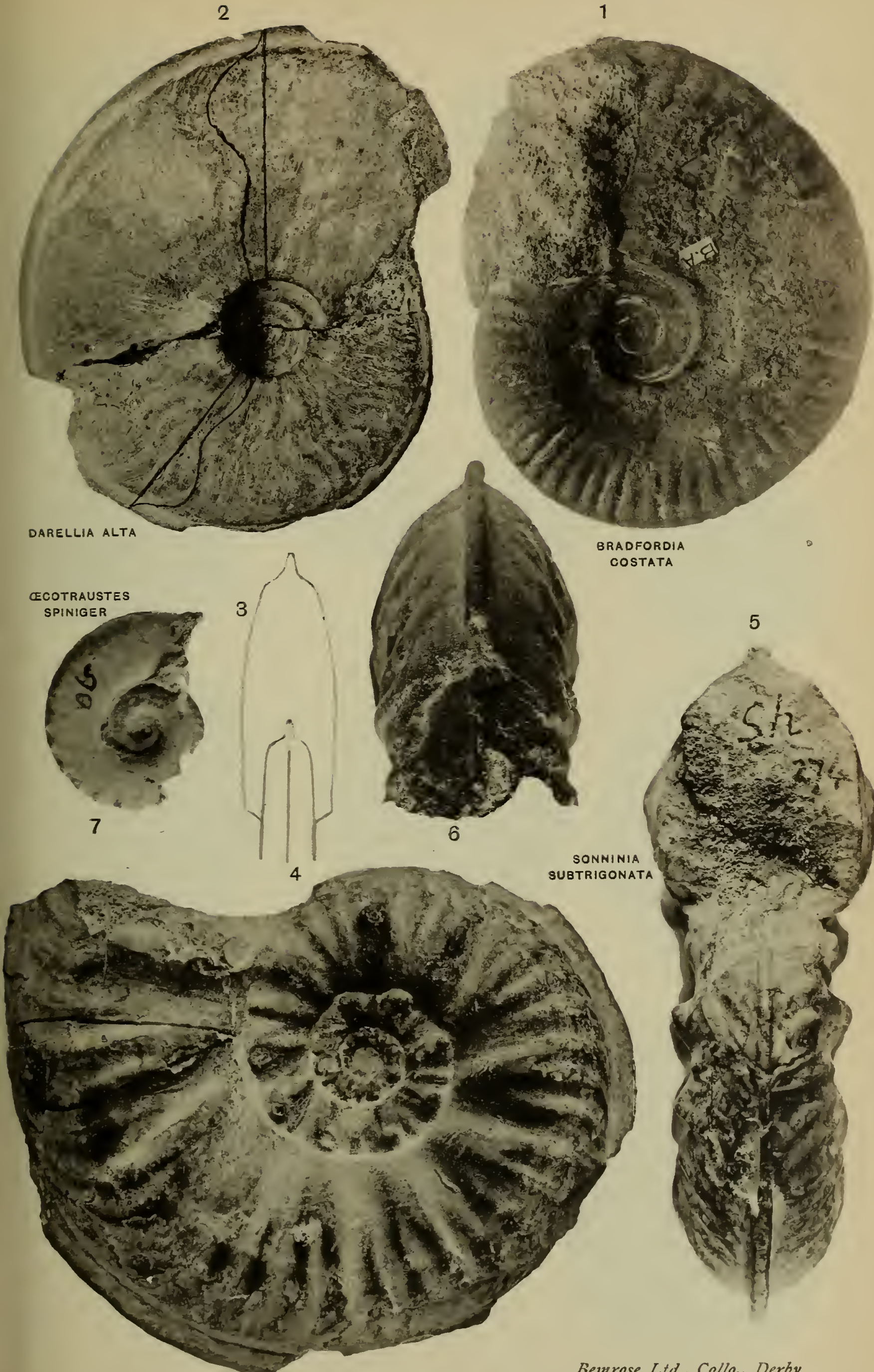

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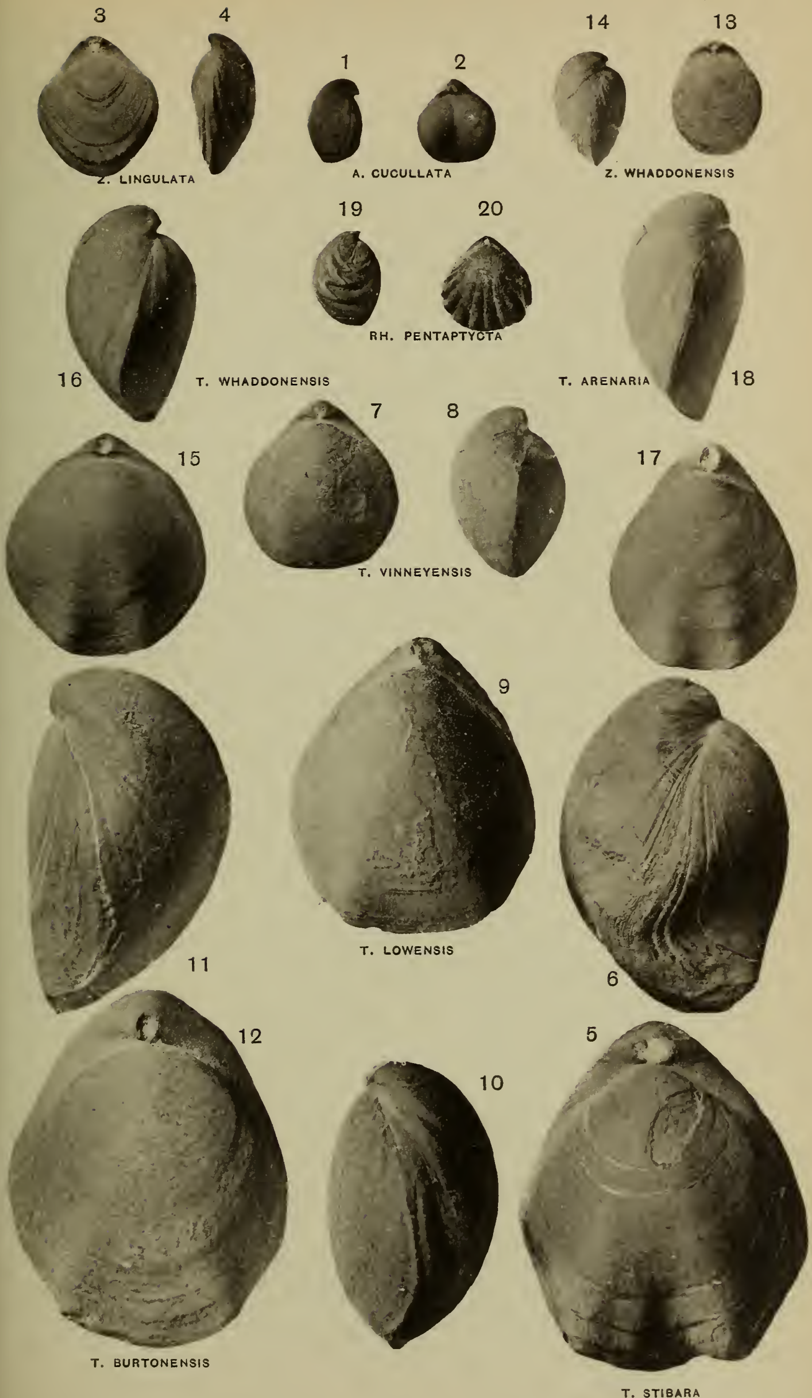
SONNINIA, BRADFORDIA, DARELLIA, AND ŒCOTRAUSTES



J. W. Tutcher, Photo. *Bemrose' Ltd., Collo., Derby*

BRACHIOPODA

Discussion [on the two foregoing papers].

Mr. E. A. Walford stated that he had studied the Dorset sections cited by the Author. The Middle Lias in the Midlands contained, he thought, representatives of the Dorset beds. In the Ammonite fauna there was a complete change from the beds below—signifying a long interval of slight deposition, the full record of which might possibly be found in other countries. In a paper on 'Gaps in the Lias' the speaker had described the welding of three Liassic zones—*Ammonites communis*, *A. serpentinus*, and the Transition Bed—into one limestone-block 2 feet thick. Although familiar with the Chideock Hill quarries many years ago, he had not seen the higher Bajocian beds which the Author had described; and, considering the general fragmentary character of the Inferior Oolite deposits, he thought that it would be wise to restrain much increase of zonal definitions until more was known, and to keep to broad lines.

Mr. James Parker observed that the Author repeatedly referred to the Bridport Sands. He would ask whether these were now reckoned as a geological division. Some forty years ago he remembered that, when showing some specimens he had collected from those beds to the late Prof. Phillips, the Professor would not allow the name, contending that Midford Sands had the priority, that name having been given to the beds by William Smith, whom Prof. Phillips looked upon as the father of English Geology. The speaker further said that, in arguing the point, he had considered that the thickness of 150 feet of the bed exposed on the Dorset coast, as compared with the very slight exposure at Midford, entitled the beds to be named after Bridport, just as the clay-beds on the same coast a few miles to the east had received the name of Kimeridge, and that not only in England, but in France and elsewhere. He asked whether the Author considered the sands at Bridport to be the equivalent of the Midford Sands.

The President (Prof. Sollas) congratulated the Author on the very interesting manner in which he had presented a highly technical subject. The correlation of thin seams with thick deposits was a matter of great importance, and called to mind Suess's remarks on the partings in the Trias. It might afford some hints as to the order of magnitude of the scale of time. If we assumed that 1 foot of sediment might accumulate in a century, in an area of maximum deposition, then in the case of the seam 2 inches thick which was represented by 250 feet in the Cotteswolds, the rate of formation would be less probably than 1 foot in 150,000 years. In regard to the existence of the numerous zones traced out by the Author, he thought that observation should be extended over wider areas in order to establish them on a firm basis.

The Author, in reply, remarked that Jurassic zones were by no means the result of local observation only: they had been followed widely, even the new ones; the thinness of zones was no test of their importance or otherwise, being often only a local accident of alternating deposition and denudation. The net increase of deposit must have been much less than 1 foot in a century, as this seemed too rapid for the faunal changes involved. In conclusion, the Author begged the Fellows to accept his thanks for their kind reception of his papers.

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Vol. LXVI. MAY 31st, 1910. **No. 262.**
Part 2.

THE

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OF THE

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

SESSION 1909–1910.

1910.

Wednesday, June 15*

[*Business will commence at Eight o'Clock precisely.*]

The asterisk indicates that the Council will meet on that day.

5. *On a* Skull *of* Megalosaurus *from the* Great Oolite *of* Minchinhampton (Gloucestershire). By Arthur Smith Woodward, LL.D., F.R.S., Sec.G.S. (Read January 26th, 1910.)

[Plate XIII.]

Although the carnivorous Dinosaur *Megalosaurus* was first discovered in the Stonesfield Slate nearly 80 years ago, and is now represented by numerous fossils from the Bathonian and later Mesozoic formations of England, its skull has hitherto been known only by unsatisfactory fragments of jaws.[1] Our acquaintance with the Megalosaurian type of skull has depended solely on discoveries of nearly complete specimens in the Jurassic and Cretaceous formations of North America.[2] At last, however, Mr. F. Lewis Bradley, F.G.S., has been able to submit to the Society the greater part of a skull obtained some time ago from the Great Oolite in an excavation for a reservoir at Minchinhampton (Gloucestershire); and he has prepared the specimen with so much skill and success that it is beautifully exposed for study from the left side (Pl. XIII, fig. 1). It is rather small, measuring only 26 centimetres in total length, but there cannot be much doubt that it belongs to the genus *Megalosaurus* itself.

The upper portion of the fossil is unfortunately destroyed by an irregular fissure in the rock, which is partly filled with calcite. The cranium is, therefore, scarcely seen; but there are traces behind of the occiput, which is somewhat deeper than wide above the foramen magnum, and lies in a plane inclined much forwards. The external bones of the temporal region and face are remarkably thin and delicate, and in their crushed condition it is difficult to distinguish the sutures between them. The large vacuities, however, which form so conspicuous a feature in the American Megalosaurian skulls, are very clearly defined, and their boundaries are probably not distorted. The lateral temporal vacuity (*T.*) is narrow and deep; the orbit (*O.*) is wider, with a gently curved lower margin,

[1] W. Buckland, 'Notice on the *Megalosaurus*' Trans. Geol. Soc. ser. 2, vol. i (1824) p. 390 & pls. xl–xli; T. H. Huxley, 'On the Upper Jaw of *Megalosaurus* Quart. Journ. Geol. Soc. vol. xxv (1869) p. 311 & pl. xii; J. Phillips, 'Geology of Oxford, &c.' 1871, p. 197 & diagrs. lvi–lvii; R. Owen, 'On the Skull of *Megalosaurus*' Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 334 & pl. xi. The so-called brain-case of *Megalosaurus* described by F. von Huene (Neues Jahrb. 1906, vol. i, p. 1 & pl. i) from the Stonesfield Slate was found isolated, and now appears to be more likely referable to *Cetiosaurus* than to the former genus.

[2] See especially O. C. Marsh, 'The Order Theropoda' Am. Journ. Sci. ser. 3, vol. xxvii (1884) p. 330 & pls. viii–ix; H. F. Osborn, 'The Skull of *Creosaurus*' Bull. Am. Mus. Nat. Hist. vol. xix (1903) p. 697, with text-figs., and '*Tyrannosaurus*, Upper Cretaceous Carnivorous Dinosaur' *ibid.* vol. xxii (1906) p. 281 & pl. xxxix; O. P. Hay, 'On certain Genera & Species of Carnivorous Dinosaurs, with special reference to *Ceratosaurus nasicornis*, Marsh' Proc. U.S. Nat. Mus. vol. xxxv (1908) p. 351, with text-figs.

but is also evidently deeper than wide; the antorbital vacuity (*A.*) is especially large, as wide as the other two together, and distinctly wider than deep; while the narial opening (*N.*) is elongate-oval in shape, three times as wide as deep, with its long axis inclined downwards and forwards. As shown by the position of the overlying quadrato-jugal (*qj.*), the quadrate bone is nearly vertical, not inclined backwards; and the lower temporal arcade is slightly bent downwards from the hinder end of the maxilla, as if the axis of the facial region were inclined a little to that of the cranium. The jugal bone (*j.*) clearly rises into the postorbital bar, seems to be truncated in front where it meets the maxilla in a jagged suture below the lachrymal, and is excluded by the latter element from the margin of the antorbital vacuity. The lachrymal (*l.*) forms the lower part of the antorbital bar, and tapers above, where it must have articulated originally with the prefrontal. The maxilla (*mx.*) is a relatively large triangular bone, excavated in its hinder half by the antorbital vacuity, beneath which it remains as a narrow bar. Its anterior ascending portion is truncated where it reaches the cranial roof, and its straight anterior border forms the lower margin of the narial opening. The outer face immediately in front of the antorbital vacuity is impressed by an extensive fossa; and in the middle of this is a small deeper depression (*x*) which may even be another vacuity. The oral margin of the bone is straight, and bears sockets for eighteen teeth; while above this margin there occurs the usual series of nervous or nutritive foramina. The premaxilla (*pmx.*) is distinctly separated from the maxilla by a suture, which is vertical below, but curves gently backwards above; it is also separated with equal distinctness from its fellow of the opposite side. This bone is about as deep as wide, vertically truncated in front, and with a straight oral margin, which bears sockets for four small teeth. Its antero-superior angle is produced upwards and backwards to form a narrow bar, separating the right and left narial openings in their front half, and then uniting in an extended suture with the attenuated end of the nasals (*na.*), which continue the bar between the hinder half of the same openings. The nasal bar is of extreme interest, as bearing a laterally-compressed bony excrescence (*h.*), of which only an anterior basal fragment remains in the fossil. This excrescence has a roughened surface with indications of vertical grooves, and may be appropriately described as a horn-core. It obviously corresponds with the nasal horn-core already discovered by Marsh in *Ceratosaurus nasicornis*, from the Upper Jurassic of Colorado.[1]

A narrow, longitudinally-extended plate of bone appears within the antorbital vacuity, and evidently represents a fragment of the palate crushed upwards. It is suggestive of a pterygoid element (*pt.*), and from its hinder portion there projects downwards and outwards another small bar of bone, which may perhaps be ecto-pterygoid (*ecpt.*).

[1] Am. Journ. Sci. ser. 3, vol. xxvii (1884) p. 330 & pl. viii.

The shape of the left ramus of the mandible is completely shown, but its hinder half is so much fractured that its constitution cannot be exactly determined. The very slender dentary bone (*d.*) tapers to a blunt point at the symphysis, where its four anterior teeth are relatively small. It gradually deepens in its hinder half, and its >-shaped sutural union with the angular (*ag.*) is distinct below the small oval vacuity (*V.*), which occurs behind it between the angular and surangular bones. On its outer face may be observed a sparse longitudinal series of large nutritive foramina, those in the hinder half being placed in a shallow groove which inclines upwards posteriorly. The coronoid region is the deepest part of the mandibular ramus, its maximum depth equalling a seventh of the total length; but its upper margin is only gently rounded (not raised into a process), and it rapidly tapers behind to the very low articulation for the quadrate bone.

Most of the teeth are well displayed, and exhibit a tendency to replacement alternately, as in crocodiles. Those of the premaxilla are remarkable for their very small size, the height of the third or largest tooth not quite equalling half the height of the largest maxillary tooth. They are thick, round or oval in cross-section, very slightly recurved, and only compressed to a sharp edge behind, where they are regularly serrated to the base. Their outer face is marked by a few slight vertical flutings, which are best seen in the third tooth (Pl. XIII, fig. 2). The fourth or hindmost premaxillary tooth is not exserted; but the other three are completely in functional position, and gradually decrease in size forwards. The foremost tooth of the maxilla, which is seen in its broken socket, is as stout and small as the premaxillary teeth; but all the others of the series are much laterally compressed and recurved, with a sharp serrated edge behind and a blunter, more finely serrated edge in front. The largest teeth of the mouth are those within the front half of the maxilla; while those in the hinder half of the same bone rapidly become smaller, until the hindmost (shown only in impression) are very short and broad. The three teeth preserved at the symphysial end of the mandible are as small as the premaxillary teeth opposed to them, and apparently similar; but the other teeth of the dentary, so far as shown, resemble the principal teeth of the maxilla in shape, and only differ in being much smaller. All the serrations of the teeth (Pl. XIII, fig. 3 *b*) are in regular series, blunt, and not inclined upwards.

On the rock below the mandible occurs the long and slender curved bone shown in Pl. XIII, fig. 4. It is smooth, and only impressed by a shallow longitudinal groove near its thicker end. Both its ends are indefinite, as if originally cartilaginous. It is probably one of the hyoid elements, which have already been noticed by Marsh in *Ceratosaurus*.

As shown by the discoveries in North America, all the skulls of Megalosauria are remarkably similar, and it is difficult to find generic differences between them. In fact, they can scarcely be distinguished, except by the number and arrangement of their premaxillary teeth, which appear to be constant for each genus. If the European genera of Megalosauria may be similarly characterized, the skull from Minchinhampton belongs to *Megalosaurus* itself, for the distinctive number of four premaxillary teeth has already been found both in the type species, *M. bucklandi*,[1] from the same stratigraphical horizon, and in a specimen from the Oxford Clay.[2] It cannot be referred to *Ceratosaurus*, the only other Megalosaurian in which a nasal horn-core has been observed, because in this genus there are not more than three premaxillary teeth.

If, however, the new skull be correctly assigned to *Megalosaurus*, it is readily distinguished from the only satisfactorily-defined species, *M. bucklandi*, by the shape of the maxilla and more especially by the relatively small size and stoutness of the few anterior teeth in both jaws. It is also comparatively small, though this feature may perhaps be due to immaturity. Its dentition is scarcely comparable with the isolated teeth from higher horizons which have received names; and no reference can be made to the forms known only by limb-bones or vertebræ. I propose, therefore, that the specimen now described be regarded as the type of a new species, to be known as *Megalosaurus bradleyi*, in honour of its discoverer.

EXPLANATION OF PLATE XIII.

[Skull and mandible of *Megalosaurus bradleyi*, sp. nov., from the Great Oolite, Minchinhampton (Gloucestershire). Collection of F. Lewis Bradley, F.G.S.]

Fig. 1. Left side-view, two-thirds of the natural size. *A.*, antorbital fossa; *N.*, narial opening; *O.*, orbit; *T.*, lateral temporal vacuity; *V.*, vacuity in mandible; *ag.*, angular; *d.*, dentary; *ecpt.*, ectopterygoid (?); *h.*, bony horn-core; *j.*, jugal; *l.*, lachrymal; *mx.*, maxilla; *na.*, nasal; *pmx.*, premaxilla; *pt.*, pterygoid (?); *qj.*, quadrato-jugal; *x*, depression or vacuity in antorbital fossa.

2. Third premaxillary tooth, twice the natural size.

3 *a*. Largest maxillary tooth, twice the natural size, with (3 *b*) serrations enlarged 7 diameters.

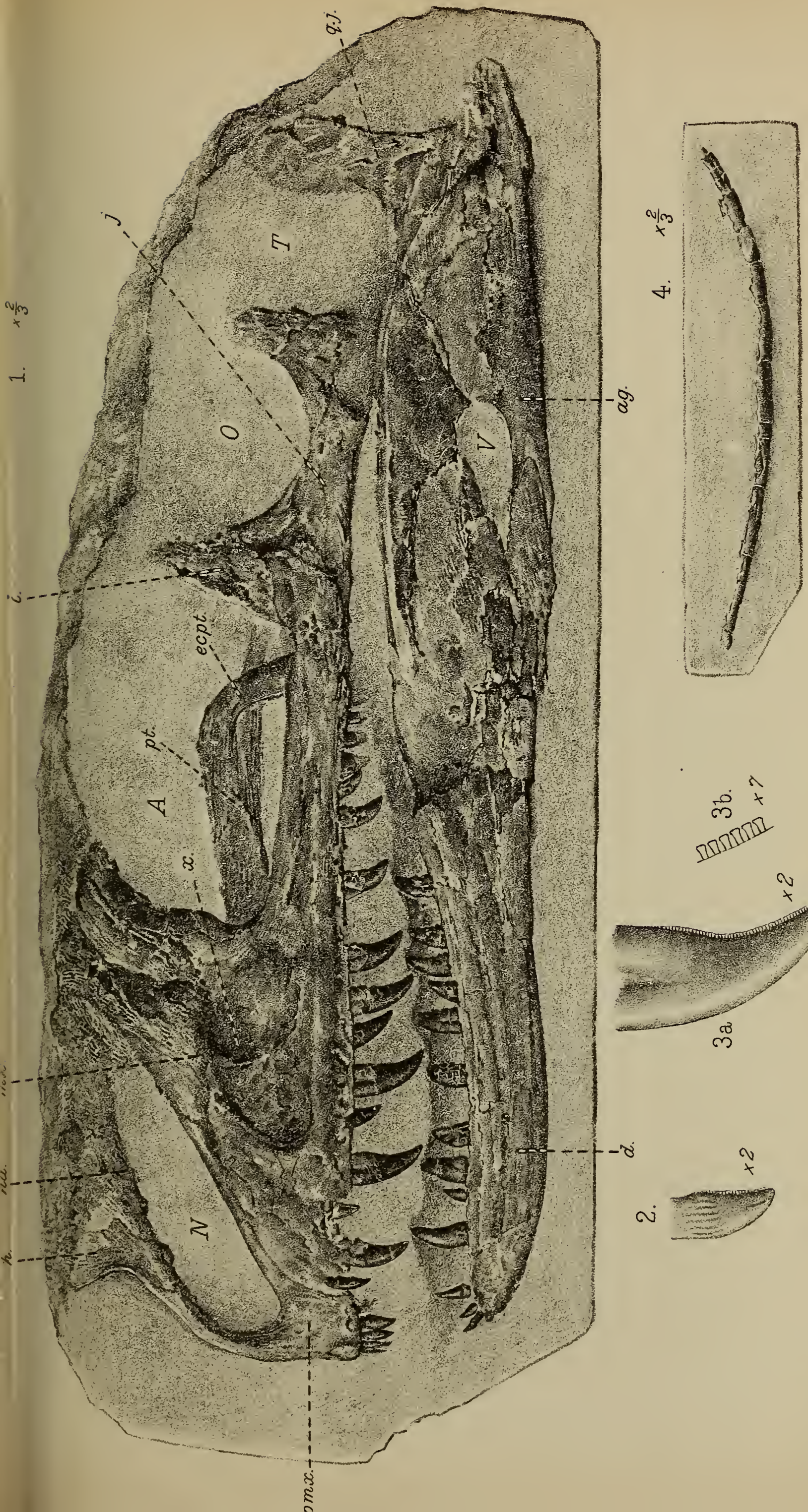
4. Supposed hyoid bone, crushed and broken, two-thirds of the natural size.

Discussion.

The President (Prof. W. J. Sollas) welcomed this remarkable accession to our knowledge of *Megalosaurus*, and only regretted that it was not to rest side by side with the original specimen in the Oxford Museum. Its resemblance to *Ceratosaurus* was very striking. Evidently part of the skull was still enveloped in the matrix, and could be displayed by serial sections without injury to the exposed portion.

Dr. C. W. Andrews congratulated Mr. Bradley on having had the good fortune to preserve so beautiful a specimen, and remarked

[1] R. Owen, Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 336.
[2] J. Phillips, 'Geology of Oxford, &c.' 1871, p. 320 & diagr. cxxiii.



J. Green del.

West, Newman imp.

MEGALOSAURUS BRADLEYI, sp. nov.

on the importance of his work in collecting from temporary exposures.

Mr. E. T. Newton also congratulated Mr. Bradley and the Author. He remarked on the great difference in the form of the premaxillary teeth and those of the maxilla, which showed how easily one might be misled in trying to identify isolated teeth. Mr. Newton asked the Author to what extent the front margins of the maxillary teeth were serrated, and whether the teeth themselves were lodged in distinct alveoli or in an alveolar groove.

The Author, in reply, said that the serrations of all the teeth, except those in the front part of the jaw, appeared to resemble those of the teeth in *M. bucklandi.* He could not determine definitely that the teeth were in distinct sockets, but thought appearances suggested that this was the case. He had noticed thick Megalosaurian teeth, much resembling those of the new fossil, among the isolated specimens from the Wealden.

6. *The* Skiddaw Granite *and its* Metamorphism.

By R. H. Rastall, M.A., F.G.S., Fellow of Christ's College, Cambridge. (Read December 15th, 1909.)

[Plate XIV—Map.]

Contents.

I. Introduction.

The main object of this paper is the investigation of the alteration of the sedimentary rocks of the Skiddavian Series by the intrusion of the mass of igneous rock which is commonly known as the Skiddaw granite. One or two cognate subjects will be touched upon, such as the composition and petrographical character of the intrusion, and the general structure and tectonic relations of the sedimentary series; but, in the main, the paper is a study in metamorphism. The Skiddavian Series includes rocks of varying lithological character, grits, flags, shales, and slates, so that the products of metamorphism are not by any means uniform in character; and, in addition to this, the problem is complicated by the occurrence throughout the area of a varying though generally high degree of folding and cleavage. Hence it is necessary to study the effects of thermal metamorphism superposed upon those of a previous dynamic metamorphism.

During my examination of the Buttermere and Ennerdale granophyre, I was naturally led to study the effects of this intrusion on the surrounding rocks, which are well-marked. This subject proved to be an unusually difficult one, and I then turned my attention to the metamorphism of the Skiddaw intrusion, in the hope that this would throw some light on the puzzling phenomena presented in the former case. It seemed advisable, therefore, to make a complete study of the Skiddaw metamorphism; and since this latter is in itself the more important case, and probably the more instructive from a general point of view, the results are here presented. This investigation has been assisted by a grant from the Government Grant Committee of the Royal Society, which has defrayed the cost of the very large number of rock-slices that were found necessary.

II. The Skiddaw Granite.

The visible exposures of the Skiddaw granite are three in number, namely, a small one in Sinen Gill, which is the northernmost tributary of the Glenderaterra valley on the left or eastern bank; a much larger exposure in the floor of the Caldew valley; and a third, of fairly large size, near the junction of Grainsgill Beck with the River Caldew. In connection with each of these there is some point worthy of special note, and they may be dealt with in the order above stated.

So far as can be seen from the very limited exposure, it seems probable that the granite of Sinen Gill is of the nature of a large dyke, an apophysis of the main mass. The junction of its upper surface with the Skiddavian rocks is clearly displayed in the stream; it is obvious that the junction cuts almost at right angles across the general strike of the district, and it appears to dip steeply to the east. Hence it cannot be either a sill intruded along the bedding planes, or a portion of the upper surface of a laccolith, as is probably the case with the larger exposures. Also, so far as my observations go, the size of the exposure seems to have been greatly exaggerated. It is highly improbable that the granite extends so far south as is indicated on the published maps of the Geological Survey. In these granite is shown at the surface nearly as far as Roughten Gill, but there is no evidence for this. On the contrary, to judge by the low grade of metamorphism in Roughten Gill, it would seem that the rocks here are at a considerable distance from the margin of the granite. Unfortunately there are no exposures in the lower part of the ridge separating the two gills, so the question cannot be definitely settled. At all events, nothing resembling the intensely altered, so-called 'mica-schist' of Sinen Gill is to be seen in Roughten Gill, even at the point where the frequent exposures in the stream ought, according to the published maps, to lie close to the granite; and even the second grade of alteration is hardly attained. The northward extension of this exposure of granite is even less defined, as no rock *in situ* is seen on the hillside for a long distance north of Sinen Gill: the whole is covered by a thick mass of moss and peat overlying drift. It may be summarily stated that the only certain fact is the occurrence of a thick mass of granite in the bed of Sinen Gill; the upper margin is clearly seen, but the lower margin is very much a matter of inference. It follows that we have no real means of judging of the form of this intrusion; but, in all probability, it is a thick inclined sheet, or dyke, cutting obliquely across the bedding, and forming an apophysis of a mass which is continuous with the larger exposures in the Caldew valley and near Grainsgill.

The second exposure is of much greater extent, and of a very different character; it covers an area of about a mile from east to west and half a mile from north to south, forming a large portion of the floor of the Caldew valley in its widest expansion, due north of the summit of Saddleback and east of Skiddaw. The major part of this area is covered with peat, but the boundaries of the granite can be traced in the tributary streams, although it is mostly hidden in the intervening spaces.

The form of the exposure, as thus defined, indicates that what is here seen is the more or less horizontal upper surface of a large intrusion, which is most probably in the nature of a laccolith. This laccolith undoubtedly underlies the whole of the metamorphosed area at a small depth—thus accounting for the intensity of the alteration produced in the rocks, and for the great size of the aureole, in comparison with the smallness of the visible exposures of igneous rock.

The third and most interesting exposure occurs at the junction of Grainsgill with the Caldew valley, and it comprises more than one variety of rock. It consists in part of normal granite, similar to that of the other exposures, and in part of a quartz-mica rock or greisen. This latter has been exhaustively described by Harker.[1] The Grainsgill intrusion is very irregular in form, and it must be regarded as an apophysis rather than as an exposure of the laccolith. Both the igneous intrusion and the surrounding rocks are traversed by large and numerous quartz-veins, often containing peculiar minerals and especially compounds of tungsten (wolfram and scheelite), which are now being somewhat extensively worked at the Grainsgill Mine. There is here clear evidence of the occurrence of pneumatolysis of a rather peculiar type.

Petrography of the Granite.

To the naked eye the granite shows little variation ; when fresh it is white or grey, and is seen to consist of quartz, felspar, and biotite, with generally some muscovite in addition. The texture is often rather coarse, and commonly large phenocrysts of white felspar, measuring up to 2 inches in length, are scattered here and there throughout the mass ; varieties wholly free from porphyritic felspars are not common.

Specimens from the three visible exposures are very similar, and all three show much the same range of variation, so that it is hardly necessary to describe each in detail. The freshest examples are to be found in the River Caldew, above Grainsgill, and this may be taken as a type for the northernmost intrusion, when in its normal unaltered condition, without conversion to greisen.

A typical example of this rock is somewhat coarse in texture and of fairly even grain, without much tendency to porphyritic structure. It consists of quartz, various felspars, muscovite, and biotite, with few accessory minerals. Quartz is abundant, and quite normal in character : it is in most cases the last mineral to crystallize. The

[1] Quart. Journ. Geol. Soc. vol. li (1895) p. 139.

felspars show a considerable range of composition; they include both alkali-felspar and plagioclase, and the alkali-felspar is as a rule distinctly more turbid and decomposed than the plagioclase. The large phenocrysts, when present, consist of a somewhat coarse-textured variety of perthite, and the great majority of the smaller individuals of alkali-felspar also show the perthitic structure with greater or less clearness. This perthite is probably to be referred to the secondary type.[1]

The plagioclase possesses a low extinction-angle, usually not more than 10°, and generally less, while its index of refraction, when tested by the Becke bright-line method, is lower than that of quartz. It may, therefore, be referred to albite-oligoclase or oligoclase. Both white and brown micas are present, and in some specimens from near Grainsgill the white mica is the more abundant. This is correlated with the fact that, as noted by Harker, the granite of Grainsgill is more acid than that of the other localities. The two micas are commonly intergrown in parallel position, and there is no reason to doubt the original nature of the large flakes of muscovite. They show no evidence of a secondary origin due to greisening in the southern part of the exposure, although the greater part of the colourless mica in the northern part of the same mass (the Grainsgill greisen) is certainly secondary. The biotite is of a peculiarly brilliant foxy-red colour, and strongly pleochroic; it is, however, often more or less completely converted into green chlorite and epidote. The only other mineral present is a very small quantity of magnetite. The microscopic structure of the rock on the whole is granitic, although some specimens show a distinct tendency to the graphic. There are to be seen rough micropegmatitic intergrowths of quartz and alkali-felspar (perthite) and also in one or two cases intergrowths of felspar and muscovite, a much less common phenomenon.

The granite of Sinen Gill differs from that of the Grainsgill district in texture rather than in composition; it is of finer grain, and more distinctly porphyritic. The mutual relations of the quartz and felspar are variable: sometimes the quartz occurs as rounded grains, and sometimes interstitially; in many places there is a rude graphic intergrowth. The constituent minerals are precisely the same as in the case last described, and here also muscovite is abundant, though subordinate to biotite. The latter is for the most part converted into green chlorite.

The more distinctly porphyritic character of this rock is precisely what might have been expected, in view of its mode of occurrence as a comparatively small apophysis of the main mass; and, taking into account both microscopic structures and field-relations, it would be most correctly identified as a granite-porphyry, whereas the Caldew and Grainsgill rocks should be called porphyritic granites.

The rock of the largest exposure, which can be well seen in the neighbourhood of Wiley Gill, varies a good deal in character.

[1] A. Harker, 'The Natural History of Igneous Rocks' 1909, p. 258.

Some specimens are fairly even-grained and non-porphyritic, whereas others show large phenocrysts of white felspar. The minerals and structures seen are similar to those described in the preceding cases.

With regard to the classification of this rock, it is somewhat difficult to assign its position in the absence of a trustworthy analysis. The only published analysis appears to be that by Hughes quoted by Clifton Ward, and reproduced by Harker for comparison, but this is obviously an impossible composition. There is not nearly enough alumina to form felspars and micas with the alkalis present, to say nothing of the lime, magnesia, and ferrous iron, which also must exist in these minerals. Taking these figures for what they are worth, we find 3·996 per cent. of soda and 4·516 per cent. of potash. This gives a molecular ratio for soda slightly higher than for potash.

In the slices examined for the purposes of this paper it was estimated that the alkali-felspar and plagioclase exist in approximately equal proportions; probably the former is slightly in excess of the latter. This would bring the rock within the adamellite category of Hatch.[1] Probably, however, the proportion of lime in the plagioclase is very low, so that the rock may be provisionally described as an alkali-granite.

The occurrence of abundant perthite and several types of micrographic intergrowth, together with a well-marked porphyritic structure, in this rock opens up interesting questions as to the origin of these structures and the physico-chemical laws which have governed their formation. The porphyritic felspars are somewhat indefinite in outline, without sharp boundaries, and often showing inclusions of the other minerals of the rock. It seems, therefore, unlikely that they can be of prior consolidation. All the available evidence suggests that these phenocrysts were formed in their present position concurrently with the final solidification of the rock. The tendency of modern ideas as to the physics of crystallization of rock-magmas is towards the belief that phenocrysts of this sort represent the excess of one component above the eutectic ratio for the several components. In this case the felspar molecule was in excess and crystallized first, while the finer groundmass, including the various forms of micropegmatite, represents the eutectic of the remaining components. Here, however, a further complication ensues from the fact that the bulk of the felspar is perthite, which is itself also a eutectic of a special kind, with partial miscibility of its components, orthoclase and albite. A micropegmatitic intergrowth of quartz and perthite must, therefore, be regarded as a ternary eutectic, in which the mutual relationships of the components are somewhat different, since quartz is immiscible with either of the felspars, while orthoclase and albite can form mixed crystals within certain limits.

[1] 'Classification of the Plutonic Rocks,' in 'Science Progress' 1908, p. 246.

These are not, however, the only minerals showing graphic intergrowths in the Skiddaw granite. A parallel intergrowth of alternate lamellæ of muscovite and biotite is common. This is a feature often observable in similar rocks, and probably indicates a close relationship between the two minerals, with incomplete isomorphism.

The most interesting and unusual case is that of a well-developed graphic relationship of the type usually associated with eutectics between muscovite and a perthitic felspar, which is by no means uncommon in this rock. From its general appearance there is every reason to believe that the muscovite is original, and not a secondary product of greisen-formation: the white mica formed in this way in the greisen-modification of certain parts of the granite mass shows a very different development, and is always distinctly scaly and fibrous; whereas in the graphic patches many distinct sections embedded in the felspar show a uniform cleavage and optical orientation over a large area. All are obviously parts of one and the same crystal. In one or two instances quartz also takes part in this structure, so that we have here an instance of a eutectic of four components.

The complete list of mineral molecules recognizable in this rock is six: namely, quartz, orthoclase, albite, anorthite, muscovite, and biotite; of these the albite is divided between perthite and plagioclase, so that in practice the number is reduced to five, namely, quartz, perthite, plagioclase, muscovite, and biotite. Hence the eutectic last mentioned contains nearly all the components, and approaches the theoretical eutectic of the magma.

From these considerations it appears to follow that the order of crystallization was that which finally led to a eutectic composition which expressed itself as a graphic intergrowth of a varying number of components. The large and comparatively pure phenocrysts represent the excess of certain components over this eutectic ratio.

III. The Metamorphic Aureole.

So far as is known, all the rocks comprised within the area affected by metamorphism belong to the Skiddaw Slates. This term, however, is a somewhat vague one, and there is no doubt that, as commonly employed and indicated on the maps of the Geological Survey, the name Skiddaw Slate includes rocks of greater antiquity than the Skiddavian division of Dr. Marr, and also some rocks of younger date, Lower and possibly even Middle Llandeilo (Glenkiln). The Skiddaw Slates, as at present defined, also include sediments of Cambrian age, and there is reason to believe that some at least of the coarser grits may be pre-Cambrian, corresponding to the Torridonian and Longmyndian Systems, and showing a very strong lithological resemblance to the coarse grits of Ingleton. A large exposure of coarse grits of this type is just touched by the aureole on its northern margin, but can scarcely be said to be involved in it. Grits of a less coarse type are abundant in the north-eastern and central parts of the aureole, and are well seen on the western face of Skiddaw; but there is no obvious reason for assigning these to a pre-Cambrian age, since they appear to be perfectly conformable to and continuous with the slaty bands containing fossils of Arenig age.

In most parts of the area there are fairly rapid alternations of lithological character, indicating variable conditions of deposition; but usually one type of sediment or another is dominant over a considerable thickness of strata, so that in one part the rocks are mostly grits, in another mostly shales, and so on. Around the metamorphic aureole three fairly well-marked rock-types may be distinguished: these, when unaltered, comprise pale grey grits of different degrees of coarseness, rather soft sandy flags of varying colours, and lustrous black slates. Between these types numerous transitional forms occur. The alterations which have been brought about in these rock-types by the granite intrusion form the main subject of the present paper.

The general strike throughout the district is remarkably uniform, varying but little on either side of an average of E. 15° N.–W. 15° S. The boundaries of the principal lithological bands also possess this direction, so that there is evidently not much fear of complications from variations of lithological character along the strike. When we come to consider dips, however, great difficulties arise, and it has not hitherto been found practicable to work out the tectonic structure of the district. The area is a very large one, and over the greater part of it exposures are few and far between, owing to a thick covering of drift and peat. Where exposures are numerous, it is evident that the structure is of intense complexity: the rocks often show the most violent folding and contortion on a small scale, even in hand-specimens, and there is every reason to believe that the folding on a large scale is equally well developed. The rocks are so strongly cleaved and slickensided, that it is often difficult, if not impossible, to determine the direction of the original bedding. The unravelling of the structure of the Skiddaw Slates would be a task of immense difficulty, and would probably not repay the expenditure of the necessary time.

Within and around the region affected by metamorphism, as before stated, three well-defined rock-types occur, and these show a considerable amount of regularity, as follows:—the southern portion, including most of the Saddleback massif, Lonscale Fell, and the southern part of Skiddaw, consists of a rather soft black slate, which is often very much crushed and slickensided. Certain bands of this, which have escaped crushing, contain a few fossils, especially tuning-fork graptolites, and *Caryocaris*. Next to this on the north comes a fairly broad band of grey somewhat flaggy slate, which stretches from the north side of Bowscale Fell past the north side of Sinen Gill, and appears to pass below the surface on reaching the higher ground south of the summit of Skiddaw. The middle part of the area is occupied by a very broad band of hard grey grit, which stretches from the southern side of Carrock Fell to the western face of Skiddaw. To the north of this again comes another belt of flags, and then a repetition of the soft black slates of the southern side. This series seems to be cut off by a fault on the north bringing in the coarse grits of Great Cockup, previously referred to as possibly of pre-Cambrian age.

From this brief sketch of the distribution of the different rock-types, it appears that the same sequence is repeated in inverse order on either side of a central line running from the southern side of Carrock Fell towards Skiddaw, approximately along the upper course of the Caldew. Such a structure must be either an anticline or a syncline; and, if we take into account the relation of the different rock-bands to the form of the ground, the former alternative seems to agree better with the observed facts: thus the outcrop of the central grit-band is much narrower on the high ground of Skiddaw than in the comparatively low ground at the eastern extremity, and it is in part concealed by the arching over of the outer members of the series, which on this supposition are higher in stratigraphical order. There is no doubt that in detail the structure is much more complicated than a simple anticline; and, taking into account the frequent alternations of different types of sediment and the known repetition of certain fossiliferous bands, the conception of a deeply denuded anticlinorium, pitching towards the south-west, seems best to meet the necessities of the case.

The position of the granite intrusion is in entire harmony with this view, since it would thus appear to have been intruded along the main axis of the anticlinorium, and in all probability its injection closely followed or even accompanied the folding. Direct evidence of the age of the granite is wanting, but it almost certainly belongs to the same phase of igneous activity as the granites of Shap and Eskdale, that is, to late Silurian or early Devonian times. The rocks of this district were certainly uplifted, folded, and denuded before the deposition of the Polygenetic Conglomerate, which is almost certainly of Devonian age, though commonly assigned to the base of the Carboniferous.

A point of some interest, which arises in the course of the investigation, refers to the peculiar relations existing between the metamorphic aureole and the topography of the district. Since the general effect of the metamorphism is to increase the apparent hardness of the rocks affected, it would naturally be expected that the altered area would stand up as elevated ground. But in actual fact this is far from being the case: the aureole, broadly speaking, forms a great basin, which is bounded by the highest mountains in the neighbourhood, such as Bowscale Fell, Saddleback, Skiddaw, Great Calva, Carrock Fell, etc., while the exposures of granite occupy a limited area in the floor of the Caldew valley. More remarkable still, it so happens that the outer limits of the aureole, as at present exposed, pass over the summits of these mountains, thus strongly accentuating the basin-like form of the whole. There can be no doubt that the highly altered cordierite and andalusite-rocks of the inner part of the aureole, in which bedding and cleavage have been completely obliterated, should present much greater resistance to the ordinary agents of denudation than the cleaved slates and well-jointed grits of the normal unaltered Skiddaw Series; but it is clearly evident that they do not, and it is impossible at present to offer any reasonable explanation of this curious anomaly.

The altered area surrounding the Skiddaw granite is an unusually large one, and out of all proportion to the visible exposures of igneous rock. It is generally admitted, therefore, that a large mass of granite must underlie the whole district at a comparatively small depth. The aureole is roughly circular in form, and has a maximum diameter from east to west of nearly 6 miles; the diameter from north to south is slightly less, being about 5 miles. Unfortunately, over a large part of this extensive area the exposures are very poor, owing to great accumulations of drift and peat. This is particularly the case in the upper and wider part of the Caldew valley, between Grainsgill and Skiddaw House; the northern flank of Saddleback also is almost completely covered by a great mantle of drift bearing thick grass, and exposures here are very few and far between. The only exposures with any pretence to continuity are in the streams which run into the Caldew: Blackhazel Beck, and one or two others on the south side, and Wiley Gill, Burdell Gill, etc. on the north. In most of these the junction of granite and sedimentary rocks is fairly well seen. Another district which presents special difficulties is the western face of Skiddaw: the outer margin of the aureole runs far below the summit on this side, over the enormous screes which are so conspicuous a feature of the upper part of this mountain, and it is consequently very difficult to follow and map accurately. For these reasons many of the lines shown on the accompanying map (Pl. XIV) must be regarded as approximate only.

IV. The Metamorphism.

Although this is so well-known an example of metamorphism, no complete account of the phenomena has ever been published, and the only description of any length is that contained in Clifton Ward's memoir.[1] Some of the conclusions to which he came were soon after controverted by Rosenbusch.[2] At that time microscopic petrography was in its infancy, and the whole subject has never yet been investigated by modern methods, although a few notes on minor points have been published from time to time.

[1] 'The Geology of the Northern Part of the English Lake District' Mem. Geol. Surv. 1876, pp. 5–12.

[2] 'Die Steiger Schiefer' 1887, p. 211.

Clifton Ward recognized three zones, and summarized the results of his observations as follows :

'On approaching the altered area, the slate first becomes faintly spotty, the spots being of a somewhat oblong or oval form, and a few crystals of chiastolite appear. Then these crystals become more numerous, so as to entitle the rock to the name of Chiastolite Slate. This passes into a harder, more thickly bedded, foliated and massive rock, Spotted (or Andalusite) Schist; and this again into Mica Schist of a generally grey or brown colour, and occurring immediately around the granite.' (*Op. cit.* p. 9.)

Rosenbusch, in his classical memoir on the Steiger Schiefer, criticizes this statement, and states that from his own observations the development of chiastolite here as elsewhere precedes the formation of spots : hence chiastolite-slate must be regarded as the equivalent of spotted clay-slate (Knotenthonschiefer), and this is succeeded by spotted mica-slate (Knotenglimmerschiefer).

From a careful study of the literature, as well as from my own observations, it appears that these two writers were not referring to the same thing, hence the misunderstanding. There are, in point of fact, two spotted zones: the first or outer spotted zone is not everywhere developed, but occurs in several places, as, for example, the western face of Skiddaw, outside of the chiastolite zone. This is the type referred to by Ward in the first sentence of the extract just quoted. The inner spotted zone is the Knotenglimmerschiefer of Rosenbusch, and in this zone, as was pointed out by Harker,[1] the spots consist of cordierite; this is also the spotted (or andalusite) schist of Ward. Rosenbusch appears to ignore altogether the highly micaceous facies, which is not noticeably spotty.

Ward's description, therefore, with some modifications, may be regarded as substantially correct with reference to the sequence of rock-types as seen in the Glenderaterra valley ; but it does not take into account the great variations of lithological type in the unaltered and altered rocks in other parts of the area. As will be shown in detail in the following pages, these originally different rock-types give rise to metamorphic rocks showing also a considerable amount of variation.

It is obviously impossible to give a detailed description of all the varieties of altered rock, which are endless in number and shade indefinitely into one another. However, as has been before stated, three fairly well-marked types are involved in the aureole : namely, black slate, grey flaggy slate, and rather massive grit. The effects of metamorphism on each of these will be considered separately as a matter of convenience, taking them in the following order :—

(1) The soft black slates of the Glenderaterra district on the south, and Dead Crags, near Dash, on the north.
(2) The grey flaggy bands which succeed these slates on the north and south respectively.
(3) The central grit-band of the Caldew valley.

This order is probably the inverse of the stratigraphical age, and is adopted merely as a matter of geographical convenience.

[1] 'The Naturalist' Leeds, 1906, p. 121.

Type I.—The Black Slate.

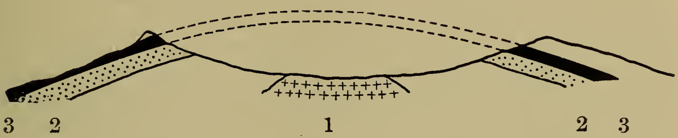
The rock here described as black slate represents the finest type of sediment, deposited in fairly deep water, so that it is comparatively free from gritty particles. As a result of the dynamic metamorphism at an earlier date a certain amount of mineralogical change was induced, of which the most important feature was in the majority of cases the formation of secondary mica in minute flakes, but different specimens show a considerable amount of variation.

A typical example of such a rock is seen under the microscope to consist, for the most part, of a felted aggregate of small flakes of colourless mica, with occasional minute grains of quartz, and a considerable amount of black material, which appears to include both carbon and iron ores; in some specimens iron pyrites is abundantly developed. There is also commonly present in large quantities a mineral the exact nature of which is still somewhat uncertain: it occurs in very minute, long, slender prisms, not well terminated, and often showing a cross-fracture somewhat like that of apatite. It is nearly colourless, or with a very faint greenish tinge, and perhaps exhibits slight pleochroism, although, owing to the minute size of the crystals and the paleness of the colour, this is difficult to determine with certainty. The strongest absorption appears to be parallel to the long axis. The refractive index is high and the double refraction very weak, giving steel-blue or grey of the first order. Most individuals seem to be simple twins, with a very narrow extinction-angle. It is optically negative. This mineral seems to be more nearly related to ottrelite than to anything else, and it is not improbable that the latter should occur in these rocks as a result of the dynamic metamorphism.

(*a*) The outer spotted zone.—In some localities, though not everywhere, the first sign of alteration seen on approaching the metamorphic aureole is the development on the cleavage-faces of the slate of indistinct whitish or silvery spots. Except for the presence of these spots, the slate is entirely unchanged. They seem to develop most freely in the very black carbonaceous slates, and are absent where the beds are at all gritty; but they occur also in the grey flag series. The outer spotted zone appears to be very narrow, and sometimes extends over only a few yards, so far as can be judged, since it passes gradually on the one hand into the unaltered slates, and on the inner side crystals of chiastolite begin to appear along with the spots. In one or two places, however, where the form of the ground is especially favourable, it covers a large area. The best instance of this is on Grey Crags, on the western face of Skiddaw below the Low Man, where the outer spotted zone covers nearly 1500 feet of vertical height. This is to be accounted for by the fact that the outer boundary of the aureole very nearly coincides with the slope of the ground (see fig. 1, p. 127).

The spots are whitish or slightly silvery in appearance, and either rounded or rectangular in form, as noted by Clifton Ward. Sometimes a darker spot can be seen in the centre, and it is a curious fact that this spot is more noticeable in photographs of specimens of this rock than in the specimens themselves. The presence of

Fig. 1.



1 = Granite ; 2 = Chiastolite-zone ; 3 = Outer spotted zone.

[This figure illustrates the variations in width of the outer spotted zone, according to the form of the ground. It is purely diagrammatic, and does not exactly represent any particular line of section.]

this spot and the angular outline suggest that the spots are in effect embryo crystals of chiastolite; but this cannot always be the case, since the light spots are often abundant in specimens which contain well-formed and large crystals of chiastolite.

(*b*) The chiastolite-slate.—It is perhaps hardly necessary to enter into much detail as to the structure and composition of this very well-known rock-type. Chiastolite is one of the most characteristic products of a low grade of metamorphism of argillaceous rocks, and is found in many localities.

Chiastolite, in the strict sense of the term, is largely developed wherever argillaceous rocks have been metamorphosed. The same mineral under a slightly different form (andalusite) occurs largely in the more gritty portions, and the distinction between andalusite and chiastolite is purely artificial. Most commonly, when the mineral is white and opaque in its appearance to the naked eye owing to decomposition, it is called chiastolite; and when clear, fresh, and glassy, it is called andalusite.

An ordinary specimen of chiastolite-slate in most cases differs only from the unaltered slate, or from that of the outer spotted zone, in the presence of more or less well-developed crystals of chiastolite. Sometimes these appear among the whitish spots of the outer spotted zone, and in other cases the chiastolite comes on at the outer margin of the aureole without any preliminary spotting. In all essential respects the character and composition of the groundmass remains unchanged, while the ottrelite mineral is commonly present and is frequently enclosed in the chiastolites. A typical specimen of chiastolite-slate from the Glenderaterra valley has a highly micaceous ground-mass, with a good deal of carbon and very little quartz. It shows some rather indistinct round or oval spots, which seem to differ from the rest only in the partial loss of the black colouring-matter. The chiastolites are large and well developed, showing the usual black cross. They seem to consist of a sort of matted aggregate of very minute flakes of a micaceous mineral, and show none of the optical properties of ordinary andalusite. There is no confirmation of the idea that the rounded pale spots eventually develop into chiastolite—in fact, their general appearance is suggestive of embryo crystals of cordierite.

It so happens that in no case does this type of black slate approach very closely to the granite exposures, so that it is not possible to say what effects are produced in it by the higher grades of metamorphism. The reason for this will be obvious from the map: the northern limit of the black slate in the Glenderaterra valley occurs about a quarter of a mile south of Sinen Gill, and the other exposures of granite lie wholly in the bands of grey slate and grey grit. Hence it appears that Clifton Ward's zones were not originally all of the same lithological character.

At certain localities on the eastern side of the Glenderaterra valley, especially just above the high-level cart-track, there are to be seen unusually large crystals of chiastolite or andalusite, often an inch or even an inch and a half long. These possess a peculiar metallic lustre, and strongly recall the well-known crystals of the same mineral in the schistes maclifères of the Salles de Rohan in Brittany. It is also frequently noticeable that these large crystals are bent and distorted, so that there has evidently been considerable dynamic metamorphism after or accompanying the intrusion of the granite.

As showing the low grade of metamorphism which suffices to produce well-developed crystals of chiastolite, the fact may be mentioned that on Gibraltar Crag, and elsewhere near the summit of Skiddaw, there are to be found specimens showing both chiastolite and graptolites. A similar association is also known in specimens from Brittany.

Type II.—The Grey Flags.

As already pointed out, the black slate is succeeded on the north by a belt of rocks of a distinctly different character. The dominant colour of these rocks when unaltered is grey or brownish, and certain bands possess a very characteristic silvery lustre. This belt varies somewhat in width according to the form of the ground, but possesses an average breadth of outcrop of about a mile. Included in it are the well-known exposures of Roughten Gill and Sinen Gill, which have been so often mentioned as types of the Skiddaw metamorphism. The same rocks are again well exposed at the head of the River Glenderamackin, in Bannerdale Crags, and in some of the crags in the neighbourhood of Bowscale Tarn. On the western side of the aureole the exposures are poor. A similar belt occurs again on the north, running through the summit of Skiddaw and Little Calva towards Coomb Height; here again exposures are not very frequent. Consequently the development as seen in the northern half of the Glenderaterra valley may be taken as typical of the metamorphosed grey flags, and thus may be compared with the little-altered rocks of the Bowscale district or Bannerdale.

The metamorphism of the rocks of this belt possesses certain very distinctive features, of which the most important are a strong tendency to the development of spots, and the formation of cordierite and mica. Andalusite is usually subordinate, though present in considerable quantity.

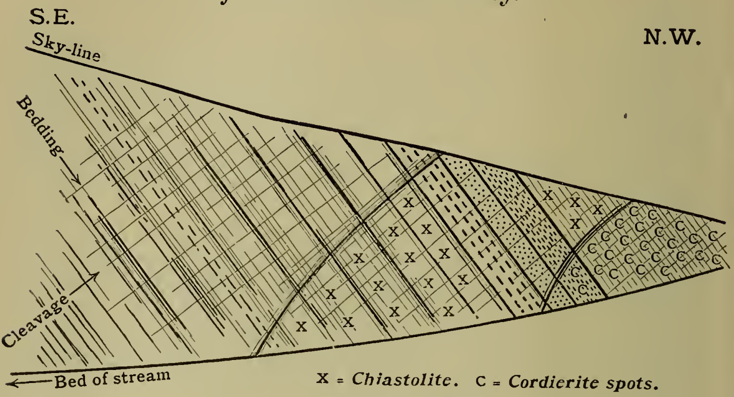
As a type of the unaltered rocks we may take those exposed on Bowscale Fell to the east of the tarn. These are, for the most part, well-cleaved slates with a distinctive silvery lustre, very different from the black slates hitherto described. When weathered these slates frequently possess a yellowish or brown colour, doubtless due to oxidation of the iron, but when fresh the characteristic colour is grey.

An average specimen of this rock from the neighbourhood of Bowscale Tarn, when examined under the microscope, is seen to consist for the most part of small flakes of a colourless mica, with minute dark grains of indeterminable nature, probably either iron-ore or carbon, and a considerable number of crystals of the ottrelite mineral before described. The mica-flakes are often arranged with radiate or stellate grouping, and the whole texture of the rock is very spongy. The foregoing description relates to the unaltered rock.

On approaching the metamorphic region spots begin to develop, and quickly become very abundant. The effects produced by slight alteration are very similar to those seen in the black slate. As an example of moderate alteration we may take specimens from the head of the River Glenderamackin, where exposures are very frequent. In the upper part of the valley, north-east of the summit of Saddleback, the field-relations of the rocks are very clearly displayed, and appear to be as shown in the accompanying diagram (fig. 2, p. 130). At this point the valley runs almost exactly across the strike, so that several different lithological types are exposed. The outer limit of the aureole is here in the black-slate band, and this is succeeded by a belt of spotted slate; still farther north this passes into a rock somewhat harder and characterized by cordierite, showing a higher grade of metamorphism. The cleavage is approximately at right angles to the bedding, and the outer edge of the aureole appears to be distinctly curved in a vertical plane (see fig. 2).

When examined microscopically, a thin slice of the spotted flags is seen to consist of a very fine-textured base including numerous spots and a few crystals of chiastolite. The spots are of two kinds: the smaller ones are ragged and ill-developed crystals of a rather pale brown biotite, which usually have a definite orientation in the rock. The axes of maximum absorption almost invariably lie transversely to the cleavage of the rock, so that the cleavages of the mineral do not, as might be expected, lie parallel to the schistosity-planes of the rock, but at right angles to them. The pleochroism is strong (reddish brown to colourless) and the birefringence rather low ($\gamma - \alpha = \cdot 02$ approximately).

Fig. 2.—*Diagrammatic sketch of the right bank of the upper part of the Glenderamackin valley.*



Certain clear areas, circular or oval in form, and free from crystals of mica, are obviously incipient crystals of cordierite, and in many cases faint indications of the usual complex twinning can be seen in them. The optical characters of the cordierite will be dealt with later, in connexion with specimens in which the crystals show a more complete development.

The rare crystals of chiastolite are easily discriminated from the cordierite by their more definite outline, greater clearness, and freedom from inclusions. They now consist of a micaceous or chloritic substance of moderate birefringence, occurring as aggregates of minute flakes, and showing a general structure which, when examined under a high power, strongly recalls serpentine.

Associated with this type are certain bands of a more gritty character, consisting for the most part of minute grains of quartz. In these the same brown biotite is shown, but cordierite appears to be absent: this is what would naturally be expected.

The most interesting feature of the specimens from this locality is the clear evidence that they afford of incipient crystallization: the cordierite is obviously developing at the expense of the white mica of the original slate, but it is not clear what mineral or combination of minerals gave rise to the brown mica. In this low grade of alteration new white mica is not developed to any extent; but, under a high power, occasional flakes can be seen enclosed in the brown mica, and often in parallel intergrowth with it.

The rocks of this type never come into contact with either of the larger visible masses of granite; therefore, as an example of the effects produced on them by a high grade of metamorphism, we may take the well-known exposures of Roughten Gill and Sinen Gill. Between the district just described and the head of Sinen Gill there is a large spread of peat with no exposures, and when next seen in place the rocks are obviously much more highly altered. In fact, the upper part of Sinen Gill may be taken as a typical locality for the so-called 'cordierite-gneiss,' and this gradually passes into the rock commonly spoken of as mica-schist. Here also are to be found gritty bands, but these seem to be quite subordinate, and are neglected in the following descriptions.

Cordierite-gneiss.—As a typical example of this rock, we may select a specimen from a point in Sinen Gill about 180 yards above the visible outcrop of the granite. To the naked eye it is a massive dark-brown or bluish-grey rock, very hard and weathering out into very large blocks. On a weathered surface it shows conspicuous banding, owing to slight differences of hardness in successive bedding-planes, and these lamination-planes are thrown into the most extraordinary folds and contortions, so that a surface of 3 or 4 square feet often shows a most complicated series of sharp folds and faults. From these it is evident that observations of dip are of no possible significance.

The microscopic structure of this rock is very simple. It consists of cordierite, andalusite, white and brown mica, with a few grains of opaque black iron-ore, which is probably magnetite. The cordierite occurs in large and well-developed crystals, often 2 or 3 millimetres in diameter, and roughly spherical. They show the usual optical properties, a rather low refractive index, about equal to that of quartz, and moderate birefringence (about ·011). The crystals are commonly twinned on the usual law, giving rather complex interpenetration-twins, frequently in six sectors, of which the opposite pairs extinguish together, so that the twins consist of three individuals. These crystals have been very fully described by Harker,[1] and for further details reference may be made to his description. The andalusite occurs almost exclusively as an aggregate of irregular grains, showing no definite crystal outlines. Now and then, however, fairly well developed crystals are seen, and these often show, especially in their central parts, the very characteristic rose-coloured pleochroism. Both brown and colourless mica occurs in great abundance, and it is noticeable that the latter generally shows much more definite outlines than the former. The two are often intergrown in parallel position. The micas occur largely as inclusions in the cordierite crystals, but the andalusite tends rather to concentrate in the spaces between them. In some parts of the rock, however, the crystals of cordierite are continuous, and enclose all the other minerals.

A specimen collected about 40 yards from the granite is very similar to the last, but shows occasional gritty bands, in which

[1] 'The Naturalist' Leeds, 1906, p. 121.

quartz-grains are the chief constituents. This sharp differentiation into bands showing aluminous silicates and those consisting chiefly of quartz suggests that there has been comparatively little diffusion of material, indicating a small range of molecular movement.

In another specimen, taken about 15 yards from the granite, the same minerals are shown, and cordierite is particularly abundant, with the usual twinning and conspicuous inclusions of quartz, of rounded form, which are so common and characteristic in this mineral. The shapeless grains of andalusite often exhibit pink pleochroism. Brown mica occurs in large ragged flakes, and shows many pleochroic haloes.

Another specimen, only a yard away from the granite, presents some especially fine examples of twinned crystals of cordierite. Although andalusite and brown and white mica are abundantly present, cordierite is certainly the dominant mineral.

I am indebted to Miss G. L. Elles for two specimens collected within a few yards of the granite outcrop: one of these is a peculiarly fine specimen of a cordierite-mica-schist, similar to those above described, but the other is unlike anything that I have myself observed in the field. On a weathered surface it is very similar to the rest, but when broken it is a pale-grey rock of very fine texture. Under the microscope it is seen to consist almost exclusively of a nearly colourless or very pale green actinolite, in bundles of minute radiating needles: the colour is so pale, that it is impossible to determine whether any pleochroism is shown; the extinction-angle $C \wedge Z$ is about 17°. There is also a very small quantity of a colourless interstitial material, which may be either quartz or cordierite; the latter is more probable, but the amount is too small to determine this point with certainty. This rock presumably represents a thin calcareous or dolomitic layer, interbedded with the slate. A very similar rock-type has been observed in the Skiddaw Slates of Ennerdale, where they are metamorphosed by the great granophyre-intrusion.

As before mentioned, the actual contact of the granite and the sedimentary rocks is well displayed in Sinen Gill, and close to the junction some interesting specimens were obtained. These, however, show a good deal of variation, and it is rather difficult to draw up a general description. It is quite clear that both arenaceous and argillaceous types are represented: in the former quartz is abundant, and has apparently undergone little alteration; in the latter the dominant mineral is mica, either brown or white.

As an example of the highly micaceous type, we may select a specimen which was taken within a few inches of the contact. To the naked eye it is a brownish rock, with a conspicuously crystalline appearance, though with little or no sign of schistosity, and the name mica-schist, applied by the older writers, is hardly appropriate. Under the microscope it is seen to consist almost exclusively of flakes of mica, with a few scattered quartz-grains, and a small quantity of interstitial matter, of which the true nature is very difficult to make out. Brown mica and white mica are almost equally abundant, though the crystals of the former are somewhat larger and better developed; its colour is a rather pale yellowish-brown and the pleochroism fairly strong: pleochroic haloes are quite common. They surround small crystals which are presumably zircons; but, owing to their minuteness, it has not been possible to determine this with certainty. The crystals of white mica are on the whole less regular in form and generally smaller, although the two micas often occur intergrown in parallel position. The small amount of interstitial matter is colourless and transparent, with a rather low refractive index, and shows no very definite optical properties. After a very careful examination, I am inclined to think that it is, in part at any rate, slightly decomposed cordierite, which is in process of being converted into a kind of shimmer-aggregate; and this idea is confirmed by the fact that other specimens show fairly well-defined patches of shimmer-aggregate having the typical form of the cordierite crystals of the kind previously described.

The foregoing description applies only to the more argillaceous types of sediment, in which little or no quartz appears to have been originally present; in the more gritty bands the development is slightly different. An interesting specimen was obtained from the contact in Sinen Gill, within an inch of the granite, on the right-hand side of the exposure, as one faces up stream.

This is a reddish-brown micaceous rock, containing conspicuous garnets. These are usually 2 or 3 millimetres in diameter, pale pink in colour, and showing well-developed dodecahedral faces. Under the microscope the rock is distinctly banded, consisting for the most part of white and brown mica, with quartz and cordierite, the last being partly represented by a micaceous shimmer-aggregate. There are also a few shapeless crystals of andalusite. Some bands are almost entirely composed of a mosaic of quartz-grains. The garnets are colourless in thin slices, with many minute inclusions, which appear to be quartz: except for the inclusions, they are absolutely isotropic. Certain bands show fairly large and rather shapeless patches of a mineral of a bright yellow or orange colour, with a rather high refractive index and very variable birefringence. Owing to the brilliant yellow colour the latter property is difficult to determine. The mineral frequently occurs as an aggregate, but sometimes as continuous crystals with definite extinction. The precise identification of this mineral was rather troublesome, and Dr. Bonney very kindly gave his assistance in the matter. In his opinion, it is to be regarded as an early and imperfect stage in the crystallization of staurolite. It shows the closest possible resemblance to some specimens of typical staurolite in Dr. Bonney's collection. This mineral is confined to particular bands, and it only occurs within a very short distance of the granite.

Besides the above-described connected series a large number of specimens have been collected and examined from various scattered and isolated exposures within the limits of the grey-slate belt, as indicated on the map (Pl. XIV); all of these are very similar, and it is unnecessary to describe them in detail. In certain bands andalusite occurs in fair quantity, but is by no means universally distributed.

From the foregoing description of the progressive metamorphism of the grey-slate series, it appears that the dominant minerals produced are cordierite and mica, while andalusite is quite subordinate, and garnet and staurolite occur only in immediate contact with the granite.

It was hoped that in this series it would have been found possible to distinguish definite zones of metamorphism and to indicate them on the map; but, owing to the very gradual transitions and the absence of exposures over large areas, this was found impracticable and the idea was abandoned.

Type III.—The Grey Grit.

Owing to the poorness of the exposures, it has been found very difficult to map the boundary between the grey flags and slates just described and the grey grits of the central portion of the aureole. These two types undoubtedly pass one into the other by insensible gradations, and the line traced on the map must be regarded as a mere approximation over part of its length. On the north-eastern side, however, on Bowscale Fell, the distinction on the ground is clear, and the boundary runs on the south-east side of Bowscale Tarn. Passing towards the south-west, another good continuous section is seen in the upper part of Blackhazel Beck; but after this, exposures of rock in place are few and far between, until we reach the higher slopes of Skiddaw. On the northern side there are fairly good exposures in Wiley Gill and Burdell Gill, and a long continuous section in the bed of the Caldew, near its junction with Grainsgill. Here the grits are seen actually in contact with the granite and greisen of Grainsgill. Unfortunately, in none of these cases does the section run along the strike of the beds. All the tributaries of the Caldew are dip-streams, and the course of this river itself near Grainsgill, where the best exposures occur, is distinctly oblique to the strike. It is, therefore, impossible to be certain that a series of specimens from any of these localities were originally of the same lithological character. The Grainsgill section affords the nearest approach to the desired arrangement, and, from an examination of other parts of the grit-belt, it appears that little variation may be expected; this area is therefore selected for description as most typical of the metamorphism of this series.

The grit-belt has a maximum width of about a mile and a half in the centre, and completely encloses the largest granite mass; the southern side of the Grainsgill mass also abuts against it.

Towards the south-west the outcrop of grits becomes narrower, and appears to sink underground below the higher parts of Skiddaw. The grits have not again been recognized with certainty on the western side of this mountain, where grey and black slates are predominant.

In a careful and detailed examination of the ground, one of the most striking features is the much greater intensity of the metamorphism at the north-eastern corner, as compared with the rest. The altered rocks here come into contact with the igneous complex of Carrock Fell, and at first sight it might be supposed that this great intrusion was responsible for the higher degree of alteration here observed. But a very cursory examination suffices entirely to disprove this idea. The contact between the gabbro and the sedimentary rocks can be followed closely all the way up the Caldew valley from Mosedale to Grainsgill, and beyond, a distance of over 2 miles. According to the officers of the Geological Survey and to Mr. Harker this junction is a faulted one, but there is no evidence on the ground in favour of this supposition. On the hill-side, a few yards above the village of Mosedale, the actual contact of grit and gabbro is very clearly seen, and the grit is practically unaltered. It may be mentioned in passing that it is possible here to collect small hand-specimens showing grit and gabbro completely welded together, which is inconsistent with the idea of a faulted junction. As we follow the contact along the side of Carrock Fell towards Grainsgill the grit gradually becomes increasingly metamorphosed, until near the farm of Swinside the alteration is intense, and so continues up to the outcrop of the granite rocks. This clearly shows that the alteration is progressive in a direction parallel to the edge of the gabbro, and perpendicular to that of the granite; it is therefore clearly due to the latter alone, and in the study of the metamorphism of this region the Carrock Fell complex is a negligible factor.

In explanation of the greater intensity of the alteration in this part of the aureole, it is significant that the granite of Grainsgill has been largely converted into a greisen by pneumatolytic processes, and the whole of this district is extensively permeated by mineral veins. It may be suggested that the residual vapours and liquids of the granite magma acted more especially and efficiently on the rocks of this area, and produced a more extensive alteration here than elsewhere.

The Caldew-Grainsgill section.—As before mentioned, a series of specimens were collected from the bed of the River Caldew and from Grainsgill Beck, as nearly as possible in the direction of strike. These range from the first field west of Swinside, up to the actual contact of grit and greisen in Grainsgill, a total distance of about three-quarters of a mile. On the whole, all these are very similar, and the amount of mineralogical change shown in microscope-sections is much less than would be expected from the appearance of the specimens to the naked eye. This is doubtless to be attributed to the highly siliceous nature of the rocks, which renders them little susceptible to metamorphism.

A specimen of what appeared to be a highly metamorphosed rock was collected from the middle of the first field west of Swinside, where there is a small boss of well-glaciated rock in place. It is of a deep purplish-brown colour, and shows very well-marked contortions on a small scale, as in Sinen Gill. Under the microscope it is seen to be a fine-grained aggregate of grains of quartz, with some felspar (which is probably clastic), together with irregular flakes of the usual brown biotite and subordinate white mica. In places crystals of cordierite are beginning to develop, apparently from quartz and white mica. The crystals are very poorly formed, and are evidently in an embryonic stage. They occur chiefly in bands of finer texture than the rest, where original mica was presumably more abundant. The outlines of the quartz-grains are for the most part irregular, and, where most free from mica, the rock approaches a quartzite in character.

Another specimen, taken from about a quarter of a mile below the junction of Grainsgill Beck with the Caldew, is on the whole very similar in general character, but the crystals of cordierite show much more perfect development. In this specimen also andalusite occurs in rather small crystals, which are generally irregular, but sometimes idiomorphic; they frequently show rose-coloured pleochroism.

On approaching nearer to the granite the most noticeable change is that the biotite becomes more and more completely converted into a pale-green chloritic mineral, the other constituents remaining the same. Andalusite is present in some specimens, but not in others. The most interesting of all is one taken from the actual contact of the grits with a large dyke of greisen in the bed of Grainsgill Beck. This rock consists solely of quartz, white mica, with a little green chlorite, and abundant garnets: no andalusite or cordierite can be identified. The garnets are very small, colourless in thin section, and isotropic. One slice of this rock shows the actual junction of the sediment and the igneous rock, and in general characters the two are very similar, though easily distinguishable by the naked eye, as well as in the slice. The greisen consists of quartz and muscovite only, and possesses a somewhat coarser texture. The garnets and a small amount of chlorite, together with finer texture and a distinct banding, serve to distinguish the sediment. The general character of the rock suggests that the pneumatolytic action which produced the greisen has also had some influence on the surrounding sediment. The metamorphosed rocks in this part of the district are, on the whole, much paler in colour than elsewhere, apparently because brown mica is absent. This difference in colour is probably due also to pneumatolytic action, since pale or colourless mica is well known to be one of the most characteristic products of gas-action.

Andalusite-bearing rocks.—In the area just described andalusite is not an important constituent of the metamorphosed rocks, probably on account of a deficiency of alumina, but in certain other localities this mineral occurs abundantly, even under a high grade of metamorphism. In these more highly altered rocks the andalusite is fresh, whereas the chiastolite crystals of the outer zone seem to be always represented by decomposition-products. The best development of such large andalusite crystals occurs in a transition-zone between the grey flags and the grey grits, and they are well seen in Blackhazel Beck, on the north side of Saddleback.

A hand-specimen of this rock shows large prismatic crystals of andalusite, which are commonly clear and colourless, with a glassy lustre, when absolutely fresh; sometimes they are grey or white, and in these the dark cross can often be distinguished. The ground-mass is fine-textured and generally very dark in colour, often almost black. Under the microscope this rock does not differ much from the altered grits before described, except in the presence of the large andalusite crystals. The ground-mass consists of small grains of quartz, with abundant flakes of a rather deep brown mica; in some specimens there are in addition rounded crystals of cordierite. There are also occasionally rather large rounded spots stained a bright yellow; the true nature of these was not determined, but they do not seem to be of much importance.

The andalusite crystals are clear and colourless, with a fairly high refractive index, and birefringence a little higher than that of quartz ($\gamma - \alpha = \cdot 012$ approximately). The mineral shows very well-marked cleavage and straight extinction. The black cross or some other symmetrical figure is very conspicuous, and inside it there is frequently to be seen a core of clear andalusite which often shows pink pleochroism. The outlines of the crystals are quite sharp, and they do not enclose other minerals.

The contact of the grits with the granite is well exposed in the bed of Blackhazel Beck, but the rock-types here seen are not of much interest. The grits seem to have been exceptionally free from aluminous matter, so that andalusite and cordierite are almost absent. The latter is probably represented by a few small patches of shimmer-aggregate. The greater part of the rock consists of clear grains of quartz, with a varying amount of both white and brown mica: close to the granite the latter is a good deal bleached, as at Grainsgill. No garnets or staurolite could be found.

V. General Conclusions.

From the preceding detailed account of the metamorphism produced by the Skiddaw granite in different parts of its aureole certain general conclusions can be drawn; in the first place, it is evident that a considerable variety of rock-types are involved, and that a description taken from one area may be inapplicable to others. Furthermore, it follows from this that the descriptions given by earlier writers, and especially their definitions of zones, do not hold, since the rock-types described were originally different.

In the broadest sense, three well-marked rock-types can be recognized in the Skiddaw district: black slate, grey flags, and grey grits. The chiastolite-slate of Clifton Ward and others is chiefly derived from the black slate, which is never seen to undergo the higher grades of metamorphism. The best examples of this type are to be seen in the Glenderaterra valley on the south and at Dead Crags, near Dash, on the north. The cordierite-rocks of Sinen Gill and the central parts of the aureole generally are derived from the grey flags, as is also the so-called 'mica-schist' of Sinen Gill. In these the dominant minerals are cordierite and biotite, andalusite being quite subordinate and occurring chiefly in the more argillaceous bands; garnet and staurolite are developed only in immediate contact with the granite. The grey grits occupy all the central parts of the aureole, and both of the larger exposures of granite are seen in contact with them. In the more siliceous members of this group metamorphism is much less marked than in the other types, and many examples resemble impure quartzites. By far the most abundant mineral, besides quartz, is brown mica, but in the neighbourhood of the granite and greisen of Grainsgill this is, for the most part, represented by pale-green chlorite; the difference is probably due to the bleaching and reducing action of pneumatolytic vapours. Here and there in the grey grit series are to be found more aluminous bands, and these have given rise to cordierite and andalusite-bearing rocks, much like those of the grey flags. Here also garnet is only found in immediate contact with the granite.

With regard to the chemical and mineralogical changes which have taken place as a result of the intrusion, it is rather difficult to say anything definite. In the first place, it is clear that the Skiddaw Slates had undergone very extensive dynamic metamorphism previous to the intrusion of the granite, since the cleavage, foliation, and folding are still clearly visible, although the divisional planes have been sealed up by the recrystallization induced by heat. Now intense pressure itself sets up well-marked mineralogical changes, so that when the heating process began the rocks were no longer in their original condition, but had doubtless undergone a considerable amount of alteration. The most important of these changes appear to have been the abundant formation of secondary mica, and of the mineral which has been somewhat doubtfully identified as ottrelite. These are characteristic of the Skiddaw Slates in their normal condition; and, for all practical purposes, we may consider that the principal constituents of the slates before alteration by the granite were quartz, mica, oxides of iron, and carbon.

The leading minerals produced by metamorphism are cordierite, andalusite, biotite, and muscovite, all of which are aluminous silicates: hence it follows that the rocks were originally rich in alumina; the formation of abundant cordierite indicates the presence of a large amount of magnesia, which must have been contained in the finely-divided mica of the slates; while the original iron must have entered into the biotite. The alkalis appear to have formed colourless micas rather than felspar, which is, indeed, conspicuous by its absence. In the few cases where felspar was observed it appears to have always been original (that is, clastic). Although kyanite and sillimanite were sought for diligently, they were not found; and this fact is significant. The absence of these minerals may be taken as a conclusive proof that the rocks were never subjected to a very high temperature. All the evidence is in favour of the maintenance of a moderate temperature for a long period of time, thus allowing of a very complete recrystallization for a long distance from the margin, although the changes close to the intrusion are not of a very striking character. It thus appears to be demonstrated that the Skiddaw granite was not very hot at the time of its intrusion, and also that it was intruded under a thick cover, so that the heat was maintained for a long time. By this means the molecules were kept in a state of active vibration for a lengthened period, and were thus enabled to enter into new combinations over a very wide area.

So far as concerns the chemical composition of the metamorphosed rocks, there is no indication whatever of any addition of material from the intrusion, except possibly in the neighbourhood of the Grainsgill greisen, where there is some evidence of pneumatolysis. This question can, however, be decided by general considerations alone, since it is clear that chemical analyses would be utterly useless, owing to the impossibility of ascertaining whether the altered and unaltered rocks were originally similar. The aureole is on a very large scale, and there are no continuous sections of sufficient length to enable any given bed to be traced right through the metamorphosed region. Considerable variations of lithological character occur within a very small thickness of strata, and conclusions founded on comparison of analyses could have no possible value.

The phenomena here displayed may be very briefly summed up as an example of a moderate degree of thermal metamorphism due to the intrusion of a great mass of granite, at a comparatively low temperature, into a series of rocks of somewhat variable composition, but on the whole rich in alumina. The most important minerals produced are cordierite, andalusite and its modification chiastolite, biotite and muscovite; while garnet and staurolite are only found close to the granite. Owing to the great variation in lithological character, it has not been found practicable to divide the aureole into definite zones, but the alteration is gradual and progressive from without inwards.

In conclusion, I have much pleasure in expressing my great obligation to several friends for help in the somewhat arduous field-work necessary for this investigation, which not seldom involved a good deal of physical discomfort, owing to the inclemency of the weather and the roughness of the ground. I have received valuable assistance from Dr. F. H. Hatch, Mr. P. Rigby of Christ's College, Mr. A. H. Noble of Queen's College, Cambridge, and especially from Mr. James Romanes of Christ's College. To all these I return my most hearty thanks.

EXPLANATION OF PLATE XIV.

Geological sketch-map of the Skiddaw district, on the scale of 1 inch to the mile. The map is oriented north and south. Altitudes are indicated in feet.

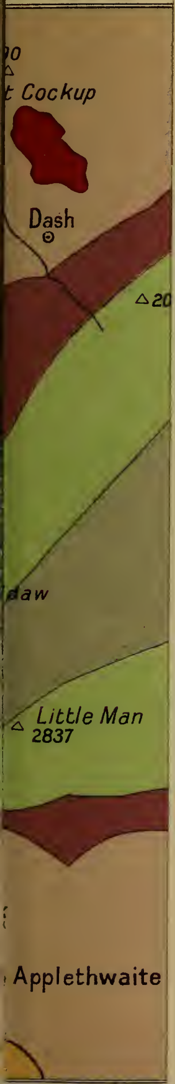
Discussion.

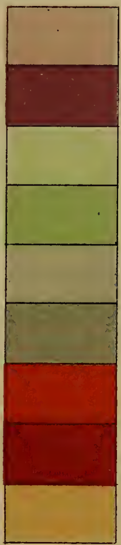
The President (Prof. W. J. Sollas) remarked that the supposed identification of a granitic intrusion with the core of an anticline was of particular interest at a time when increasing scepticism was felt as to the existence of a direct relation between granitic masses and tectonic features. As a rule, granitic magmas seemed to make their way upwards in independence of folding.

Dr. J. W. Evans referred to the importance of pressure in determining the character of the metamorphism of sedimentary strata by intrusive rocks, and especially in inducing the formation of minerals with greater density and less molecular volume. The presence of kyanite, the aluminium silicate with highest specific gravity, would be an indication that the metamorphism occurred under considerable pressure; for under low pressure kyanite was converted into fibrolite at a high temperature. Andalusite was also converted into fibrolite when strongly heated. The presence of andalusite and the absence of kyanite and fibrolite in the metamorphic rocks described by the Author would, therefore, constitute evidence that the granite was intruded at a comparatively low temperature, and at the same time under quite moderate pressure.

Mr. Postlethwaite welcomed the Author's confirmation of his own opinion, that the extensive aureole of metamorphosed rock indicated the presence of a large mass of granite at a little distance beneath the surface. If the progress of denudation had been somewhat less, there would have been no exposure of the granite, and the existence of an igneous mass beneath could only have been inferred from the altered character of the superincumbent strata.

Mr. Lamplugh remarked that, some years ago, on visiting the district described by the Author, he had been impressed with the difference in the degree of metamorphism shown by the rocks of Skiddaw in the neighbourhood of the granite, as compared with that shown by the similar rocks in the Isle of Man near the Foxdale granite. At Foxdale the gradual shelving of the granite-surface beneath the slates had been actually proved by mining operations; yet the alteration was often comparatively slight. In the Isle of Man he was forced to surmise that there had been some other active factor besides the heating of the sediments by the igneous intrusion, namely, differential movement in strata that were already heated nearly up to the critical temperature.





Black Slate.

Do. do. Metamorphosed.

Grey Flags

Do. do. Metamorphosed.

Grey Grit

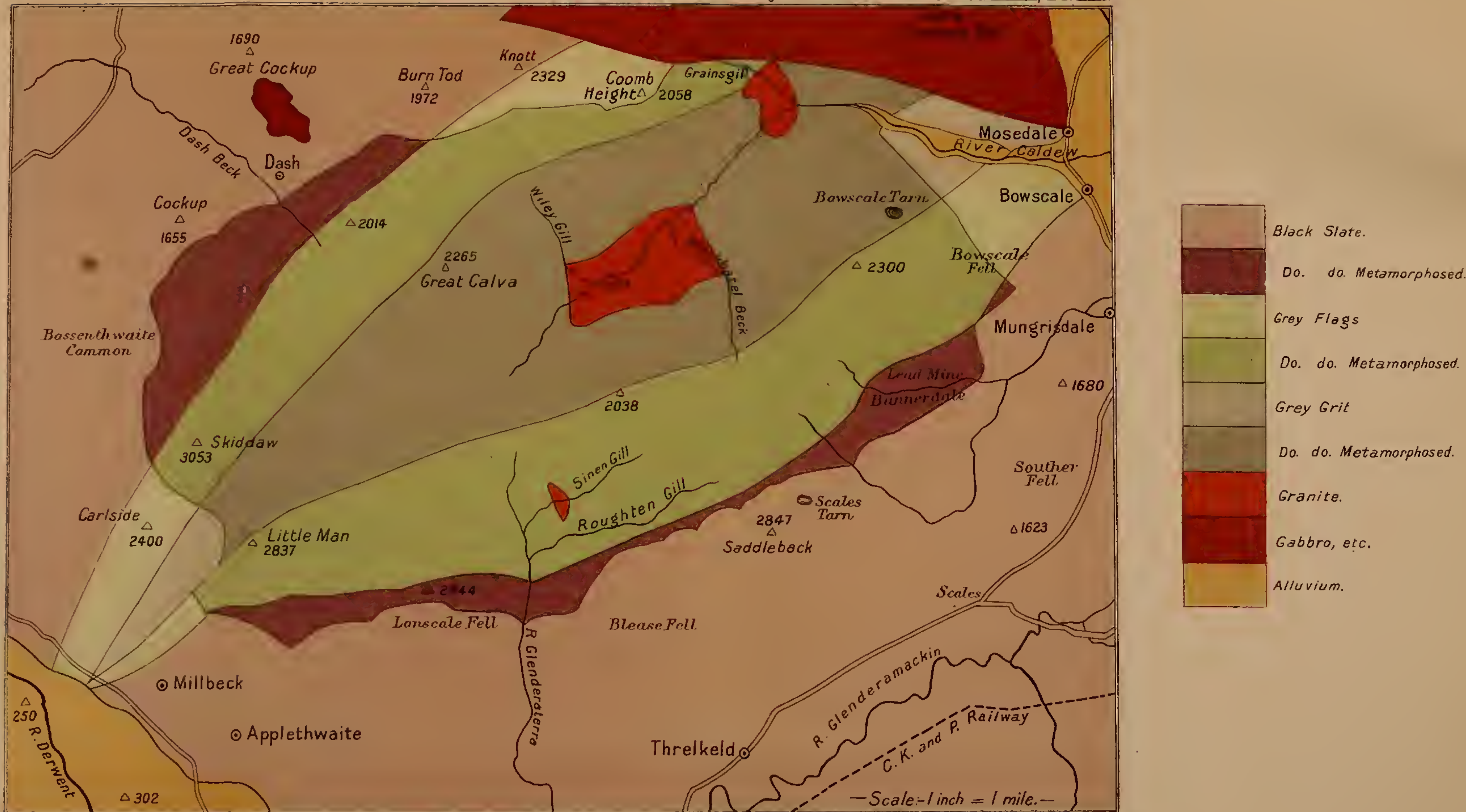
Do. do. Metamorphosed.

Granite.

Gabbro, etc.

Alluvium.

OGICAL S



GEOLOGICAL SKETCH-MAP OF THE SKIDDAW DISTRICT.

Mr. Whitaker asked whether the Author considered that the three outcrops were part of one mass connected underground at no great depth, and, if so, whether from the character and amount of the metamorphism away from the granite-outcrops, any estimate could be made of the depth of the granite.

The Author, in reply, thanked the Fellows for their kind reception of his paper, and regretted that time did not permit him to deal with all the interesting points raised in the discussion. He had made a most careful search for kyanite and sillimanite, and had found neither: hence it must be concluded that the temperature of the intrusion was not very high. He believed the intrusion to be one of very large volume, and thought that the three visible exposures were undoubtedly connected at a small depth. As suggested by Mr. Whitaker, the depth of the upper surface of the granite could be approximately estimated at any point, from the observed slope of the outer margin of the aureole. He did not wish to lay any stress on the term 'laccolith,' and suggested that the granite came up along an axis of uplift, of Caledonian strike, which was possibly continuous through the Isle of Man into the South-East of Ireland. The granites of all these districts were very similar in their general characters. With regard to the age of the granite, the Author made no suggestions, from want of data, but believed it to be undoubtedly older than the Carrock Fell complex, which did not seem to be metamorphosed by it.

7. *The* Tremadoc Slates *and* Associated Rocks *of* South-East Carnarvonshire. By William George Fearnsides, M.A., F.G.S., Fellow of Sidney Sussex College, Cambridge. (Read December 1st, 1909.)

[Plates XV–XVII—Sections & Map.]

Contents.

I. Introduction.

The ancient parish of Ynyscynhaiarn lies along the northern shore of Cardigan Bay, at the mouth of the Afon Glaslyn, and forms the south-eastern corner of the county of Carnarvon. The area to be described in the present paper is the country represented upon the 6-inch Ordnance Survey maps of Carnarvonshire, Sheet XXXIV S.E. (Criccieth) and Sheet XXXIV S.W. (Portmadoc), with portions of Sheets XLII N.E. & N.W. and XXXIV N.E. & N.W. to the north and south of these. It includes portions of all four quarter-sheets of Sheet 75 of the 1-inch Geological Survey map.

This area is a rectangular block of some 20 square miles, and includes the townships of Portmadoc and Tremadoc (now united as the Urban District of Ynyscynhaiarn) and the flourishing health-resorts of Borth-y-gest and Criccieth. It is traversed by the Cambrian Railway, between Barmouth and Pwllheli, and is approached either by that railway or by the London and North-Western Railway (through Bangor and Afonwen), or again by the narrow-gauge railway from Ffestiniog.

For its scenery the district has long been famous, and there are few British districts which can show so great a variety of tide-flat, salt-marsh, sea-cliff, sand-dune, park, coppice, meadow, cornland, bog, moor, lake, and mountain, even over an area of many times its size. The bigger hills of the district, rising abruptly almost to

1000 feet above sea-level, occur in the north and east; and while, both geologically and topographically, Tremadoc may be said to lie among the Snowdonian foothills, Criccieth stands outside upon the foreland and belongs to the head of the Lleyn peninsula.

My first introduction to the district was as a member of Prof. Hughes's field-class in the summer of 1901. The field-work upon which the present paper is based was begun in 1902,[1] and each year since that time, sometimes alone, and sometimes with a small party of Cambridge pupils, I have spent a month or more among its rocks. The interpretation of the general structure of the district, which is here put forward, was arrived at in the summer of 1906; but, as the result differs so greatly from the views arrived at by earlier writers, I have kept back publication until I could confirm its detail, and by mapping the area of the Moelwyns have proved its extension over a very much wider area.

II. Previous Literature.

The district of Ynyscynhaiarn has long attracted the attention of geologists, and its literature affords an interesting insight into the mode of evolution of some of our larger geological terms.

The first recorded incursion into the district seems to be the visit of Sedgwick in 1831,[2] but, beyond the statement that the rocks are to be included within the newly suggested Cambrian System, little result survives. The first paper devoted to the district is one by J. E. Davis, which appeared in 1846, and is entitled 'On the Geology of the Neighbourhood of Tremadoc.'[3] In this the author recognized that the hills of the district are due to differential denudation, and speaks of the Traeth as a recently-filled fjord or sea-loch. He records the unusual general strike of the rocks, and speaks of the major hill-masses as due to intrusive igneous sills. He also announces the discovery of abundant *Lingula* at various points, along what we now know to be the outcrop of the *Lingulella* Band.

In Daniel Sharpe's general memoir on the 'Geology of North Wales' we find the district mentioned, the observations due to Davis being in the main confirmed.[4] In this memoir is found the first account of the ironstones of the Ynys about Tremadoc, and we are told that the intrusive greenstones belong to the Snowdonian (mountain) rather than to the Lleyn (peninsular) type.

In 1847,[5] in Sedgwick's revision of his Cambrian System, we

[1] See Rep. Brit. Assoc. (Belfast) 1902, p. 614.

[2] Introd. to M'Coy's 'Brit. Pal. Foss. Geol. Mus. Univ. Cambridge' 1855, p. xli; see also Preface to J. W. Salter's 'Catal. Cambr. Silur. Foss. Geol. Mus. Univ. Cambridge' 1871, p. xv.

[3] Quart. Journ. Geol. Soc. vol. ii, p. 70.

[4] *Ibid.* p. 283.

[5] 'On the Classification of the Fossiliferous Slates of North Wales, &c.' *ibid.* vol. iii, p. 139.

find an accurate description of a section across the heart of the district, and meet with the term 'Tremadoc Group' applied as a name for the slates between and below the greenstone intrusions, that is, as a term embracing all rocks from the Upper Llandeilo (Zone of *Climacograptus peltifer*) downwards to the Maentwrog Beds or Lower *Lingula* Flags. We are told that such a group can be recognized by its mineral character, and great stress is laid upon the diagnostic value of the occurrence of pisolitic iron. We are informed that the slaty members of this Tremadoc Group have yielded two graptolites, an *Asaphus* and a *Lingula*. We gather further from that paper that the bed containing the *Lingula* (*Lingulella* Band) has been traced a great way around the Harlech dome, and that it affords an excellent datum-line for the determination of the geological horizon of other beds, both above and below.[1] A little farther on in the paper the beds below and about the *Lingula* datum-line in the Tremadoc district are compared with similar rocks to the south of Ffestiniog, and the term 'Ffestiniog Group' is hinted at as a name for these.[2] In the final summary, however, the terms Tremadoc and Ffestiniog are used synonymously, and in the figure of the general vertical section the Tremadoc Group is shown resting upon 'Crystalline Slates' (*op. cit.* p. 156).

By 1851 it would seem that the progress of the official geological survey of Wales under Ramsay and Selwyn, and in this district by Salter especially, had shown the necessity for an amplification of the 1847 scheme: hence, in the introduction to M'Coy's 'Systematic Description of the British Palæozoic Fossils in the Geological Museum of the University of Cambridge' 1855, p. xx, we find the nomenclature entirely recast, and the older Ffestiniog or Tremadoc Group subdivided by Sedgwick thus:—

CAMBRIAN.	Upper.	Bala Group.	Upper Bala. Lower Bala.
	Middle.	Ffestiniog Group.	Arenig Slates and Porphyries. Tremadoc Slates. *Lingula* Flags.
	Lower.	Bangor Group.	Harlech Grits. Llanberis Slates.

In this scheme the term Ffestiniog is retained as a collective name for the three middle subdivisions, while Tremadoc is completely specialized and applied to a definite slate series forming the middle member of the Ffestiniog Group.

In Sedgwick's classic paper on the 'Classification & Nomenclature of the Lower Palæozoic Rocks of England & Wales'[3] the

[1] Quart. Journ. Geol. Soc. vol. iii (1847) p. 143.
[2] *Ibid.* p. 144.
[3] *Ibid.* vol. viii (1852) p. 136.

various subdivisions of this scheme are further defined, and we are again told that the Tremadoc Slates are to be recognized by their peculiar mineral structure[1]; but, as great stress is laid upon the occurrence of mineral veins, and of beds and concretions of magnetic and pisolitic iron, it would seem that the graptolitic shales of the Upper Llandeilo were still included. The definition of the *Lingula* Flags, as extending downwards from the base of the Tremadoc Slates to the sea at Treflys, would seem to be entirely satisfactory.

The paper by Ramsay on the 'Physical Structure & Succession of some of the Lower Palæozoic Rocks of North Wales, &c.',[2] which followed in 1853, has only a passing reference to the Tremadoc country, but bears intrinsic evidence that the term *Lingula* Flags was then held by the Geological Survey to include Sedgwick's Tremadoc Slates, although, as shown by Salter's paper 'On the Tracks of a Crustacean in the *Lingula* Flags',[3] the district had been worked over in the summer of 1852. From that time until the appearance of Ramsay's great memoir on the 'Geology of North Wales' in 1866, the Tremadoc area seems to have been recognized as Salter's particular preserve; and, except for the excellent collecting work of Homfray and Ash, all the later work seems to be due to him.[4] From the Introduction to M'Coy's 'Brit. Pal. Foss.' already quoted, we learn that Salter was taken over the ground by Sedgwick in 1847 and 1848; but, according to Salter,[5] it was Barrande who, in maintaining that the *Lingula* Flags belong to his Primordial Zone (Stage C) of Bohemia, caused him to return again. By Salter also we are told that already in 1853[6] he had obtained palæontological evidence of a threefold division of the *Lingula* Flags; and from Ramsay[7] we learn that [after 1857] Salter was able to demonstrate the value of the Tremadoc Slates as a formation containing a distinctive fauna.

Salter claims to have followed and mapped the Tremadoc rocks and the three divisions of the *Lingula* Flags from Portmadoc all around the anticline to Criccieth in 1860 (Mem. Geol. Surv. vol. iii, 1866, p. 246). After 1860 he turned his attention to the subdivision of the Tremadoc Slates; but, although the determination of an Upper and a Lower division and the section across the Deudraeth peninsula are in the main satisfactory, his application of the results to the actual Ynyscynhaiarn area is not so easy to follow.

From 1866, the date of publication of Ramsay's 'Geology of North Wales,' although we find frequent mention of the district in

[1] Quart. Journ. Geol. Soc. vol. viii (1852) p. 148.
[2] *Ibid.* vol. ix (1853) p. 161.
[3] *Ibid.* vol. x (1854) p. 208, & Rep. Brit. Assoc. (Belfast) 1852, Trans. of Sections, p. 58.
[4] Mem. Geol. Surv. vol. iii (1866) pp. 67 & 242.
[5] *Ibid.* Appendix, p. 245.
[6] *Ibid.* p. 246.
[7] Quart. Journ. Geol. Soc. vol. xix (1863) p. xxxviii, & Mem. Geol. Surv. vol. iii (1866) p. 7.

the various papers on Cambrian rocks in general, there is little evidence of actual progress of field-work within its boundaries. Very important in their general bearing are papers by Salter and by Salter & Hicks,[1] on the separation of the Menevian from the base of the *Lingula* Flags, and especially the great classic of Belt,[2] in which the remaining upper part of the *Lingula* Flag Series is broken into the three groups, Maentwrog, Ffestiniog, and Dolgelly, which are defined with all the exactitude of modern palæontological methods.

Turning now to the subdivisions of the Ordovician System, we are told [3] that in the very year (1843 or 1844) in which Sedgwick had discovered the *Asaphus* and graptolites at Tremadoc, he and Salter had also obtained *Calymene parvifrons* and *Ogygia selwynii* from beds which they called 'Tremadoc,' on the western flanks of Arenig. These (Arenig) beds, however, were never correlated with any member of Murchison's Shropshire series; and, although Salter had described the fossils in 1847, it was not until 1853 that he determined them as of age intermediate between the fauna of the Tremadoc Slates and the better-known fauna of the Bala or Caradoc beds.

In 1854 Salter went with Murchison to Shropshire, and on p. 52 of the second edition of 'Siluria,' which appeared about the end of the year 1859, he figures fossils exactly similar to those that he knew from Arenig, along with others from the lower lead-bearing series of Shelve. The rocks containing them are spoken of indifferently as Highest *Lingula* Flags or Lower Llandeilo.

Throughout his later work in Wales,[4] and especially in his Presidential Address of 1863,[5] Ramsay always insisted upon the importance of the break and unconformity at the top of the Tremadoc Slate of the Deudraeth, and hence must have given up any idea of the synonymy between Tremadoc and Lower Llandeilo at a very early date. In so doing, he must of necessity have opened the way for Hicks,[6] who was working in South Wales, to supplant the Murchisonian term 'Lower Llandeilo' by the scientifically defined revival of the Sedgwickian Arenig. Salter, too, in 1866, seems to have been very ready for the new arrangement, and his lists of Llandeilo fossils in the Geological Survey memoir (vol. iii, pp. 255–59) are obviously arranged upon the Hicksian plan. The lists, however, are unfortunate, in that certain beds which at Ty Obry and at Tyddyn-dicwm, within the area here described, contain Upper Llandeilo (Hicks) graptolites, are identified as Lower Llandeilo, and in the second edition (1881, p. 371) have their fossils included

[1] Quart. Journ. Geol. Soc. vol. xxiv (1868) p. 510.
[2] Geol. Mag. 1867, pp. 493, 536.
[3] Mem. Geol. Surv. vol. iii (1866) p. 257.
[4] *Ibid.* pp. 63, 71.
[5] Quart. Journ. Geol. Soc. vol. xix, p. xxxviii.
[6] *Ibid.* vol. xxxi (1875) p. 167.

among the lists of Arenig species. This mistake was recognized by Mr. Hopkinson & Prof. Lapworth in 1874,[1] and is pointedly referred to by the latter in his 'Distribution of the Rhabdophora,'[2] but was allowed to pass uncorrected into the second (1881) edition of Ramsay's great work.

The papers by Hicks fully establishing the faunistic classification-scheme were published in 1873 and 1875[3]; and, in addition to their incidental application of the new terms to the naming of the rock-series within our district, they contain the suggestion that the Upper Tremadoc Slates (as the term was employed by Salter) are the equivalents of, and are to be included within, his (Hicks's) Lower Arenig. Such a suggestion, involving, as it does, the placing of the Tremadoc as the lowest member of the Ordovician System, is still a matter of interest; but, as it may involve the complete absorption of the ancient term 'Tremadoc Slates,' it cannot, I think, be proceeded with on the evidence before us.

The scheme of classification of the rocks that I have found most useful in working out the rocks of the district is an amplification of the one which I adopted in describing the corresponding rock series at Arenig,[4] and, like the older schemes of Sedgwick and Salter, is based upon a combination of the palæontological and lithological evidence locally obtained. It is as follows:—

	Western or Criccieth District.	*Eastern or Tremadoc District.*
CARADOC SERIES.	Rhyolitic ashes and agglomerates.	
	Variable dark-grey and black shivery slates, banded, but with no distinguishable horizons.	Grey slate series, often strongly banded, with a few shelly fossils (*Trinucleus* and *Orthis*) in the upper part.
		Andesitic ashes and ashy shales. Vesicular andesites.
LLANDEILO SERIES.	Dark banded slates with intense cleavage; no fossils found.	Blue-black slates containing graptolites. Zone of *Nemagraptus gracilis.*
		———
	Earthy slates, with occasional 'tuning-fork' graptolites.	
ARENIG SERIES.	Shivery slates passing down into Flaggy grits yielding *Calymene parvifrons.*	———
	Basal conglomeratic grit.	Conglomeratic grit of Ynys Towyn.

Unconformity.

[1] Quart. Journ. Geol. Soc. vol. xxxi (1875) pp. 631 *et seqq.*
[2] Ann. & Mag. Nat. Hist. ser. 5, vol. iv (1879) p. 340.
[3] Quart. Journ. Geol. Soc. vol. xxix, p. 39, & vol. xxxi, p. 167.
[4] *Ibid.* vol. lxi (1905) pp. 612 *et seqq.*

Tremadoc Series.	**Garth Hill Beds:** (Incomplete in the Ynyscynhaiarn area.) Grey-blue slates with *Angelina*.
	Penmorfa Beds: Flaggy mudstones and thinly-bedded slates with *Shumardia* and the Shineton fauna.
	Portmadoc Beds: Thickly-bedded felspathic slates, with occasional *Asaphellus*.
	Moelygest Beds: Banded grey slates and mudstones; few fossils, *Acrotreta* and *Bellerophon*.
	The *Dictyonema* Band: A constant and characteristic band of bright-rusting blue-grey mudstones, with abundant *Dictyonema sociale*.
	Tynllan Beds: Thinly-bedded rusty shales, with some hard grey mudstone-bands, containing *Niobe* and *Psilocephalus (Symphysurus)*.

Dolgelly Series.	Sooty-black mudstones, with *Peltura scarabæoides*.
	Blue-black mudstone, with *Agnostus trisectus*.
	Black slates, with calcareous bands often crowded with *Orthis lenticularis*.
	Dark flaggy slates, with *Parabolina spinulosa*.
Ffestiniog Series.	Grey-blue slates and flags, crowded with *Lingulella davisii*.
	Grey flags and grauwacke, with some coarser bands (1800 feet thick).
Maentwrog Series.	Rusty grey and blue slates, with thin bands of felspathic grauwacke.

I shall now briefly describe the rock series in the order of their formation.

III. The Maentwrog or Rusty Flag Series.

The oldest beds in the Ynyscynhaiarn district are exposed in the cliff-sections between Mount Pleasant and Cefn, and form the low promontory to the south and west of Treflys Church, as far as Caregyr-Eryr and the Black Rock. They are a series of ill-cleaved, banded, dark grey, black, or green slates, silky in fracture. Their exposed surfaces are soon filmed over with rust, and in weathering they break up into bladed fragments about the size and shape of a man's hand. Interbedded with the slates, in all except the lowest bands, are numerous coarser felspathic or gritty 'ringers,' which are massive in their bedding and well defined from their surroundings. These ringers range from something less than an inch up to a foot in thickness, and, though irregular in their distribution, seem to become more abundant as we pass up the series.

The measured succession below the columnar greenstone of the shore east of Craig-ddû (Black Rock) is:—

	Thickness in feet.
Thin and thick, alternating grey and blue, flaggy shales, much cleaved and puckered, with ringers 4 to 6 feet apart. Notable ringers at 20 and 60 feet below the sill, and a 3 to 6-inch grit-band at 40 feet	80
Sill along which the main cave has been eroded	3 to 6
Flaggy slates with ringers: 4-inch ringers at the base	10
Splintery shales with thin ringers: 4-inch ringers at the base	20
Flaggy beds with strong double ringer: 9 inches to 1 foot thick at the base	30
Rusty slaty flags, with strong ringers, composite: 1-foot ringer at the base	50
Intrusive sill.	
Rusty slates, with about three ill-defined ringers to each yard.	50
Massive, fine-grained, flaggy band	1
Thinly-bedded silky flags or slates, without ringers	50
say	300

Ill-preserved specimens of *Olenus cataractes* from 1 to 2 inches long are found in the splintery slates, some 25 feet below the sill of the main cave; small *Agnosti* and an indeterminate *Conocoryphe* are not infrequent in the silky flags and rusty slates at the base of the series.

This section is much complicated by small anticlinal folds and by faulting, the effect of which is not easy to make out. It is, however, washed clean by the tide and fretted or polished by the wind-driven sand, and so affords a most instructive exposure. Joints and decayed sills and dykes of an ancient dolerite have given scope for differential erosion by the waves, and the beautiful caves so produced have long been famous. In these caves the colour-banding of the slates and flags which form their walls adds largely to the fascination. Greens, greys, and purples are the colours which appear; and one can often count some two or three large, and perhaps twenty to thirty small colour-changes on each inch of rock.

The cliffs below Cefn on the east of the bay were probably at one time equally well exposed, but now the sand-hills partly covering and partly protecting the cliffs from the direct action of the sea have spoiled the section, and one can do little more than note the rarity of ringers among the slaty flags exposed. The contorted *Olenus*-bearing flags of Ffynnon-Ochr-cefn appear to be identical with the fossiliferous splintery slates which form the low detached stack on the other side.

Rocks referable to the top of the Maentwrog Series appear again along the old sea-cliffs to the east of Morfa Bychan, from Gareg-wen to Fechan Point, and in the outstanding rocks of Careg-cnwc and Gareg-gôch. In all these places they are thinly bedded and well striped, but not very rusty. They contain trilobite fragments and small *Lingulæ*, and are associated with greenstone intrusions.

The land topography of the Maentwrog Series is uniform and uninteresting. The ringer-beds of the coast-section seem to conceal themselves, while the igneous sills which weather into sea-caves stand up in slight relief. The soil is everywhere scanty, but is generally fertile enough to be worthy of cultivation.

IV. The Ffestiniog or Grey Flag and Grauwacke Series.

The Ffestiniog Series of the district is a thick and massive shallow-water deposit, which, by reason of its monotony and the paucity of its fossils, I have not been able to subdivide. The outcrop varies from about half a mile to one and a half in width, and is continuous. The lowest beds are not well marked off from the highest Maentwrog Beds, but the line of dolerite sills which comes in from the sea at Craig-ddû and goes out at Gareg-gôch, near Borth, serves as a convenient line for mapping. This line of intrusion can be followed from Craig-ddû along Careg-yr-Eryr ; it appears in the marsh of Llyn Ystumllyn, a quarter of a mile south-east of St. Cynhaiarn's church and along the side of the field south of the barn of Coed-y-llyn, again in the crags of Capel Siloam, at Ynys Cyngar, Careg-cnwc, and finally at Gareg-gôch, near the bathing-place of Borth.

Like the Maentwrog Series, the Ffestiniog Beds show innumerable alternations in the coarseness and fineness of the material. Usually of a flaggy nature, they include at many horizons bands of massive and very compact grauwacke grits, rich in felspars more or less decayed, and set with quartz-grains, in a tough chloritic, or micaceous, muddy base. These, although sometimes massive through a thickness of 3 feet or more, are never coarse enough for real grits, and a new term to describe them is badly needed.

Their lithology and association with more slaty beds is strongly reminiscent of the ringers in the Maentwrog Beds below, but the marking-off of the beds is rarely so well defined. A notable feature of the coarser of the grauwackes is the occurrence of false bedding, and with it a more complicated arrangement of bedding-planes which I would term 'curled.' The minute unconformities and overlaps which constitute false bedding are well known, and are common to all sediments deposited by drift-bedding in shallow water. They are associated with true ripple-drifting and with worm-tracking, *Scolithes*, *Cruziana*, etc., occurring upon the upper surface of the coarser beds. The 'curled' bedding and general contortions of the planes of deposition within massive strata is less easy either to describe or to explain.

Curled bedding is generally seen only in section. As so observed, it bears a strong resemblance to the figures and description of the contortions of the Langdale slates given by Sorby.[1] It is always associated with considerable variations in the thickness of the bed which it affects, and often where the curvature is strongest cracks have formed transverse to the bedding and are now filled with quartz.

When seen in plan or upon an exposed dip-surface the curled-bedded grauwackes are seen to be broken into nodular pavements. These, in extreme cases, become discontinuous ; and in their general behaviour the curled-bedded masses even strongly resemble the nodular cement-stones of the Middle and Lower Lias. The curling

[1] Quart. Journ. Geol. Soc. vol. lxiv (1908) pl. xiv.

of the bedding within the nodules involves curvature in three dimensions; but, although the actual nodules in the pavements seem to have a directional elongation due to the later cleavage-stress, I am unable to discover any polarity in the actual arrangement of the curled bedding-planes. A certain amount of discontinuity and some evidence of sliding is usual between a curled-bedded grauwacke and the super- or subjacent flag or slate.

Under the microscope the curled-bedded grauwackes have little to distinguish them. They contain much fresh felspar, and possibly the recrystallization of the quartz-grains and quartz-cement is more advanced than in the evenly-bedded flags, but I have not examined enough specimens of either sort to be sure. It is the quartz-cement and its recrystallization in crystalline continuity with the quartz-grains which makes the rocks so tough.

I have measured several sections across the moorland exposures of the Ffestiniog Beds, but cannot discover either fossil bands or well-characterized lithological groups within them, and have therefore had to rest content with making a strike-map of their exposures (see map, Pl. XVII). The most open section is through the farm of Ty'n-y-mynydd on the south side of Moel-y-gest, where the total thickness exposed is about 1700 feet. In this section the rocks appear to fall into five groups, each marked by a convexity on the hillside, and having a flat or hollow separating it from its neighbour.

The lowest group (about some 400 feet thick) consists of rather dark-grey flags with thin and thick beds alternating. These, from a distance, show some eight or nine subsidiary features, with the hard bands (Nos. 5 & 6) most prominent.

The second group is more massive, and has but few and very thin bands well bedded enough to be called 'flags.' It also is nearly 400 feet thick, and might be further subdivided according to some four or five grit maxima.

The third group, about 300 feet thick, is less massive in its bedding, and consists of thickly-bedded flags with not infrequent *Lingulella*. It would subdivide into either three or five, by the grouping of its resistant bands. The house Ty'n-y-mynydd stands on the ledge at the top of this third group.

The fourth group begins with a set of very strong, thickly-bedded, grey-weathering, massive grey grits, with grey flag-partings. These gradually diminish in weather-resisting power upwards, and pass into grey flags. They are about 250 feet thick, and might subdivide into five.

They pass gradually upwards into the fifth group, which consists of flags of a much darker and more rusty colour. These subdivide readily into some seven grit maxima, and are about 350 feet thick. The highest big grauwacke is about 100 feet from the top of the series and 50 feet below the base of the well-marked *Lingulella* Band, which in this, as in the Arenig district, is very distinctive.

The *Lingulella* Band.

The topmost layers of the Ffestiniog Beds are characterized by the presence of very numerous specimens of *Lingulella davisii* in a bright-rusting flaggy grey slate. The fossiliferous flags are about 50 feet thick, and can be mapped continuously. They come in from the sea at the cliffs south of Rhiw-for-fawr, near Ogof-ddû (Criccieth), and pass northwards by Ystumllyn House to the quarry by the turnpike at Pencraig. Thence by Gareg-felen to Glanbyl they are drift-covered, but at the farmyard of Gwern-ddwyryd they reappear, striking east and west. From the little reservoir on the stream east of Bryn Cilynen, south-eastwards along the hillside behind Wern, they form a dip-slope and make a great exposure. South of the railway they occupy the slopes of Coed-y-chwarel, and through the Coed-y-capel plantation can be followed to the meadows south of Bron-y-foel. Thence over the col by Beudy Pencerbi they pass to the farm of Llanerch, where a fault intervenes displacing them some half a mile to the south.

On the southern shores of Llyn Gareg-wen they reappear, and so by the cowhouses on the hill can be traced through the quarry near the schoolhouse and on through the village to form the southern shore and promontory of the harbour at Borth.

The topography of the Ffestiniog Series is in this district very characteristic. The rock weathers very slowly, and bracken, gorse, bell-heather, bramble, and a thin wire-grass form the usual vegetation. Even these flourish only upon the flaggy outcrops and along the shatterings due to joints, and the grauwacke grits stand up as lichen-covered cliffs and rock-knobs, which even close to sea-level give the impression of a rough mountain-country and are exceedingly picturesque.

Though thus giving rise to a diversified moorland topography, the Ffestiniog Series does not, as a whole, behave as a resistant formation; and it is noticeable that in this district it forms the low ground of Llyn Ystumllyn at the centre of the anticline, and does not at any point attain an elevation greater than 400 feet.

V. The Dolgelly or Black Band Series.

The Dolgelly Series follows directly upon the *Lingulella* Band. Whether we consider the series in its original signification as including only the dark slates of the Black Band, or whether we allow it to include all the beds up to the horizon of the *Dictyonema* (as suggested in my Arenig paper),[1] it is in this district perfectly well defined, and lends itself beyond all other series to the plotting upon a large-scale map.

The lithologically defined Black Band is especially convenient from this point of view, and, following round the Ynyscynhaiarn anticline outside the line of the *Lingulella* Band, above described,

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 614–15.

can be traced with great accuracy. Across the northern end of the district about Gwern-ddwyryd and on to Coed-yr-Eglwys above Penmorfa Church, the outcrop is cut out by a fault; but from St. Beuno's Church it is readily followed through Wern and Bron-y-foel round the southern slopes of Moel-y-gest to Llanerch, and again from the head of Llyn Gareg-wen to the bay of Borth-y-gest.

The best exposures are the cliff-section by the railway at Ogof-ddû, the road-and-stream section below Penmorfa Church, the old Bron-y-foel slate-quarry, and the field banks between Gareg-wen and Borth. The section at Ogof-ddû is as follows:—

	Thickness in feet.
Blocky tough blue slate, weathering dark, which clinks when struck. Used for buildings. It makes black walls, but rusts to a foxy-brown colour on inside joints. It contains small pyrito-calcareous nodules, which weather to white elongate spots upon the surface	12
Ill-exposed splintery blue rock, weathering dark and with yellow rust on the inside joints. White pyrito-calcareous spots in the lowest 4 feet	20
Hard banded blue grit, with pin-head particles bedded in ribs, each about 4 inches thick	6
Rusty grey-blue slates with paler bands in the upper part, becoming darker below	15
Finely-banded (30 bands to an inch) blue-black slate, breaking into long splinters and weathering to a dark colour, very rusty	6
Dead-black rock, with blue-grey streaks, homogeneous, and breaking into splinters. Contains some spangles of mica	10
Finely banded, splintery, blue-black slates. Very rusty. Minutely jointed and with rust working in from the joints. The rock-cores bleach to a bluish grey. *Agnostus* Band with *Peltura*, *Dikellocephalus*, and numerous other fossils 7 feet from the top and generally throughout; small specimens of *Orthis lenticularis* abundant in the lower part. These slates generally break into bands about 2 to 6 inches thick	18
Granular felspathic ash-band	2 inches to 1 ft.
Hard, dark blue-grey or black, gritty slate with three rows of large concretions of iron carbonate. The dominant line of concretions seems to have grown round discontinous masses of a 2-inch bed of coarse gritty material, which contains angular pebbles up to ¼ inch in diameter. The largest concretion is an ellipsoid measuring 3 by 4 by 2 feet, which has obviously grown *in situ*, distorting the slates in contact with it, and making the bands within it swell out to about 10 times their original thickness. The non-concretionary slate is banded with about 20 beds to the inch, and contains abundant *Sphærophthalmus*	12
Finely banded (40 to inch) black rock, with a dark streak, becoming fine-grained below, containing small pyrite crystals throughout. When the rock has become rusty and has lost its pyrite in the weathering, the banding is very prominent	12
Not exposed	6
Rather hard, splintery black slate, with a dark-blue streak. Banded, and with thin ashy bands up to a quarter of an inch thick at intervals of about 3 inches. Mica everywhere abundant. Small *Obolus* and still smaller *Orthis* not rare. A concretion measuring 6 by 4 by 3 feet lies in the midst	12
	130

	Thickness in feet.
	130
Black rock with blue streak. Outside surfaces covered with thick rust	6
Intensely black rock with black streak. Very finely laminated. Shining mica-flakes along the bedding. Bedded in 4- to 5-inch bands. Very rusty	6
Blocky black rock, showing black outside, finely laminated within, and having visible colour-bands, up to a quarter of an inch thick, at intervals of about 3 to 4 inches. Some of the beds are nodular	12
Hard black calcareous nodules alternating with splintery black shales. The topmost band appears almost pisolitic, the lowest is like an ashy grit, but weathers to a rottenstone. Mica-flakes abundant, lamination well marked	6
Black non-laminated slates, with band of cone-in-cone ironstone concretions weathering out into holes, measuring 3 by 2 by 1 foot at the base	6
Banded blue-black and dark-grey slates, soft, and rusting deeply with a thick crust. Cleavage rather good; bad fossils occasionally, *Parabolina spinulosa*	8
Rock not exposed. Once eaten out into a cave	6
Dark-grey, finely-banded splintery flags, smooth, and grey-weathering on the outside. *Parabolina spinulosa* not rare ...	10
Dark-weathering splintery flags, breaking into fragments which measure often about 12 inches by $\frac{3}{4}$ by $\frac{1}{2}$ inch. These during weathering become covered with a hard dark crust, and where broken in the cliff have often had their cores removed, leaving holes like finger-stalls	6
Grey dark-weathering flags, with ill-defined knobby ringers ...	10
Bright-weathering grey flags, banded in the upper part, and with a prominent 1-foot ringer at the base. Crowded with *Lingulella davisii*...	20
Total.........	226

The road and stream-section south of St. Beuno's Church at Penmorfa does not lend itself to absolute measurement, but the total thickness exposed is much the same as at Ogof-ddû, and the variations of lithology follow the same order. The *Parabolina* Beds at the base have their trilobites unspoiled by cleavage, and the overlying impure limestone-bands, seen under the southern wall of the road where it rises from the corner towards Coed Bryntwr, are rich in *Orthis lenticularis*, the remains of which probably supply the calcareous material. The very black beds above these contain *Agnostus pisiformis* sparsely throughout, and also yield occasionally the compact tails of a *Niobe*-like trilobite. The *Sphærophthalmus* Beds crop out in the ditches on either side of the road from Tyn-llan Farm down to Wern, and the *Peltura* Beds lower down the same road and south of the burn.

The Wern gate-cutting exposure, the field-side cuttings, and the blocks of slate ploughed up in the arable ground above Llanerch, and between Llyn Gareg-wen and Borth, have long been known as hunting-grounds for those who would collect trilobites from the Black Band. At each and all of these localities the detailed succession confirms the section measured at Ogof-ddû, and goes to show that even the minutest variations of lithology, in Dolgelly rocks, are constant over several miles of country.

The Bron-y-foel slate-quarry was worked in the lower part of the Black Band, and afforded a black, closely-laminated slate, which is too soft and full of pyrite to enter into serious competition with the slates of Ffestiniog.

The Black Band, as the least resistant rock of the district, is usually weathered into a hollow, and deeply covered with soil. Its outcrop is therefore marked by a succession of arable fields and smooth meadows, with copses and plantations along the stream-courses. Its outcrop can also usually be recognized by the flaky black slates and the ochreous springs which come out at intervals along its course.

VI. The Tremadoc Series.

(1) The Tynllan or *Niobe* Beds.

Resting upon the Black Band, and lying between it and the horizon of abundant *Dictyonema*, come the *Niobe* Beds. These are a series of fine-grained, silky grey slates, and with the Black Band preserve their characteristics unchanged round the Ynyscynhaiarn anticline, from Ogof-ddû to Borth.

The section at Ogof-ddû is a striking one. The highest beds adjoin the *Dictyonema* Band, while the lowest beds are continuous with the Black-Band section just described. The section is as follows:—

	Thickness in feet.
Rough, dark leaden-grey slates with some whitish partings and white-weathering pyritous spots. Ill-cleaved, and breaking into long tile-like fragments, with splintery ends, weathering grey or rusting to a rather bright tan colour	50
Hard, blocky, blue to grey-blue beds with pyritous spottings, in bands about 4 inches apart, uncleaved. This series is bedded in 1- to 3-foot bands, most massive in the higher part, and often showing conchoidal fracture. *Obolus* is found on certain bedding-planes of these blocky rocks, which weather blue or drab, and do not rust. The middle beds are often sufficiently rough-grained to be worthy of the name of grit, but generally the beds are hard mudstones	40
Splintery or shivery black-weathering shales with an earthy fracture. The topmost 12 feet are passage-beds to the more massive grey-weathering bed above. The lower beds are very thinly bedded, and when far weathered turn brown and flake into short flat splinters	40
Splintery, smoothly-breaking blue beds without pyritous nodules. They either bleach or rust to a foxy-brown colour during weathering	20
Hard, clinking blue rock, very massive, and showing cleavage-joints only. It breaks conchoidally, but has some slight banding. It contains *Acrotreta*, and rusts thickly. This rock forms the outstanding crag through which the railway-cutting at Ogof-ddû has been made	40
Total	190

The cave of Ogof-ddû was worn out by the sea along a 3-foot band of well-banded blue and grey rock, which forms the base of this mass.

The corresponding sea-cliff section on the east of the anticline is at Trwyn-cae-iago, east of Borth Harbour. The lowest beds seen are the clinking blue rocks of Craig-y-don. Splintery rocks (first without spots, and then well spotted) follow, and have yielded a good many specimens of *Niobe* and *Psilocephalus*. The blocky spotted grey rocks of the *Obolus* Band follow, and determine the edge and highest part of the cliff-bound promontory, being themselves overlain by the banded, well-jointed, ill-cleaved beds, which at the entrance to Maenofferen Wharf underlie the *Dictyonema* Band. Here, too, the total thickness is about 200 feet.

The Tyn-llan exposures behind Penmorfa Church were known to Homfray and Salter as a locality for *Niobe* and *Psilocephalus* as long ago as 1860. Again, it is the spotted splintery beds some 60 feet from the base which contain the most abundant trilobites. The best exposure is a small crag in the field immediately to the east of Coed-yr-Eglwys, and between that wood and the road by Wern Lodge to Carnarvon. The stream-section along the wood side is also productive, but is difficult to work.

The fossils usually found are *Niobe homfrayi*, *Psilocephalus innotatus*, and *Hymenocaris vermicauda*. With these I have obtained some small sheared specimens of a *Shumardia*, an *Agnostus*, and a *Theca*. *Acrotreta*, *Lingulella lepis*, and a big *Lingulella* very like *L. davisii*, but pointed in front and rectangular behind, occur just below the trilobite-bed, and are abundant in the massive beds a little lower down the field.

The *Obolus* Beds make a small feature, which crosses the Wern-Carnarvon road just below the old tramroad bridge, and continues down the east side of that road to the corner of Coed-tyn-llan. This set of beds is very hard and cherty: by its spotting and white weathering it is easy to follow and map in detail, and so affords a fine datum-line from which to measure up 50 feet, and thus arrive at the exposures of the fossil band with *Dictyonema*. By this indicator stratum, *Niobe* Beds have been mapped continuously from the Portmadoc-Criccieth road, south of Wern by Cefn-cyfanedd, round the southern slopes of Moel-y-gest, to the north-and-south fault through Llanerch, and again by way of Moelfra, through the woods of Parc-y-Borth, to the Trwyn-cae-iago section described above. The same bed is also useful as a datum-line across the moorland and between Ystumllyn and Ogof-ddû.

The outcrop of the *Niobe* Beds is generally rough and rocky.

(2) The *Dictyonema* Band.

Characteristic beyond all other beds known in the Ynyscynhaiarn district is the belt of strata, 15 to 20 feet thick, which contains *Dictyonema sociale*. This band wherever exposed is abundantly fossiliferous, and certain of its bedding-planes are completely covered with the nets of this graptolite. Somewhat less resistant in its weathering than the beds above and below, the *Dictyonema* Band generally crops out along a slight hollow, and the fossils must be sought along the under side of the outstanding rock-rib which comes next above the prominent *Obolus* Bed described above. The *Dictyonema* rock itself is quite distinctive. It is a fine-grained rock of a darkish blue-grey, and with faint pale bandings, which come to maxima three or four times in each inch. It breaks not along its bedding, but along joints, into pieces shaped like irregular paper-knives, with very sharp edges, each three or four times as long as broad. As it weathers the surfaces first turn green, and then to an iridescent gold which is characteristic; later, they are covered with a foxy-brown rust-film, which they retain until the whole rock is bleached to a pale but bright creamy paste.

Dictyonema sociale was discovered and first described by Salter[1] from this district, but his specimens were not of the best, and the species and its variations require, and are worthy of, a modern revision. As generally collected, the specimens are in the form of casts, filled with iron oxide; but, although such specimens show the form of the net and the association of individuals, they do not retain the details of original cell-structure, and from a zoological point of view are uninteresting. Fragments of more satisfactory specimens are occasionally to be obtained from fresh and unweathered rock, but the slate will break along the bedding only by accident, and the pieces of the graptolite seen are small. In such rock the *Dictyonema* is found replaced by the unstable form of pyrite (marcasite) and is preserved in full relief.

The outcrop of the *Dictyonema* Band is indicated with sufficient care upon the map (Pl. XVII), and I need only add some notes upon localities at which one can be sure of finding the rock in a condition suitable for the collecting of fossils.

At the eastern outcrop, by the sea, below Bron-y-garth, the richest fossil bed is mostly covered by scree. At Lletty and along the little cliff which bounds the paddock between Bryn-parc and the wood of Parc-y-Borth, there is a fine exposure, which is maintained through the northern corner of the wood and through the plantation beyond the Morfa Bychan road along the cart-road to Llanerch Farm. The fault there carries the outcrop to the 400-foot contour south of the eastern summit of Moel-y-gest, and there fine exposures occur. Hence rising, it attains 600 feet at the wall south of the western summit, whence descending it skirts Coed-y-cefn, and crosses the road from Wern to Bron-y-foel, just below the 300-foot contour, with open moorland exposures all the way. Lower down, at the 200-foot contour on the same road, is the original locality of Salter's *Dictyonema* (called from the keeper's house Cefn-cyfanedd), and there, at the turn of the road, is a wall every

[1] Mem. Geol. Surv. vol. iii (1866) Pal. Appendix, p. 331.

piece of which when broken open is fit for preservation in a museum. North of Wern the exposures are more difficult, and I shall only mention the old tramway-cutting at the 200-foot contour east of the bridge over the Tyn-llan road; the field opposite Wern Lodge; and the quarry for road-metal at the 300-foot contour close to the second milestone out of Tremadoc, on the southern branch of the Carnarvon road.

Exposures on the Criccieth side of the anticline are difficult to work, for their cleavage is overwhelming, the dip steep, and the bed determines only a hollow in the moorland. Loose slabs with some *Dictyonema* are nevertheless not infrequent among the heather.

Along with the *Dictyonema* occur usually a few elongate *Lingula*, cap-like *Acrotreta*, and especially spicules of a sponge which may be *Protospongia*. I have also found occasional tails of *Psilocephalus*, loose thoracic segments of some broad and large trilobites, and the head of some *Peltura*-like Olenid and of another trilobite not unlike *Hysterolenus törnquisti*. The *Protospongia* is especially characteristic of the harder slates which overlie the *Dictyonema* Band.

(3) The Moelygest Beds.

Above the *Dictyonema* Band come a series of rusty-grey slaty mudstones which appear to be almost devoid of fossils. For this subdivision of the Tremadoc Series, from the circumstance that it forms the underscarp and dip-slope of Moel-y-gest, I have taken the name Moelygest Beds.

The best continuous exposure is along the road-cutting behind the wharves at Portmadoc, south of, and beneath, the rock which has been so extensively quarried. The bulk of the rock is an ill-cleaved dark-grey mudstone, sometimes splintery, but usually more noticeable by the obliqueness and rippled surfaces of its joints.

The following subdivisions may be distinguished:—

	Thickness in feet.
Dark-weathering bladed rusty slate, fine-grained and dark within, joints very much rippled where they cross coarser and finer beds	100
Paler-weathering blue slate, with very occasional white-weathering pyritous spots. Some gritty partings, also a well-marked band of cone-in-cone ironstone nodules, which sometimes run together as a continuous bed	50
Strongly banded, tough, rusty-weathering, dark-grey slate with rippled joints	40
Very uniform, blue-grey slate, with some white-weathering pyritous spots forming a passage-zone to the *Dictyonema* Band and like it containing *Protospongia*	50
Total	240

Along the dismantled tram-road above Penmorfa the banded beds are beautifully seen in the cutting east of the Carnarvon-road bridge. There the joints are clean cut, and the rocks shiver rather than break under the hammer. They are overlain by the more thinly-bedded grey slate, which not infrequently contains *Acrotreta.* The great laccolite of Moel-y-gest follows approximately the bedding of the paler slates above the line of ironstone concretions, and about 150 feet above the *Dictyonema* Band; and the small sill quarried in the old railway above Penmorfa is at a similar horizon. Everywhere in the vicinity of these intrusions the rocks have lost their cleavage, and, being hardened almost to recrystallization, have had their bedding and flaggy character rendered very prominent.

Among the upper portion of the Moelygest Beds I have found no trace of fossils, and this despite a long-continued search over the open dip-slopes on the north of Moel-y-gest.

The Geological Survey Memoir (vol. iii, 1866, pp. 251, etc.) records fossils from the northern slopes of Moel-y-gest, but their exact localities are now lost. In the Memoir it is also stated (pp. 69 & 256) that all the localities for Lower Tremadoc fossils (*Niobe* and *Psilocephalus*) occur along a line about 100 feet above the *Dictyonema* Band; but with Homfray I agree in regarding this statement as due to a mistaken conception of the position of *Dictyonema*.

On the hill-side between Tyddyn-dicwm-uchaf and the Carnarvon turnpike there are many exposures of the Moelygest Beds, but, owing to strike-faulting, I have not made out the tangle of their succession. At Ty'n-y-coed, and along the bank above Llwyn-derw, I have collected specimens of an *Orthis*, very like the *Orthis christianæ* figured by Moberg,[1] and these I think must belong to the banded lower portion of the Moelygest Beds.

The exposures in the rough pastures of Caer-dyni near Criccieth show slates of similar type, too crushed and slickensided for successful fossil-hunting. The pale bands which here occur about the middle of the series are associated with gritty or felspathic bandings and partings.

(4) The Portmadoc Flags.

The flaggy beds which overlie the rusty bladed slates of the highest Moelygest Beds are quarried along the wharf-side at Portmadoc, and as they have provided the stone of which the town is built, I suggest for them the name 'Portmadoc Flags.'

The change from slates to the more massive and coarser beds, which have been termed 'flags,' takes place rapidly, and is associated with the appearance of a more massive and regular arrangement of the jointing, which makes the quarrying of building-blocks possible. The rock quarried is a minutely-banded blue-grey stone, with ten or twelve flag-like laminæ to each inch, and with prominent pale, and somewhat coarser, felspathic bands every few inches. By reason of a rude cleavage, the rock does not split along all these

[1] '*Ceratopyge* Regionen' Med. från Lunds Geol. Faltklub, ser. B, No. 2, 1906, pl. ii.

bands, but bedding-planes with actual discontinuity come in at intervals of from 2 to 6 feet, and the quarry is mostly worked by 4-foot shot-holes along the direction of cleavage and at right angles to these.

Cone-in-cone ironstone nodules, sometimes spreading into beds, occur at irregular intervals through the quarry, and sporadic pyrite-crystals or white-weathering nodules are not uncommon. In weathering the sulphides leach out to the surface, which becomes first black, and then bleaches without much rusting. The heading joints are very clean cut, but only occur at long intervals, and when the weathering eventually breaks up the rock into small pieces it splits into long, rod-like, prismatic masses which have their greatest elongation along the direction of the cleavage.

The best stone is provided by the more felspathic beds, which occur at the southern end of the quarry, and belong to the basal beds; but stone has been got all along the wharf-side, and a thickness of some 180 or 200 feet of strata has been worked over. Upwards above this the texture becomes finer and the rock more pyritous, and though some of its beds are still massive and flaggy, the bulk of it passes into a splintery rusty-weathering needle-slate.

A similar succession can be confirmed along the road by Garth Terrace to Bron-y-garth, and also along the main road to Borth-y-gest. In the quarry opposite the end of Ffordd Morfa-bychan, the lower gritty beds are worked for slabs and building-stone. At Pen-y-clogwyn, and at the cliff above the gate to Morfa Lodge, from this same road, the gritty beds make a fine exposure, and from it can be traced continuously to their abutment upon the Llanerch Fault, at the eastern end of Moel-y-gest. West of this fault the Portmadoc Beds are much broken by strike-faulting, and, although I have mapped the gritty beds, I have not been able always to distinguish the needle-slate above from the Moelygest Beds below them, and the grit outcrop accordingly appears as a set of discontinuous augen in a slaty matrix.

The grit of the augen which includes the two farms of Tyddyn-dicwm (isaf and uchaf) has long been known. One of its grits is massive and almost a quartzite, and has been taken by some to represent the basal Arenig grit. It is, however, only 4 feet thick, and the flags above it contain Tremadoc trilobites in fair abundance.

The gritty augen on the Criccieth side of the outcrop contain coarser and even stronger grits. The slates among them are much crushed and very ill exposed, but the quartz-cemented felspathic grits generally protrude through the scanty soil and can be readily discovered. One of these cropping out along the 300-foot contour, a quarter of a mile south of the farm of Mynydd-ddû, is 16 feet thick and almost massive throughout. Below the 100-foot contour, 100 yards north of Caer-dyni, a whole bundle of similar grits is exposed.

The fossils of the Portmadoc Flags are few and ill preserved. Occasional tails and broken fragments of *Asaphellus* can be got by breaking the cone-in-cone ironstone nodules along their centres, but this requires much knowledge and skill. The higher flags, with 'needle-rock' between, contain *Bellerophon* and *Asaphellus* in some abundance.

(5) The Penmorfa Beds.

Closely related to the beds quarried along the wharf at Portmadoc are the coarse-textured banded needle-slates which overlie them. These contain a distinctive fauna, and are so generally fossiliferous that I have thought it well, although I cannot separate them with great precision on the map, to give them a distinctive name. This name I have chosen from the village in the street of which I find the best exposure and the richest assemblage of trilobites.

Unfortunately, about Penmorfa there is no open section where the 100 feet of rock which separate the gritty beds from the fossil band can be examined. Such rocks as can be seen in the fields and roads west of Penmorfa are generally thin-bedded, shivery, and presenting occasional coarse bands, which are notably micaceous. They are everywhere pyritous; in wet places they rust with an inky aspect, and where reasonably dry become brightly ochreous. South of the village the fossil band can be dug out of the cattle-track which leads down to the Morfa. Below the fossil band the section is obscure for about 15 feet, and the next exposure is of a flaggy rock. This flaggy rock, which is seen to a thickness of about 30 feet, has alternating bands of harder and softer material. It passes down into dark blue-black slates, which weather into long blade-like splinters and contain *Asaphellus*.

The fossil band of Penmorfa occurs in the village-street at the fork of the New and Old Carnarvon roads between Capel Garisim and the Post Office. Fossils are also found in the raw rock shown behind the cottages, south of the three roads and west of Bwlch-edwin. The fossiliferous rock appears again in the corner of the playground of the village school, and ranges continuously up the hill almost to the new reservoir, from which the village now takes its water-supply. Near the Capel (chapel) blue and brown micaceous flaggy beds contain large trilobites, such as *Dicellocephalus* and the broad form of *Asaphellus*. It is the beds above these, rather fine smoothly-bedded but earthy slates, which yield the richest fauna: *Shumardia*, *Holometopus*, *Agnostus*, *Macrocystella*, *Symphysurus*, along with the larger *Asaphellus*, *Cheirurus*, and *Angelina* being characteristic. So far as I can discover, the fossil bed with *Shumardia* is only 8 feet thick, but the bigger trilobites are found through a much wider range of strata. Below the *Shumardia* Band at Penmorfa *Angelina* is very rare, while above that band one can be sure of finding fragments of *Angelina* in almost every bed.

At Portmadoc the outcrop of the Penmorfa Beds is built over by the houses of the suburb of Garth. There they are seen as rusty grey-blue or leaden-grey needle-slates, with some coarser mica-bearing bands, and have yielded many fragments of big trilobites. At Pen-y-clogwyn and at the entrance to Morfa Lodge they are better exposed, and in the old days provided Homfra and Ash with many trilobites. Their coarse-textured needle-slates form the country-rock into which the Tu-hwn't-i'r-bwlch sill of porphyritic dolerite is intruded, and over much of their outcrop to the east of Moel-y-gest they are altered by that intrusion.

The old quarry at Tyddyn-llwyn is opened in the beds immediately overlying the Portmadoc Flags, and is just within the metamorphic aureole. Here the slates exhibit no needle-cleavage, but break rather along the bedding, showing a fracture with a silky sheen. At the top of the quarry (nearest the intrusion) some of the beds become pale and spotted almost to a desmoisite, and the coarser bands come away in massive flagstones of first-class quality. The pyrite which at Garth gives rise to very rusty weathering is here concentrated into sporadic bands of small, well-formed, cubic crystals.

The Tu-hwn't-i'r-bwlch quarry on the north side of the sill, and close to the Criccieth-Portmadoc road, is also partly within the zone of alteration. There, too, the rock has little cleavage, but the shape of the fossils gives ample proof of great distortion. The rock quarried is of a blue colour, and comes away in massive slabs along certain more gritty bedding-planes. The bedding-planes are generally silky, and in the deepest part of the quarry some of the beds show the beginnings of a 'desmoisitic' spotting. Fossils, abundant when the quarry was less advanced, are now difficult to obtain at Tu-hwn't-i'r-bwlch. The finding of a *Holometopus* and a *Macrocystella* at the entrance to the quarry persuades me that the fossil band of Penmorfa is not far above.

On the hill-side overlooking Ystumllyn (near Criccieth) finely-bedded blue-grey slates overlie the grit-belt. From these I have obtained a few specimens of *Asaphellus* and a *Cheirurus*, but the shivering and cleavage are so intense that fossil-collecting is a slow process. From the banded slates in the field north of the Criccieth road, next but one east of Tan-y-rhiwiau, I have recently obtained the tail of a *Dicellocephalus*, and by it am further confirmed in my identification of the Penmorfa Beds in this district.

(6) The Garth Hill Beds.

Overlying the Penmorfa fossil-band are the thinly-bedded, rusty, flaggy slates containing *Angelina*, which from the time of Salter's survey of 'the region extending from Tremadoc to Ffestiniog' in 1853[1] have been known as uppermost Tremadoc Slates. These have their most open exposure along the slopes of Garth Hill near Minffordd on the south side of the Afon Glaslyn, and outside our district; but, as they form a dip-slope, and are richly fossiliferous along Garth Terrace above Portmadoc, the name taken from the famous collecting-ground across the river will also serve here.

Perhaps the most accessible exposure is the cliff at the edge of the alluvium or morfa south of Penmorfa village. The section

[1] Mem. Geol. Surv. vol. iii (1866) p. 308.

begins at the cart-track 150 yards S. 40° W. from the first milestone on the Tremadoc-Carnarvon road.

	Thickness in feet.
Thinly bedded dark-blue slate, bladed irregularly along the bedding, weathering to iridescent tints and a rich red-brown. Contains abundant tails of *Ogygia* and numerous pitted heads of *Angelina*	20
Very thinly-bedded shivering slate-rock, with thin white-weathering bands. Some of its beds are calcareous, and almost consist of broken fragments of *Angelina*	20
Flaggy slate, prominently ribbed in 3-inch bands, paler and not so rusty as the higher beds, and forming an outstanding rock-rib. Large nodules of cone-in-cone ironstone not infrequent. A flaggy bed in the midst has yielded several specimens of *Dicellocephalus furca*	30

Above these rocks, between the *Ogygia* Band and the great Penmorfa Fault, comes some 50 feet of thinly-bedded *Angelina*-bearing slate, but this is too much crushed by the fault to yield good specimens.

At Garth Terrace the rock is similarly thin-bedded and silky; but the needle-cleavage is strong, and it is difficult to break open any bedding-plane over the area of a whole trilobite. At the lodge-gate to Tu-hwn't-i'r-bwlch, and along the Criccieth road as far as the Tu-hwn't-i'r-bwlch quarry, similar banded needle-rock is exposed, and fragmentary fossils can generally be had for the seeking. As we go westwards along the road the needle-jointing gives place to blading, and fossils become easier to get. Farther west, at Penrhyn-llwyd and north of the railway at Penamser, quite good trilobites have been collected, and at the last-named locality the same succession as at Penmorfa has been made out.

On the Criccieth side of the anticline three specimens of *Angelina* were taken from a block of hard blue slate on the road-bank, 250 yards south of Braich-y-saint.

Another famous locality for *Angelina* is Ynys-towyn, on the east side of Portmadoc Harbour. Most of the Tremadoc rock there was quarried away in the making of the road-and-railway embankment, but the remaining hill-mass shows a fine exposure of Garth Hill Beds and of the overlying Ordovician grit. Along the Oakeley slate-wharf the rocks are needle-slates like those of the Garth Hill dip-slope; but north of the roadway the higher beds, less intensely cleaved, are pyritous leaden-grey mudstones with coarser flaggy partings. These weather with an inky or ochreous-brown rusty crust, which is very characteristic, and contain rows of spreading sheet-like concretions of cone-in-cone ironstone at many horizons. Some of the mudstone beds are quite massive, to a thickness of more than a foot. The Tremadoc rocks exposed at Ynys-towyn are about 90 feet thick.

The Yynys, upon which Pen-syflog House is built, shows rock like that of Ynys-towyn. The small rock in the field south-west of the farm yields abundantly *Ogygia* and *Angelina*.

VII. The Arenig and Llandeilo Series.

(1) The Basal Grit.

Upon the Garth Hill Beds at Ynys-towyn rests a strong, massive, quartzose pea-grit which is supposed to overlie the Tremadoc beds unconformably.

The base of the grit rests upon a rough surface, which shows erosion-pockets some few inches deep and a foot or two wide, but I am unable to prove any continuous discordance in the dip. The lowest grit is clean, compact, and well-cemented. It builds a bank almost 20 feet thick, which is massive or irregularly jointed throughout. In the midst of this bank a pebble-bed with quartz-pebbles up to an inch in diameter occurs, and along with the quartz-pebbles occasional flakes of shale, which also may have been pebbles, are observed, but do not break the massive character of the grit.

Above the basal grit-bank small shale-pebbles abound, and flaggy partings break the second 20 feet into irregular 1 to 3-foot banks not quite so coarse-grained as the basal mass. The upper 30 feet are again massive, but, except in the topmost bed, the dip-slopes of which are washed by the waters of the harbour, there are no evident pebbles.

The cementing material of the grit is almost wholly quartz in crystalline continuity with the quartz-grains, but in some places adjoining the more vertical joints interstitial iron pyrites serves the same purpose. Some of the quartz-grains are quite hyaline and blue, and small quantities of various fresh felspars, including microcline, are not infrequent.

As to the exact age of this grit, we know little. The grit itself seems to contain no fossils; but, by analogy with the grit of Garth Hill, Minffordd,[1] and elsewhere, it is generally considered to be the original local base of the Ordovician.

On the Criccieth side of the district here described, from Tan-y-rhiwiau by the eastern ridge of Moel-bach and Pen-ystumllyn Farm to Pen-mynydd-dû and Bryn Braich-y-saint, a more or less massive felspathic grit much crushed by faulting may be traced continuously, and seems to separate Tremadoc from Ordovician slates all the way. As at Ynys-towyn, it is rich in hyaline quartz, and is often very pyritous. Generally the crushing is extreme, and, although slaty beds are usually interstratified with the grit at many localities, they may be crushed in, and no information as to the succession can be obtained.

Below the first gate across the cart-track, 75 yards north-east from Tan-y-rhiwiau, an exposure of rusty, fine-grained, gritty rocks forms a passage series between the normal grits and slates, and overlies the basal grit. This rock closely resembles some beds of the *Calymene*[2] Ashes of Arenig or the flag series[3] of Manod-bach, and like them contains occasional examples of *Obolella plumbea* and *Ogygia selwynii*. From a loose block adjoining this exposure I

[1] Presid. Address, Quart. Journ. Geol. Soc. vol. xix (1863) p. xxxviii.
[2] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 619.
[3] Mem. Geol. Surv. vol. iii (1866) p. 60.

have also obtained a single specimen of *Calymene parvifrons.* These are the only definite Arenig fossils yet discovered in the Ynyscynhaiarn district.

(2) The Western Slate Rocks.

The basal grit just considered is overlain in the Criccieth district by a thick series of slates, which, although they occupy a great area, offer little opportunity for the making out of their succession. Near Portmadoc the possible slate-outcrop is deeply buried beneath the alluvium of the Afon Glaslyn.

Along the foot of the Tremadoc scars the slates are so mixed up in the great thrust-faults which I shall describe later (p. 167) that I am unable to disentangle their succession, and in the Criccieth country (Moel-bach and Braich-y-saint), where the outcrop is widest, the only exposures are the low hummocks of rock which protrude through the scanty soil of well-cultivated land.

In this western district I have at three places measured an apparent thickness of more than 1000 feet of rock; but, knowing the complexity of the strike-faulting in the grit-beds below, I suspect isoclinal folding from the west, and am little disposed to attach importance to the measurement.

The lowest slates, which adjoin the grit, are generally dark, and contain bands of coarse rock with kaolinized felspars (probably of volcanic origin). From 50 to 200 yards west of the grit-outcrop, the slates are very dark in colouring, but soft and earthy in texture. These generally refuse to break along their bedding-planes, and crush when struck with a hammer. In the Ceunant-du (a strange glacial overflow-channel on the south-western slopes of Moel-bach) the black rocks are seen to pass up into silky, blue-grey, spotted slates, which are well exposed, and have yielded a few tuning-fork graptolites that seem to belong to an early form of *Didymograptus murchisoni.*

At the foot of the Ceunant and along the hill-slopes to the old Gloddfa slate-quarry, which is now used as a reservoir for the Criccieth water-supply, the slates become paler and rather prominently banded. Some of the bands there are ashy and almost flaggy in texture, and, unlike the slates between them and the basal grit, take on a bright rusty tone as they weather.

The slates quarried were soft and almost too well cleaved; they are dark blue-grey in colour, showing rusty bands as they weather, and break with a lustrous silky sheen. They are exceedingly like the Llanvirn Slates of Llanfihangel-y-pennant and the northern Snowdon slate-belt.[1]

The exposures of beds higher than these are all unsatisfactory, but it would seem that there is a further series of dark-blue mudstones, and of very shivery blue shales, before we come to the sooty, mica-spangled, black beds which underlie the felsites of Moel Ednyfed and Ystum-cegid. I have been unable to find any fossils in these higher slates.

[1] Rep. Brit. Assoc. 1903 (Southport) p. 665.

(3) The Criccieth Felsites.

Overlying the black slates of Moel Ednyfed and of the valley east of Ystum-cegid, as far south as the village of Dolbenmaen, is a great mass of fine-grained, cream-coloured or pink, felsitic rock with small porphyritic crystals of felspar, and generally without visible quartz. This rock is either a set of lava-flows or of sills, and, from the character of the platy and columnar jointing and the general absence of associated ashy beds, I incline to the latter view. There is, however, practically no evidence of metamorphism along the junction; and hence, while suggesting that the rock is one of the Lleyn rhyolites, which were intruded at the time of the Snowdonian volcanic activity, I would leave the matter open. The fine columnar rhyolite of Dinas and the sea-cliffs of Criccieth Castle form the seaward continuation of the same rock-mass. It is noticed by Mr. Harker[1] as one of those rocks which is probably intrusive; but, so far as I can find its exposures, they show no stratigraphical relations except with the Drift. At Ystum-cegid-bellaf the rhyolite mass is seen to be overlain by andesitic-rhyolite ashes and agglomerate, which it seems to cut transgressively.

VIII. The Tremadoc Country.

In the consideration of the Cambrian and Tremadoc rocks it was found possible to make out a stratigraphical succession from the evidences of the accidental dip-sections which circumstances have provided, and to carry on that succession unchanged around the whole Ynyscynhaiarn ring. The Ordovician rocks are not so simple, and the Ordovician succession about Tremadoc appears very unlike the slate-rock series near Criccieth, which I have just described. This difference was long ago recognized by Sharpe, who, in 1846,[2] remarked that the Tremadoc district with its greenstones belongs to Snowdonia; but, except in so far as Ramsay[3] and after him Harker[4] have noted that Tremadoc lies within the westerly extension of the Lower Ordovician volcanic products, while Criccieth is outside, the matter has received little comment.

When one begins to measure a horizontal section along the dip, say from Tyddyn-dicwm to the base of the Snowdonian rhyolites of Ynys-wen or Moel-ddû across this Tremadoc country, one is impressed by the apparent tremendous thickness of the rocks traversed. Such a section measured directly seems to show about 4000 feet of slate-rock between Tremadoc and the base of the Snowdonian rhyolites. In the old days, when the Tyddyn-dicwm rocks with their iron-ores were thought to be 'Tremadoc Slate,' a thickness of 4000 feet to represent the Tremadoc, Arenig, and Llandeilo series might be received with little comment; but, when Salter in 1857 had shown that the rocks at Tyddyn-dicwm contained graptolites,

[1] 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, p. 12.

[2] Quart. Journ. Geol. Soc. vol. ii, p. 303.

[3] Mem. Geol. Surv. vol. iii (1866) chapt. xi.

[4] 'Bala Volcanic Series of Caernarvonshire' 1889, § vi.

which he identified as of Arenig age, the 4000 feet for the Upper Arenig and Llandeilo rocks seemed a good deal; and when Hopkinson & Lapworth,[1] and Lapworth,[2] had further shown that these graptolites belong to a horizon which is higher than the Llandeilo limestone of South Wales, the acceptance of 4000 feet for the thickness of Upper Llandeilo rocks became impossible. There must be repetition, and, as there is no evidence of isoclinal folding, that repetition must be accomplished by faulting.

The Penmorfa Fault.

Like most great faults, the Penmorfa Fault is a series of parallel shatterings, which have a common direction. It separates formations as far apart as Tremadoc and Upper Llandeilo; but, since it brings slate against slate along the strike, its exact position is, in the absence of fossils, very difficult to localize.

The eastern course of the fault as it enters the district here described is concealed by the Glaslyn alluvium. It must pass between Yyns-towyn and Ynys-galch, probably by way of the Cambrian Railway-station. It ranges through the Ynys on which Pen-syflog House is built, and brings the Garth Hill Beds with *Angelina* there, within 50 yards of Llandeilo slates containing *Climacograptus schärenbergi.*

Across the Morfa to Glan-morfa it lies beneath recent sand and silt; but, along the south-western edge of the mound Hen-fynwent (the site of the Roman villa), a little cliff on the field side shows a fine section of an overdrag affecting Ordovician slates. In Penmorfa village the road-cutting at the corner between Capel Seion and Plas-isaf shows Garth Hill Beds and splintered Ordovician rock side by side. The new well-house is on the Ordovician side of the fault, but Tremadoc fossils can be found 50 yards to the west of it. Above Tyddyn-dicwm the fault continues obliquely up the hill, and passes the 600-foot contour before it comes down, and is buried beneath the Cwm Ystradllyn Drift. Some 2 miles farther along, a fault of similar hade and direction can be proved along the crags of Tyddyn, south of the river, at Dolbenmaen.

Along this line the fault maintains an even course, the geometry and general outcrop of which indicate a strike of about N. 50° W. to N. 60° W. and a general gentle dip to the north of north-east. In order the better to study the fault-plane, I arranged with Mr. Greaves (Wern), the owner, and Mr. Jones, the farmer, to have trenches cut across the fault, at the locality, above Tyddyn-dicwm, where its course is most open, and where the Tremadoc and Llandeilo fossils had been proved in closest apposition. The spots chosen are in the big field containing the westernmost of the Tyddyn-dicwm iron-ore trial-holes, and are both above the 600-foot contour, on the southern slopes of Craig-y-gesail. The sections are dip-sections and are best described by true-scale diagrams (see figs. 1 & 2, pp. 168–69).

[1] Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 636.
[2] Ann. & Mag. Nat. Hist. ser. 5, vol. iv (1879) p. 340.

Fig. 1.—*Section of the hillside above Tyddyn-dicwm, showing the relationship of the Tremadoc and Llandeilo rocks across the Penmorfa Fault.*

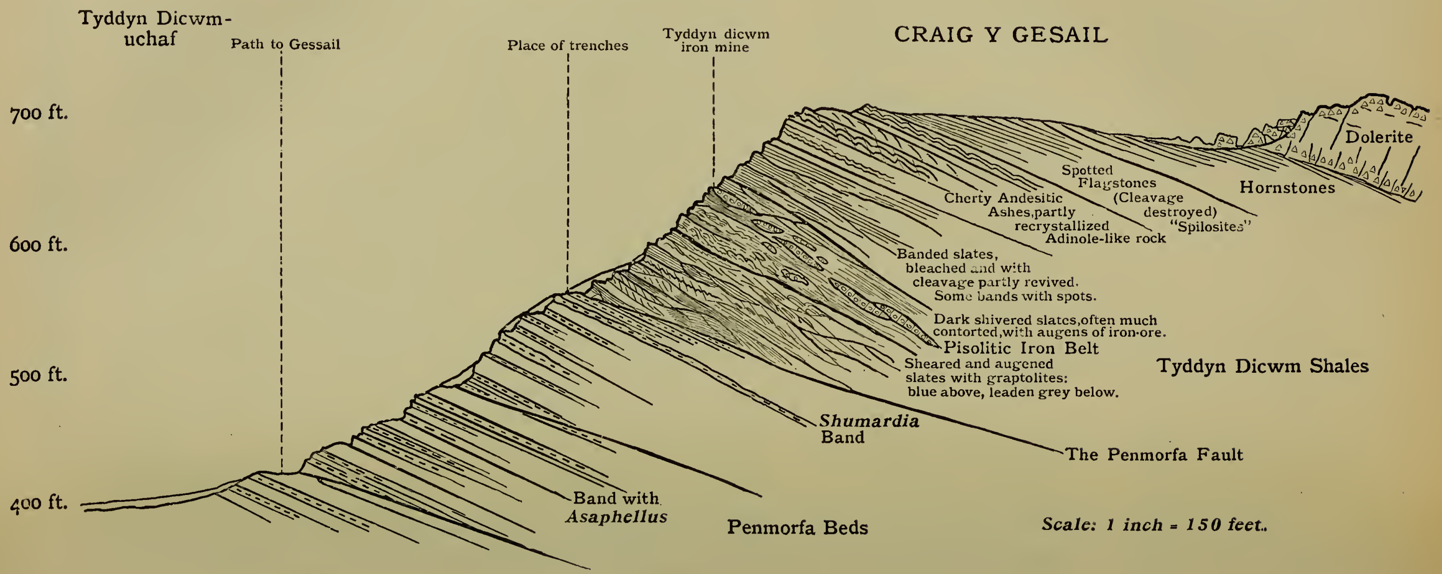
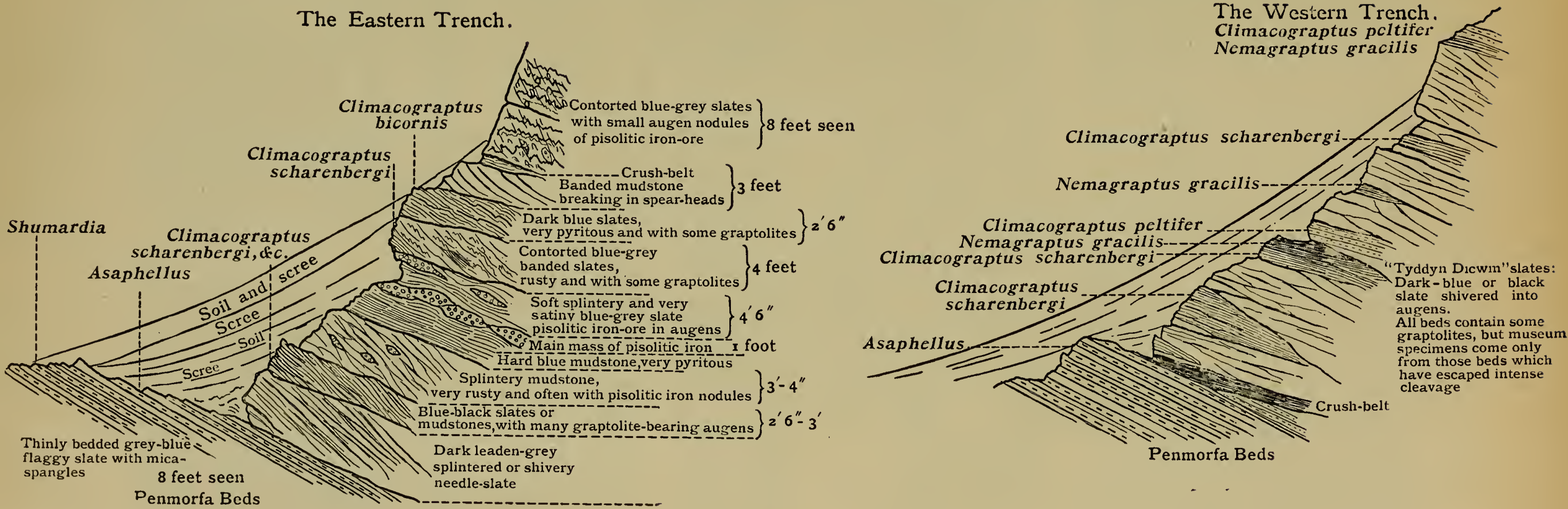


Fig. 2.—*Sections of the eastern and western trenches, Tyddyn-dicwm, on the scale of 15 feet to the inch.*



Tremadoc trilobites were found in the rocks at the foot of the eastern trench, and graptolites frequent in some of the rocks of the eastern were abundant at the top of the western trench. In the making of these trenches it was found that the Tremadoc rocks of the sole of the thrust are little affected by induced minor cracking, but the Ordovician slates are cut again and again by small overthrust-faults, each a little steeper than the great plane of discontinuity at their base.

In the eastern trench the Ordovician rocks are often gnarled and shivered beyond description. They break into sheared and slickensided, augen or spearhead-shaped masses, which are set with their long axes a little more nearly north and south than the dip of the thrust, which is here striking N. 60° W. and dipping at 25° to N. 30° E.

In the western trench the Llandeilo rocks are partly pyritized and somewhat mineralized, and so, although broken by the minor thrust-planes, form larger augen within which the slates retain their bedding. From these augen the graptolite fauna recorded in the Rep. Brit. Assoc. (Belfast) 1902, p. 599, was obtained.[1] In making the trench it was noticed that there are three kinds of graptolite-bearing rock characterized respectively by:—

(1) Swarms of *Climacograptus schärenbergi*,
(2) *Nemagraptus gracilis*,
(3) *Climacograptus peltifer*,

each distinct one from the other. The occurrence of these in the trench is plotted in the diagram, which surely gives abundant proof of reduplication by faulting. Though the graptolitic assemblages in the three bands are quite distinct, the evidence before us is not sufficient to make it clear that the bands belong to distinct graptolite zones.

The Pisolitic Iron-Ores and Tyddyn-dicwm Shales.

The rocks next above the Penmorfa thrust-plane are gnarled, shivered, and kneaded into a regular augen-schist through a thickness (measured at right angles to dip and strike) which varies from

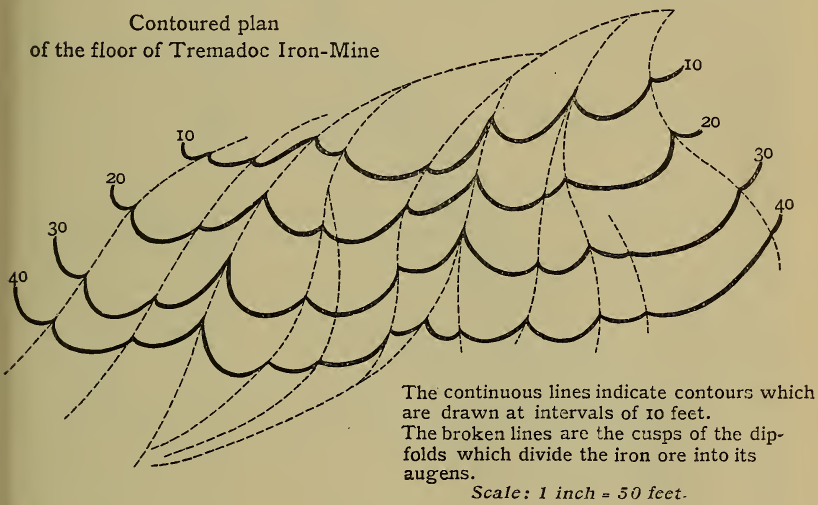
[1] The following list, kindly prepared for me by Miss G. L. Elles, D.Sc., includes all the specimens of graptolites from Tiddyn-dicwm which are preserved in the Sedgwick Museum to January 1st, 1910:—

Didymograptus superstes, Lapw.
Dicellograptus sextans, Hall.
Dicellograptus intortus, Lapw.
Dicellograptus divaricatus, Hall.
Dicellograptus moffatensis, Carr.
Dicranograptus ramosus, Hall.
Dicranograptus rectus, Hopk.
Dicranograptus ziczac, Lapw.
Dicranograptus furcatus, var. *minimus*, Lapw.
Dicranograptus nicholsoni, Hopk.
Nemagraptus gracilis, Hall.
Climacograptus schärenbergi, Lapw.
Climacograptus bicornis, Hall.
Climacograptus bicornis, var. *peltifer*, Lapw.
Climacograptus antiquus, Lapw.
Climacograptus antiquus, var. *bursifer* (Elles & Wood).
Amplexograptus perexcavatus, Lapw.
Glyptograptus teretiusculus, His.
Orthograptus priscus, E. & W.
Orthograptus whitfieldi, Hall.
Glossograptus hincksii, var. *fimbriatus*, Nich.
Cryptograptus tricornis, Carr.

about 100 feet at Tyddyn-dicwm to perhaps 300 feet in the Ynys near Tremadoc. Within this crush-belt the slates are so flaked and shattered by the jointing, that both cleavage and bedding are difficult to observe. Soft, silky, or earthy in their texture, they are dark enough in colour to have persuaded some prospectors to dig for coal among them, and it was in the search for coal that the pisolitic iron-ore was discovered.

The pisolitic iron-ore masses, like all other rock-units within the crush, occur in the form of augen or lenticular lumps which vary from the size of a bean to that of a 100-ton schooner, and have a distribution which seems to be sporadic all through the dark shale of the crush-band. Until 1860 the ore was worked with great zeal; but, as in the deeper workings the proportion of sulphur increased, it

Fig. 3.—*Sketch-plan of the surface from which the iron-ore has been stripped.*



became unprofitable. The plotting of the contour strike-lines of the surface from which ore has been stripped in the Tremadoc mine between Tremadoc and Glanmorfa gives the accompanying diagram (fig. 3), which shows well the augen character of the large ore-units. The puckering of the dip-surfaces between which the augen lie, illustrated in the second diagram (fig. 4, p. 172), is also characteristic.

Though, from their mode of occurrence, the ore-masses must be related to the crushing movements, the individual ore-masses, whether large or small, show no signs of crushing, and the pisolitic grains within them maintain their sphericity, right up to the surface. The slates around may be rolled out to a regular sericitic mylonite, and pieces of shale within the ore be of similar character, but the ore itself is never in the very least affected. This, and the circumstance

Fig. 4.—*Section showing the mode of occurrence of the pisolitic iron-ore among the slate-rocks, in the iron-mine north of the Penmorfa road, Tremadoc.*

that the largest ore-bodies occur near the top of the crush-zone, where it abuts upon the metamorphic aureoles [1] of the late intrusive dolerites, has led me to urge that the ore is of secondary or metasomatic origin, and owes its distribution to the position of the fault.

The country-rock about the mines consists always of blue-black or dark leaden-grey slates, which rust to an uniform dead brown colour. Most of the slates seem devoid of fossils, but at Ynys-galch, Pen-syflog, and the old tramway-cutting 50 yards north-west of the Tremadoc mine, *Climacograptus schärenbergi* and *Dicellograptus sextans* occur in some abundance. It was from the débris turned out of the iron trial-holes at Tyddyn-dicwm that Salter and later observers have obtained the graptolites which they record. The country-rock of the pisolitic iron-ore is therefore of Llandeilo age, and, like the graptolite-bearing rock in the trench at Tyddyn-dicwm, was originally of that open-water

[1] Geol. Mag. 1907, p. 422.

facies which we call Glenkiln.[1] It is noteworthy that from the time of Sedgwick to that of Cole [2] and Jennings & Williams,[3] slates with pisolitic iron-ore have been regarded as the most characteristic of the 'Tremadoc' Slates, and rocks at Llanelhaiarn, Abersoch, Cader Idris, etc., are identified as of Tremadoc age, because they are rather similar to these Llandeilo rocks.

Above the belt of pisolitic iron-bearing rocks the slates lose their dark colour, and pass into blue or greenish-grey banded slates, with coarser flaggy or ashy beds above them. Fossils in the higher rocks are difficult to find, and I have been compelled to map the area on lithological evidence alone. Upon the map I distinguish the following four very distinct lithological types:—

(1) The well-known gabbroid dolerites,[4] which form the crags of Y Gesail Y Castell above Tremadoc, and Pant-ifan behind Tan-yr-allt.
(2) Banded blue-grey slates, into which the dolerites are intruded, and which they, when in contact with them, have altered into 'spilositic' flags and hornstones.[5]
(3) Ash-bands, usually of andesitic composition, and varying in their texture from fine tuffs to agglomerates.
(4) A non-porphyritic vesicular rock, probably once an andesitic lava, which underlies, and is closely associated with, the most prominent ash-bands and agglomerate.

Regarding the slate-rock (2) as a matrix in which the others are set, it is apparent that on the map the dolerites (1), the ashes (3), and the vesicular andesites (4) alike appear as strings of elongate lenticles. Since the time of J. E. Davis [6] these dolerites have been recognized as intrusive, but, unless we postulate a separate volcanic vent for each lenticle of ash or agglomerate, the stringing-out of the andesite exposures (4) can only be explained by faulting; and since we have proved such faulting along the line of the pisolitic-iron belt, it is not unreasonable to explain the further repetitions and general 'shuffled' arrangement of the whole country to the north-east of it upon a similar plan.

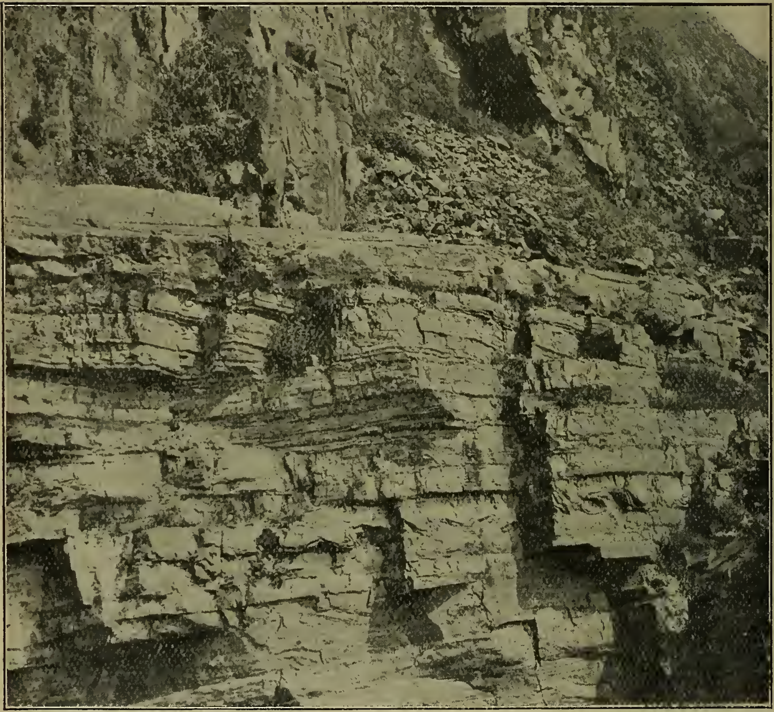
The Andesitic Volcanic Rocks.

The main outcrops of the andesitic rocks (3) and (4) form subsidiary cliffs on the scarp-faces of the hill-masses which are determined by the dolerites. They occur in four main series of exposures. The westernmost exposure of these is on the south-western face or edge of Craig-y-gesail (fig. 1, p. 168). This exposure shows only a few feet of cherty ash, which is too much baked by the

[1] C. Lapworth, Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 253.
[2] G. A. J. Cole & V. Jennings, *ibid.* vol. xlv (1889) p. 436.
[3] V. Jennings & G. J. Williams, *ibid.* vol. xlvii (1891) p. 372.
[4] A. Harker, 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, § vi.
[5] J. J. H. Teall, 'British Petrography' 1888, p. 219.
[6] Quart. Journ. Geol. Soc. vol. ii (1846) p. 70.

dolerite to yield further information. The second series of outcrops is seen on the path up from Penmorfa to Beudy'r-garth, and can be traced continuously for some half a mile along that path, as far as the old Penmorfa flag-quarry on the slopes of Allt Wen. In the quarry it consists of several distinct beds, altogether about 8 feet thick. In this exposure the crumpling of the bedding of the ash-bands under the stresses which produced a slaty cleavage in the beds above and below is beautifully shown, and is most characteristic (see fig. 5, below).

Fig. 5.—*Exposure in the Penmorfa flag-quarry.*



[The above view shows the andesitic ashes of the 'second series' of exposures interstratified with slaty rocks now metamorphosed to desmoisitic flags. The slates, by compression under cleavage-stress, have suffered uniform distortion; while the andesitic ashes (now almost adinoles) have become crumpled.]

Due north of the Tremadoc iron-mine the ash-band appears again, and is underlain by 25 feet of the vesicular rock (4), which itself overlies a dark slate with ill-preserved *Diplograptus*, and these three beds follow on together until they are covered by the screes of

Y Castell. Farther south-east, beyond Tremadoc Church, shivering shales with graptolites are seen in Ynys-fadog, and are overlain by the vesicular rock and a couple of ash-bands. At Bodawen gate a flaggy ash-band underlies the *Diplograptus*-bearing slate, which is overlain first by the 30-foot mass of vesicular andesite of Ynys-hir, and then by the massive ashes and agglomerates of Y Nursery, which are at least 50 feet thick. The rocks above these are dark needle-slates, very like the crush-rock at Ynys-galch. At Ynys Cerrig-duon, east of Portmadoc, another mass of ash is underlain by an andesite the larger vesicles of which, not having come within range of the dolerite metamorphism, still contain some zeolitic minerals.

The third range of andesitic rocks is much more massive, and forms the hill-ridges of Y Fedw and Y Glog, as well as the outstanding promontory on which the Roman Altar was built. Though massive to a thickness of at least 100 feet, just south of Llyn Cwm-bach, the outcrop thins to vanishing point at the western end of that lake. It is also completely pinched out for a considerable distance in the woods of Tan-yr-allt, between Y Glog and the foot of the hill. West of Y Fedw, above Cwm-mawr House, the slates for 150 feet or more below the agglomerate are very flaggy, and enclose strings of thin ash-lenticles. These continue past the Cwm-bach farmhouse, and approaching the Y Glog ash-mass are separated from it only by a vesicular andesite. The section through Y Glog is, therefore, identical with that at Bodawen and Ynys-hir mentioned above, and it is satisfactory to find that the slates among the flaggy ashes at both places yield specimens of *Diplograptus*. The small outcrop of ash in the wood, 150 yards north of Tan-yr-allt House, is also underlain by vesicular rock.

A fourth range of andesitic ashes and agglomerates forms the culminating ridge of Pen-yr-allt. There are, however, no vesicular rocks; and, as the rocks below the ash-bands show a complete and gradual passage down into slate, I wait for palæontological evidence before venturing to suggest that these rocks also belong to the same horizon with the three outcrops below the dolerites just discussed.

A diagrammatic section from Tyddyn-dicwm to the corner of the map passing through Y Glog and Pen-yr-allt is appended (Pl. XV, section B). On this section it will be noted that the reduplicating thrust-planes are occupied by the dolerite sills; but, with this interpretation, though I am unable to find any other explanation of the phenomena, I am not altogether satisfied.

The Banded Slates.

Having now seen something of the structure of the country, we are in a position to discuss the age of the grey and banded slates. Since the latter overlie the graptolite-bearing *Climacograptus-peltifer* beds of Tyddyn-dicwm, there is no reason to believe that they are older than these; but, pending the discovery of more fossils, we must leave open the question of an upper limit. In this connexion it is interesting to find that Sedgwick[1] records a *Homalonotus bisulcatus* above the dolerite of Pant-Ifan. In similar rock from the waste heaps of Portreuddyn, Mr. J. G. Black in 1909 turned out a *Trinucleus*, and I an *Ogygia*; and in the cliffs of Prenteg, which, as I believe, are a continuation of the rocks of Pen-yr-allt, various ill-preserved specimens of *Orthis* (*O. elegantula*, *O. actonii*, *O. calligramma*) are not rare.

Such indications as we have, suggest therefore, that the grey and banded upper slates and their associated andesites belong to a high Llandeilian or a low Caradocian (Snowdonian) horizon, and this the further tracing of the andesites to a source upon the Moelwyn seems to confirm.

The sediments of the Ynyscynhaiarn country having now been described, there remain the rocks which are intrusive into these, and the structures which have been impressed upon the country by post-Ordovician earth-movements. These I shall consider in what was probably the chronological order of their development, and shall give the evidence for this chronology as I describe the phenomena.

IX. The Folding.

The most outstanding characteristic of the geological map of Ynyscynhaiarn is the ring-like arrangement of the *Lingula* Flags and Tremadoc rocks about a centre which lies among the sandhills half a mile east of Craig-ddû and midway between Borth and Criccieth (see Pl. XVI, sections C & D). From this centre, an anticline, with its axis pitching at about 1 in 6, ranges N. 5° E. through the marshes of Llyn Ystumllyn, and onwards until it is lost beneath the Drift at Gwern-ddwyryd, half a mile beyond the village of Pentrefelin. From this axis the rocks dip away eastwards at about 10° or 20°. To the westward the dip is steeper; but this, in part, is due to the later (parasitic) sharp folding which has developed irregularly along this western side.

Half a mile east of the main anticline the arrangement of the strike-lines between Treflys Church and Coed-y-cefn, south of Wern, shows a syncline which ranges along a curving line considerably east of north, and dies away north-eastwards. The anticline which corresponds to this follows the hollow from Bron-y-foel to Morfa-bychan, and runs more nearly north and south.

From some points of view, the southward thrown fault-mass upon which Borth stands may be regarded as the syncline that corresponds to the Ynyscynhaiarn anticline; but the evidence before us is not sufficient to decide whether the Llanerch displacement, which bounds it on the west, is earlier or later than the cleavage. The manner in which the dolerite mass of Capel Siloam crosses the Llanerch Fault at Ynys Gyngar Farm seems to show that that dolerite is more recent than the fault.

[1] Quart. Journ. Geol. Soc. vol. iii (1847) p. 141.

X. The Older Dolerites.

Probably the oldest of the intrusive rocks of the district are the sills of 'white trap' the outcrop of which I have taken to mark the line of separation between the Maentwrog and the Ffestiniog Beds. These were once dolerites of an andesitic type, but are now become aggregates of calcite, chlorite, leucoxene, zoisite, and other secondary minerals only. They and their feeder dykes, which trend N. 40° E., form the crags of Craig-ddû and Careg-yr-Eryr, the low *roche moutonnée* in the midst of the Ystumllyn marsh, and again appear in the crags which overlook the Portmadoc golf-links, at Morfa-bychan, and Ynys Gyngar.

Wherever found, the form and the distribution of the sills are partly determined by the folding of the strata among which they lie; and as they are also universally affected by foliation and distortion due to cleavage, we must conclude that they are of an age intermediate between the folding of the Ynyscynhaiarn anticline and the oncoming of the cleavage.

XI. The Cleavage.

The modification of the sedimentary rocks of the Ynyscynhaiarn district, by stresses at some period subsequent to their accumulation, is a circumstance which forces itself upon the attention of the most casual observer. All the rocks, except the gabbroid dolerites, show evidence of intense compression, and even the most rigid of the grits have lost their porosity. Speaking generally, all the finer-grained rocks have become slates, and by the uniform rearrangement of their particles have suffered distortion, but have maintained the continuity of their bedding.

Rigid and coarser-grained rocks have behaved differently. Sometimes their individual beds have crumpled up separately, as at the Penmorfa flag-quarry (see fig. 5, p. 174). Sometimes, shearing across, the rigid beds have piled themselves up into 'knoll-reef' lenticles—such as the augen of grit in the Portmadoc Flags near Criccieth, or those of andesitic ash above Tan-yr-allt. Sometimes, again, as among the Ffestiniog grauwackes of Moel-y-Gadair and St. Cynhaiarn's Church, where the compression has been very intense, they have buckled or broken into sharply-pitching isoclinal folds.

Within our district, the most patent effect of the compression has been a complementary elongation of the mineral particles in a direction at right angles to the stress. All rocks alike and every fossil found show such distortion, and have been drawn out along an axis which varies from N. 5° E. in the west and south to N. 35° E. in the extreme north-east. A normal steeply-dipping slaty cleavage, also ranging N. 5° E., has been developed in the Arenig and Llandeilo slates of the west; but over the eastern half of the district the slaty rocks show only a less intense cleavage which at Bron-y-foel dips at 35° to E. 10° S.

In working over this district, I have been unable to obtain specimens that can be made to show the characteristic arrangement of mineral particles constituting the needle-cleavage, which so frequently affects the Tremadoc and later beds: so, for the present, I will postpone further consideration of the subject. I cannot, however, agree that a needle-cleavage is the result[1] of the superposition of two cleavages.

XII. The Faulting.

After the cleavage came the faulting, which, as I believe, must belong to a continuation or later phase of the same set of earth-movements as those that produced the cleavage. Elongation of deep-seated rocks can never continue indefinitely; and, as the prolongation of the postulated N. 5° E. and N. 35° E. cleavage-axis would lead us among the rigid igneous rock-masses of Snowdonia, it is obvious that expansion could not take place far in that direction. Conversely, the rocks between the district here described and Snowdonia which were also compressed would have to expand southwestwards; and, according to my view, it was their riding to the surface which compelled the formation of the Penmorfa Fault and of the pisolitic-iron crush-belt. The strike-faulting in the country to the north-east of the Penmorfa Fault has been already described (pp. 167–75), and I know of no other faulting in that region.

The belt of country south-west of the Penmorfa Fault is affected by several parallel faults, induced by the shearing movement of the over-riding mass. One of these which, from Glan-byl (see Pl. XV, section B) to the top of the woods behind Penmorfa Church, cuts out the whole of the Dolgelly Beds, must be a thrust of some magnitude, but there are hosts of others too small to map. The rocks on the northern slope of Moel-y-gest also are similarly placed in respect of the continuation of the Penmorfa crush beneath the Morfa, and they, too, are cut into detached lenticles along the strike. It was between two of these lenticles that the pisolitic iron-ore was found and worked south of Penamser.[2] The most evident of the strike-faults of Moel-y-gest is one along which the main road passes north of Penamser (see Pl. XV, section A); it continues through the Cemetery, and forms the hollow in which Penrhyn-llwyd stands. This fault gives rise to a repetition of the Portmadoc Flags; but it is more particularly interesting from the circumstance that it cuts off the north-and-south fault which so markedly displaces the *Lingula* Flags and Tremadoc Beds in the neighbourhood of Llanerch. This Llanerch Fault (see Pl. XVI, section D) is a displacement with a steep hade to the west, and about Llanerch has a downthrow to the east which brings the *Dictyonema* Band against the *Lingulella* Band of the Ffestiniog Beds. It is associated with a local flattening of the dip, and may represent

[1] A. C. Ramsay, Mem. Geol. Surv. vol. iii (1866) p. 235.
[2] *Ibid.* p. 252.

a small syncline on the eastern flank of the Ynyscynhaiarn dome. The course of the fault is sufficiently indicated by the map (Pl. XVII), and as a line of topographic features between Moel-y-gest and Ynys-gyngar Farm is very evident. It is traversed by, and is, therefore, probably earlier than, the doleritic intrusion of Moel-y-gest.

A parallel fault through the hollow along which the road from Portmadoc to Borth Harbour passes is of less importance. It also has a downthrow to the east.

The faulting which displaces the Dolgelly Beds south of Wern is also interesting; but, although the fault-face is evident in the road-cutting west of Wern gate, I cannot determine its importance.

XIII. The Later Dolerites.

Most prominent of all the topographical features of Ynyscynhaiarn are the great dolerite cliffs of Moel-y-gest, Y Gesail, Tremadoc, and Tan-yr-allt. These are the most recent rocks (other than Pleistocene accumulations) that occur in the district. They and their attendant metamorphic effects have been described by Dr. Teall[1] and again by Mr. Harker,[2] and I shall not at present add to these descriptions. Mr. Harker, however, says that 'one effect of the alteration has been to prevent the impression of the cleavage-structure on the argillaceous strata'; and, as he goes on to distinguish this from the examples where cleavage has been obliterated by metamorphism, and so infers that the dolerites are older than the cleavage, I must put forward some additional evidence as to their age. First of all, however, it will be convenient to say something of the jointing of the region.

XIV. The Jointing.

The joints in this district are complex, even for a region of older Palæozoic rocks, but in the plotting of the map their detailed variations have proved of great value in distinguishing between the different rock-series.

As might be expected from cracks which have opened along the directions of least breaking strain, during the folding or weathering of the rocks, many of the joints follow the structures of the rocks with great closeness. The direction of greatest elongation of the rock-particles by the cleavage is the direction of the most regular of the joints, which in most rock-exposures serve as 'leaders.' In rock in which a slaty cleavage has fully developed these leaders dip with that cleavage, but in the harder rocks where fracture still in the main follows the bedding-planes, they break at right

[1] 'British Petrography' 1888, p. 216.
[2] 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, p. 79.

angles to the bedding. 'Heading' joints, approximately at right angles to the cleavage-direction, are also common. These generally make an angle of 10° to 20° with the vertical, and dip with the cleavage. They cut across the bedding, and open with a 'rippled' surface, which is very characteristic. The individual ripples on these joints mark the alternations of harder and softer beds.

Strike-joints, also nearly vertical, are frequent, but are rarely traceable over any considerable distance. They, too, sometimes show rippled surfaces, but they may be clean cut.

Dip-joints are never common, and when found are usually 'bevels,' the association of which with the direction of dip is mostly accidental.

Bedding-planes, cleavage-joints, and either strike-joints or headings are the planes of discontinuity, which detach the distorted parallelipipeds of rock that litter the quarries and exposures of sedimentary rocks.

Of minor jointing the most noteworthy is that which follows the needle-cleavage, and splits up the rocks into the rods, needles, or blades, already described. Where needle-cleavage occurs, the weathered rock breaks into fragments, the long axes of which agree with the main cleavage-direction of the country, irrespective of the strike of the rock. Where undisturbed, the rock-pieces lie inclined along the cleavage at an angle which is some few degrees steeper than the bedding, and maintain their inclination over considerable distances irrespective of the dip of the bed. In most rock-beds the transverse section of the individual needles is characteristic. Sometimes almost square, with one face steeply inclined and the other nearly flat (rodded structure), they are at other times flattened down to a knife-blade, with the roughest of conchoidal fracture along their faces (bladed structure); and all the stages between these extremes can be found, if sought for. Usually, the cross-section is more or less of a parallelogram, which has its longest side dipping eastwards.

Besides these jointings, which belong to the minute structures and arrangements of the particular rock-beds, there are also certain joints or structure-lines, which cross the *Lingula*-Flag and Tremadoc-Slate country irrespective of everything. These, in the district here described, range between 50° and 60° W. of N., and hade like normal faults. Their directions agree fairly well with that of the Penmorfa thrust-plane; but, as their inclination is almost vertical, I do not think that the directional relationship can be more than accidental. They are especially evident in the bare Ffestiniog-Group country, south and west of Moel-y-gest and north of Pentrefelin. There, crossing the alternating flag and grauwacke outcrops, they determine the faces of the scarps which are formed by the harder beds; and hence, though each individual crag marks the outcrop of a hard bed, the alignment of the crags on the hillside or on the map is plagioclinal.[1]

[1] C. Callaway, Geol. Mag. 1879, p. 216.

Coming now to the jointing of the igneous rock-masses, we find that those (the andesites) which are contemporaneous behave as do the grits and grauwackes, and have joints in similar directions. The early dolerites of Craig-ddû, etc. do likewise, but show some evidence that when they were foliated by the cleavage-stress, they were also sheared along certain pre-existing columnar joints. This shearing is particularly evident at Gareg-gôch, Careg-cnwc, and at several points along the edge of the golf-links of Morfa-bychan.

The later gabbroid dolerites of Moel-y-gest, Craig-y-gesail, Y Castell, and Pant Ifan, etc. behave very differently. Where not too massive, as at Morfa Lodge, Portmadoc, they exhibit only the rude columnar jointing which is characteristic of basic sills. Where coarse-grained and very thick, they show similar columnar structures in the fine-grained rock at their edges, but within the main mass they break up more regularly along master-joints. The most prominent of the master-joints are those which determine the slab-like character of the cliff-faces, and these not following any other rock-structure in the district range east and west and have a steep hade to the south. On the bare hill-exposures, the east-and-west joints frequently determine subsidiary crags, and with dip-joints, occasional strike-joints normal to the sill surface, and a platy structure which follows the elongation of felspar-crystals, break up the gabbroid rock into blocks which are rudely cuboidal.

The hornstones immediately in contact with the gabbroid dolerites have a system of jointing which is very complete, and partakes of the arrangement of the columnar joints within the margin of the dolerite. Completely recrystallized, they have lost all original structures, except the chemical banding of their bedding which has often become emphasized.[1]

The slabby rocks, 'desmoisites and spilosites,'[2] of the outer zone of metamorphism have also a few east-and-west master-joints in common with the altering rock; but, although they have now no tendency to break along a cleavage, their most dominant jointing always follows the cleavage-direction of the country. This circumstance is suggestive, in that it helps to confirm the post-cleavage age of the dolerites, and it is interesting to note that the worm-tracks, nodular concretions, etc., which are sometimes preserved upon the bedding-surfaces show evidence of having been pulled out in a similar direction. The puckerings of interstratified coarser bands and a certain 'flakiness' of the surface of the finer-grained slabs also show an elongation in this same cleavage-direction.

[1] A. Harker, 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, § vi.

[2] J. J. H. Teall, 'British Petrography' 1888, p. 219.

XV. The Age of the Gabbroid Dolerites.

I may now summarize the evidence as to the age of the gabbroid dolerites of Tremadoc, Y Gesail, Pant Ifan, and Moel-y-gest.

(1) The gabbroid dolerites have everywhere altered the rocks in contact with them, both above and below. They are, therefore, intrusive, and later than the Ordovician sediments of the country.

(2) The laccolites of dolerite follow the general strike of the sediments of the country, but do not follow the course of any individual bedding-plane for more than a few yards together. The outcrops do not, however, partake of the discontinuities that affect the rigid members of the sedimentary series with which they are associated. The dolerites have, in fact, metamorphosed sedimentary rocks which had already attained their present discontinuous arrangement, and are therefore later than the tearing of the Ordovician volcanic rocks into lenticles.

(3) The dolerites are completely unaffected by any shearing or foliation which has an orientation related to the cleavage of the country, but, as shown by the distortion and jointing of the rocks which they alter, are later than the cleavage.

(4) The Moel-y-gest dolerite cuts, and is later than, the Llanerch Fault.

(5) At Tyddyn-dicwm the metamorphic aureole of the Craig-y-gesail dolerite extends into the crush-belt of the Penmorfa Fault. Within this crush-belt there is no interfaulting of altered and unaltered rock, but the margin of the metamorphic aureole, as in other places, is regular. The Craig-y-gesail dolerite is consequently later than the Penmorfa Fault.

Probably, therefore, the gabbroid dolerites of Tremadoc are of late Devonian or Carboniferous age.

XVI. The Pleistocene Accumulations.

A discussion of the sequence of events which took place in Ynyscynhaiarn between the time of the later dolerites and the Pleistocene would require consideration of an area much larger than the district studied, and will not here be attempted.

The Pleistocene accumulations also, though interesting, do not locally afford sufficient evidence of their origin, and these, after brief mention of their lithological character and distribution, I shall leave over for another occasion.

The oldest Pleistocene deposit that I have discovered in the district is the shore-talus or 'head' occurring close under the cliff, and is overstepped by the Boulder-Clay which is banked against the Criccieth Castle rock. This ancient cliff-deposit is seen on both sides of the Castle, and consists of angular unworn rock with scree-like stratification. It rests quite undisturbed upon a wave-cut platform within a foot or two of the present limit of the highest tides.

The Glacial accumulations of Ynyscynhaiarn are practically all boulder-clays. These occupy a very considerable area in the northern part of the district, and north of a line running north-eastwards from Criccieth by Eisteddfa and Gesail Gyfarch to Foel-yr-erw, cover and completely conceal the outcrop of the solid rock. The hills of Pen Mynydd-ddû, Bryn Braich-y-saint, Moel Ednyfed, Ymwlch, and Ystum-cegid are exceptions. To the south-east of this line also the constant occurrence of striated pavements, roches moutonnées, travelled rocks perched upon eminences, and drift-pockets under the lee of upstanding crags, makes it certain that the whole country has been intensely glaciated.

Two types of Boulder Clay may be distinguished. The most dominant is the Northern Drift, characterized by boulders from Cwm Ystradllyn, Moel Hebog, and the Pennant Valley. This covers the whole of the Drift area above the 300-foot contour, and as far south as Moel Ednyfed. The other type is the Western Drift, containing travelled boulders from the Lleyn (West Carnarvonshire) and Anglesey, which locally seems to have come in-shore from Cardigan Bay. This Western Drift is well seen in the shore-cliffs both west and east of Criccieth Castle, and its eastward extension forms the ground-rock of the Criccieth 'New' Esplanade and the stony promontory of Merllyn, half a mile to the east of the town. Travelled rocks of the type seen *in situ* on the Rivals are found in the grounds of Bron Eifion, and as far up the hill as the reservoir which supplies Bron Eifion with water; but the limit between Northern and Western Drift is not an easy one to define.

The boulders found scattered over the south-eastern driftless area all belong to rock-types found in the Glaslyn Valley, and as the striations noted also point to a glaciation from north-east to south-west, we may take it that there the glacial sculpture was accomplished by the Glaslyn glacier. Such a glacier with an ice-supply from high up among the mountains of Snowdonia would be more powerful than its neighbour from Cwm Ystradllyn; and it is possible that while the former was able to carry its débris right out to sea, the latter, checked at Criccieth by the bar of western ice, was compelled to stagnate behind that bar, and so deposited its burden of boulder-clay on the land. The Glaslyn ice must have advanced directly across the 'grain' of the Tremadoc country, and in its passage has sculptured each outstanding scarp from Pen-yr-allt to Moel-y-gest into a roche moutonnée. The glacial plucking and removal of all scree and loose rock on the steep south-westward facing scarps seems also to have been accomplished very completely.

Of post-Glacial phenomena one of the most striking is the very complete removal of all fine-textured débris from the south-eastern tract of the area here described. Except locally, where covered by scree from a steep upstanding crag, hardly a trace of Drift remains; and, in many places, the rocks are still so bare that the soil can hardly support the most meagre vegetation. Such scouring is possibly of late Glacial date, and may be due to floods coursing along the edges of the waning valley-glaciers at a stage when they were becoming rather short of, or perhaps free from, lateral moraine. It is a phenomenon which is common to the southward-facing slopes of the lower courses of many of the valleys of Carnarvonshire and Merionethshire.

Of post-Glacial accumulations Ynyscynhaiarn has its full share. A raised beach I have not certainly identified, but the promontory of Craig-ddû seems to show a wave-cut platform about 10 feet above most tides, and at Ynys Gyngar, Careg-cnwc, Gareg-gôch, Trwyn-y-borth, and Trwyn-cae-iago (Craig-y-don) about Borth, I think that I can recognize a similar but less deeply cut wave-notch. The various Ynys about Tremadoc also show wide rock-platforms a little above the level of the morfa; but it would require careful measurement to determine their relationship to the tide-level outside the embankments.

The alluvial deposits of the Afon Glaslyn and the manner in which tidal silt is building up the Traeth Mawr into land is well known. The cliffs beyond Tan-y-graig below Craig Pant-ifan have no scree at their base, and are pierced by caves as fresh now as in the days when they were washed by the tide. The Roman inhabitant of Hen Fynwent was a fisherman, and the find of kitchen-middens of cockle-shells (*Cardium edule*) at Wern shows that the silting up of the whole morfa of Penmorfa is not much more ancient. There was a sea-bathing place at Tremadoc at the beginning of last century.

The morfa of Morfa-bychan is of similar date, but owes its formation to the sand blown in from the tidal sands and to the growth of salt-marsh plants in the bogs behind the sand-hills.

The pebble-bank between Criccieth and Craig-ddû is also worthy of notice. It is formed by tidal drift from the west, and consists of well-sorted rounded pebbles from the Western Drift-mass of Criccieth; and, as in their eastward migration the pebbles are unable to pass Craig-ddû, it is still growing. Pushed out as a spit from the cliff of Ogof-ddû, the beach has barred the outflow of the waters which come from the hills into Llyn Ystumllyn, and holding up the lake has compelled its waters to find exit between the pebbles or through the well-jointed rocks of Craig-ddû, which they do most effectually, appearing at low tide as springs on the foreshore.

XVII. General Summary and Conclusions.

The district of Ynyscynhaiarn consists of Cambrian and Ordovician rocks arranged about a northward-pitching north-and-south anticline, which has its axis through Llyn Ystumllyn close by St. Cynhaiarn's Church. The rocks have been cleaved along lines which range a little east of north and south, dip eastwards, and are broken by a series of thrust-planes, which are inclined to the north-east. Into the sedimentary rocks, possibly along the lines of the thrust-planes, large laccolites of gabbroid dolerites have been intruded at a date subsequent to both cleavage and faulting, and a metasomatic development of pisolitic iron-ore has taken place along the line of the most notable (Penmorfa) thrust. Glacial accumulations mask the geology of the north-western district, but the adaptation of surface-features to underground geology is very perfect, and the exposures of the outcrops in the driftless area of the south-east are very complete. There is a considerable development of post-Glacial accumulations at or near sea-level.

The stratigraphical succession begins with the Maentwrog Beds and ends somewhere in the Upper Llandeilo or Caradoc. As far as the unconformity which transgresses the Tremadoc Slates the succession is simple and complete; but the Arenig rocks are not well exposed, and the Llandeilo and later rocks have been involved in much earth-movement.

The Maentwrog Beds are dark rusty-grey slates with ringers of felspathic material, and are like the Lower rather than the Upper Maentwrog Beds described by Belt at Llanelltyd.

The Ffestiniog Beds are a thick series of grey flags and compact grauwackes, with the *Lingulella* Band at their top.

The Dolgelly Beds are black slates, as at Arenig, but at the base of the *Peltura* horizon contain thin felspathic bands as at Dolgelly.

The Tremadoc Beds I have described in detail. Tremadoc in Ynyscynhaiarn is the name-locality at which Sedgwick first distinguished Tremadoc Slates; and, although the slates of the village of Tremadoc with their pisolitic iron-ore are of Llandeilo age, this need not affect the nomenclature.

The Tynllan Beds or 'Lower Tremadoc' of Salter are thinly-bedded rusty-grey slates with a harder cherty band near the top, and have characteristic white-weathering spots due to small pyritous concretions. They are the *Niobe* horizon of Arenig, and have not been recognized elsewhere.

The *Dictyonema* Band, 15 feet thick, is a notable horizon. I have discussed its importance and distribution in another place.[1]

The Moelygest Beds are a barren series of banded grey slates or mudstones, containing enough pyrite to cover their weathered surfaces with rust. They correspond exactly with the *Bellerophon* Beds of Arenig.

The Portmadoc Flags are the coarsest of the Tremadoc Slates. They contain the débris of much felspathic material, and in the west include considerable masses of ashy grit. They are the *Asaphellus* Beds of Arenig.

The Penmorfa Beds are micaceous and slightly calcareous. They occur at Penmorfa as flaggy blue mudstones without much cleavage, and elsewhere as thinly-bedded banded needle-slate. They contain *Shumardia* and the Shineton fauna,[2] and with it occasional

[1] Geol. Mag. 1907, pp. 260 *et seqq.*
[2] C. Callaway, Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 652.

specimens of a variety of *Angelina*. They are the 'Middle Tremadoc' of Salter and the *Shumardia* Shales of Arenig.

The Garth Hill Beds are finely-bedded grey-blue slates with some flaggy bands, and are always very rusty. They are the 'Upper Tremadoc' of Salter, and are characterized by the abundance of *Angelina*.[1] There is no evidence upon which to correlate them with any particular formation in South Wales, and they are certainly cut out by the Ordovician unconformity at Arenig.

The Arenig Grit of Ynys-towyn is 70 feet thick. It is placed in the Arenig by analogy only; but near Criccieth a few Arenig fossils have been found in ashy beds which overlie a similar deposit. The strata above the ashy beds with Arenig fossils at Criccieth are slates, so cleaved and crushed that the collecting of fossils is impossible, and the local distinction between Arenig and Llandeilo slates remains unknown. In the eastern district the Penmorfa Fault has cut out the Arenig beds.

The Llandeilo Beds of the east are dark slates, much crushed and broken into slickensided augen by the faulting. From certain of their augen in which cleavage has been destroyed and bedding partly revived by the metamorphism due to a later dolerite, the graptolites of Tyddyn-dicwm, Ynys-galch, and Pen-syflog have been collected. These all belong to the zone of *Nemagraptus gracilis* or to the overlying subzone of *Climacograptus peltifer*, and are of the horizon of the Glenkiln Beds of Moffat,[2] or of the shales immediately above the Mydrim Limestone in South Wales (Llandeilo).[3]

The higher grey slates are everywhere crushed, cleaved, or baked by the dolerites, and have yielded no fossils which determine their horizon. The andesites of the Tremadoc Ynys and the related andesitic ashes and agglomerates of the Penmorfa flag-quarry, Y Glog, and several localities, are interstratified among these grey slates. They thin out south-westwards and thicken eastwards, and may be attributed to some volcanic source upon the Moelwyn. The felsites of the Criccieth district are intrusive, but belong to the Snowdonian stage of volcanic activity. The intrusion of the gabbroid dolerites[4] of Moel-y-gest, Y Gesail, Tremadoc, and Pant Ifan is of some date more recent than the impression of the cleavage of the country.

EXPLANATION OF PLATES XV–XVII.

Plate XV.

Sections showing the relations of Cambrian and Ordovician rocks across the Penmorfa Fault, on the scale of 6 inches to the mile:—A, from Morfa-bychan to Fach Gôch; B, from Glan-byl to Pen-yr-allt.

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[1] H. Hicks, Quart. Journ. Geol. Soc. vol. xxix (1873) p. 43 & vol. xxxi (1875) p. 175.

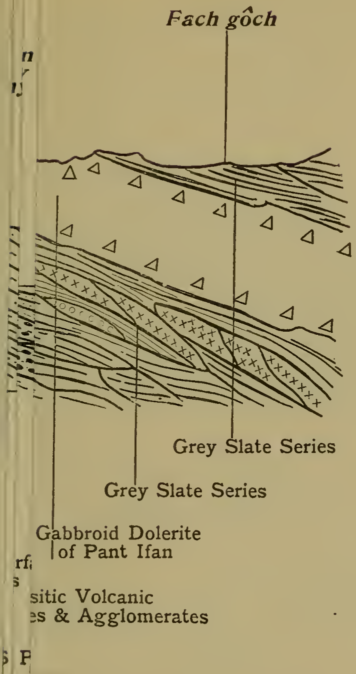
[2] C. Lapworth, *ibid.* vol. xxxiv (1878) p. 253.

[3] Summary of Progress of Geol. Surv. 1906, p. 44. See also 'Geology of the Country around Caermarthen' Mem. Geol. Surv. 1909, p. 49.

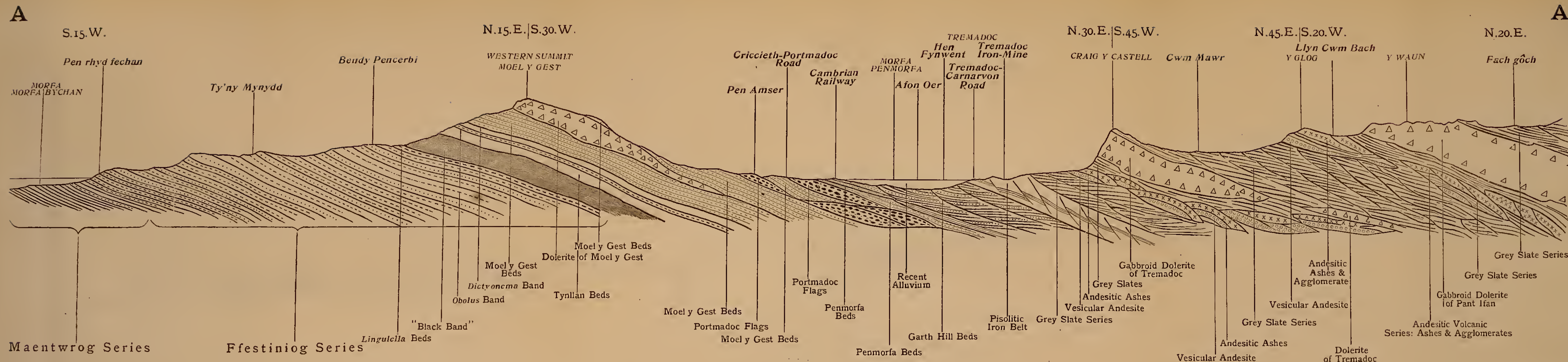
[4] A. Harker, 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, pp. 76–79.

A

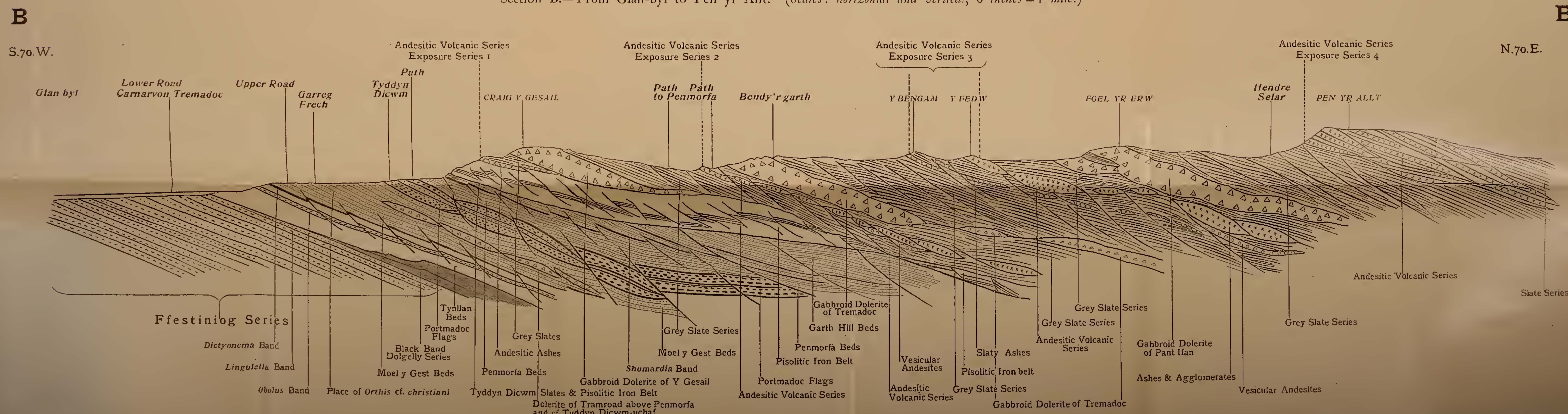
N.20.E.


Fach gôch
Grey Slate Series
Grey Slate Series
Gabbroid Dolerite
of Pant Ifan
sitic Volcanic
es & Agglomerates

Section A.—From Morfa Bychan to Fach-gôch. (*Scales: horizontal and vertical, 6 inches = 1 mile.*)



Section B.—From Glan-byl to Pen yr Allt. (*Scales: horizontal and vertical, 6 inches = 1 mile.*)

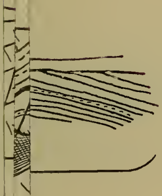


XVI.

C

S.55.E.

P. Beach



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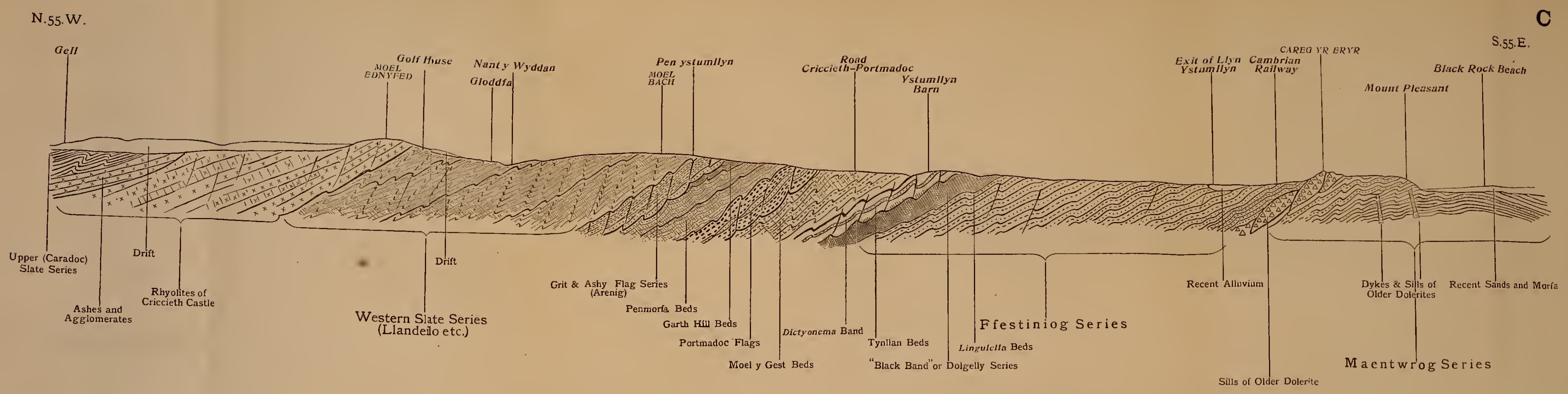
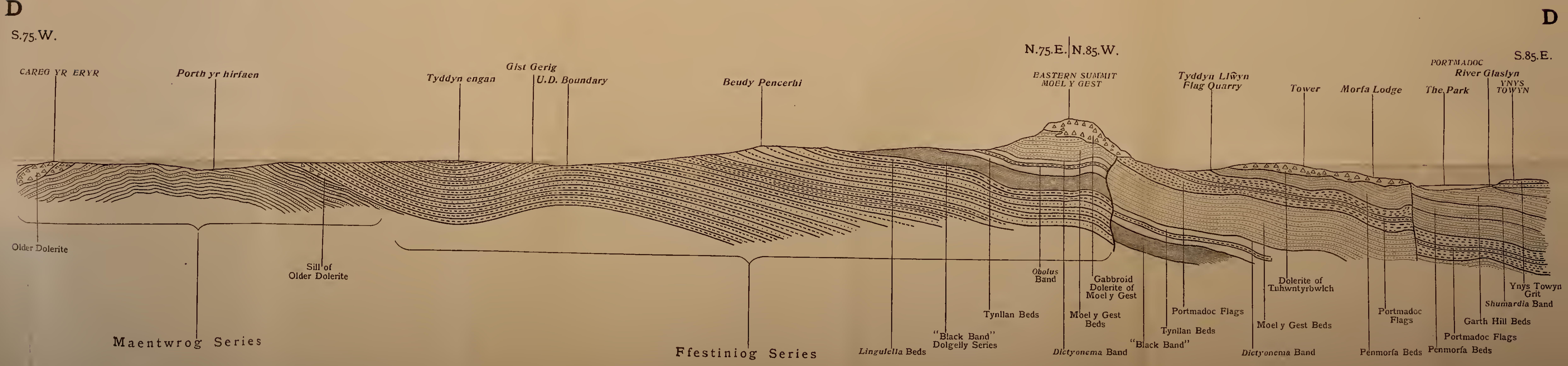
ıd

Section C.—From Gell to Black Rock Beach (*Scales: horizontal and vertical, 6 inches = 1 mile.*)



Section D.—From Careg yr Eryr to Ynys Town. (*Scales: horizontal and vertical, 6 inches = 1 mile.*)



W. G. Fearnsides, fecit.

E. Wilson, Cambridge.

Plate XVI.

Sections across the Ynyscynhaiarn anticline, on the scale of 6 inches to the mile:—C, from Gell to Black Rock Beach; D, from Careg-yr-Eryr to Ynys-towyn.

Plate XVII.

Geological map of the Ynyscynhaiarn District (South-East Carnarvonshire), on the scale of 3 inches to the mile.

Discussion.

The President (Prof. W. J. Sollas) congratulated the Author on his admirable account of a classic locality; it was complete in every respect—in mapping, in palæontology, and in tectonics. The problem of deceptive conformities was one of great importance, and awaited investigation. The presence of a visible unconformity at Tremadoc which could not be detected in South Wales was a case in point; another would seem to be that which in many localities occurred at the base of the Upper Silurian, and in others was apparently absent over wide areas. The intrusion of basic rocks along the thrust-planes afforded an additional instance to those already made known by Suess. The most magnificent example was afforded by the 'exotic blocks' of the Himalaya.

Dr. Marr said that he would have wished to refer to many things, such as the position of the *Dictyonema* Band, and the correct designation of the fossil referred to that genus; but at that late hour he would only congratulate the Author on his paper, wherein he had practically completed one piece of work, and given a great impetus to another. He had in this and in a previous paper shown definitely what were the Arenig Beds of Arenig and the Tremadoc Beds of Tremadoc, for which all students of the Lower Palæozoic rocks, at home and abroad, must thank him. He had, by his careful study of the tectonics of the district, added largely to that most interesting subject, the building up of North Wales, and pointed the way to much future work therein.

Prof. Watts remarked that the Author's work was bringing the Tremadoc Beds of Tremadoc into line with those of Shropshire.

Mr. J. F. N. Green observed that, near St. David's, where folding and thrusting similar in many respects to the phenomena described by the Author occurred in rocks of the same age, quartziferous and hypersthene-bearing dolerites had been described in detail by Mr. J. V. Elsden. That author and the speaker came independently to the conclusion that these dolerites were later than the main faulting.

The Author, in reply, thanked the President and Fellows for their very generous appreciation of his paper.

In answer to Mr. Green, he said that, although in the district under consideration he had found no fault such as could be mapped later than the dolerite-intrusions, there was at Garth Hill Quarry, Minffordd, a very prominent fault of such a character which had converted a thick belt of rock on either side into the condition of a quartz-chlorite-schist. That fault was a normal fault of slight throw.

Further, he could offer no opinion as to the exact relative ages of the *Angelina* Beds and the beds with *Peltura punctata* in South Wales. He had collected several examples of a *Peltura* not unlike *Peltura punctata* from the Penmorfa Beds, and could see no inherent reason for excluding the *Peltura-punctata* Beds from the Tremadoc Series.

He believed that the unconformity between the Garth Hill Beds and the basal Ordovician grit was due to the same north-and-south folding as that which had corrugated the Cambrian rocks of the Harlech country; and as, at Llanystumdwy (1 mile west of Criccieth), there was complete passage from the uppermost Ordovician into the Skelgill facies of the Lower Llandovery, he could not agree that the stratigraphical break between the Cambrian and the Ordovician Systems in this area was of less importance than the unconformity between the Ordovician and the Silurian.

8. *The* Geology *of* Nyasaland.[1] By A. R. Andrew, M.Sc., F.G.S., and T. E. G. Bailey, B.A., F.G.S. *With a* Description *of the* Fossil Flora, *by* E. A. N. Arber, M.A., F.G.S.; Notes *on the* Fossil non-Marine Mollusca *and a* Bivalved Crustacean (*Estheriella*), *by* R. B. Newton, F.G.S.; *and a* Description *of the* Fish-Scales *of Colobodus, etc., by* R. H. Traquair, M.D., F.R.S., F.G.S. (Read November 17th, 1909.)

[Plates XVIII & XIX—Fossils.]

Contents.

I. Introduction.

In the past several African travellers have explored parts of what is now known as Nyasaland, and have given a brief account of its geology, while in more recent years comparatively detailed geological work has been carried out in neighbouring countries. A short summary of these researches is given below:—

1865.—Livingstone (1)[2] spent most of his time outside of the Protectorate, but he also travelled to the southern end of Lake Nyasa, and for a short distance on its west coast. He discovered the coal at Tete in Portuguese East Africa. He also reported coal from the neighbourhood of Port Herald. His description would lead one to think that coal occurred on the slopes of Malawe Hill, though really there is none nearer than 6 miles away.

1881.—Stewart (2) passed up the shores of Lake Nyasa, and discovered coal in the Zindira Stream (Chesindire), near the mouth of the Malawe or Southern Rukuru River.

1881.—Joseph Thomson (3) passed through what is now German territory to the north of Nyasaland, and found there a large development of volcanic rocks, near the northern end of the lake.

[1] Published by permission of the Director of the Imperial Institute.
[2] Numerals in parentheses refer to the Bibliographical List, § VI, p. 237.

1882.—An expedition (4) was sent out to study the resources of Portuguese East Africa. Its members were chiefly occupied with the district near Tete, from the coal-seams of which Prof. Zeiller identified eleven species of fossil ferns.

1888.—Drummond (5) discovered the sedimentary beds with Karroo fossils at Mpata, near Karonga.

1890.—Prof. T. Rupert Jones (6) described the fossils obtained by Drummond, and compared them with similar fossils from the Karroo of Cape Colony.

1896.—Moore (7) traversed the country, and touched on a few points of its geology.

1896.—Dr Bornhardt (8) investigated the geology of German East Africa. He published a very interesting and detailed account of his researches, giving some description of the one or two places that he had examined in British territory, as, for example, Mount Waller, Monkey Bay, and the Songwe River.

1903.—Henderson (9) gave a brief but interesting account of the Mount Waller beds.

1903.—From the examination of a number of specimens collected by the political officers resident in the Protectorate, Sir Thomas Holland (10), basing his opinions on the similarity of these specimens to the rocks of India, gave an outline of his expectations in regard to the general geology of the country.

1903–1906.—During these years many specimens which had been sent to the Imperial Institute (11) by residents in the Protectorate were examined, and the results published from time to time.

1904.—Mr. Molyneux (12) investigated the geology of Southern Rhodesia, an area which in many respects resembles Nyasaland.

1907.—Mr. Lamplugh (13) investigated the geology of the country near the Victoria Falls, which, although about 800 miles away, also resembles in some respects the Nyasaland Protectorate.

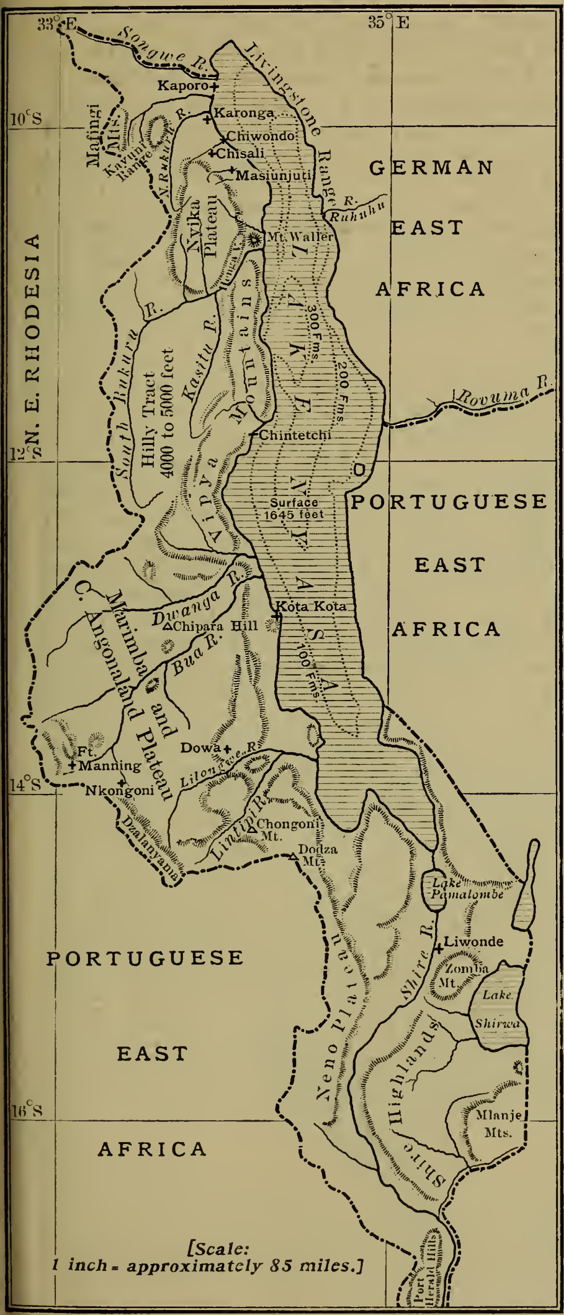
1907.—Mr. Wallace (14) published an account of North-Eastern Rhodesia, a country which marches side by side with Nyasaland for a considerable distance.

1908.—The two present authors were sent out to Nyasaland in 1906 by the Imperial Institute; and the results of investigations at that Institute of minerals collected by them, so far as these investigations concerned minerals of economic importance, have been published as official reports in the Colonial Office Series (15).

1909.—Mr. Molyneux (16) published an account of the Karroo formation in North-Eastern Rhodesia, in the Luangwa Valley, about 400 miles distant from Nyasaland. His results, like those of Bornhardt, are closely comparable with our own.

In the preparation of the present paper we have been greatly indebted to Mr. T. Crook, F.G.S., for the help which he has given us in examining, at the Imperial Institute, the rock-specimens collected during our stay in Nyasaland, and also to Mr. G. W. Lamplugh, F.R.S., and to Dr. J. W. Evans, F.G.S., for putting us in touch with the results of geological exploration in neighbouring

Fig. 1.—*Topographical map of Nyasaland.*



countries, and to Mr. E. B. Bailey for many valuable suggestions and criticisms.

The fossils brought back to England have been presented to the British Museum (Natural History), and have been examined by various specialists.

II. Topography.

Nyasaland forms a narrow strip of country, some 480 miles long, lying directly to the west and in part to the south of Lake Nyasa (fig. 1). The area of this strip is roughly comparable with that of England. The northern border is defined by the Songwe River, across which lies German East Africa; the western boundary has been drawn along the water-shed separating the Luangwa and direct Zambezi drainage, on the one hand, from that of Lake Nyasa and the Shire River, on the other. To the south, Nyasaland is completely encircled by Portuguese territory, and is thus cut off from direct communication with the sea. The country consists for the most part of high table-lands or mountain-masses rising irregularly one above the other. The greatest altitude (9843 feet above sea-level) is attained by one of the Mlanje peaks in Southern Nyasaland. Farther north the Chongoni mountain-group reaches nearly 8000 feet, while a considerable area in the Nyika Plateau varies from 7000 to 8000 feet in altitude. Lake Nyasa occupies the bottom of a deep north-and-south trench, bordered on the east and west by the truncated edges of the plateau-regions. These at times drop steeply down below the waters of the lake; but usually the western edge of the latter is fringed by a sandy coastal plain, 3 to 20 miles across.

Lake Nyasa has a length of about 300 miles, a maximum breadth of some 45 miles, and a maximum depth of more than 670 feet below sea-level, while the surface of the lake lies at an elevation of 1645 feet.

The lake-trough is continued both north and south of the lake. On the north the valley, with an alluvial floor, rises gradually until it is choked with lavas of recent and perhaps Tertiary age. On the south the lake bifurcates, and drains out through its eastern arm into the Shire Valley. Even at first, the latter is several miles in width, and it widens out very considerably farther down. The gradient of this valley for a long distance does not exceed 1 foot per mile. A large but shallow lake, known as Pamalombe, lies near its head: this, however, is rapidly dwindling in size, and will soon be completely silted up. Below Liwonde the Shire Valley swerves westwards to meet the continuation of the western limb of the lake-trough, and for many miles now runs in a wide and deep depression between the Neno Plateau on the west and the Shire Highlands on the east. Somewhat below Port Herald, and in Portuguese territory, the Shire at last escapes from the mountains, and thenceforth meanders across a flat plain on its way to join the Zambezi near Morambala Mountain, a lofty isolated ridge which can be seen for miles across the grass- and tree-covered river-flats. There are only three lakes in Nyasaland, and two of these have already been mentioned. The third, Lake Shirwa, is about 20 miles long, and lies in a shallow depression to the north of the Mlanje Mountains. This lake is very shallow, and has no outlet: its water is distinctly brackish, in contrast with that of Lake Nyasa, which is perfectly fresh. A low but broad ridge of gneiss separates Lake Shirwa from the Shire Valley and Lake Pamalombe. These minor lakes probably represent a local sagging in of the earth's crust, consequent upon the great earth-movements which gave rise to the Nyasa trough. This is a subject which will be dealt with more fully in a subsequent portion of the paper (p. 233).

III. Geology.

The rocks of Nyasaland may be broadly divided into (*a*) a crystalline series comprising crystalline schists, gneiss, and plutonic intrusions, and (*b*) a later sedimentary series with which may be included the associated lavas and dykes.

Fig. 2. Geological Map of Nyasaland.

(*a*) The Crystalline Series.

Throughout the greater part of the country the crystalline schists and gneisses have a regular banded appearance. As a rule, banding and planes of schistosity agree in direction.

This stratiform appearance is, in some cases, due to original bedding in a sedimentary series, and in others to original banding in an igneous rock. At times, however, it can be shown to be of secondary origin, induced in homogeneous igneous rocks by local crushing. Quartz - reefs also crossing plutonic masses have occasionally been so crushed and granulated as to simulate altered sedimentary rocks.

To rocks of undoubted sedimentary origin, however, belong the quartzitic and micaceous schists of the Nyika and the quartzitic schists of Central Angonaland, near and south of Fort Manning. The muscovite - gneisses, which occupy so large an area between the Songwe and Northern Rukuru Rivers of Northern Nyasaland, are also of sedimentary type.

A very distinctive group of rocks forms the eastern portions of Central Angonaland. This consists of graphitic gneisses interbanded with fine-grained felspathic gneiss, thick beds of crystalline limestone and kyanite-schists, the two last-named frequently containing flakes of graphite. The graphitic gneiss consists of quartz and felspar, with numerous flakes of graphite scattered throughout the mass. Occasionally this graphite is concentrated into veins and lenticles, and in such cases the gneiss is more or less kaolinized.

The limestones are highly crystalline and generally impure. The crystalline impurities consist for the most part of diopside and forsterite, the latter now largely converted into serpentine. From the abundance of such impurities it is evident that the limestones were originally dolomitic in character. Impure calcareous bands, rich in garnets and lime-silicates, are found in association with these limestones.

The kyanite-bearing gneisses are generally coarse-grained, and consist of quartz, felspar, white mica, and graphite. The kyanite frequently forms crystals exceeding an inch in length, and is usually dirty grey in colour, but sometimes blue. Stringers of limonite are common in these gneisses. In certain localities, as, for instance, near Chiwambas on the Lilongwe River, the graphitic gneiss contains numerous sill-like masses of garnet-amphibolite, a dark, well-crystallized rock composed of hornblende and large red garnets.

This series of graphitic gneisses and limestones can be traced southwards for a considerable distance down the Shire Valley, and is again met with in the Port Herald district. Graphitic gneisses are also known in a detached outcrop to the north, near Usisya, on the coast of Lake Nyasa.

Among gneisses of more doubtful origin may be included well-banded hornblende, biotite, quartz-felspar gneiss, felspathic gneisses in which ferromagnesian minerals are rare, and garnet-gneisses and granulites. Gneisses and schists of obviously igneous origin are well developed. In the Nyika and Vipya areas, bands of talcose schist, sometimes of considerable thickness, probably represent basic intrusions. Chiramimbi Hill, near Fort Manning, is composed of serpentine converted in places into talcose schist.

Fine-grained gneisses with platy structure may be traced in the field through every gradation into augen-gneiss, which in turn is found to pass into slightly foliated syenite or granite. Augen-gneiss, obviously of granitic origin, is of common occurrence in Northern Nyasaland, where it forms narrow sill-like lenticles in the steeply dipping schists and gneisses, and also broad bands several miles across.

Plutonic intrusions.—It is impossible to draw any hard-and-fast line between the augen-gneiss and the plutonic intrusions, for in many places, as already stated, the one passes into the other.

The plutonic rocks, for convenience of description, may be roughly divided into the following three classes:—

Class (i).—Foliated intrusions which lie, with the exception of the Dzalanyama granite, to the north of latitude 14° S.

Class (ii).—Unfoliated intrusions which are found, for the most part, south of latitude 14°.

Class (iii).—Certain coarse-grained intrusions of acid granite.

The foliated plutonic intrusions grouped under Class (i), while differing widely among themselves in age, show certain common characteristics which allow of their separation into a distinct class. They consist, for the most part, of granite or syenite with well-developed porphyritic crystals of felspar. The granites rarely contain much quartz, and resemble the associated syenites in the abundance of microcline, and the occurrence, at times, of perthitic felspars. The great granite intrusion which forms the central portions of the Nyika Plateau is of somewhat peculiar type, consisting of large felspars of acid plagioclase, microcline, etc., quartz, and a very little biotite. The felspars show a parallel arrangement, but are otherwise unaltered. The quartz, however, appears to have been crushed and converted into a granular aggregate, the indivinual granules of which are just visible to the naked eye.

In the Fort Manning range of Central Angonaland a dark even-grained granite occurs, in which the quartz is of a blue or smoky colour. Pyroxene appears to be a fairly common constituent of this rock.

Class (ii).—Under this heading are included the huge boss-like intrusions which compose the high plateaux of Zomba and Mlanje. Though superficially isolated, there can be no doubt that the Zomba-Mlanje masses, in common with the large intrusion to the east of Lake Pamalombe, are genetically related. The Mlanje mass is built up of hornblende-granite, which consists of microperthite and other felspars, hornblende and a little quartz. The crystals of hornblende may reach several inches in length in the coarser varieties of the Mlanje granite. The Zomba mass consists of granite and syenite of similar type. A marginal modification is found about 7 miles from Liwonde, on the Liwonde-Zomba road. This is a banded syenite, rich in nepheline and occasionally sodalite. Hornblende sometimes occurs in the form of very long lath-shaped crystals, grouped together in veins crossing the syenite. The last stages of intrusion are represented by numerous nepheline-bearing dykes which traverse the syenite and the adjacent gneiss. A very similar nepheline-sodalite syenite, of a beautifully blue colour, is found far to the north in the Nyika Plateau: sodalite is here an abundant constituent.

Basic intrusions of plutonic rock are of rare occurrence. Certain narrow dyke-like masses of norite are found in the Shire Highlands, and contain a small quantity of nickeliferous pyrrhotite. Farther north an intrusion of gabbro, showing no foliation, was noticed in the Lower Henga Valley, east of the Nyika Plateau.

Class (iii).—Coarse-grained, often pegmatitic granites are found occasionally, as near Dowa and Deep Bay. The felspars of the Dowa mass are chiefly microperthite and microcline.

Age of the plutonic masses.—The age of the plutonic intrusions will probably never be definitely settled. It is true that no instance is known of a typically plutonic rock having been intruded into Karroo or later beds, but the poor development of unaltered sediments, other than the most recent, might account for this. There can be no doubt, however, that the highly foliated granites of the northern area are of pre-Karroo age. West of the Nyika Plateau, foliated granites form the floor of the Karroo Series, and boulders of the granite are found in the basal conglomerates.

In the case of the foliated granites the question arises, as to whether the foliation practically synchronized with the intrusion of the granite, or originated after its solidification. This is satisfactorily settled for the Dzalanyama intrusion by the discovery of a pegmatite vein, which has been displaced by a series of small tear-faults and foliated across its length in a direction parallel with the foliation of the granite. It is obvious, in this case at least, that the foliation post-dated the solidification of the granite.

That the foliated intrusions of Class (i) are of pre-Karroo age may be taken as certain. It would, however, be a matter of pure speculation to assign any limits to the age of the plutonic rocks of Class (ii). The rocks of this class are typically alkaline in character, and show a certain magmatic resemblance to the Tertiary and recent lavas of the Great Rift Valley system. This resemblance, however, loses most of its significance when one remembers that in the Transvaal nepheline-syenites and other alkaline intrusions form part of the 'Red Granite,' which is considered to be of pre-Karroo age. Moreover, the foliated granites and syenites of Northern Nyasaland belong to an alkaline set of intrusions. We have already referred to the association, in the Shire Highlands, of nickeliferous pyrrhotite with certain intrusions of norite. A similar association occurs in the norites of the Transvaal, which belong to the 'Red Granite' suite of intrusions.

On the whole, it appears probable that the plutonic rocks grouped under Classes (ii) and (iii), while later than those of Class (i), are themselves of pre-Karroo age.

Quartz and pegmatite-veins.—A description of the crystalline rocks of Nyasaland would not be complete without some mention being made of the numerous veins of quartz and pegmatite which traverse the older rocks. There appears to be no clear line of separation between quartz and pegmatite-veins, for the one shades off into the other, and few veins or reefs of quartz are to be found entirely free from felspar. Tourmaline is widely distributed in these veins, especially in the more typical pegmatites. As a rule, the tourmaline occurs in large well-formed crystals, but the streaked and banded tourmaline-quartz veins of the plateau-region behind Neno approach more closely to schorl-rock. The frequent occurrence of felspar, and more rarely tourmaline, in the quartz-veins of Nyasaland, lends colour to the belief that they represent the mother-liquor of an igneous magma rather than the products of lateral secretion.

Very rarely has any connexion been observed between the distribution of the quartz and pegmatite-veins and that of the plutonic masses. Near Dowa, in Central Angonaland, however, typical pegmatite-veins and dykes are very abundant, and increase in number and width when traced towards the large mass of coarse-grained granite already mentioned. The thicker bands of pegmatite not infrequently show graphic intergrowths between the quartz and the felspar. The quartz varies in colour from grey to mauve, and even black. These graphic pegmatites have, therefore, a very distinctive appearance.

(*b*) The Sedimentary Groups.

The following divisions have been recognized among the later sedimentary rocks of Nyasaland:—

3. Recent deposits.
2. The Karroo Series.
1. The Mafingi Series.

(1) The Mafingi Series.—The rocks of the Mafingi Series form an isolated group of mountains in the north-western corner of Nyasaland, and cross the border into North-Eastern Rhodesia. The Mafingi Mountains range for about 18 miles in a north-and-south direction, and rise to over 7000 feet above sea-level, or nearly 3000 feet above the surrounding plateaux. This mountain-group consists of steep, bare, scarp-like ridges separated by deep and narrow V-shaped valleys, a type of scenery not to be found elsewhere in the country. High mountains of gneiss lie along the eastern edge of the wide Mbalise Valley, and afford with their softer outlines a striking contrast to the rugged quartzite-ranges of the Mafingi just across the valley.

The Mafingi Series consists of a great thickness of whitish quartzites with phyllitic bands, schistose flags, felspathic sandstones, and grits. According to a traverse made in an east-south-easterly direction, from the upper waters of the Luangwa in North-Eastern Rhodesia to Kayalise village on the Mbalise River, it appears that the series may be roughly divided into the following groups, in descending order:—

	Approximate thickness in feet.
Top not seen.	
1. Strongly-bedded, often schistose flags	1300
2. White quartzites with 'honeycomb weathering', and felspathic sandstones	470
3. Brown and grey, sometimes schistose flags, with occasional bands of conglomerate consisting of white quartz-pebbles in a siliceous and micaceous matrix, and with 10 feet of dark carbonaceous phyllite at the base	2470
4. Hard, compact, very thickly-bedded quartzites	600
5. Hard and soft, white or pinkish, felspathic sandstones and grits, with some flags and quartzites	4050
6. Brown and grey, very felspathic sandstones, with few flags	220
7. Soft white flags and sandstones	680
Base not seen.	
Total seen	9790

The structure of the area is simple, except in the northern extremity, where complications arise. The general strike is roughly north-east and south-west, and the dip varies from 40° to 75° towards the north-west. In places, however, the beds may become vertical, and in one case are overturned. In the north the strike changes to an easterly and westerly direction and the beds dip at times from 50° to 80° southwards. Near Namitawa Mountain the beds are folded into a small syncline, with comparatively low dips. The northern junction with the gneiss is probably a faulted one. No fossils have been discovered in the Mafingi Beds, and so their age is uncertain; but, from the general character of the rocks, it is safe to assume that they are earlier than the Karroo System. In German East Africa Dr. Bornhardt has described what appear to be a similar series of quartzites, grits, and sandstones, and has compared them with the Cape Beds of South Africa. Quartzite formations are also known in the Transvaal.

(2) The Karroo Series.—The ancient quartzite formations of the Transvaal are succeeded by a thick series of sandstones, conglomerates, shales, and volcanic rocks, which lie with considerable unconformity upon the older rocks beneath. This system is known as the Waterberg, and is in turn overlain unconformably by the Karroo. The question arises as to how far the Waterberg Series may have extended northwards. While there is a temptation to include some of the older sandstones and shales of the Congo-Tanganyika area with the Waterberg Series of the Transvaal, the fossil evidence appears to be conclusive that the sandstones of the Nyasa region belong exclusively to the Karroo, with the exception of limited exposures on the north-western border of the lake, which are of recent age. Karroo beds occur in the north of Nyasaland, and along the south-western border. The two occurrences are separated by a wide expanse of crystalline rocks. The Karroo of Northern Nyasaland forms isolated patches of comparatively low ground,

sandwiched in between high plateau-regions or steep ranges of gneiss. It is obvious here that the Karroo owes its preservation to faulting. In the south of the Protectorate rocks of Karroo age are exposed along the eastern edge of a low broken plain which drops gradually towards the Zambezi River.

In the northern area the Karroo may be traced in isolated patches from the Anglo-German border as far south as the southern extremity of the Nyika Plateau. The prevalent dip of the series is in an easterly direction, but occasionally the beds are thrown into gentle anticlinal and synclinal folds.

Trough-faulting is of common occurrence, and has the effect of letting down long narrow strips of Karroo into the gneiss and schists below. The dominant trend of these trough-faults is from north to south. Not infrequently, the fault running along the western side of these troughs dies out. In this case the prevalent easterly dip of the Karroo in the faulted troughs or basins brings to light the basal beds, which are invariably found resting unconformably upon the older crystalline rocks. Owing to the patchy distribution of the Karroo and the paucity of fossils, a close correlation of the beds in the various localities cannot as yet be attempted. The Karroo of Northern Nyasaland is, however, divisible into certain broad divisions, which are recognizable with comparative ease: these are as follows:—

3. Upper Grit and Limestone Division.
2. Shale, Coal, and Mudstone Division.
1. Lower Sandstone and Basal Conglomerate Division.

No fossils are known in Division 1. Division 2 has yielded fronds of *Glossopteris*; but, as a rule, the shales and mudstones of the coal-group prove unprolific. In Division 3 fossils are more plentiful. The massive grits themselves have only yielded one silicified tree-trunk. Certain thin shale-bands in these grits, however, contain leaves of *Glossopteris*, usually in a bad state of preservation. The overlying limestones, where these are developed, are also associated with fossiliferous shales from which fish-scales and lamellibranchs have been obtained, first of all by Drummond near Mpata (B, fig. 2, p. 193), and later by us in the Nkana (A, fig. 2) district some 20 or 30 miles north of Mpata. The limestones and mudstones which Mr. Moore has called by the name of 'Drummond Beds' are not, as has been stated, unconformable to the lower grits of Division 3, but rest upon the same with perfect conformity, and are probably of Middle Karroo age. The apparent discordance which is to be observed near Mpata is due to faulting. The Drummond Beds, although of considerable thickness and importance, have not been placed in a separate division. This is due to the fact that the limestone group is missing in the faulted troughs on the west, and is probably represented by grits, as the upper grits appear to thicken considerably when traced westwards.

Perhaps an ancient shore-line existed on the west: for, concurrently with an increase in thickness of the upper grits, there is a decrease in thickness of the lower sandstone division. Near Mpata the latter has a thickness of nearly 1000 feet, while west of the Nyika Plateau (D, fig. 2, p. 193) the coal-group rests directly upon the basal conglomerates, here about 100 or 200 feet thick.

The divisions into which the Karroo of Northern Nyasaland has been separated will now be described in more detail, and subsequently a brief account will be given of the various localities in which these beds occur.

Lower Sandstone and Basal Conglomerate Division (Division 1).—The basal conglomerates are found in various districts, and, in consequence of the prevalent easterly dip of the beds, occur as a rule along the western margins of the isolated troughs and basins filled in with Karroo rocks. The immediately underlying gneiss or granite is often weathered, and in one locality was seen to be traversed by cracks and fissures infilled with mudstone.

The conglomerates either lie directly upon the gneiss, or are separated from the same by fine to medium-grained, white or, more rarely, red sandstones. The conglomerates are in some cases well bedded, and consist of subangular to rounded pebbles of gneiss and granite, while in other cases they are represented by lenticular masses of coarse boulder-bed in which large boulders, somewhat rounded at times, lie side by side with smaller stones and pebbles in a fine to coarse-grained sandy matrix. These masses are usually interbedded with sandstones or finer conglomerates. In the Mwapo area (C, fig. 2, p. 193), and again west of the Nyika, a curious type of bed is found associated with the conglomerates. This consists wholly of angular fragments of vein-quartz scattered through a sandy matrix, and closely resembles the weathered soil littered with quartz-fragments which covers the hill-slopes of Nyasaland at the present time. It is probably the remanié product of a highly weathered surface-soil formed in early Karroo times.

The coarse boulder-beds consist of ill-assorted material, great blocks 2 feet or more in length lying side by side with small stones. In some cases, the boulders appear to be completely separated by the sandy matrix. These boulder-beds may, in certain respects, be compared with the glacial beds of the Dwyka. We have, however, failed to note any single instance of a boulder showing facetting or striation; while, on the other hand, boulders sometimes occur which have a distinctly waterworn appearance. Moreover, the interbedded conglomerates of finer grain were obviously deposited by water. Taking all the facts into consideration, it appears probable that the basal conglomerates of Nyasaland are torrential deposits, and not of direct glacial origin. This accords with the opinion expressed by Dr. Bornhardt as to the origin of the basal Karroo conglomerates in German East Africa.

Lower Sandstones of Division 1.—The basal conglomerates are usually overlain by a group of beds varying greatly in thickness, but characterized by the presence of fine- to medium-grained sandstones, either white or pale in colour. In the Nkana area, near the Songwe River (A, fig. 2, p. 193), this group has a minimum thickness of 700 feet; while farther south, at Mpata (B, fig. 2), the thickness is at least 1000 feet. Traced westwards, however, the group thins out, as has already been mentioned.

Shale, Coal, and Mudstone Division (Division 2).—Above the lower sandstones comes a series of dark shales, dark-grey muddy grits and sandstones, with seams of coal or coaly shale, and in places conglomerates. As a rule the coal is distinctly laminated, and consists of venules of bright coal alternating with dull earthy material or silt. By increase in the amount of earthy material the coal graduates almost imperceptibly into a coaly shale, and thus in some localities it is difficult to draw the line between coal and carbonaceous shale. Near Mount Waller (E, fig. 2, p. 193), however, the coal is of far superior quality to that found in other areas, and compares favourably with good English coal.

The floor and roof of the various coal-seams present no regular characters, but may consist of either shale, or sandstone, or mudstone, and in places conglomerate. The usually lenticular character of the seams, their variation in character from place to place, the apparent absence of typical fire-clays and rootlet-beds, and their association at times with conglomerates, are characters which suggest that the coal owes its origin to transport and not to growth in place. The total thickness of this division is small, and probably does not exceed 200 feet.

Upper Grit and Limestone Division (Division 3).—The coal-group is directly overlain by massive yellow and brownish grits or coarse-grained sandstones, and also mudstones and shales, which latter play a subordinate part. The grits are often highly felspathic, and sometimes slightly calcareous. They are always false-bedded, but the false bedding is generally at a low angle to the true bedding. Lenticular seams of pebbles of vein-quartz occur, especially towards the top of the series: these seams rarely exceed a few inches in thickness. In certain beds, however, the pebbles are not so concentrated, but are distributed evenly throughout the mass of sandstone. Despite the presence of pebble-seams and beds, true conglomerates are rarely found.

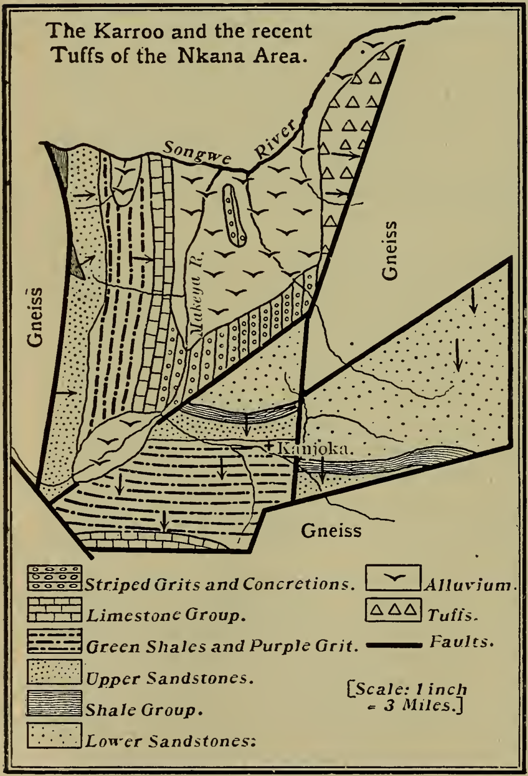
In the north-east of Nyasaland this typically gritty series is overlain by calcareous beds and mudstones. The limestones are usually grey, very compact and argillaceous. Oolitic limestones and limestones of gritty texture are also developed. Near Nkana (A, fig. 2) the limestone group, which includes fossiliferous shales and mudstones, has a thickness of about 150 feet, and is overlain by sandy beds. At Mpata (B, fig. 2), however, the group has swollen to a thickness of at least 700 feet. The limestone group is unrepresented in the western areas, but its absence appears to be compensated for by the increased development of grits, which probably reach 3000 feet in thickness. In the Mount Waller area (E, fig. 2), again, no true limestone is found; but the upper mudstones are distinctly calcareous, and are probably in part equivalent to the calcareous beds of the north.

Detailed descriptions of the isolated patches of Karroo which occur in Northern Nyasaland will now be presented under the following heads:—

(A) Nkana Area.
(B) Kasante, Lufira, and Lower Rukuru Area.
(C) Mwapo and Sere River Area.
(D) Western Nyika Area.
(E) Mount Waller Area.
(F) Henga Area.

(A) Nkana Area.—This is a low-lying district some 20 square miles in extent, and situated at the northern extremity of the Nyasaland Protectorate. It is bounded on the south and east by a hilly region, which forms a very irregular sloping platform between the high mountains on the west and the low sandy plains fringing the lake. The northern limit is defined by the Songwe River, the international boundary between German East Africa and Nyasaland. On the west lie mountain-ranges, a prolongation of the Msuko Hills. The Nkana area is practically identical with the drainage-area of the Makeya Valley. That valley has, in fact, been excavated out of the comparatively soft Karroo rocks which have here been trough-faulted into the surrounding gneiss. The broad Makeya Valley offers a striking contrast to the deep V-shaped valleys of the rivers, commensurable in size, but confined to the hard gneisses and crystalline schists of the neighbouring region.

Fig. 3.



The Karroo of the Nkana area consists of sandstones, shales, limestones, etc., and, except on the north, is bounded by faults, the most important of which run in a roughly north-and-south direction. In addition to the boundary-faults, there is also an important fault traversing the sedimentary rocks in a north-easterly and south-westerly direction, thus dividing the series into two parts. In the northern part the rocks strike north and south, and dip eastwards at angles which increase from 10° to 30° as the outcrops are crossed towards the west. Close to the western boundary-fault the beds steepen, and dip at 60° to 70°. In the southern part the strike is very variable, but probably averages east-north-east in direction, the beds dipping about 20° south-south-eastwards.

The northern boundary of the Karroo as defined above is purely arbitrary, for the same formation continues across the Songwe River and has been described by Dr. W. Bornhardt.[1]

The beds composing the Nkana Series are, as follows, from the top downwards:—

	Thickness in feet.
Upper Division.	
6. Striped Grits with Concretions	?
5. Limestone Group	150
4. Green Shales and Purple Grits	450
3. Upper Sandstones	150
Middle Division.	
2. Shale Group	60
Lower Division.	
1. Lower Sandstones	700
Total exceeding	1510

(1) The Lower Sandstone Group is at least 700 feet thick, the lower 400 feet containing a great number of grey, red-grey, and yellow hard flags with some fine-grained grits. The upper 300 feet consist of medium-grained felspathic sandstones, usually grey but becoming pinkish on weathering. Towards the top occasional black shales are found.

(2) The Shale Group is not well exposed in any section. Near Kanjoka's village, however, about 60 feet of mingled mudstones, clays, shales, fine-grained sandstones, and coals occur. Most of the mudstones, clays, etc. are dark, owing to the presence of carbonaceous matter. In the coal-seams it is common to find cracks at right angles to the bedding-planes, about 4 to 6 inches wide, now filled with felspathic sandstone.

(3) The Upper Sandstones and Grits are somewhat more reddish in tinge than the Lower Sandstones; they are medium to coarse in grain, very felspathic, and, like the Lower Sandstones, crumble readily on the exterior after exposure.

[1] 'Deutsch Ost-Afrika' vol. vii (1900) pp. 144, 150, &c.

(4) Towards the bottom the Green Shale and Purple Grit Group consists of a set of red-brown shaly mudstones: then follow fine-grained purple grits and, finally, grey-green shales. Thin bands of limestone occur in the grits, and calcareous concretions are frequent in the shaly mudstones.

(5) The Limestone Group comprises argillaceous limestones, magnesian limestones, and shales. None of the individual bands of this series is very thick, 5 feet being perhaps a maximum.

The limestones form a conspicuous feature rising about 80 feet above the floor of the Makeya Valley, running in a north-and-south direction for a distance of 4 or 5 miles. Near Makeya's village, in the bed of the Makeya River where the latter bifurcates, there are two small outcrops of dark-grey shale lying close together, which contain numerous casts of freshwater lamellibranchs (*Palæomutela oblonga*), and also fish-scales (*Colobodus africanus*) similar to those discovered by Prof. Drummond at Maramura, near Karonga, some 20 to 30 miles away to the south (see Appendices II & III).

(6) The Striped Grits with concretions are very crumbly and non-coherent. They contain, however, occasional compact bands of sandstone and frequent calcareous concretions. The group is of considerable thickness, but is largely masked by the alluvium of the Makeya River. The present course of the Makeya has doubtless been determined by the soft and non-coherent character of these grits.

(B) Kasante, Lufira, and Lower Rukuru Area.—The hilly platform of gneiss lying south and east of Nkana drops somewhat abruptly into the wide plain bordering Lake Nyasa. The Karroo rocks occur along the junction of the hills with this plain, and form a fringe running roughly north and south—at first narrow and broken, but widening out southwards towards the Northern Rukuru River (fig. 2, p. 193). The Karroo is thus flanked on the west by crystalline rocks, from which it is separated by lines of fault, and is overlain unconformably on the east by recent gravels, sands, and clays.

The northernmost exposure lies a little to the west of Kasante village, where the river of that name emerges from its gorge to flow tranquilly across the coastal plains of the lake. The Karroo here forms a small block some 3 miles square, inset into the edge of the crystalline region, and bounded on three sides by lines of fault. The beds dip, at angles varying from 10° to 30°, in a south-easterly direction. They can be grouped into an Upper Division, consisting of easily weathered yellow and reddish felspathic grits and sandstones; a Middle Division, consisting from the base upwards of dark-grey argillaceous grits with large flakes of white mica, then coal and coaly shale, followed by greenish lumpy shales with pale bands of mudstone containing ill-preserved stem-like impressions; and a Lower Division formed of white or cream-coloured sandstones, near the top of which occur curiously shaped concretionary bodies, formed by the partial cementation of the sandstone by limonite. Owing to faulting, the actual thickness of the Lower Sandstones is unknown, but must exceed 400 feet. The Middle Division is about 30 to 40 feet thick. The thickness of the Upper Division is also unknown, as the grits and sandstones are covered unconformably by recent alluvium.

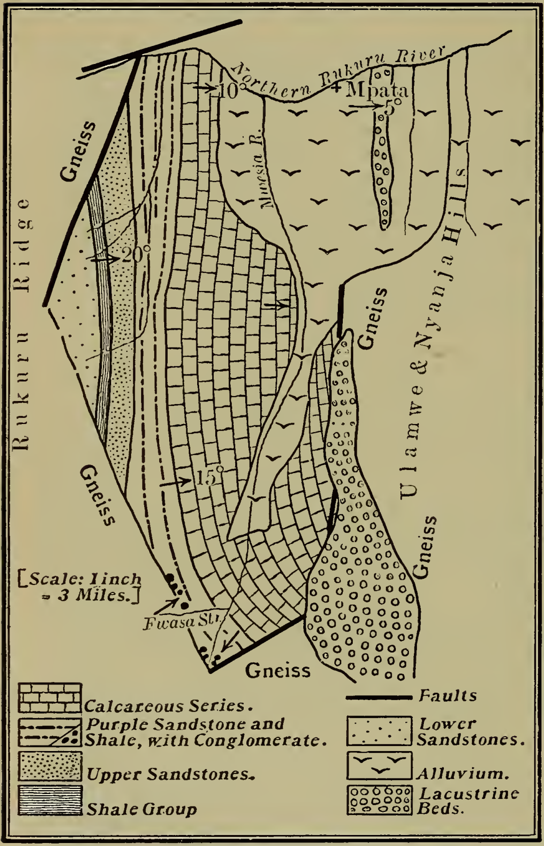
Proceeding southwards along the edge of the gneiss, Karroo beds are again seen exposed near Maulamba's village. A fine section is obtained near here at the entrance to the Lufira Gorge. The Karroo, as usual, is faulted against the gneiss on the west, and overlapped by recent gravels and sands on the east. The series strikes roughly north and south, and the dip varies from 10° to 30° eastwards. The same three divisions can be recognized as at Kasante, and the rocks are very similar in character. The Lower Sandstones, however, contain pebbly bands, and the coals of the Middle Group are much thinner and very earthy. The crystalline rocks on the west consist of quartz-muscovite schists and gneisses, identical with those near Kasante.

Continuing southwards, the Karroo is again faulted out, but reappears about 3 miles farther on, near Kasisi's village. To the south of Kasisi an important fault, running in a north-easterly and south-westerly direction, throws back the gneiss more and more to the west. The Karroo now, as a rule, strikes north and south against the fault and dips eastwards, so that the beds of the lowest division are not met with until the Rukuru River is crossed in a south-westerly direction.

Between Kasisi's village and the Rukuru the upper grits and sandstones form a series of hills followed on the east by low ridges of limestone and calcareous mudstone, which run nearly due north and south. The calcareous series disappears gradually under the recent alluvium of the lake-plain. The sandstones and grits, mentioned above, belong entirely to the Upper Division. They are usually felspathic, and sometimes micaceous in character. Thin bands of reddish shale and mudstone with calcareous concretions occur in this group. The limestone series consists of a considerable thickness of compact, grey, argillaceous limestones, whiter limestones of gritty texture, and grey mudstones, the last-named predominating. Near the Rukuru these are found resting on the lower gritty sandstones, which here contain lenticular seams of pebbles, and a band of hard red shale with ill-preserved leaves of *Glossopteris*.

The Karroo is more fully developed south of the Rukuru River in the Mpata district (fig. 4, p. 206). It is separated off from the northern area by an east-and-west line of fault, with a downthrow to the south. The Mpata district, so called from the large village of that name, covers an area of about 15 square miles. Its eastern boundary is defined by the Ulamwe and Nyanja group of hills; its western by a nameless ridge which separates it from the north-and-south limb of the Rukuru River. To this ridge we shall refer in future as the Rukuru Ridge. The Karroo deposits occupying this district lie in a broad valley-depression, and are bounded on three sides by lines of fault which bring down the sedimentary deposits against the gneiss. On the south-west, however, the junction with the gneiss is a normal one, and is marked by the occurrence of a boulder-conglomerate and a distinct overlap of the newer beds upon the older crystalline rocks. The general strike of the Karroo Series is, as before, in a north-and-south direction; and the beds, although somewhat folded, dip as a whole eastwards at an average angle of about 10°.

Fig. 4.—*Karroo and lacustrine beds of the Mpata area.*



The Karroo Beds fall into the usual three divisions, and are exposed as follows:—

Upper Division.

5. Calcareous Group, consisting of mudstones interbedded with thinly-bedded argillaceous, sometimes oolitic limestones. Minimum thickness = 700 feet.

4. Purple Sandstones and Shales, containing calcareous seams and concretions, just as in the similarly placed beds of the Nkana area. Thickness = about 500 feet.

3. Upper Sandstones, or Grits and Conglomerates, consisting of pebbly felspathic sandstones, with conglomerates and occasional flaggy bands. Thickness = about 500 feet.

Middle Division.

2. Shale Series, comprising black shales, grey grits, carbonaceous shales, and coals. Thickness = about 170 feet.

Lower Division.

1. Lower Sandstones, under which head are included hard striped flags, grey fine-grained grits and mudstones, and pebbly sandstones near the top. Thickness = about 1000 feet; but the base is not seen.

In the south-west, as already stated, a boulder-conglomerate occurs, which may probably be referred to the same horizon as the purple sandstones. This conglomerate appears to be faulted out on the north. As exposed in the Mwesia stream, close to its junction with the Fwasa, it is found to consist of quartz and gneiss boulders, occasionally measuring as much as 4 feet in length. These boulders are subangular, and closely packed without assortment.

The Mpata succession compares very well with the Karroo of the Nkana area. The chief difference lies in the much greater thickness of the calcareous group near Mpata.

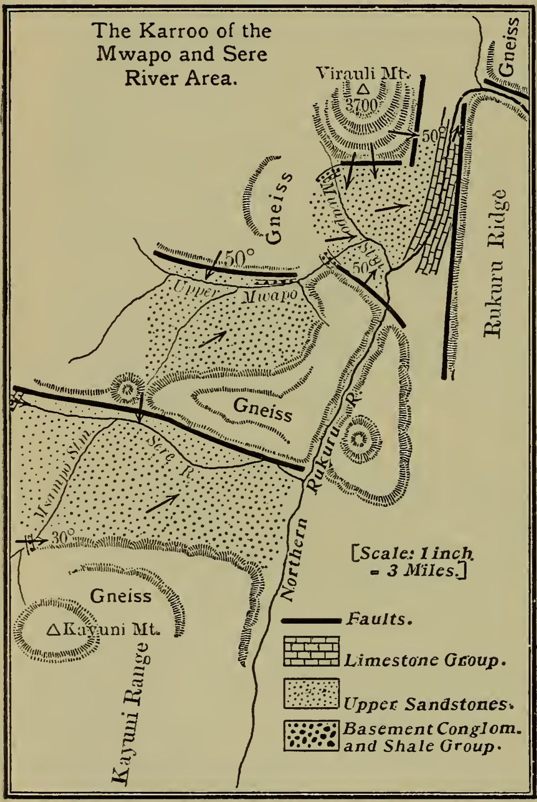
The only fossils as yet known in this district were found by Drummond. These consist of fish-scales (*Colobodus africanus*, *Acrolepis? drummondi*, etc.) and lamellibranchs (*Palæomutela oblonga*); see Appendices II & III. They do not appear to afford definite evidence as to what portion of the Karroo System it is to which these beds belong.

(C) Mwapo and Sere River Area.—If the Rukuru River be traced up-stream from Mpata village, it is found to pass through a narrow gorge in the gneiss hills. Above the gorge there is a sharp right-angled bend in the course of the river, which is now found flowing in a nearly south-to-north direction within a trough-shaped valley. This valley is bounded on its eastern side by the Rukuru Ridge, formed of gneiss, and on the west by a much higher mountain-ridge known as Virauli Mountain (fig. 5, p. 208). The Rukuru Ridge drops steeply down to the bottom of the valley, and runs for some miles in a remarkably straight north-and-south direction. The Virauli Ridge, on the other hand, is much shorter, terminating abruptly on the south. The trough so defined is filled in with Karroo Beds dipping usually in an easterly direction, at angles steeper than the general slope of the valley-floor. At the southern end of Virauli Mountain the sedimentaries run back and up to the west, and form a bay-like extension through which the Lower Mwapo stream passes on its way to the Rukuru. The bay-like extension is terminated on the south by a ridge of gneiss, which runs at first south-eastwards and then turns more or less parallel with the Rukuru Ridge, thus leaving a narrow trough filled with Karroo rocks, but not occupied by the Rukuru, which has cut clean through the ridge of gneiss on the west.

A few miles away to the south-west, and across this ridge, lies a remarkable basin-shaped area of Karroo surrounded, except on the west, by a horseshoe ring of hills composed of crystalline rocks. The two depressed areas of Karroo are connected by the Mwapo stream, which breaks through the dividing-ridge in a narrow gorge.

Yet a third depression occupied by rocks of Karroo age occurs on the south-west, and forms the drainage-basin of the Sere River, another tributary of the Rukuru. It is bounded on the south by the high Kayuni Range of mountains, and on the north by a long ridge of gneiss.

Fig. 5.



The three districts in which Karroo rocks occur constitute respectively the Mwapo and Rukuru trough, the Upper Mwapo basin, and the Sere basin. The general dip of the Karroo in the first of these districts is in an easterly direction, at an average angle of perhaps 15°. The junctions with the surrounding gneiss are, in nearly all cases, faulted ones. The most important fault runs along, and practically coincides with, the western slope of the Rukuru Ridge. This is marked in places by a line of flinty crush-rock which has undergone later brecciation and silicification, and is associated at times with a broad vein of calcite. Other important faults occur along the junction of the gneiss and the Karroo, round Virauli Mountain and elsewhere. The beds near these faults are frequently tilted at high angles.

The only exception to the rule of faulted junctions is found south-west of Virauli, where the basal beds of the Karroo rest unconformably upon the gneiss. These beds consist of sandstones, conglomerates, and boulder-beds, and are followed by the Middle Shale Group, consisting of dark-grey argillaceous grits, gritty mudstones, carbonaceous shales, and coals, presenting a total thickness near the Mwapo Gorge of about 150 feet. These in turn are overlain by a thick series of felspathic grits and sandstones, containing pebbly seams near the top and one band of limestone. The sandstones are followed by limestones and mudstones, which abut directly against the Rukuru Ridge.

While the Upper Grits and Sandstones are well represented, the Lower Sandstone division appears to have thinned out very considerably. Thus in the Mwapo stream, just below the gorge, only some 15 feet of pale cream-coloured sandstones separate the Middle Shale Group from the basement gneiss; while farther north, where conglomerates are developed, no hard-and-fast line can be drawn between the Shale Group and the underlying beds. The only fossils so far discovered were found in soft yellowish shales, associated with coarse bluish grits belonging to the Upper Division: these consist of *Glossopteris* [?].

Little is known of the Upper Mwapo basin. The Karroo here appears to dip on the average in a north-easterly direction at fairly low angles, except just along the northern ridge of gneiss, where westerly dips up to 40° were noted. Basal conglomerates, including two thin coal-seams, are exposed for a short distance in the Mwapo stream, perhaps a mile above the gorge. The greater part of the basin is, however, occupied by sandstones, presumably belonging to the Upper Division. The character of the junctions with the gneiss has not been clearly determined, but the evidence points to the existence of a double fault-line on the north, and perhaps also a single fault along the southern boundary (see section 1, fig. 9, p. 218).

The Sere basin is similarly bounded by a fault or faults on its northern side. On the west and south-west, however, the junction with the gneiss is a normal one. The basal Karroo is well exposed in the Msampo stream, a tributary of the Sere, just below the lofty Kayuni range. It is represented by lenticular boulder-beds, which consist of subangular to rounded boulders measuring up to 2 feet in length. Interbedded with these are fine red sandstones, overlain by perhaps 200 to 300 feet of thinly-bedded greenish mudstones with violet shales of smooth texture and well laminated. This middle group of mudstones and shales contains no coal-seams or even carbonaceous shale. It is followed by a great thickness of felspathic sandstones and grits, which at one point include two thin seams of earthy coal. The harder bands of this Upper Sandstone series form low ridges running one behind the other, and rising towards Kayuni Mountain. The usual dip is from east-north-east to north-east at fairly low angles, which increase to 30° below Kayuni. Westerly dips are sometimes noted near the northern fault-line.

The Sere succession can be divided into the usual three divisions. The Middle Shale Group, however, shows considerable divergence from the usual type, and can only be described as corresponding in position with that of the Lower Mwapo area. The Upper Sandstones and Grits, on the other hand, agree closely in character with those of the Mwapo-Rukuru basin.

Viewing the district as a whole, it is clear that faulting has played an important part in isolating the Karroo Beds into the various troughs and basins just described (Section 1, fig. 9, p. 218). Subsequently, or during this period of faulting, denudation must have levelled off the inequalities and reduced the area to something approaching a peneplain. The drainage-system was then rejuvenated, owing perhaps to earth-movements connected with the formation of Lake Nyasa. The rejuvenation of the rivers gave rise to the present gorges in the gneiss and the cutting out of the softer Karroo Beds in the troughs and basins. No other explanation seems adequate to account for the general disregard which the Rukuru and its tributaries show to the present topography.

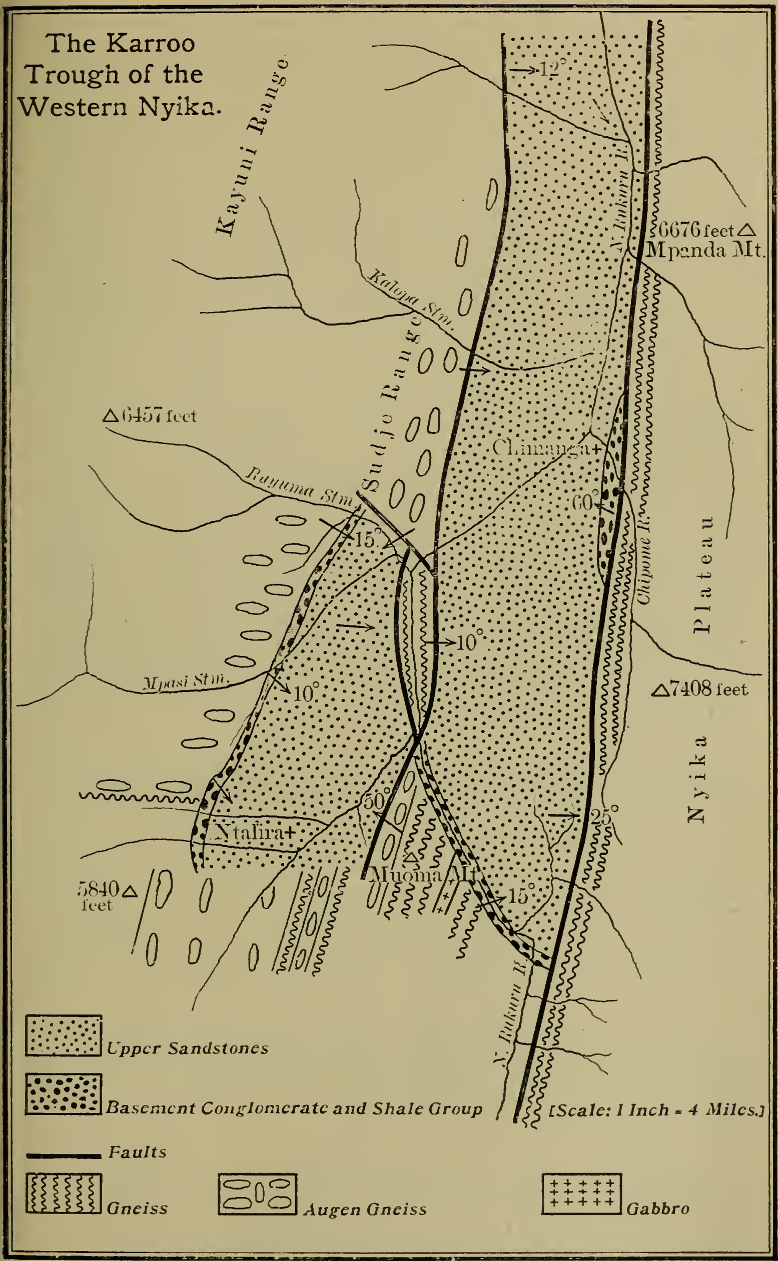
(D) Western Nyika Area.—The Karroo, here, occupies an area of about 70 square miles. It forms the floor of a deep trough, through which the Rukuru River passes on its way to Mpata and Karonga. The trough runs almost due north and south, and is bounded on the west by hills of gneiss, above and behind which rise the lofty mountains of the Kayuni Range. A great mountain-mass known as Mpanda lies on the east, followed on the south by the western edge of the Nyika Plateau. The eastern border so constituted runs in a nearly straight north-and-south line for upwards of 20 miles. The edge of the Nyika is at first fringed by lower ranges of gneiss, but finally drops as a huge grassy wall, 3000 feet in places, down to the tree-covered valley below. The western mountains run parallel with the Nyika edge at a distance of some 5 miles, but die out eventually southwards, leaving a gap which is filled in, about 8 miles farther south, by a series of north-and-south ranges. These abut on the east against the edge of the Nyika Plateau, and constitute the southern boundary of the Karroo.

In its northerly extension the Karroo forms a simple faulted trough, separated from the gneiss by long lines of fault. The eastern and more important of these runs nearly due north and south along the edge of the Nyika Plateau. The western lies roughly parallel, and towards the south coincides with the eastern side of the Sudje Range. The Karroo, here, consists of a great thickness of felspathic grits and sandstones, obviously belonging to the Upper Division. The beds dip, as a rule, eastwards at angles greater than the general easterly slope of the valley-floor.

Farther south the series is divided into an eastern and a western area by a narrow north-and-south horst of gneiss, some 4 miles long and having a maximum width of perhaps half a mile. This lenticular strip of gneiss serves as a connexion between the Sudje Range on the north and the Muoma ridge of gneiss on the south. The remarkable point about this horst lies in the fact that it forms a depression occupied by a limb of the Rukuru River, and bounded on each side by low scars of sandstone.

The general dip of the Karroo, as in the north, is in an easterly direction. The basal conglomerates are consequently exposed on the west, and can be traced for about 7 miles in a north-and-south

Fig. 6.



The Karroo Trough of the Western Nyika.
Kayuni Range
Sudje Range
Kaloga Stm.
Rayuma Stm.
Mpasi Stm.
6676 feet
Mpanda Mt.
6457 feet
7408 feet
5840 feet
Chimanga+
Ntafira+
Muoma Mt.
N. Rukuru R.
Chipome R.
Plateau
Nyika
12°
15°
10°
10°
60°
50°
25°
15°
Upper Sandstones
Basement Conglomerate and Shale Group
Faults
Gneiss
Augen Gneiss
Gabbro
[Scale: 1 Inch = 4 Miles.]

direction. They lie on an eroded platform of augen-gneiss or foliated granite, which rises gradually westwards and occupies the gap already described as existing south of the Kayuni Range. The lowest beds are well exposed in the dry bed of the Mpasi (Nquarlewele) stream, and the Ruyuma or Kawala stream near Sudje Hill. They consist of a series of whitish sandstones, coarse boulder-beds, and finer conglomerates. In the Mpasi stream these are associated with carbonaceous shale and interbedded coal-seams lying rather above the main mass of conglomerates. These in turn are overlain by a great thickness of felspathic sandstones and grits, with bands of red mudstone in the lower half, and pebbly beds in the upper. This upper division is faulted down to the east against the Muoma ridge of gneiss. The Muoma Fault runs in a roughly north-and-south direction and bifurcates to the north, thus enclosing the narrow horst of gneiss already described. East of the Muoma ridge the basal conglomerates are again exposed (section 2, fig. 9, p. 218), and they here form the bed of the Rukuru River for about 5 miles, as also the lower slopes of a scar facing the stream. Above the conglomerates comes a series of carbonaceous shales and mudstones with shaly coal. The actual scar is formed out of the hard felspathic grits and sandstones of the Upper Division. These dip eastwards, and eventually abut against the Nyika Fault. Tracing this fault for some miles to the north, the lower beds are again found exposed near Chimanga village on the Chipome River. These consist of whitish sandstones, conglomerates, carbonaceous shale, and coal-seams. The beds frequently dip at high angles westwards, and the actual junction with the gneiss appears to be a faulted one.

From the foregoing description, it seems possible to divide the Karroo of the Western Nyika area into the following divisions:—

3. Upper Division ...	Felspathic grits and sandstones, with beds of mudstone. Thickness = 3000 feet (?).	
2. Middle Division...	Carbonaceous shales, coals, mudstones, and conglomerates.	Thickness = 200 to 300 feet.
1. Lower Division	Conglomerates and whitish sandstones.	

The only fossil obtained was a silicified tree-trunk in the pebbly sandstones of the Upper Division, near Sudje Hill and close to the Rukuru River; but the general similarity of the series with that of the Mwapo-Rukuru area leaves little or no doubt that it is of Karroo age.

It is obvious that the present position of the Karroo is due to trough-faulting. The remarkable, almost wall-like edge of the Nyika Plateau might be considered as an indication of the recent age of the faulting. A closer examination fails to sustain this view. The Rukuru Valley, for instance, shows a progressive development of its eastern tributaries when traced down stream, after the manner of normal valleys of erosion. As a result of this, the Nyika edge is broken up on the north into the lofty Mpanda mountain-group.

Moreover, from comparison with other areas, we know that the Karroo sandstones and shales are much more susceptible to weathering and erosion than the harder gneiss against which they are faulted. Thus, rivers which cross the adjacent gneiss in deep and narrow gorges give rise to broad and open valleys in the Karroo. There are a few exceptional cases, such, for instance, as the depression formed by the horst of gneiss in the area here described. In this case, however, the gneiss probably was much shattered by faulting and so rendered non-resistant.

The Rukuru trough west of the Nyika may, therefore, be considered as a normal valley eroded out of a faulted strip of sedimentary beds.

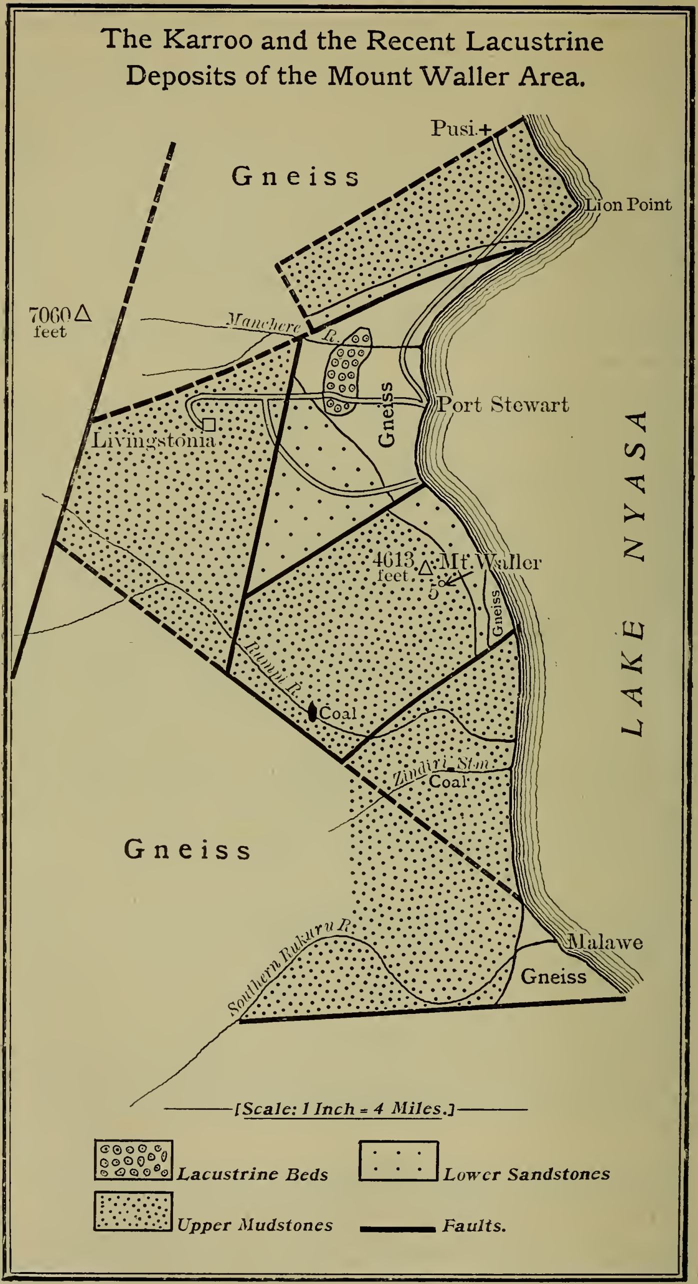
(E) Mount Waller Area.—The Karroo of the Mount Waller area (fig. 7, p. 214) occupies a tract, some hundred square miles in extent, lying east of the Nyika Plateau. Mount Waller, from which the series has received its name, is a flat-topped mountain carved out of a platform of sedimentary rocks rising to about 3000 feet above the lake. The descent to the lake-shore from this platform is often abrupt, and the almost horizontal beds exposed in cliff-sections form a conspicuous feature, as seen from the lake. It is therefore hardly surprising to find that the Karroo of this district has received special attention from earlier investigators, beginning with Stewart in 1879. Facing Mount Waller, almost on the opposite side of the lake, in the Ruhuhu area, Karroo rocks are also found, and have been described by Dr. Bornhardt as dipping southwards against a roughly east-and-west fault-line which throws the beds against the gneiss. Very probably, as has been suggested by Mr. Moore, the two formations were at one time continuous, stretching right across what is now the site of Lake Nyasa: their present isolation being due to the rift-faulting which gave rise to the Nyasa depression. Before this severance was made, however, the Karroo of both regions was evidently traversed by an earlier series of faults, probably synchronizing with those bounding the isolated troughs and patches already described as occurring at Nkana, Mpata, and west of the Nyika. In the last-named areas the Karroo was found to fall into three groups, and the same division is applicable to the Mount Waller beds.

In a section taken from the lake-shore, immediately south of Port Stewart, and thence over the north-eastern face of Mount Waller, the following succession of beds dipping gently westwards is observed:—

		Thickness in feet.
3. Upper Group.	Mostly mudstones	1500
2. Middle Group.	Sandstones with shales and coals	200
1. Lower Group.	Sandstones	1300

The Lower Group consists of coarse- to medium-grained white to yellow felspathic sandstones, with pebbly sandstones and fine conglomerates.

Fig. 7.


The Karroo and the Recent Lacustrine Deposits of the Mount Waller Area.
Pusi
Gneiss
Lion Point
7060
feet
Manchere R.
Port Stewart
Gneiss
Livingstonia
LAKE NYASA
4613
feet
Mt. Waller
Gneiss
Rumpi R.
Coal
Zindiri Stm.
Coal
Gneiss
Southern Rukuru R.
Malawe
Gneiss
[Scale: 1 Inch = 4 Miles.]
Lacustrine Beds
Lower Sandstones
Upper Mudstones
Faults.

The Middle Group is formed of very thickly-bedded sandstones, often hardened through silicification, and thus giving rise to prominent scarp-features. Interbedded with these are several bands of shales and flags, the former being sometimes very carbonaceous and containing ill-preserved plant-remains. It is probably from this group that Drummond identified macrospores of lycopods: while some miles away from the present section we have found coal-seams with recognizable fronds of *Glossopteris*.

The Upper Group comprises thickly-bedded yellow and grey mudstones with fine-grained grits, a few sandstones, and grey (occasionally blue) shales. These crop out in the steep scarp right up to the top of Mount Waller. The Upper Group, apart from this section, is also found in low-lying ground round Lion Point.

Comparing the above-described groups with those of Nkana and Mpata, we find that in all these areas a central division characterized by coal or shale is developed. So far, the comparison is clear. If, however, we examine the Upper Group, say of Mpata, we find that this is composed of grits followed by limestones and mudstones, constituting the Drummond Beds. No limestones are known in the Mount Waller area, but the various members of the Upper Group are often distinctly calcareous, and so the divergence is rather apparent than real. Finally, the Lower Sandstones of Mount Waller seem thicker and coarser in grain than their northern equivalents; but a complete coincidence is not to be expected in areas so widely separated, and, on the whole, the Mount Waller beds may be held to fall into line with those of other areas in Northern Nyasaland.

(F) Henga Area.—Karroo rocks are found some little distance to the south of the Mount Waller district, and constitute the floor of the Upper Henga Valley. This depression runs roughly north and south between the Nyika Plateau and the Vipya Mountains, and slopes southwards to meet the wide trough-shaped valley of the Southern Rukuru River. The Rukuru, just below the junction, enters a gorge and so passes through the Vipya Mountains to the lake (figs. 1 & 2, pp. 191 & 193).

The Karroo of the Upper Henga appears to form a narrow syncline, pitching south-westwards and truncated on the east and west by trough-faults. The northern junction with the gneiss is also faulted, but the southern boundary is ill-defined, for the ground is greatly obscured by wash or by the alluvium of the Rukuru River. A small isolated patch of mudstone is, however, found in the Lower Henga or Rukuru Valley; and it is possible that the Karroo extends under the alluvium to as far south as the junction of the Kasitu with the main river, or perhaps into the Kasitu Valley itself.

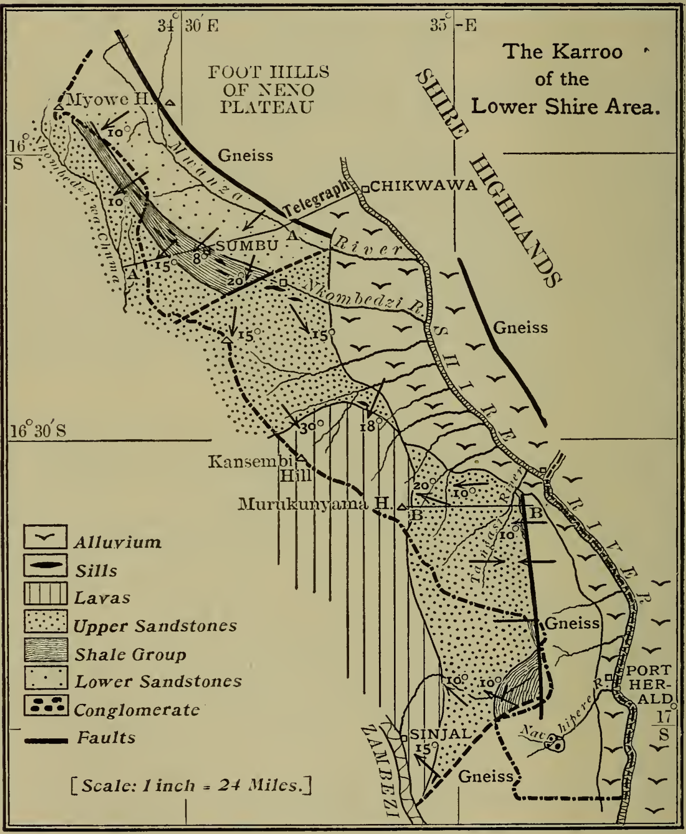
The rocks of the Upper Henga consist of calcareous mudstones, with bands of grit, which evidently belong to the upper group of beds in the neighbouring area of Mount Waller.

Doubtful Occurrences of Karroo near Masiunjuti and in the Kasitu Valley.

A small patch of sedimentary deposits occurs near Masiunjuti, between Karonga and Mount Waller (fig. 1, p. 191). These are similar in appearance to the purple sandstones and shales of Mpata, and their general dip, 30° eastwards, also favours the assumption that they are of Karroo age.

Considerably farther south, in the Kasitu Valley, a large isolated block of pebbly sandstone was found lying on the alluvium. The

Fig. 8.



sandstone is typically Karroo in character, and could not have been carried far. It is, therefore, possible that Karroo rocks may be discovered in the Kasitu Valley many miles to the south of the area where they are now known in Northern Nyasaland.

The Karroo of the Lower Shire District in Southern Nyasaland.—The Karroo succession in this area is of great thickness. In Southern Nyasaland the Karroo occupies about 800 square miles of low-lying country covered with stunted thorn-trees, and is exposed along the south-eastern border of the Protectorate, roughly between lat. 16° and 17° S. The Karroo is bounded on the east by the gneissic foot-hills of the Neno Plateau, then by the wide alluvial plain of the Lower Shire River, and, finally, by the crystalline schists and gneisses of the Port Herald Hills. The junction between the gneiss and the sedimentary rocks appears in all cases to be a faulted one. The western boundary of the Karroo is purely arbitrary, being formed by the Anglo-Portuguese boundary-line. The Karroo, as a matter of fact, crosses the border, and stretches without interruption to the Zambezi River. It is divisible into the following six groups, in descending order:—

	Approximate thickness in feet.
6. An uppermost division of pebbly sandstones, found only in Portuguese territory near Sinjal	(at least) 200
5. A Lava Group containing a few interbedded sandstones...	5000
4. An Upper Sandstone or Grit Group, consisting of a great thickness of massive sandstones or grits, in beds measuring up to 25 feet in thickness. Pebbly sandstones are of frequent occurrence	10,000 (?)
3. A Shale Group, consisting of a mingled set of sandstones, black and grey shales and mudstones, with thin seams of coal and ironstone. The shales contain several species of *Glossopteris* (*G. browniana*, *G. indica*, etc.), while *Vertebraria* (?) and *Schizoneura* (*gondwanensis*?) occur.	4000 (?)
2. A Lower Sandstone Group resembling the Upper Sandstones closely, but with perhaps fewer pebble-beds. The Lower Sandstones are also more conspicuously current-bedded, and, unlike the upper group, have not been proved to contain fossil wood..........................	6000
1. A group of coarse boulder-beds, black carbonaceous shales, and conglomerates, forming a small isolated block completely surrounded by gneiss. This group is only found near Nachipere, and its boundaries seem to be faults, but it is presumably the basal member of the Karroo sequence. Bright streaks of coal occur with the carbonaceous shale at one point	450

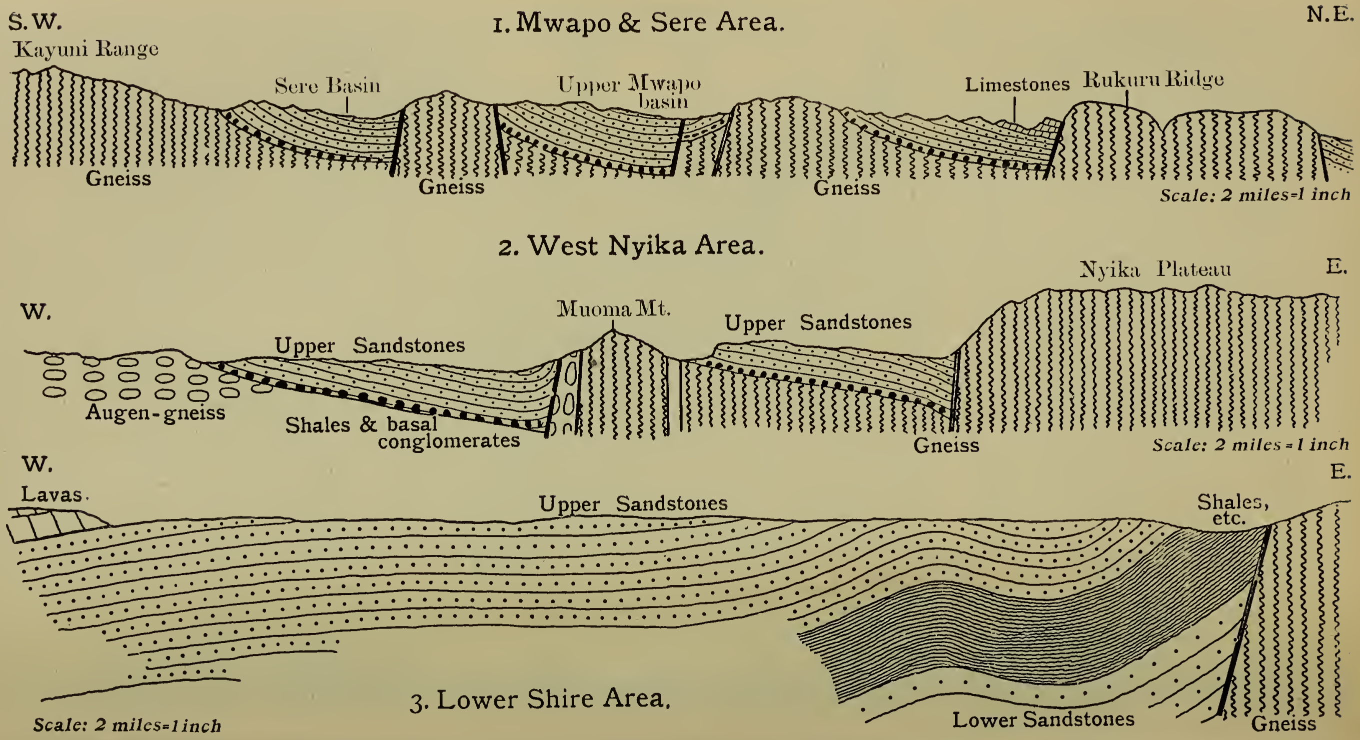
The general structure of the Shire district is fairly simple. In the north the Karroo beds are faulted against the eastern gneiss and dip on the whole westwards, with the result that the newest beds are found in this direction. Farther south a west-south-westerly fault throws back eastwards the Upper Sandstone Group, and this now forms a synclinal basin with the lavas in its centre.

The Upper Sandstones are overlapped by the recent alluvium of the Shire River, and farther south are faulted against the gneiss of the Port Herald Hills. Patches of Lower Sandstones, however, crop out along this fault-line. A small outlier of possibly basal Karroo is found at Nachipere in the Port Herald Hills, apparently isolated by faults.

The following sections illustrating the structure of the Shire area will now be described:—

(A) Sumbu Section, comprising Groups 2, 3, & 4.
(B) Murukunyama, comprising Groups 3, 4, & 5. (Section 3, fig. 9, p. 218.)

Fig. 9.—*Sections through typical areas in Nyasaland.*



[The igneous dyke east of Mount Muoma in section 2 has been erroneously left blank.]

(A) Sumbu Section, from the Mwanza River in the east to the Nkombedzi wa Chuma, along the African Transcontinental Telegraph line (or across A′A of the map, fig. 8, p. 216).

The junction of the Karroo with the gneiss is obscured by the alluvium of the Mwanza River, but is evidently a faulted one. The lowest beds exposed, although they belong to the Lower Sandstone Group, dip eastward towards the gneiss. The exposures are poor at first; but, on travelling westwards, the sandstones are clearly seen to be thrown into a series of gentle anticlinal and synclinal folds with occasional dips of 30° to 40°. Some 4 miles from Sumbu the beds begin to dip steadily westwards at an average angle of about 15°. The bulk of the Lower Sandstones are massive and usually current-bedded. Pebble-beds are of common occurrence, though sometimes only one pebble thick. Curious large cavities resembling pot-holes occur in places: these sometimes contain water, and were probably formed by a partial rotting away of the sandstone, consequent upon water collecting in original slight depressions on the surface. The sandstones are often felspathic or slightly calcareous, and are thus somewhat readily attacked and disintegrated. The whole group is from 6000 to 7000 feet thick. The shales of Group 3 come on to the west near Sumbu, and form a low tract of ground below the undulating sandstone country. The shale group consists of the usual fine-grained sandstones and black and grey mudstones, with thin seams of coal and ironstone. The average dip is about 8° westwards. Fossil leaves of *Glossopteris* are comparatively common, and numerous specimens may be obtained near the telegraph-track at Sumbu. Only a small part of the Upper Sandstone Group is exposed along the line of traverse. The Upper Sandstones follow conformably on the shales, without any change in contour of the ground. A number of pebbles of compact earthy limestone of recent origin are scattered in places over their weathered surface, and similar material is found filling cracks in the more calcareous bands. The sandstones dip westwards, but become almost horizontal on the north.

(B) Murukunyama Section, from near Panyanole's Village on the Tangasi, through Panga village to near Kasembe Hill on the west (or roughly along the line B′B of the map, fig. 8, p. 216, and section 3, fig. 9, p. 218).

Proceeding westwards, the following groups are seen to be exposed:—

(3) Shale Group.—The members of this group are faulted against the gneiss on the east and only some 500 feet are seen. The actual fault-line is occupied by a drusy quartz-band, which sometimes passes into a siliceous breccia containing fragments of silicified sandstone. This fault-vein is of great width, and forms a line of hills separating the gneiss from the Karroo. Somewhat

similar, though thinner, fault-veins occur far to the north, in the Mwapo and Western Nyika areas. The Shale Group consists of flags, mudstones, and shales, with layers of ironstone, the shales containing leaves of *Glossopteris*.

(4) Upper Sandstone Group.—This group is much obscured by alluvium. The sandstones follow conformably upon the underlying shales, and dip at first westwards. Some 3 miles out the dip turns over to the east, and continues so for some distance. Farther on, however, the dip again turns over, and with this dip the sandstones pass under the lavas of the upper group.

The sandstones and grits are, as usual, thickly bedded and pebbly in places. The whole group has a thickness of some 7000 feet.

(5) Lava Group.—The lavas dip steadily westwards to near Kasembe Hill, where the dip changes to east. They consist for the most part of vesicular basalt, while some appear to be andesites, and banded rhyolite has been observed, though not *in situ*. The vesicles are usually filled with chalcedony or more rarely calcite. Agates are often plentifully scattered over the weathered surface of the lavas. The individual beds appear to be of considerable thickness. No tuffs or laterites are found between the flows. About 1000 feet of lavas are exposed in almost vertical section at Murukunyama Hill.

Near the base of the Lava Group there is at least one interbedded stratum of sandstone, and similar sandstones are found above the lavas in Portuguese territory. Below Myowe Hill, close to the Mwanza River, a narrow strip of amygdaloidal basalt is found faulted against the gneiss on the east and the Lower Sandstones on the west. The eastern fault-line is marked by a great quartz-reef occasionally brecciated: this forms the Myowe ridge.

Sills, dykes, and laccolites in the Karroo Series of the Lower Shire District.—Numerous sills of fine-grained basalt, or more rarely dolerite, are found intrusive into the members of the shale-group, near Sumbu and Zimbawe. Similar sills are also observed in the shales of the Nachipere district. Dykes or sills appear to be very rare in both the Upper and the Lower Sandstones. It is obvious that the distribution of the sills was determined by the non-resistant qualities of the soft shales.

Irregular laccolitic intrusions of dolerite, however, occur in the upper sandstones, as near Nkombedzi villages. Although these dolerites are obviously intrusive, they are nevertheless amygdaloidal in character. It seems probable that the intrusion of dolerite was followed closely by minor earth-movements, which not only cut off the laccolite from its parent magma, but released the pressure on the intrusion, so allowing the occluded vapours to escape.

Very occasional quartz-porphyry dykes have been noticed cutting the lavas themselves.

Dykes in the gneiss of the Lower Shire District.—Though dykes are rarely found either in the Lower or in the Upper Sandstones, they occur in great numbers in some of the neighbouring gneissic areas. Thus, between the Mwanza River and Chikwawa, dykes of basalt are exceedingly numerous. In the Chikwawa Hills some of these intrusions are composite, with broad fine-grained margins or fine-grained interior. The Chikwawa dykes are probably connected with the emission of the Karroo lavas. The absence of tuffs among these lava-flows and the uniformity in character of the latter over wide areas suggest that the lavas are the outcome of fissure-eruptions.

It may be remarked that unfoliated dykes are comparatively rarely found in Northern Nyasaland, even in the gneiss; and, with the exception of the Mount Waller area, no dykes are known in the Karroo.

Comparison of the Southern and Northern Karroo of Nyasaland.—In the north it was found possible to separate roughly the Karroo into a lower sandstone division, a middle shale division, and an upper sandstone and calcareous division. In the south a somewhat similar sequence is observed, but the upper and lower sandstones, in common with the intervening shale group, are vastly thicker than their northern analogues. Again, the limestones and calcareous mudstones, so characteristic of the upper portion of the Karroo of Mpata and Nkana, appear to be unrepresented in the south; yet a few thin beds of oolitic and argillaceous limestone do occur in the Upper Sandstone Group near Nkombedzi villages. On the other hand, the thick lava group of the southern succession is missing in the north. It is possible that lavas once filled the gap which now exists between the Karroo of Mpata and the overlying recent deposits, but the general scarcity of dykes or sills in the north, coupled with the absence of derived pebbles in the overlying recent conglomerates, rather indicates that vulcanicity in Karroo times was restricted to the south.

It will be seen, then, that no very close comparison can be made between the Karroo of Northern and that of Southern Nyasaland. In Rhodesia, Mr. Molyneux[1] has described a series of basal conglomerates followed directly by a coal-bearing group (Lower Matobola Beds), which is overlain by a group with limestones (Upper Matobola Beds), grits (Escarpment Grits), sandstones (Forest Sandstones), and, finally, by the Tuli or Batoka lavas. The Matobola Beds contain freshwater shells belonging to the genus *Palæomutela* and fish-remains: they are therefore similar, in fossil contents, to the calcareous group of Nkana and Mpata in Nyasaland.

The apparent thickness of the Karroo in Rhodesia seems to be commensurable with that of Northern Nyasaland; moreover, the position of the coal-bearing group, lying, as it does, directly upon the basal conglomerates without the intervention of a thick series

[1] Quart. Journ. Geol. Soc. vol. lxv (1909) p. 421.

of sandstones, is reminiscent of the Karroo sequence in the Mwapo and Western Nyika areas. On the other hand, the Tuli and Batoka lavas can only be compared with those found in the Lower Shire district. The Karroo of Rhodesia, as regards its general characters, seems, in consequence, to occupy an intermediate position between the Northern and the Southern Karroo of Nyasaland.

The Tuli and Batoka basalts which occur at the top of the Rhodesian Karroo are now considered to be of Stormberg age, and there can be little doubt that the similarly placed lavas of Southern Nyasaland may also be roughly referred to this horizon. Up to the present, lavas (belonging to the same regional outbreak of vulcanicity in Stormberg times) are known in Cape Colony, the Transvaal, Rhodesia, and Nyasaland: their northern limit has yet to be defined. In the Karroo of Cape Colony a series of sandstones, shales, conglomerates, etc., amounting in all to about 1400 feet in thickness, are found to underlie the Stormberg lavas.

Traced northwards, the various groups included in this series appear to thin out considerably, so that in Rhodesia the minimum thickness of the whole Karroo System is put at about 4700 feet. It is interesting, therefore, to find that the system swells out again in Southern Nyasaland to a thickness even exceeding the 18,100 feet given as a maximum figure for the Cape Colony Karroo. This thickening of the Karroo appears, however, to be a comparatively local phenomenon, restricted, so far as we know, to the Lower Shire district and to the adjoining portions of Portuguese East Africa.

(3) Recent Deposits.

These may be divided into (*α*) volcanic and (*β*) sedimentary deposits.

(*α*) Volcanic deposits.—Tertiary and recent lavas occur immediately north of the Songwe River in German territory. According to Dr. Bornhardt, these comprise basalts, andesites, and trachytes. The lavas are overlain by tuffs, which mark the final phases of volcanic activity in the district.

Lavas of recent age are not known in Nyasaland, but a small patch of pumiceous tuff is found banked up against the eastern wall of the Nkana Valley in the extreme north of the country (fig. 3, p. 202). This tuff is associated with gravels containing pebbles of trachyte, phonolite, and other volcanic rocks. Blocks of tuff are also found near Chungu, on the southern edge of the Songwe flats, and about 9 miles east of Nkana. These blocks are probably remnants of a sheet of tuff which has been removed by erosion.

(*β*) Sedimentary deposits.—These may be grouped under two heads:—

1. Deposits within the Lake-basin.
2. Deposits occurring outside of the Lake-basin.

1. Deposits within the Lake-basin.—Littoral deposits consisting of sand or silt are found in many places along the western margin of Lake Nyasa. These were evidently formed at a time when the lake-level was from 10 to 30 feet higher than it is at present. Recent lacustrine deposits also occur at higher levels, and are especially well developed on the north-west between the Songwe River and Mount Waller.

Travelling southwards from the Songwe, roughly along the junction of the western hills of gneiss with the coastal plain (fig. 2, p. 193), we encounter a series of isolated patches of gravel. These gravels may be observed near Kasante, north of the Lufira, and a few miles south of the same river. They usually consist of pebbles of vein-quartz set in a soft, sometimes felspathic matrix. The deposits run more or less parallel with the trend of the hills on the west, and give the impression of an old stretch of beach formed against a steep shore-line.

Farther south, from Mpata (fig. 4, p. 206) to Mount Waller (fig. 7, p. 214), high-level deposits are of frequent occurrence, and are sometimes found at very considerable heights above lake-level.

Near Mpata, immediately east of the Karroo outcrop already described, these may be divided into a probably lower series of white, slightly calcareous sands containing pebbles and boulders of quartz, and an upper, partly consolidated, ferruginous conglomerate, formed of boulders of quartz weighing sometimes as much as 5 lbs. The beds rest upon a floor of gneiss or of Karroo rocks, and are found at a height of about 400 feet above lake-level. The dip is roughly 3° eastwards.

Some miles to the south of Mpata, somewhat finer red conglomerates were noted. These are roughly 100 feet thick, lie at about 700 feet above lake-level, and usually dip very gently eastwards. Locally, however, the beds are turned sharply up, apparently near a fault, and dip eastwards at an angle of 35°.

About 3 miles west of Chiwondo (fig. 1, p. 191) a series of marls, sands, and pebble-beds are found resting upon the gneiss, at about 350 feet above lake-level. At Chisali recent beds also occur, and have been cut up by streams into a series of low hills. The beds, as usual, dip gently eastwards, and may be divided up as follows :—

(3) Dark red conglomerates with friable, sometimes micaceous sandstones. —About 400 feet above lake-level.

(2) Shelly marls consisting of comminuted shells of *Viviparus*, overlying grey limestones with grains of quartz and felspar. The lower limestones also contain casts of *Viviparus*, probably identical with species now existing in Lake Nyasa (see Appendix II, p. 239).—About 400 feet above lake-level.

(1) Friable grey and greenish sandstones and mudstones.—From 250 to 350 feet above the lake.

Near Masiunjuti, some 15 miles from Lake Nyasa, a series of dark-red conglomerates and white sands occur. These form a sort of terrace 700 feet above the lake. The deposits are faulted in places, the displacement produced in one case amounting to 100 feet.

Siliceous limestones with purple sandstones were observed near Deep Bay, 320 feet above the lake; while calcareous sands occur 400 feet above the lake, close to Mount Waller, on the new Mission road to Port Stewart.

From Mount Waller southwards comparatively little is known of the actual border of the lake, our observations being mainly restricted to hasty traverses. High-level gravel-deposits were, however, observed a few miles south of Chintetchi (fig. 1, p. 191), as also at the entrance to the Dwangwa gorge and on the slopes of gneiss behind the coastal plain of Kota Kota. Of these the Dwangwa gravels lie some 400 feet above the lake, and were obviously deposited by the Dwangwa River on a gently inclined rock-slope before its present gorge was cut. Some of the other gravels occurring south of Mount Waller bear a similar relation to the neighbouring rivers. It is, however, significant that well-rounded gravel-deposits are almost, without exception, restricted to the edge of the lake-basin. In the north, between Mpata and Mount Waller, we have also seen that large patches of obviously lacustrine gravels lie at an average height of 400 feet above the lake. Very probably, therefore, the Dwangwa and other southern gravels were formed at the mouths of rivers at a time when Lake Nyasa stood some 400 feet higher than at present.

The causes leading to the subsequent shrinkage in the lake have not been sufficiently investigated. It is possible that a barrier, some 400 feet high, once existed to the south of Liwonde in the Shire Valley, and that this held back the waters of the lake until it was cut through by the waters of the Shire. This, however, fails to account for the 700-foot gravels, and it seems possible that the whole effect may be due to earth-movement.

2. Deposits occurring outside of the Lake-basin.—These require but passing mention. Wide stretches of alluvium have been formed by the Lower Shire and its tributaries in the south of the Protectorate. Marls are met with occasionally in the Upper Shire valley. Sandy loams are found to cover a great part of Central Angonaland.

The rarity of alluvial terraces and the paucity of gravels throughout the country are worthy of note.

Soils and Surface-Accumulations.

The greater part of Nyasaland consists of plateau, covered with surface-soil derived directly by weathering *in situ*. The character of these accumulations naturally depends upon the underlying rock. Where this consists of gneiss, the overlying soil is represented by red, usually rather sandy, clays containing angular fragments of quartz derived from the disintegration of the numerous quartz-veins traversing the gneiss. These veins can be seen running up from the underlying rock into the weathered clays above. While the bulk of the rock is easily weathered, certain of its constituents may prove highly resistant: in this case, if in sufficient quantity, they will be found scattered on the surface-soil. Kyanite, for instance, occurs at times in large, well-formed crystals in a gneiss consisting of felspar, quartz, white mica, and graphite. This gneiss weathers rapidly, leaving the kyanite littered on the surface.

An equally striking case of differential weathering is very occasionally exhibited by certain porphyritic granites or syenites, especially when exposed on steep slopes. These granites contain large felspar crystals measuring over an inch in length: the larger crystals are less easily attacked than the finer ground-mass, and concentrate upon the surface. The crystals of this concentrate are sometimes quite angular, but more often become considerably rounded through solution and attrition. The best instance of this type of weathering is found at Chipara Hill (fig. 1, p. 191), a little north of Kasungu, on the Marimba Plateau. This is a roof-shaped monadnock, practically bare of vegetation and subject to the rapid diurnal changes in temperature which occur in high plateau-regions. Its steep slopes afford a ready run-off for rain-water, so that altogether the conditions are peculiarly favourable to dry weathering. Chipara is built up of a foliated syenite with large well-shaped felspars, 1 to 3 inches long. While the top of the hill is formed of solid rock, its lower slopes are covered with huge boulders which disintegrate, leaving a concentrate of large and remarkably angular felspars.

A feature about Nyasaland is the absence of typical scree-deposits below the steep slopes and scarps of the plateau-country. This is due to several causes: in the first place, the rock forming the slopes of the ridges or scars tends to break up into huge boulders rather than small angular fragments. Again, owing to rapid weathering of the scar-top, the streams which course down the slopes in the rainy season may have a sufficient supply of loose soil to form a talus-deposit at the foot of the scar. Any loose rocks and stones carried down by gravity are, in consequence, gradually smothered by the wash from the slopes. In time, moreover, the enclosed boulders disintegrate *in situ*. If the talus is of a sandy character, as at the foot of the Mchisi range, near Fort Manning, water is able to percolate freely downwards, carrying iron in solution, which may cement the boulders into a hard conglomerate-like deposit. In other cases, the iron-bearing solutions become more concentrated, and on evaporation deposit limonite—thus converting the sands and clays into an impure ironstone, which is brought to light on the removal by erosion of the overlying wash. The porosity of these ironstones is due, in some cases at least, to the imperfect cementation of the sand about which the limonite is deposited. Pockets of sand are left, which are rapidly removed by weathering. Ironstone of a similarly porous character, and sometimes pisolitic, is found far out in the wide plains of the Central Angonaland plateau. Near Nkongoni, on the Bua River, limonitic iron-ore occupies considerable areas on the low slopes on each side of the marshy valley.

It has at times a curious bedded appearance, and occasionally contains angular fragments of vein-quartz. Owing to its impervious character, it not infrequently holds up the surface-water in small pools. The pisolitic varieties of this rock may be compared with the derived laterites of India; but it would, nevertheless, hardly be correct to describe this ironstone as a laterite.

Among other accumulations worthy of note is travertine or calcareous tufa. This is forming at the present day at the base of small rock-falls, along the course of dry stream-beds cut through rocks rich in lime. As a rule, the sandy beds of these streams, a few feet below the surface, contain a sufficient supply of moisture to allow of an intermittent seepage across any rocky barrier in the stream-course. The streams fill with water only in times of exceptional rain, and so the deposits are more or less protected from erosion. In one instance, however, a stream has partly removed the travertine in its bed, leaving it as a terrace 8 feet deep.

Another form of calcareous deposit may be compared with the kunkur of India and East Africa.[1] This is typically developed in the alluvium of the Lower Shire district, and in the weathered soil derived from the Karroo Beds of this area. It here forms small irregular concretions scattered within, and, to a certain extent, concentrated upon the surface of the soil.

Processes of Erosion.

Rain, wind, weathering, and river-erosion all play a more or less important part in the denudation of Nyasaland. Vegetation, on the other hand, has a conservative effect, and by binding the soil together tends to protect the surface of the land from the ravages of wind and rain. The greater part of Nyasaland is covered with stunted forest-growth. The trees lose their leaves during the hot season, but partly regain them a little before the rains have set in. In consequence, the forest-country is to a certain extent protected from the torrential storms which usher in the wet season. There are, however, tracts covered only with a sparse grass, and here a very considerable part of the ground is bare and at the mercy of the rains. In many places, the surface-soil consists of a sandy clay covered with fragments of quartz. The hard fragments shield the underlying soil from the beat of the rain, and so tend to stand out above the general surface on tiny earth-pillars an inch or two high. Earth-pillars of much larger size, but of imperfect development, are occasionally found along the banks of streams.

Where the rain has a rapid run-off, as down a steep stream-bank cut in soft alluvium, it may sometimes give rise to a narrow groove. Under favourable circumstances this will widen rapidly and eventually form a deep trench, or wadi, 100 yards or so long. These wadis are found in various parts of the country, and were

[1] H. B. Maufe, 'Reports relating to the Geology of the East Africa Protectorate': Colonial Reports—Miscellaneous, No. 45, 1908, p. 23.

obviously formed during periods of abnormal rainfall not necessarily far removed from the present time. The soil of Nyasaland is, as a rule, sufficiently compact and bound together by vegetation to prevent much transport by wind. Sand-dunes are occasionally formed along the shore of the lake, as to the south of Chintetchi (fig. 1, p. 191), but never inland.

Weathering plays a very important part in disintegrating the rocks, and thus rendering them more susceptible to erosion. Weathered products are spread broadcast over the country, and owe their present extent and thickness to the absence of recent glaciation. Following, however, a fairly widespread rejuvenation of the rivers, exposures of solid rock are of comparatively frequent occurrence. Moreover, even in the heart of the plateau-regions, where the mature topography is still preserved, there are a considerable number of hills and ridges formed out of solid rock. In that these hills constitute rock-islands surrounded by weathered soil, they may be compared with the tors of Devon, but generally differ from the latter in their smoother pseudoglaciated outline and in their greater altitude.

There are certain kinds of rock which, on exposure to atmospheric agencies, tend to break on their surface into large lenticular fragments. By the splitting-off of these flakes a rocky hill will assume a dome or whale-backed shape. The curious dome-shaped hills of gneiss, round Songani Mountain on the Neno Plateau, for instance, have possibly received their finishing touches in this manner.

River-erosion in Nyasaland is governed by somewhat different conditions from those of Northern Europe, since the rainfall, though heavy, is limited to four or five consecutive months of the year. The rains are followed by a dry season. during which an enormous amount of evaporation takes place. In consequence, numerous streams, and even rivers, which are active in the rains dry up later on in the year. During the hot months the conduct of a river depends largely upon the presence or absence of neighbouring uplands of sufficient height to provide a continuous supply of water. It often happens that a river flows in its upper reaches, but becomes dry lower down in its course, although occasionally these conditions are reversed when the high land lies down-stream. It thus follows that, during the long dry season, erosion comes to a standstill in the low-lying parts of a river, but may yet be in continuous operation on all those tributaries which come from the well-watered uplands: a condition of things obviously favourable to the production of peneplains by selective erosion of the upland tracts, although, as the bulk of the erosion is performed in the wet season, this effect cannot be regarded as of more than secondary importance. There are certain of the larger rivers in Nyasaland which appear too small for their present valleys. The Kasitu and the Lower Southern Rukuru of Northern Angonaland are cases in point. The latter river, before it reaches the Nyika Plateau and receives thence an abundant supply of water, occupies a wide sandy bed traversing a region of hills and mountains. The river to the south of the Nyika is a mere chain of marshes in the dry season. It gives the general impression of a valley which has been silted up, owing to the failure of its water-supply. Both the Kasitu and the Lower Southern Rukuru have a remarkably low gradient, despite the fact that they traverse a much broken tract of country and lie at an elevation of more than 3000 feet. Erosion, even during the rains, must be very slight in the main river-valleys, for the rivers have as much as they can do to keep their courses clear. On the other hand, the lateral tributaries coming from the high ground have, perhaps, a sufficient supply of water, and are of sufficient gradient to erode their channels, and so in time to lower their drainage-areas. Even where river-erosion is almost negligible in the hilly country, weathering is in constant operation, and the detritus from the hills is washed down during the rains into the valleys. As a result the high lands are being lowered, while the low-lying country constituting the larger river-valleys is kept at a general level, or even perhaps raised. If the above operations were allowed to go on undisturbed, a subaërial peneplain at an altitude exceeding 3000 feet would at last be produced.

We have suggested that the Kasitu and the Lower Southern Rukuru Rivers have dwindled in size. This may perhaps be explained by beheading, or be attributed to climatic changes producing desiccation. The former suggestion seems hardly applicable to the Kasitu. The whole subject, however, requires more careful study than we have been able to devote to it. The traveller crossing a waterless tract in the dry season, with perhaps not a trickle or pool to be seen in the stream-courses which he crosses on his journey, might well imagine that the land was always dry and that river-erosion had ceased to be. If, however, just before the rains, he has been tempted by some shade-tree to place his tent close above a dry stream-bed, he may shortly have occasion to change both his camping-ground and his opinions. A dry stream after a few hours of heavy rain may fill to the brim, 8 feet or more, the water, after its first advent, rising with extraordinary rapidity. Another few hours and the flood may be reduced to a muddy rivulet 3 or 4 inches deep, providing, of course, that the neighbouring drainage-area has not been thoroughly saturated by recent rains.

It is possible that certain valleys which are only marshy during the rains are valleys of intermittent erosion. That is to say, they owe their formation in the first place, and their continuance in the second, to occasional very wet seasons; therefore, the presence of such valleys is not necessarily an argument in favour of the desiccation of a country through climatic changes.

It is a well-known fact that climate exerts an influence on vegetation and *vice versâ*. By exerting a control over vegetation, man also plays some part in varying climate. It is the custom among the natives to fire the country shortly before the rains set in. A fire, once started, may continue for miles into the neighbouring forests. These fires do but little damage to the forest, as the bulk of it consists of acacia and mimosa, etc., which outlive the scorching. It is not impossible, however, that the dense tropical vegetation, now found only in patches, extended at one time throughout the length and breadth of Nyasaland, and that its destruction was hastened, though probably not initiated, by forest-fires. This change from the leafy tropical vegetation to stunted forest-growth, leafless for many months of the year, would no doubt tend to render the climate less humid.

The destruction of vegetation may have a marked effect upon the erosion of an area. In Nyasaland villages are often so few and far between, that the clearings in the forest effected by man are almost negligible. Where, however, the population is dense, a considerable area of forest is frequently cut down for firewood and other purposes. This leaves the soil unprotected, and allows of a more rapid run-off of the rain into the neighbouring streams. The gashes cut by the streams in the talus-soil or wash along the western edge of the Dowa Hills may perhaps have originated through the destruction of the trees on the hill-slopes, and the consequent increase in volume and erosive power of the streams during the rains. Even far away from any habitation, the bush-fires, by burning off the long grass and thus laying bare the ground to the force of the rains, may promote a certain wasting away of the surface-soil. On the whole, however, the works of man appear to have had so far but a trivial effect in altering the face of the land.

IV. Physical Features.

A brief description of the topography of Nyasaland has already been given. We now propose to treat the subject in a somewhat more systematic way, dealing first with the various plateaux and finally with the great valley in which Lake Nyasa lies (fig. 1, p. 191).

The Neno Plateau and the Shire Highlands.

In Southern Nyasaland a narrow strip of plateau-region runs roughly north and south along the Anglo-Portuguese border. The plateau averages, perhaps, 4500 feet in height, but is very undulatory and carries numerous ridges and mountain-peaks, one of which, Songani by name, reaches 6000 feet above sea-level. Rivers draining eastwards incise the eastern edge of the plateau, forming shallow gorges opening out into the Shire Valley. The drop from the plateau-top to the Shire Valley, some 3000 feet below, is often very steep, but never precipitous. The Shire Valley forms a huge trough over 20 miles across, and is bounded on the east by the edge of the Shire Highlands, which rise steeply above it to a height of over 2000 feet. The Shire Highlands consist of a tract of fairly even undulating country, with the watershed lying to the west and almost on the summit of the steep slope leading down into the Shire Valley. Rivers flowing in an easterly direction are mature or senile, and offer a striking contrast with their juvenile neighbours across the watershed. Numerous hills and mountains occur on the Shire Highland platform, which also bears two parasitic plateaux known as Zomba and Mlanje. The Mlanje Plateau is somewhat higher than that of Zomba, and should rather be described as a collection of mountain-peaks rising from a common base to nearly 10,000 feet. Both these mountain-masses are made up of granite or syenite, and thus differ in composition from the bulk of the Shire Highlands, which has been carved out of less resistant gneiss. In this, and in other respects, the Shire Highlands are closely comparable with the Neno Plateau just described. Probably they once formed one and the same platform, crossed by rivers draining eastwards which were subsequently beheaded by the Shire Valley.

The Central Angonaland and Marimba Plateau.

This forms a very nearly flat expanse in Central Nyasaland, occupying an area of over 1200 square miles, and with an average elevation of perhaps 4000 feet. The plateau tapers southwards between the Dzalanyama Range on the west, and the Chongoni and Dowa Mountains on the east. Its eastern edge runs roughly north and south, and in the north slopes at first gradually eastwards and then more or less rapidly down to the wide plain which here fringes Lake Nyasa. In the southern and central portions the edge is bounded by ranges or mountain-masses which form a sort of raised lip or rim to the plateau.

The drainage of the plateau is effected by three rivers, known respectively as the Dwangwa, the Bua, and the Lilongwe. The last-named river rises in the Dzalanyama Range and flows eastwards, at first down the general slope of the plateau. Finally, however, as the ground rises towards the eastern rim of the plateau, the river is forced to cut its channel against the general slope, and eventually breaks its way right through the eastern mountains in a shallow gorge.

The Bua River, the largest of the three, flows for about 60 miles in a north-easterly direction across the sandy flats on the top of the plateau. Near the eastern edge it sinks gradually into a gorge, and thus drops by degrees down to the lake-plains. The Dwangwa lies at the northern limit of the plateau, and on its way to the lake crosses the foot of the Vipya Mountains in a fine gorge.

A magnificent view of the plateau is obtained from two small hills, Chiramimbi and Panavikale, which fill in a gap along the western border between the Fort Manning and Dzalanyama ranges. To the east of these hills, and as far as the eye can see in places, stretches a flat plain covered with dark forest and crossed with streaks of lighter green running in a north-easterly direction. These lighter streaks are the shallow grass-covered dambos or stream-grooves which carry the waters of the western slopes across the gently-inclined surface of the plateau to the steep drop which faces

Lake Nyasa. To the west, and across the border, one looks down upon a tumbled sea of mountains, a land of conical peaks and ridges, crossed by swift-flowing rivers travelling southwards and westwards on their way to the Zambezi.

Described in more scientific terms, it amounts to this. On the east of the watershed is a wide homogeneous plateau crossed by senile rivers flowing eastwards and rejuvenated along the eastern edge of the plateau, while on the west is a much dissected plateau incised by streams in an early state of development.

The Bua serves as a type of the senile eastern rivers. For many miles it flows sluggishly at the bottom of a wide shallow groove in the alluvium, forming in places a long line of marsh. Though subject to curves or flexures, the river can never be said to meander across the plateau. The same is true of the tributaries, which, like the main stream, have a very low gradient. Several of the smaller tributaries are little better than a line of marsh, even during heavy rains. Despite this fact, their valleys open out quite gradually into the main river-depression. This is a clear indication that erosion throughout the area has practically come to a standstill. Near the eastern edge of the plateau, however, the rivers are confined to narrow V-shaped valleys or gorges which follow sharp zigzag courses, in marked contrast with the wide even sweeps of the upper reaches. The greater part of the plateau is covered with a pale, very sandy loam. Near the eastern edge, however, this may give place to red clays: these clays are almost invariably found resting upon graphitic gneiss, and either consist of wash from the same, or are products of weathering *in situ*. Owing to the lack of exposures on the west, the actual floor upon which the sandy loam rests is rarely exposed. The deposit is, however, identical in character and continuous with the wash formed at the base of the granitic Dzalanyama Range, and has probably been derived from acid rocks, including granites, granulites, and gneisses. Several monadnocks rise from its surface, and these are almost invariably composed of such rocks, especially granite. Moreover, there appears to be little or no overlap of the sandy loam upon the clays covering the main mass of graphitic gneiss on the east. We are, therefore, inclined to believe that the loam is mainly derived from the underlying rocks, and has not necessarily been transported far from its source of origin. There appears to be no evidence to support the view that the material was transported by wind. More probably it consists of river-alluvium and wash, the latter forming an ever-broadening sheet round the isolated mountain-masses, as these gradually rot or are eroded away to the level of the plain. The monadnocks which remain at the present day are usually surrounded by a low pedestal of wash, but are often remarkable for the steepness of their sides and the comparative freshness of the rocks of which they are composed. These characters are probably dependent upon dry weathering.

The Central Angonaland and Marimba Plateau is the only one of its kind in Nyasaland that can at all be compared with the huge plateau-regions lying round the Victoria Falls of the Zambezi.[1] The other plateaux are far more uneven in character, and more closely resemble the elevated tracts of the South-West of England, such, for instance, as the granite platform of Dartmoor.

The Nyika and Vipya Plateaux.

The Nyika is a small but lofty platform of gneiss and granite covered with weathered soil. It rises in its central portions to 7000 and 8000 feet above sea-level. At its best, the plateau is distinctly undulating, and granite hills or tors are numerous towards the centre. The drainage is more or less radial, but the main rivers run southwards. These rivers have reached maturity on the central highlands, but become rejuvenated along the plateau-edge and cut back into it for a considerable distance in deep V-shaped valleys. The source of the Northern Rukuru lies on the top of the plateau. The Nyika portion is of senile character, and flows in a south-westerly direction. On reaching the plateau-edge it drops in a fine fall and cascades to a depth of 100 feet or so, and then turns sharply round and flows for some miles northwards in a deep V-shaped valley. It affords an excellent example of a hanging valley. Hanging valleys of this type are not uncommon in Nyasaland, but no instance of a typical hanging corrie has been noticed. This, of course, is due to the fact that even the highest plateaux have escaped glaciation. The hanging valley of the Upper Rukuru has evidently been formed by the rapid cutting-back of the main river, probably along a north-and-south line of fault, beheading as it went an old plateau-river flowing southwards.

The plateau-edges, both on the north and on the south, have been carved out into mountain-peaks and ranges; but portions of the western and eastern margins are sharply defined, and drop steeply and for some thousands of feet into the valleys of the Northern and Southern Rukuru respectively. These sharply-defined edges coincide, as we have seen, with long lines of fault, separating the Karroo sediments from the older crystalline rocks.

The Vipya plateau lies to the east and south of the Nyika, and forms a long narrow strip, perhaps 80 miles long and some 10 to 30 miles broad. Its northern portion is divided off from the Nyika by the wide trough of the Henga Valley, floored on the north with rocks of Karroo age. The eastern edge of the plateau is usually steep, and drops in vaguely defined steps right down to the lake-shore. The lake lies at a height of 1645 feet above sea-level, while the Vipya plateau reaches a height of over 7000 feet in places, so that the drop is considerable. The Vipya is somewhat lower than the Nyika, and less of the old plateau scenery is preserved. On the whole, however, the two plateaux are closely comparable, and were doubtless at one time continuous. It is obvious that the flattening of these platforms must have preceded the formation of the deep

[1] G. W. Lamplugh, 'Geology of the Zambezi Basin round the Batoka Gorge' Quart. Journ. Geol. Soc. vol. lxiii (1907) p. 162.

and wide trough-shaped valleys lying east and west of the Nyika. The formation of these troughs seems to have been largely due to the erosion of comparatively soft strips of Karroo Beds let down into the gneiss by trough-faults. There appears to be no reason against supposing that the Karroo once formed a more or less continuous sheet over the present site of the Nyika. This is the view held by us, for we consider that the Nyika forms but a segment of an old denudation-platform, produced at a time subsequent to the main faulting of the Karroo and prior to the formation of the lake-depression. The apparent absence on the Nyika and Vipya plateaux of Karroo outliers, or even of gravel-deposits representing the detritus of the old basal conglomerates, seems, however, to preclude the idea that the present surface of the plateaux coincides with an old pre-Karroo land-surface brought to light again by denudation. It is probably of entirely independent origin.

The Nyasa Trough.

Our personal knowledge of Lake Nyasa is practically limited to its western shores. We have been able, however, to refer to Dr. Bornhardt's work on German East Africa for a description of the north-eastern border of the lake, and for his general conclusions with respect to its formation. A useful map of the Nyasaland Protectorate, giving some of the sublacustrine contours of Lake Nyasa, has recently been published by the War Office, and this has been used as the basis of some of the maps which illustrate the present paper.

Lake Nyasa lies in a huge trough-shaped valley, closed at its northern end, but opening southwards into the Shire Valley. This trough-shaped valley is situated at the junction of two similar series of troughs running for many hundreds of miles in a northerly direction. The entire system, including Nyasa, is roughly Y-shaped. It is now very generally admitted, in accordance with Prof. Suess's interpretation, that the whole system of troughs has been determined by comparatively recent faulting. Lake Nyasa lies in a rock-basin which attains the extraordinary depth of over 670 feet below sea-level, the total depth of the lake being no less than 2316 feet. While it is quite obvious that earth-movement has played some part in the formation of the Nyasa trough, it does not necessarily follow that the trough was altogether fashioned by faulting. It might, for instance, have originated as a great river-valley which has suffered subsequent deformation. There are, however, many difficulties in the way of accepting this hypothesis, and these will be detailed below.

The extraordinary breadth of the Nyasa trough, coupled with the height, steepness, and general straightness of its sides, must at once differentiate it from normal valleys of erosion. We have seen, however, that valleys of somewhat similar type, though on a much smaller scale, have been formed in Nyasaland by selective erosion working along soft strips of Karroo rocks trough-faulted into the hard gneiss; and it is true that such rocks occur at the northern end of the lake, with faulted junctions showing a certain parallelism with the general trend of the valley. But, on the one hand, this parallelism is by no means the rule, for in the Ruhuhu area (in German territory) the main Karroo fault runs east and west, and is sharply truncated by the lake-margin; while, on the other hand, the occurrence of Karroo rocks in the lake-basin is merely an accidental feature of the northern portion of the depression, for by far the greater part of the trough has been formed in solid gneiss or granite. Nor is there a possibility of the lake-valley having been determined by erosion along a soft band in the gneiss, since the strike of the gneiss lies for considerable distances at right angles to the trend of the lake. Again, if the lake-trough were primarily a valley of erosion, one might well expect to find the lateral tributaries of proportionate size: such is not the case. The watershed separating the rivers draining westwards into the lake from those flowing eastwards to the Indian Ocean nearly coincides with the steep eastern edge of the trough itself. This is remarkable, because the rainfall must be fairly heavy along these eastern slopes. On the western side of the lake the shortness of the lateral tributaries is somewhat less marked: the Bua, for instance, is a fairly large river. In this case, however, there is clear evidence to suggest that the tributary stream is older than the main Nyasa Valley. Taking all the facts into consideration, there seems to be no doubt whatever that the Nyasa trough originated in, and has subsequently been developed by, earth-movements. The steep edges of the plateaux facing the lake can be explained as fault features, sometimes dropping to great depths below lake-level and sometimes separated by wide fault-steps, such, for instance, as the coastal plains behind Kota Kota. The general trend of these faults is in a north-and-south direction, but in places they appear to have suffered deflection or to have died out for a space. Along the north-western border a sloping platform sinks gradually eastwards into the lake, and appears to dip in this direction until the submarine foot of the Livingstone Range is reached. This range towers up to great heights along the north-eastern shore of the lake, and sinks to considerable depths below its surface. It is possible that the fault running along the western side of the Rift Valley is deflected westwards, while the eastern fault continues along the edge of the Livingstone Range, in a way somewhat reminiscent of the older faults limiting the Karroo in the Mwapo and Western Nyika areas.

Many of the arguments which have been used in support of the tectonic origin of the Nyasa trough can be applied with equal truth to the Shire Valley, which is doubtless a direct continuation of the main Rift Valley. The method in which the Nyasa rift dies out to the south is not clearly understood, but it appears probable that the fault-feature defining the eastern edge of the Shire trough is continued for many miles to the south of its western neighbour.

The Nyasa depression lies along the axis of a north-and-south ridge. This is not an ideal ridge, with sides sloping regularly to the east and west, but consists of a series of high mountain-ranges, isolated mountain-masses, and strips of elevated plateau grouped together along a roughly north-and-south line on each side of the lake. Prof. J. W. Gregory[1] has suggested that the Great Rift Valley of East Africa is due to the falling-in of the keystone of a pre-existing arch. At first sight, objections may be raised to using this theory to account for the position of the Nyasa trough. The Lilongwe River, for instance, is rejuvenated where it reaches the edge of the lake-basin, and is consequently older than this depression; yet this river and its neighbour, the Bua, flow towards, and not away from, the lake, as might be expected on the arch hypothesis. This objection, however, may be surmounted, if we suppose that the erosion of the rivers was able to keep pace with the uplift—a view which accords with the fact that the Lilongwe and Lintipi have succeeded in crossing a barrier-ridge on their way to the lake. If it is admissible to assume that an anticlinal ridge existed on the present site of Lake Nyasa, one must allow for a very considerable lapse of time between the initiation of this ridge and the formation of the lake-trough.

Age of the Nyasa Trough.

The lake-faults cut across post-Karroo faults, and are obviously of post-Karroo age. There is, unfortunately, nothing to fill in the gap between the recent freshwater deposits of the lake-basin and the rocks of Karroo age, so that we are forced to base our conclusions concerning the age of the lake mainly on topographical evidence.

On the north of the lake, Dr. Bornhardt has described a series of alkaline lavas occupying a continuation of the Rift Valley. These lavas are in part, at least, younger than the rift, for they overlap along its western margin. When the first outbreak of igneous activity took place is doubtful, but the occurrence of volcanic cones shows that vulcanicity has lasted on to recent times. Hot springs at Mount Waller, Kota Kota, near Liwonde in the Shire Valley, and far away to the south at Morambala Mountain probably represent the last phases of vulcanicity. These springs lie along a north-and-south line of weakness roughly following the course of the lake-depression.

The discovery of recent lacustrine deposits up to 700 feet above the present lake-level opens up a field of investigation to future workers which may prove fertile.

The view that the lake is of no great age is supported by topographical evidence. The shortness of the lateral tributaries along the eastern border of the lake, despite a comparatively heavy rainfall, is readily explained on the above supposition. Again, the plateau-edges still retain in places a certain sharpness. This is especially the case with the Livingstone Range. The absence of

[1] 'The Great Rift Valley' London, 1896, p. 231.

large deltas projecting for considerable distances into the lake also points to the relatively recent origin of the lake-depression. On the other hand, the gorges of the Southern Rukuru, the Bua, and several other rivers are of considerable depth and many miles in length. These have been cut as a consequence of the formation of the Rift Valley, and are clearly not the work of a day.

V. Conclusions.

1. The greater part of Nyasaland consists of crystalline rocks which comprise:—

(A) Highly metamorphosed sedimentary beds, including graphitic gneisses with limestones, and quartz- and muscovite-schists.

(B) Foliated igneous rocks, especially augen-gneiss derived from granite or syenite.

(C) Plutonic intrusions, usually granite or syenite, more rarely norite or gabbro.

Nepheline- and sodalite-syenites are found in two localities, and are possibly identical in age with the similar post-Waterberg and pre-Karroo syenites of the Transvaal.

2. In the north-western corner of Nyasaland a somewhat altered sedimentary series forms the Mafingi Hills. This series consists of a great thickness of quartzites, grits, and sandstones, and is of pre-Karroo age.

3. Rocks belonging to the Karroo System are found both in Northern and in Southern Nyasaland. In the north the Karroo is of patchy distribution, and owes its preservation to faulting. It is evident that the Karroo had formerly a much wider distribution in this area than at the present time.

Freshwater lamellibranchs belonging to the genus *Palæomutela* and also fish-scales of *Colobodus* occur in the calcareous group of the north, while species of *Glossopteris* were discovered in the Karroo of both areas.

The Karroo of Nyasaland is comparable with that of Rhodesia and German East Africa.

4. Recent lacustrine marls and sands are found at distances of 15 miles and under from the north-western margin of Lake Nyasa, and occur to great heights above its present level.

5. Pumiceous tuffs associated with recent gravels containing pebbles of Tertiary lava are found in the extreme north of the country. Across the border, in German East Africa, Tertiary and recent lavas and tuffs have a wide distribution.

6. Nyasaland consists of high plateau-regions rising irregularly one above the other. The Nyika and Vipya plateaux were, doubtless, at one time continuous, and formed a platform of erosion produced at a time subsequent to the main faulting of the Karroo in Northern Nyasaland and previous to the formation of the great Nyasa depression, which is regarded as a true 'rift valley'.

VI. Bibliographical List.

(1) D. Livingstone. 'Expedition to the Zambesi & its Tributaries, &c.' London, 1865.
(2) James Stewart. Proc. Roy. Geogr. Soc. vol. iii (1881) p. 264.
(3) Joseph Thomson. 'To the Central African Lakes & back' London, 1881.
(4) H. Kuss. Bull. Soc. Géogr. vol. iii (1882) pp. 365–83; Bull. Soc. Géol. France, ser. 3, vol. xii (1884) pp. 303–17.
P. Guyot. C. R. Acad. Sci. Paris, vol. xcv (1882) pp. 355–57.
E. Lapierre. Annales des Mines, ser. 8, vol. iv (1883) pp. 585–93.
R. Zeiller. *Ibid.* pp. 594–98.
(5) H. Drummond. 'Tropical Africa' London, 1888.
(6) T. Rupert Jones. 'On some Fossils from Central Africa' Geol. Mag. dec. 3, vol. vii (1890) pp. 553–58.
(7) J. E. S. Moore. 'Physiographical Features of the Nyasa & Tanganyika Districts of Central Africa' Geogr. Journ. vol. x (1897) pp. 289–99.
J. E. S. Moore. 'The Tanganyika Problem' London, 1903.
(8) W. Bornhardt. 'Deutsch-Ost-Afrika' vol. vii (Geologie) Berlin, 1900.
(9) James Henderson. 'The Nyasa Coal-bed' Scot. Geograph. Mag. vol. xix (1903) pp. 311–15.
(10) T. H. Holland. Brit. Cent. Africa Gazette, April 30th, 1903, p. 63; Bull. Imp. Inst. vol. ii (1904) pp. 69–73.
(11) W. R. Dunstan. Brit. Cent. Africa Gazette, March 31st, 1903; Imp. Inst. Technical Reports & Scientific Papers (1903) pp. 1–40; Bull. Imp. Inst. vol. ii (1904) pp. 69–76; *ibid.* vol. iii (1905) pp. 133–39; *ibid.* vol. iv (1906) pp. 103–106.
(12) A. J. C. Molyneux. 'The Sedimentary Deposits of Southern Rhodesia' Quart. Journ. Geol. Soc. vol. lix (1903) pp. 266–85.
(13) G. W. Lamplugh. 'The Geology of the Zambezi Basin around the Batoka Gorge (Rhodesia)' Quart. Journ. Geol. Soc. vol. lxiii (1907) pp. 162–214.
(14) L. A. Wallace. 'North-Eastern Rhodesia' Geogr. Journ. vol. xxix (1907) pp. 369–95.
(15) W. R. Dunstan. ['Mineral Survey of Nyasaland'] Colonial Office Reports, no. 48 (1908); *ibid.* no. 60 (1909).
(16) A. J. C. Molyneux. 'On the Karroo System in Northern Rhodesia, & its Relation to the General Geology' Quart. Journ. Geol. Soc. vol. lxv (1909) pp. 408–38.

Appendix I.—Note on a Collection of Fossil Plants from the Neighbourhood of Lake Nyasa, collected by Mr. A. R. Andrew. By E. A. Newell Arber, M.A., F.L.S., F.G.S.

Our present knowledge of the palæobotany of Portuguese East Africa rests on a memoir by Prof. Potonié,[1] of Berlin, published in 1899. The following species were then recorded from Ituli:—*Glossopteris browniana*, Brongn., *G. indica*, Schimper, and *G. angustifolia*, Brongn., and from German East Africa, *Glossopteris* sp., *Vertebraria*, *Schizoneura* cf. *meriani*, and *Voltziopsis*.

Mr. Andrew's collection was derived from four localities, three from the district of the Lower Shire and one from the neighbourhood of Mount Waller. The greater number of the specimens are in fragmentary examples of shale obtained from the Middle Shale Group near Zimbawe Hill, on the Ngoma River, which

[1] H. Potonié in W. Bornhardt's 'Deutsch-Ost-Afrika' vol. vii (Berlin, 1900): 'Fossile Pflanzen aus Deutsch & Portugiesisch Ost-Afrika' pt. ii, p. 495. See also Sitzungsber. Gesellsch. Naturforsch. Freunde, Berlin, Nos. 2 & 5, Feb. & May 1899, pp. 27 & 96.

rises on the Anglo-Portuguese border and reaches the Zambezi just above Sinjal (fig. 8, p. 216), Lower Shire area. Several fragments of fronds of *Glossopteris* occur. Some of these appear to be rather small leaves of *Glossopteris indica*,[1] Schimper, with narrow elongated meshes. The fronds vary greatly in size, small leaves predominating. Some of them closely resemble the figure of *G. indica*, Schimper, from India, given by Feistmantel[2] on pl. xxxviii A, fig. 4, of his 'Lower Gondwana Flora'. Other fronds of still smaller dimensions may be compared with pl. xxxiv A, fig. 2, of Feistmantel's memoir. Such specimens are difficult to identify specifically, and possibly are only young immature fronds belonging to one of the commoner species, such as *G. indica*, Schimper, or *G. browniana*, Brongn. On the other hand, some examples seem to be identical with *Glossopteris retifera*, Feist.; and possibly *G. angustifolia*, Brongn. is represented in the collection. A specimen containing scale-leaves of *Glossopteris*[3] also occurs.

In the same locality, associated with fronds of *Glossopteris*, leaf-segments and stems of a *Schizoneura* occur which appear to be closely similar to, if indeed they are not identical with, the *Schizoneura gondwanensis*, Feist.,[4] of the Indian Gondwana beds. *Schizoneura* is a typical member of the *Glossopteris* Flora. The South African species *Sch. africana*, Feist.,[5] with which these new specimens may be also compared, has rather narrow sheath-segments, whereas those of Mr. Andrew's examples are very large and broad, in one case the breadth being 4 centimetres. An example of a stem-cast also occurs, showing a node.

Among the better-preserved specimens are those from Nkombedzi, Pwadze, in the north of the Lower Shire area. Several species of *Glossopteris* appear to occur here in the Middle Shale Group, both *G. browniana*, Brongn., and *G. indica*, Schimp., as well as scale-fronds of *Glossopteris*, being recognized. A large broad frond may be compared with *G. ampla*, Dana, and leaves of the narrow, linear type with *G. angustifolia*, Brongn. A very large and broad *Vertebraria*-like specimen was also collected from this locality, though some little doubt exists as to whether it is a true *Vertebraria*, since it does not correspond very closely with *V. indica*, Royle. It may be compared, however, with the figures of the specimens from Portuguese East Africa attributed to this genus by Potonié.[6] Two pieces of petrified wood were also collected from the uppermost shales at Pwadze, but it is doubtful whether they can be identified.

At Namalundo,[7] north of Zimbawe, brown shales occur, full of

[1] Arber, 'Monograph of the *Glossopteris* Flora' Brit. Mus. Catal. 1906, p. 64.

[2] 'The Fossil Flora of the Gondwana System: vol. iii, parts 1–3 (Lower Gondwanas)' Mem. Geol. Surv. India—Pal. Indica, ser. xii, vol. iii (1879–81).

[3] See Arber, *op. cit.* p. 38, &c.

[4] *Ibid.* p. 5 & text-figs. 1 to 4.

[5] *Ibid.* p. 13.

[6] Potonié, *op. cit.* figs. 23 & 24 on pp. 498–99.

[7] Namalundo lies to the east of the Tangasi River, practically at the intersection of the line BB′ with the fault-line, fig. 8 (p. 216), Lower Shire area.

leaf-impressions of *Glossopteris*, although the specimens are fragmentary and badly preserved. Fronds of *Glossopteris indica*, Schimp., appear to be frequent in this locality.

Other specimens from Rumpi Gorge, Mount Waller area, near Lake Nyasa, which are all very poorly preserved, show fragments of *Glossopteris*-fronds and leaves somewhat resembling those known as *Nœggerathiopsis*, but are too imperfect to be determined.

The collection, as a whole, is interesting, as confirming the occurrence of the species of *Glossopteris* previously recorded from Portuguese East Africa by Potonié, and as adding to our knowledge of the *Glossopteris* Flora as there developed. The addition of *Glossopteris retifera*, Feist., to the list is of interest, for this species has already been recorded from South Africa as well as from India. The specimens of *Schizoneura* appear to be much more perfect than those named by Potonié, and are almost certainly identical with *Sch. gondwanensis*, Feist., and not *Sch. meriani*, with which species Potonié compared his fragmentary examples. Among other new additions are possibly *Glossopteris ampla*, Dana, and specimens which may be compared with *Vertebraria* and *Nœggerathiopsis*.

Appendix II.—Notes on some Fossil non-Marine Mollusca and a Bivalved Crustacean (*Estheriella*) from Nyasaland.[1] By Richard Bullen Newton, F.G.S.

[Plates XVIII & XIX *pars.*]

The specimens described in these notes have been collected by Messrs. A. R. Andrew & T. E. G. Bailey in the north-western area of Nyasaland, during a mineral survey carried out between the years 1906 and 1908, under the auspices of the Imperial Institute, the authorities of which have kindly presented them to the Geological Department of the British Museum (Natural History). They consist of Quaternary gastropoda and Palæozoic pelecypoda, accompanied by *Estheriella*, all of which exhibit non-marine characters.

Quaternary Gastropoda.[2]

The Quaternary gastropoda include both freshwater and terrestrial forms belonging to the recent fauna of Lake Nyasa and its surrounding shores. Generally speaking, these specimens are of fresh appearance and well preserved, frequently showing remnants of coloration and periostracum—a condition which more particularly applies to the land-shells. The freshwater shells comprise the genera *Viviparus* and *Lanistes*, the former having been obtained from deposits at Chiwondo on Lake Nyasa, at an elevation of 20 feet

[1] Communicated by permission of the Trustees of the British Museum.
[2] The deposits in which these shells occur are described on p. 223.

above the water-level, as well as 3 miles west of that village at the altitude of 350 feet above the same level, where they occur as marl-casts, and again at Chisali, 15 miles west of the lake, at an elevation of 400 feet, where their casts form a limestone of some durability. Examples of *Lanistes* were collected at Chiwondo from a height of 20 feet, in association with well-preserved *Viviparus*.

The terrestrial shells are localized from Chiwondo and Masiunjuti, the latter place being situated some 12 miles west of the lake-margin, where the specimens were found on the top of the sands and marls.

The Chisali specimens appear, however, to be of greatest interest, since they indicate a considerable north-westerly extension of Lake Nyasa in Quaternary times. They occur as casts in a cream-coloured limestone, where all evidence of shell-structure has been dissolved away, although, from wax impressions of the more perfect natural moulds, it has been possible to determine, with a fair amount of certainty, their relationship to *Viviparus unicolor*, a present-day inhabitant of Lake Nyasa and other freshwater regions of Africa.

Freshwater Forms.

Genus Viviparus, Montfort.

'Conchyliologie Systématique' 1810, vol. ii, p. 246.
Type=*Helix vivipara*, Linn.
Synonym: *Vivipara*, Lamarck, 1809 [=list-name only].

Viviparus unicolor (Olivier). (Pl. XVIII, figs. 1–5.)

Cyclostoma unicolor, Olivier, 'Voy. Emp. Oth. Égypte, Perse' 1804 (=An xii), vol. iii, p. 68 & atlas, pl. xxxi, fig. 9.
Vivipara capillata, robertsoni, jeffreysi, von Frauenfeld, Verhandl. Zool.-Bot. Gesellsch. Wien, 1865, vol. xv, pp. 532–33 & pl. xxii.
Vivipara unicolor, Jickeli, Nova Acta K. Leop.-Carol. Deutsch. Akad. Naturf. vol. xxxvii (1874) p. 235.
Paludina unicolor, Blanckenhorn, Zeitschr. Deutsch. Geol. Gesellsch. vol. liii (1901) p. 432.

The few isolated examples of this species in the collection are somewhat worn, otherwise they exhibit the basal angulation and some obscure spiral sculpture. They compare favourably with Olivier's original figures and with Jickeli's later descriptions in possessing about six whorls, the earlier being more or less contabulate, while the basal bears an obscure angulation.

So far as dimensions are concerned, they also correspond with those given by Jickeli, the largest specimen having a height of nearly 25, a maximum diameter of 18, and an aperture measuring 12 by 10 millimetres.

In making this determination, the broadest view of Olivier's *unicolor* has been adopted, since the species has hitherto been regarded as belonging chiefly to Nile waters and not forming part of the Nyasa fauna. A careful comparison of forms in the Zoological Department of the British Museum has, however, induced me to include in it Frauenfeld's *capillata*, *robertsoni*, and *jeffreysi*, all of which are found in the lake at the present day. Mr. Edgar Smith, who has for long studied the mollusca of African fresh waters, agrees with me in thinking that if examples of *capillata*, at least, were mixed with a series of *unicolor*, it would be almost impossible to separate them. In this connexion, it is interesting to note that Dr. E. von Martens regards *jeffreysi* as a variety of *unicolor*, and *robertsoni* as closely allied.

Localities.—The isolated shells were obtained at an elevation of 20 feet above the present lake-level at Chiwondo; the marl-casts came from about 3 miles west of Chiwondo, at an elevation of some 350 feet; while the limestone-casts were collected at Chisali, some 15 miles west of the lake-margin, at a height of about 400 feet.

Distribution.—The species was originally described from the canal at Alexandria, and has since been recorded from most African freshwaters. Jickeli mentioned its occurrence in a subfossil state in the neighbourhood of the Libyan Desert, and in later years Dr. Blanckenhorn recognized it in the Quaternary deposits of the Nile Valley near Wadi Halfa.

Genus Lanistes, Montfort.

'Conchyliologie Systématique' 1810, vol. ii, p. 123.
Type = *Cyclostoma carinata*, Olivier.

Lanistes solidus, E. A. Smith. (Pl. XVIII, figs. 6 & 7.)

Lanistes solidus, E. A. Smith, Proc. Zool. Soc. London (1877) 1878, p. 716 & pl. lxxiv, fig. 10.

This species is represented by large (66 × 62 millimetres) and medium-sized (40 × 38 mm.) specimens in a good state of preservation, with remnants of the periostracum sometimes preserved.

Locality.—Chiwondo: at an elevation of about 20 feet above present lake-level.

Distribution.—Lake Nyasa.

Terrestrial Forms.

Genus Achatina, Lamarck.

Mém. Soc. Hist. Nat. Paris, 1799, p. 75.
Type = *Bulla achatina*, Linn.

Achatina craveni, E. A. Smith.

Achatina kirkii, E. A. Smith, Ann. & Mag. Nat. Hist. ser. 5, vol. vi (1880) p. 428.
Achatina craveni, E. A. Smith, Proc. Zool. Soc. London, 1881, p. 283 & pl. xxxiii, fig. 11; *ibid.* 1899, p. 590 & pl. xxxv, figs. 1–2.

Localities.—Chiwondo; Masiunjuti.

Distribution.—In regions between Lake Nyasa and the East Coast of Africa.

Genus Bulimina, Ehrenberg.

Hemprich & Ehrenberg, 'Symbolæ Physicæ: Animalia Evertebrata exclusis Insectis' 1831 (pages not numbered).
Type = *Bulimus labrosus*, Olivier.

Bulimina boivini (Morelet).

Glandina boivini, Morelet, 'Séries Conch.' 1860, pt. 2, p. 72 & pl. v, fig. 5.
Buliminus boivini, E. A. Smith, Proc. Zool. Soc. London, 1899, p. 587.

Locality.—Masiunjuti.
Distribution.—Nyasa Plateau (Zomba).

Genus Martensia, Semper.

'Reisen Archip. Philipp. Landmollusken' 1870, vol. iii, p. 42 & pl. iii, fig. 5.
Type = *Helix mozambicensis*, Pfeiffer.

Martensia mozambicensis (Pfeiffer).

Helix mozambicensis, Pfeiffer, Proc. Zool. Soc. London, 1855, p. 91 & pl. xxxi, fig. 9.
Martensia (*Trochonanina*) *mossambicensis*, E. von Martens, in Bornhardt's 'Deutsch-Ost-Afrika' [Möbius] vol. iv (1898) p. 46.

Localities.—Chiwondo; Masiunjuti.
Distribution.—Nyasa Plateau (Zomba).

Genus Tropidophora, Troschel.

Zeitschr. Malakozoologie [Menke & Pfeiffer], 1847, p. 44.
Type = *Cyclostoma cuvierianum*, Petit.

Tropidophora nyasana, E. A. Smith. (Pl. XVIII, figs. 8 & 9.)

Pomatias nyasanus, E. A. Smith, Proc. Zool. Soc. London, 1899, p. 591 & pl. xxxv, fig. 5.
Tropidophora nyasana, E. A. Smith, MS. (as determined in the Zool. Dept. Brit. Mus. Nat. Hist.).

Localities.—Chiwondo; Masiunjuti.
Distribution.—Nyasa Plateau (Zomba).

Palæozoic Pelecypoda.

Under this heading are included a number of natural casts of a small pelecypod shell belonging to Amalitsky's genus *Palæomutela*, and to the species *oblonga* of Prof. T. Rupert Jones, which the latter described some years since from specimens collected by the late Prof. H. Drummond at Maramura, west of Karonga on Lake Nyasa, and some 20 or 30 miles south of Nkana, whence the present material was obtained (see pp. 204, 207). The specimens occur in a blackish shale, associated with fish-scales and the remains of *Estheriella*. Parts of the same shale are of oolitic structure.

Palæomutela and its associate *Palæanodonta* belong to a series of freshwater or lacustrine pelecypods which are distributed through the lower portion of the Karroo System of South Africa, having been recognized at Beaufort, Bedford, Graaff Reinet, Kimberley, in Northern and Southern Rhodesia and North-Western Nyasaland.

Prof. Amalitsky has specially studied this molluscan fauna, and has noted its resemblance to that of the Permian beds of Russia, five species of the shells being determined as common to these two widely distant areas. The distribution of these genera is set out in a subsequent table (p. 246).

Genus Palæomutela, Amalitsky.

'Ueber die Anthracosien der Permformation Russlands' Palæontographica, vol. xxxix (1892) pp. 159, 199.

Types = *P. verneuili* & *P. keyserlingi*, Amalitsky.
Synonyms: *Iridina (?)* Sharpe, 1856; *Iridina (?)* T. R. Jones, 1890.

Distribution.—The Permian of Eastern Russia and the Karroo Formation of South Africa [= Permo-Carboniferous].

Palæomutela oblonga (T. R. Jones). (Pl. XIX, figs. 11–14.)

Tellinidæ (species of the), H. Drummond, 'Tropical Africa' 1888, p. 192.
Iridina (?) oblonga, T. R. Jones, Geol. Mag. 1890, pp. 556–57 (woodcut).
Palæomutela, W. Amalitsky, Palæontographica, vol. xxxix (1892) p. 159; and Quart. Journ. Geol. Soc. vol. li (1895) p. 341.

The specimens referred to this species are fairly well represented in a dark shaly matrix, but consisting chiefly of natural casts, like those originally described by Prof. Rupert Jones from Maramura, in which a dentition can be deciphered. With the view of testing the presence of teeth, on which the adoption of *Palæomutela* would depend as opposed to the edentulous genus *Palæanodonta*, a surface has been prepared of the dorso-posterior region of a right valve, showing a thickened hinge-plate anteriorly but becoming more slender towards the posterior end. The marginal lines of this hinge enclose a series of narrowly angulate and acute >-shaped teeth, generally suggestive of what is present in *Palæomutela*, although of greater obliquity (see Pl. XIX, fig. 13). On such evidence, the species *oblonga* is retained in *Palæomutela*, where Prof. Amalitsky grouped it when prosecuting his investigations on these freshwater shells without, however, the aid of dental characters at that time.

The valves vary in length from about 5 to 15 millimetres, being therefore somewhat smaller than those from Maramura, which exhibited a maximum length of 20 millimetres. One of the right valves still shows mineralized remnants of an external ligament reposing in a narrow elongate, lanceolate depression.

The specimens correspond with the original details of this species as expressed by Prof. Rupert Jones:—

'The shells are oval-oblong, or sub-oblong, rounded at the ends unequally; the posterior being somewhat truncate, and the anterior obliquely truncate, with an ogee-curve below the umbo. Hinge-line long and straight; ventral margin slightly curved. Various degrees of imbedment affect the visible shape; some individuals showing only a triangular outline. The surface is moderately convex, and bears rather strong concentric lines of growth. These fossils have a general resemblance to the *Iridinæ* described and figured by D. Sharpe in the Trans. Geol. Soc. ser. 2, vol. vii, pp. 225, 226, pl. xxviii, figs. 2–4. These were from the Karroo Formation at Graaf-Reynet in the Cape Colony.' (*Loc. supra cit.*)

The Maramura specimens were first referred to by their discoverer, the late Prof. Drummond, in 1888, as 'a single species of the Tellinidæ,' which indicated a family of marine shells ; but when they were subsequently examined by Prof. T. Rupert Jones, he was enabled to describe them as of freshwater origin under the genus *Iridina (?)*. Later still, Prof. Amalitsky included the species of *Iridinæ (?)* of Sharpe and Jones in his genus *Palæomutela*, for which and other genera he founded the family name of Anthracosidæ or Palæounionidæ.

Several estuarine or freshwater mollusca are now recorded from the Karroo deposits of Africa, owing chiefly in more recent years to the researches of Prof. Amalitsky, who, after studying the types contained in the British Museum and in the collection of the Geological Society, relegated them to his new genera *Palæomutela* and *Palæanodonta*, and demonstrated their unmistakable resemblance to the Permian freshwater shells of Russia, five species being found alike in the two countries (see Distribution Table, p. 246).

Formation.—Permo-Carboniferous [Karroo Beds].

Localities.—Nkana (Andrew & Bailey); Maramura (Drummond).

Palæozoic Crustacea (Phyllopoda).

Genus Estheriella, C. E. Weiss.

Zeitschr. Deutsch. Geol. Gesellsch. vol. xxvii (1875) p. 711.
Type = *Posidonomya wengensis*, Giebel.

Distribution.—The Triassic of Saxony, etc. ; Permo-Carboniferous of South Africa ; and the Upper Carboniferous of Scotland.

Estheriella nyasana, sp. nov. (Pl. XIX, figs. 15–18.)

Description.—Valves small, more or less depressed, oblong, narrow, sometimes subquadrate, moderately and regularly convex. Umbones antero-terminal. Dorsal line extended, straight, slightly oblique, nearly parallel with the ventral border; anterior margin truncated, straight; posterior margin with outward curvature. Ornamentation comprising about twelve equidistant concentric striations with a finer series occupying the interspaces, crossed by obscure radial riblets; surface more or less wrinkled, and covered with pittings or granulations.

Dimensions.—The valves measure about 1 millimetre in their longest axis.

Remarks.—At the reading of this paper before the Geological Society, I was under the impression that the obscure fossils now described might represent the embryonic condition of the associated shells of *Palæomutela (?)*, and I therefore referred to them as belonging to the glochidial stage of that pelecypod. From a further study of the specimens, however, and assisted by some excellent *camera lucida* drawings made by Mr. Highley, I regret that I am no longer able to support so interesting an interpretation, being convinced that these little fossils are the carapace-valves of a phyllopodous crustacean generally known as the genus *Estheria*.

Although the specimens are very numerous, they appear to be referable to one particular species, and the presence of radial striations (see Pl. XIX, fig. 16) is sufficient evidence for regarding it as an example of *Estheriella*, a genus founded by Weiss to include Giebel's *Posidonomya wengensis* and allied species from the Bunter Sandstone of Saxony, which possessed the usual characters of *Estheria*, but in addition a radially striated sculpture.

Prof. Rupert Jones [1] has fully recognized the adoption of *Estheriella*, and, in a final paper [2] on the subject, alludes to the presence of radial striations on his species, *Estheria tegulata* and *E. tessellata* from the Upper Carboniferous of Scotland, the same character being strongly expressed in *Estheriella radiata* (Salinas) var. *multilineata*, Jones, from the Trias of the Malay Peninsula, and more feebly so in *Estheria greyi* [3] from the Karroo of Cradock (South Africa).

The present species may be distinguished by the very anterior position of the umbones, the nearly parallel condition of the dorsal and ventral margins, and the truncated character of the anterior end. In such details it appears to be a form which need not be mistaken for any of those just mentioned, although in the clearly-cut arrangement of the concentric sculpture and in some of the valves showing a subquadrate contour, it somewhat resembles *Estheria greyi.* The integument of which these carapace-valves are composed is most delicate and thin, a feature which would account for their generally much wrinkled condition under pressure, resulting frequently in the obliteration of the extremely fine concentric striations which otherwise form part of the sculpture. The specimens also exhibit a glossy and iridescent aspect, indicating certain mineral characteristics which prevailed during the period of fossilization.

Formation.—Permo-Carboniferous [Karroo Beds].

Locality.—Nkana (Andrews & Bailey).

Conclusions.

(*a*) The freshwater limestone of Chisali, containing remains of *Viviparus unicolor*, is evidence in favour of an extension in a north-westerly direction of the waters of Lake Nyasa during Quaternary times, for a distance of about 15 miles.

(*b*) The Permo-Carboniferous shells of Nkana are of importance in joining up areas of similar age on the north-western side of Lake Nyasa; as, for instance, Maramura with Nkana, and the latter with the Kivera and Songwe-River regions (Kandete Bach, etc.) of German East Africa, where Dr. Bornhardt has recognized coal-bearing rocks with plant-remains (described by H. Potonié), which he refers to the Karroo formation.[4]

[1] Geol. Mag. 1891, p. 53. [2] *Ibid.* 1905, pp. 50–52 & pl. ii.
[3] *Ibid.* 1878, p. 100 & pl. iii, fig. 1.
[4] 'Deutsch-Ost-Afrika' vol. vii (1900) pp. 495. 501 & geol. map No. 4.

TABLE SHOWING THE SPECIFIC DISTRIBUTION IN SOUTH AFRICAN LOCALITIES OF PERMO-CARBONIFEROUS PELECYPODA, BELONGING TO THE FRESHWATER GENERA *PALÆOMUTELA* AND *PALÆANODONTA*, AND THEIR OCCURRENCE IN DEPOSITS OF HOMOTAXIAL AGE IN EASTERN RUSSIA, AS RECOGNIZED BY PROF. AMALITSKY.

Genera.	Species.	Beaufort (=Balfour).	Bedford.	Graaff Reinet, Bloemkop, &c.	Kimberley.	Rhodesia.	Nyasaland.	Russia (E.).
PALÆOMUTELA	*oblonga* (T. R. Jones)	...	...	...	...	...	×	
	rhomboidalis (Sharpe)	...	...	×				
	ovata (Sharpe)	...	...	×				
	cf. *ovalis*, Amalitsky	...	...	×				
	semilunulata, Amalitsky	...	...	×	...	...	...	×
	plana, Amalitsky	...	...	×	...	...	...	×
	trigonalis, Amalitsky	...	...	...	×	...	...	×
	murchisoni, var., Amalitsky	...	×					
	cf. *lævis*, Amalitsky	...	...	×				
	Group *keyserlingi*, Amalitsky (W. Hind) including *Cyrena? neglecta*, T. R. Jones	×	...	×	...	×		
	n. sp., Amalitsky	...	...	...	×			
	n. sp. aff. *golowkinskiana*, Amalitsky	...	...	...	×			
	n. sp. aff. *orthodonta*, Amalitsky	...	...	...	×			
	sp. (Molyneux)	...	...	...	...	×		
PALÆANODONTA	*okensis*, Amalitsky	...	...	×	...	...	...	×
	subcastor, Amalitsky	...	...	×	...	...	...	×

HISTORY OF COLLECTIONS.

Localities (South Africa).	Collectors.	Where preserved.
Beaufort (=Balfour)	A. G. Bain and R. N. Rubidge.	Geological Society.
Graaff Reinet, Bloemkop, &c.	A. G. Bain and R. N. Rubidge.	Geological Society.
Bedford	David Fraser.	British Museum (Natural History).
Kimberley	E. J. Dunn (probably).	British Museum (Natural History).
Rhodesia	A. J. C. Molyneux.	British Museum (Natural History).
Nyasaland	Henry Drummond, A. R. Andrew, and T. E. G. Bailey.	British Museum (Natural History).

Literature consulted.

W. AMALITSKY. 'Ueber die Anthracosien der Permformation Russlands' Palæontographica, vol. xxxix (1892) pp. 159–60. [*Palæomutela* founded for Permian species from Russia and from the Karroo Beds of South Africa.]

W. AMALITSKY.—'A Comparison of the Permian Freshwater Lamellibranchiata from Russia with those from the Karroo System of South Africa' Quart. Journ. Geol. Soc. vol. li (1895) pp. 337–49 & pls. xii–xiii. [*Palæanodonta* founded for species occurring in the Devonian, Carboniferous, and Permian Systems of Russia, etc., and South Africa.]

A. G. BAIN. 'On the Geology of Southern Africa' Trans. Geol. Soc. ser. 2, vol. vii (1856) pp. 175–92. [Reptiliferous or Karroo deposits regarded as of lacustrine origin, and probably equivalent to the Carboniferous Series of Europe, including in it two new species of shells under the genus *Iridina (?)*.]

M. BLANCKENHORN. 'Neues zur Geologie & Palæontologie Ægyptens: IV. Das Pliocän- & Quartärzeitalter' Zeitschr. Deutsch. Geol. Gesellsch. vol. liii (1901) p. 432.

W. BORNHARDT. 'Deutsch-Ost-Afrika—Geologie' vol. vii (1900) p. 462. [Refers to H. Drummond's discovery of Karroo fossils (shells, fishes, etc.) in North-Western Nyasaland.]

H. DRUMMOND. 'Notes on a recent Examination of the Geology of East-Central Africa' Rep. Brit. Assoc. (Aberdeen, 1885) 1886, p. 1032. [Mentions the occurrence at the northern end of Lake Nyasa of beds of uncertain age containing shells, etc., which are probably of lacustrine origin.]

H. DRUMMOND. 'Tropical Africa' London, 1888, pp. 183–99. [Refers to a species of Tellinidæ found in a shale at the northern end of Lake Nyasa—no statement as to geological age.]

E. J. DUNN. 'Further Notes on the Diamond-Fields of South Africa' Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 880. [Freshwater shells found in Kimberley Mines at a depth of 120 feet.]

G. R. VON FRAUENFELD. 'Beschreibung von sieben neuen Arten der Gattung *Vivipara*, Lam.' [Lake Nyasa, etc.] Verhandl. Zool.-Bot. Gesellsch. Wien, vol. xv (1865) pp. 531–33 & pl. xxii.

F. H. HATCH & G. S. CORSTORPHINE. 'The Geology of South Africa' London, 1905.

WHEELTON HIND. 'Notes on some Lamellibranchiate Mollusca obtained by Mr. Molyneux from the Sengwe Coal-field' [Southern Rhodesia] Quart. Journ. Geol. Soc. vol. lix (1903) p. 287. [Records the occurrence of *Palæomutela*, group *keyserlingi*, Amalitsky.]

C. F. JICKELI. 'Fauna der Land- & Süsswasser-Mollusken Nord-Ost-Afrikas' Nova Act. K. Leop.-Carol. Deutsch. Akad. Naturforsch. vol. xxxvii (1874) p. 235.

T. R. JONES. 'On some small Bivalve Shells from the Karroo Formation, South Africa' Geol. Mag. dec. iii, vol. vii (1890) pp. 409–10, woodcut on p. 558. [Describes and figures *Cyrena (?) neglecta*.]

T. R. JONES. 'On some Fossils from Central Africa' Geol. Mag. dec. iii, vol. vii (1890) pp. 553–58, woodcut figure. [Describes and figures *Iridina (?) oblonga*.]

G. LIEDER. 'Aus dem Deutsch-Ostafrikanischen Schutzgebiete' Mitt. Forsch. Gelehr. Deutsch. Schutzgeb. [Danckelmann, Berlin] vol. vii (1894) p. 272. [Alluvial deposits of northern coast of Lake Nyasa referred to, but no mollusca mentioned.]

E. VON MARTENS. 'Beschalte Weichthiere Ost-Afrikas' Deutsch-Ost-Afrika [K. Möbius] vol. iv (1898) pls. i–vii, pp. 46, 175–177. [Describes *Viviparus unicolor* var. *jeffreysi*, *Martensia mozambicensis*, etc.]

A. J. C. MOLYNEUX. 'The Sedimentary Deposits of Southern Rhodesia' Quart. Journ. Geol. Soc. vol. lix (1903) pp. 266–85. [Refers on p. 283 to unioniform shells in the Matobola Beds, regarded as of Permo-Carboniferous age.]

A. J. C. MOLYNEUX. 'On the Karroo System in Northern Rhodesia, & its Relation to the General Geology' Quart. Journ. Geol. Soc. vol. lxv (1909) pp. 408–38. [Refers to the occurrence of *Palæomutela* and *Estheria* in the Matobola Beds of this region, pp. 428, 429.]

A. MORELET. 'Séries Conchyliologiques, comprenant l'Énumération de Mollusques Terrestres & Fluviatiles, &c. Pt. 2. Iles Orientales de l'Afrique' 1860, pl. v, fig. 5, p. 72. [*Glandina boivini*.]

G. A. OLIVIER. 'Voyage dans l'Empire Othoman, l'Égypte & la Perse' [Paris] 1804 (= An xii). Atlas, pl. xxxi, fig. 9 & vol. iii, p. 68.

L. PFEIFFER. 'Descriptions of Forty-seven New Species of *Helicea* from the Collection of H. Cuming, Esq.' Proc. Zool. Soc. Lond. 1855, p. 91 & pl. xxxi, fig. 9. [*Helix mozambicensis*.]

A. W. ROGERS. 'An Introduction to the Geology of Cape Colony; with a Chapter on the Fossil Reptiles of the Karroo Formation, by Prof. R. Broom' London, 1905.

D. SHARPE. 'Description of some Remains of Mollusca from near Graaf Reinet' [South Africa] Trans. Geol. Soc. ser. 2, vol. vii (1856) pp. 225, 226 & pl. xxviii, figs. 2–4. [*Iridina?*]

E. A. SMITH. 'On the Shells of Lake Nyassa, &c.' Proc. Zool. Soc. Lond. (1877) 1878, p. 716 & pl. lxxiv, figs. 10–11. [*Lanistes solidus*.]

E. A. SMITH. 'Diagnoses of New Shells from Lake Tanganyika & East Africa' Ann. & Mag. Nat. Hist. ser. 5, vol. vi (1880) p. 428. [*Achatina kirkii* = *A. craveni*.]

E. A. Smith. 'On a Collection of Shells from Lakes Tanganyika & Nyassa & other Localities in East Africa' Proc. Zool. Soc. Lond. 1881, p. 283 & pl. xxxiii, fig. 11. [*Achatina craveni.*]

E. A. Smith. 'On a Collection of Land-Shells from British Central Africa' Proc. Zool. Soc. Lond. 1899, pp. 579–92 & pls. xxxiii–xxxv. [*Pomatias nyasanus.*]

R. Tate. 'On some Secondary Fossils from South Africa' Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 143. [Karroo shells from Kat River and Graaf Reinet are referred to, and regarded as of Triassic age.]

EXPLANATION OF PLATE XVIII & PLATE XIX (*pars*).

Plate XVIII.

[The figures on this plate are of the natural size, with the exception of fig. 5, which represents a magnification.]

Quaternary Gastropoda.

Viviparus unicolor (Olivier).

Fig. 1. An example of the limestone from Chisali, composed entirely of the casts of this gastropod. Natural size.
2. Wax reproduction of specimen made from the largest cavity represented on surface of fig. 1.
3. Front view of an isolated form from Chiwondo. Natural size.
4. Dorsal aspect of same specimen.
5. Surface of same, showing striated sculpture, magnified.

Lanistes solidus, E. A. Smith.

Fig. 6. Front aspect of a medium-sized example from Chiwondo. Natural size.
7. Dorsal view of the same specimen.

Tropidophora nyasana, E. A. Smith.

Fig. 8. Example of an adult form from Chiwondo, exhibiting a front view. Natural size.
9. Dorsal aspect of the same shell.

Plate XIX (*pars*).

[Figs. 13–18 have been drawn with the aid of the *camera lucida*, and are magnifications.]

Permo-Carboniferous Pelecypoda.

Palæomutela oblonga (T. R. Jones).

Fig. 11. External view of two right valves of different sizes attached to the matrix. Natural size.
12. Similar view of another right valve, showing the periodical growth-lines and fine intermittent striations. × 2.
13. Section of the posterior portion of the hinge-area of a fragmentary right valve, showing a succession of shell-growths forming narrow, elongate, >-shaped teeth. × 8.
14. Dorsal aspect of the specimen represented by fig. 12, exhibiting the segmented mineralized remains of the ligament reposing in the elongate posterior depression. × 8.

Permo-Carboniferous Crustacea (Phyllopoda).

Estheriella nyasana, sp. nov.

Fig. 15. External view of a pair of extended valves showing oblong form. × 8.
16. Enlargement of the same specimen, exhibiting growth-lines and obscure radial striations. × 30.
17. An example of a right valve of subquadrate contour. × 8.
18. Profile of a specimen with closed valves, showing moderate and regular convexity. × 8.

Appendix III.—Notes on Fossil Fish-remains from Nyasaland collected by Mr. A. R. Andrew and Mr. T. E. G. Bailey. By Ramsay Heatley Traquair, M.D., LL.D., F.R.S., F.G.S.

[Plate XIX *pars.*]

Nearly twenty-one years ago, the late Prof. Drummond placed in my hands some fragmentary fish-remains which he had brought with him from Maramura in Nyasaland, desiring me to write a few words about them, to be inserted in his book on 'Tropical Africa,' then in the press. The specimens were unfortunately very fragmentary, consisting, except in one case only, of detached scales and bones, and the time allowed me to make up my mind about them was only a couple of days: however, I gave names to two of them. One was a piece of the hinder part of a fish, evidently a member of the family Palæoniscidæ, to which I gave the name of *Acrolepis (?) drummondi*; the other was a detached scale which I supposed might also be palæoniscid in its nature, and doubtfully referred to the same genus under the name of *Acrolepis (?) africana*. Concerning the latter scale, I also noted that it bore considerable resemblance to some of the scales from the European Trias named by Agassiz '*Gyrolepis*.'

I had not then seen the paper by the late Prof. Dames on the Ganoids of the German Muschelkalk,[1] which was published in the same year (1888); when I did see it, I was struck by the general resemblance which this scale bore to those of *Colobodus*, as figured in that memoir, and especially to those of *Colobodus frequens*, Dames.

Some little time ago, Dr. A. S. Woodward, F.R.S., knowing that these two types were in Edinburgh, sent me a small collection of fish-remains collected by Messrs. Andrew & Bailey, also in Nyasaland, with the request that I would compare them with Drummond's original specimens, and furnish a few notes thereon. The specimens consist of portions of a hard, bluish-grey, calcareous shale, which in colour and consistency are identical with the stone forming the matrix of Prof. Drummond's specimens, whereby we are led to the conclusion that they were obtained from the same bed or beds, although the localities from which the two suites of specimens have been obtained are 20 or 30 miles apart. These pieces are mostly covered with an abundance of detached and jumbled scales of one species of fish, which I believe I am right in identifying with my '*Acrolepis (?) africana*.'

Fig. 1 (Pl. XIX) represents the specimen of '*africana*' collected by Drummond, and my original description of it is as follows:—

[1] W. Dames, 'Die Ganoiden des deutschen Muschelkalkes' in Dames & Kayser's Paläont. Abhandl. vol. iv, pt. 2 (1888).

'It [the scale] measures a quarter of an inch in height by the same in breadth; its shape is rhomboidal, having an extensive anterior covered area and a strong articular spine projecting from the upper margin. The free surface is brilliantly ganoid, and marked with furrows separating feeble ridges which pass rather obliquely downwards and backwards across the scale, and terminate in eight sharp denticulations of the hinder margin.'[1]

Fig. 2 (Pl. XIX) shows one of the scales collected by Messrs. Andrew & Bailey, magnified 4 diameters. It resembles in all essential particulars the one described above, though the articular spine is concealed in the matrix. The covered area is only slightly produced upwards at the anterior superior angle; the exposed area is brilliantly ganoid, and marked by furrows into eight feeble oblique ridges which are most conspicuous posteriorly, where they pass into sharp and prominent denticulations of that margin: the feeble ridges being again more prominent, though flattened, along the anterior margin of the ganoid area. A few punctures are also seen on the ganoid surface.

In fig. 3 the ornament is of the same general character, but more distinctly marked, and extends all over the surface. Here the articular spine, short and pointed, is well shown.

Fig. 4 shows a scale of larger size, which evidently had belonged to a fish of superior dimensions; its greater obliquity would likewise indicate a more ventral position. Here the whole free surface is covered by oblique ridges, sharp and strongly marked, slightly curved with the convexity downwards and occasionally bifurcating. Punctures are also present, and the posterior border is marked by several very pronounced sharp denticulations.

If the ridges and furrows are more pronounced on some scales, so in others the punctures are more conspicuous, as, for instance, in the portion of a large scale represented in fig. 5, magnified 3 diameters.

If it be now accepted that the scales in question belong to the species '*africanus*,' the question of their genus next comes before us. For *Acrolepis* the scales are rather too thin, the covered area proportionally not broad enough, and its anterior-superior angle not sufficiently produced, while the denticulated border is also against this reference. For, although Dr. A. S. Woodward has described and figured as *Acrolepis (?) digitata* some scales from the Karroo Formation with denticulated hinder margin, he expressly states that the name is only provisional. He rightly remarks, however, that this character is usually only of specific value, so that it does not absolutely forbid the inclusion in *Acrolepis* of a posteriorly denticulated scale.[2]

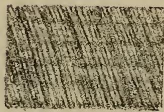
But I have already remarked on the resemblance of these scales to those of *Colobodus*, and it may now be asked whether there is any further evidence that their true position may be in this genus.

Among the specimens sent by Messrs. Andrew & Bailey is a dentigerous bone, which is represented twice the natural size in fig. 6. This bone seems to have consisted of a broad flattened portion which

[1] See Drummond's 'Tropical Africa' London, 1888, p. 194.

[2] 'Catal. Foss. Fishes Brit. Mus.' pt. ii (1891) pp. 508–509.

4.



mag.

5.

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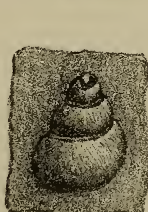

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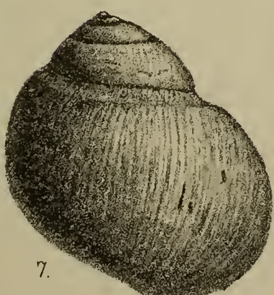

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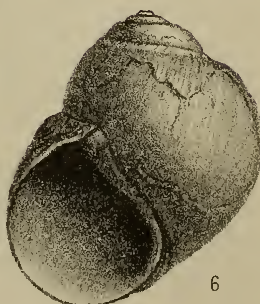
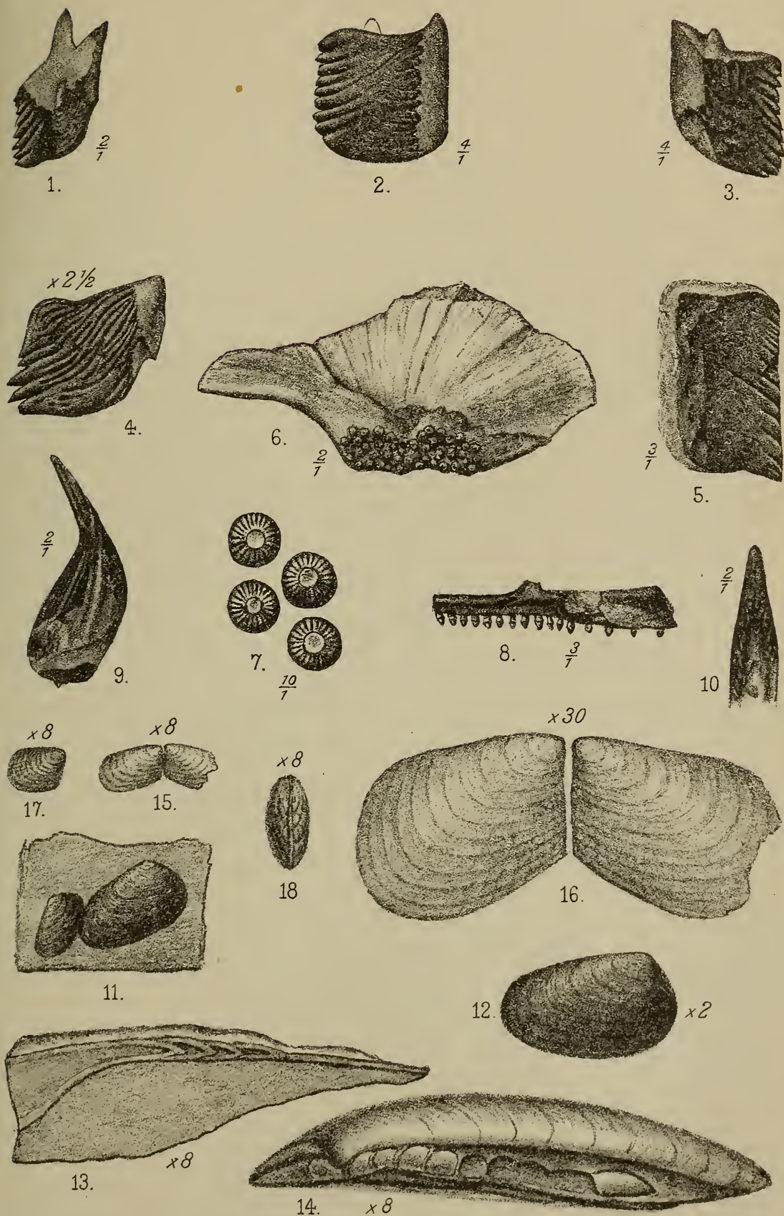


6

P. Highley del. et lith.

West, Newman imp.

QUATERNARY NON-MARINE CASTROPODA FROM NYASALAND.



P. Highley del. et lith. West, Newman imp.

PALÆOZOIC NON-MARINE FOSSILS FROM NYASALAND.

has flaked off, leaving only an impression behind, and a thickened margin, on which is situated a group of small teeth, four individuals of which, more highly magnified, are shown in fig. 7. These teeth are somewhat closely placed, are small, rounded, strongly striated vertically, with indications of an apical tubercle which is not surrounded by an annular furrow or depression.

Now, this is more or less the form of tooth described as occurring in *Colobodus*, ascribed also to *Serrolepis* by Dames; and if we assume that the above-described scales belong to the same species of fish as that which possessed this dentigerous bone, then *Colobodus* is the genus. Such a determination is rendered more probable by the resemblance, already more than once alluded to, of the scales of species referred to the last-mentioned genus. I would, therefore, propose that the name *Acrolepis (?) africana* should be replaced by *Colobodus africanus*.

Another dentigerous bone is shown in fig. 8, magnified three diameters. It is a small linear piece of bone, set with one row of minute cylindrical teeth, which appear to be quite smooth on the surface. I give no opinion as to the genus to which this bone should be referred.

As regards the Palæoniscidæ, the present collection also yields fragmentary evidence of their presence. In Pl. XIX, fig. 9 is represented the clavicle of a fish of this family, and in fig. 10 we see a caudal ridge-scale. It is manifestly impossible to name either the genus or the species to which these two relics should be referred.

EXPLANATION OF PLATE XIX (*pars*).

Fig. 1. Scale of *Colobodus africanus*, Traq., type, magnified 2 diameters. This, along with the other specimens brought home by Prof. Drummond, is in the Royal Scottish Museum, Edinburgh.
2. Scale of the same, magnified 4 diameters.
3. Another scale of the same, magnified 4 diameters.
4. A larger scale of the same, magnified $2\frac{1}{2}$ diameters.
5. Portion of a large scale of the same, magnified 3 diameters.
6. Dentigerous bone, magnified 2 diameters (*Colobodus africanus ?*).
7. Four teeth from the above-mentioned bone, highly magnified.
8. Dentigerous bone, magnified 3 diameters. Genus unknown.
9. Clavicle of Palæoniscid, magnified 2 diameters.
10. Caudal ridge-scale of Palæoniscid, magnified 2 diameters.

Discussion.

Dr. J. W. Evans congratulated the Authors on the excellent work which they had carried out over a large area in the comparatively brief period of three years. He regretted that it had not been possible to continue the survey. He thought that the notes of Dr. Traquair on the fish-remains, as also the absence of *Gangamopteris*, suggested that the Nyasa Karroo beds occupied a high position in the Karroo System, and that the basement boulders and conglomerates belonged to a higher horizon than the Dwyka glacial beds. He believed that the Authors themselves contemplated the possibility of this being the case. The presence of boulders could be easily explained by torrent-action on mountain-slopes.

Mr. Lamplugh expressed his confidence that everyone interested in South African geology would appreciate the careful work of the Authors in Nyasaland. Respecting the correlation of the complicated rock-systems older than Karroo, it was premature to speculate until further results had been obtained by the numerous capable investigators now working on these rocks in the more southerly parts of the continent. As regarded the Karroo System, it was instructive to find that its general characters and tectonic relations in Nyasaland were very similar to those in North-Western Rhodesia recently described by Mr. Molyneux. It is known that in several other districts these deposits were cast down on a very uneven floor, which introduces a factor to be reckoned with in deciphering their present relations. The Authors were to be commended for exercising caution in discussing the Karroo conglomerates, as it would be unfortunate if the difficult problem of the glacial Dwyka of South Africa should be confused by ill-founded correlations. The speaker regretted that time did not allow of the discussion of other interesting matters contained in the paper.

9. *The* Igneous *and* Associated Sedimentary Rocks *of the* Glensaul District (County Galway).

By Charles Irving Gardiner, M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S. *With a* Palæontological Appendix by Frederick Richard Cowper Reed, M.A., F.G.S. (Read January 12th, 1910.)

[Plates XX–XXII.]

Contents.

I. Introduction.

The district is a small one, having a maximum length from south-west to north-east of little more than 2 miles, and a width of about a mile. Its north-eastern margin lies about 3 miles south-west of Tourmakeady Lodge, the southernmost point in the area recently described by us.[1] That portion of the district with which this paper deals consists of the valley of the Glensaul River, together with the hills lying to the south-west, which rise to a height of 925 feet above sea-level at Lettereeneen and to nearly 700 feet at Greenaun.

The area of Ordovician rocks, with which this paper is concerned, is roughly quadrilateral in shape. It is bounded by peat and drift on its southern side, partly by peat and drift and partly by grit and conglomerate of ? Bala age on its northern side, while its western and its eastern sides are bounded by faults.

The western fault, very clearly seen along a stream-course that runs northwards down the slope of Lettereeneen, brings a fairly coarse quartzose conglomerate, forming the actual summit of the hill, against the Ordovician rocks. This conglomerate contains large felsite pebbles and smaller ones of quartz, and of red and black chert, and is quite different from the coarse conglomerate of

[1] Quart. Journ. Geol. Soc. vol. lxv (1909) pp. 104–53.

Arenig age, to be described below (p. 255). We have found no fossils in it, and an account of it is beyond the purpose of this paper, but we class it with the grits and conglomerates found on the northern side of the area as of ? Bala age.

The eastern fault which brings a coarse conglomerate of probably Arenig age against the tuffs of the area that we are describing is nowhere actually seen, this part of the country being much obscured by peat and drift.

The Glensaul district is much more faulted than that of Tourmakeady, as in addition to the big faults bounding the area on the east and west, it is cut in two by a system of faults which have had the general effect of dividing the rocks into two principal portions, and of shifting the western portion to the north-west, and at the same time of introducing a wedge-shaped and much faulted mass of country of complicated structure between the two principal portions.

However, despite the large amount of faulting, the general succession of the rocks is easily ascertained, as they succeed one another in regular ascending order from south to north, and dip, in the main, regularly to the north-north-west at about 45°.

At the outset of our previous paper dealing with the rocks of the Tourmakeady district, the scanty literature bearing upon the geology of that area is summarized[1]; and, as in those descriptions the Tourmakeady and Glensaul districts are invariably treated together, we consider it unnecessary to repeat the references given in our previous paper.

At the meeting of the British Association for the Advancement of Science at Dublin in 1908, a committee was appointed[2] to investigate the igneous and associated rocks of the Glensaul and Lough Nafooey districts in County Galway. A report on the rocks of the Glensaul district was presented at the Winnipeg meeting in 1909. In that report the same general succession was given as that described in the following pages. The Mount Partry Beds were, however, referred to as of Arenig age and the Shangort and Tourmakeady Beds as of Llandeilo age, the evidence which now leads Mr. Reed to correlate these latter deposits in both the Glensaul and Tourmakeady areas mainly with the Arenig rather than with the Llandeilo Series not being then available.

II. The Sedimentary Rocks and the Tuffs.

(a) The Mount Partry Beds.

These rocks are finely exposed along almost the whole of the southern side of the district, and the making of the new road to Barnahowna has considerably added to the facilities for their study. They consist of almost exactly the same rocks as in the Tourmakeady

[1] Quart. Journ. Geol. Soc. vol. lxv (1909) p. 105.

[2] Consisting of Prof. W. W. Watts, Mr. H. B. Maufe, and the authors of the present paper.

district: namely, coarse conglomerate, black graptolitic beds, black or grey radiolarian chert, coarse and fine grits, and subordinate tuffs.

We will now describe the exposures of these beds.

(1) On the southern slopes of the ridge running eastwards from the top of Lettereeneen.—This is by far the largest area occupied by the Mount Partry Beds, and the finest and most complete section is here exposed. The succession is as follows, in descending order:—

	Thickness in feet.
(4) Coarse grits	150
(3) Fine grits and tuffs, associated with black radiolarian cherts and graptolitic beds, and with a prominent band of coarse tuff or breccia about 30 feet thick	(?) 150
(2) Coarse grits	about 110
(1) Coarse conglomerate	about 600 seen

The coarse conglomerate, the blocks in which are mainly of grit, often reaching a length of 2 feet, is finely exposed in the stream-courses and road-tracks lying north of the village of Lettereeneen; also in a deep little ravine close to the road, and nearly due south of the top of Lettereeneen Hill, where it is seen faulted against cherts and grits.

The coarse grits, which closely resemble those of the Mount Partry neighbourhood, Tourmakeady, are seen at various points on the hillside, and probably occupy the greater part of a stretch of drift-covered country lying north of the conglomerate outcrop.

None of the rocks forming Band 3 are exposed very continuously along the hillside; but they are readily traceable, the cherts by fragments on the hillside and by occasional exposures, the breccia by a more continuous outcrop. The graptolitic beds are nowhere exposed in place, until a point nearly due south of the top of Lettereeneen Hill is reached. Here they are well seen in some watercourses which score the hillside, and are associated with a much disturbed series of black and banded radiolarian chert and fine tuff and grit. At the spot marked 334 on the map (Pl. XX) graptolites are very abundant, and the following have been very kindly determined for us by Miss G. L. Elles, D.Sc.:—

Clonograptus lapworthi, Rued.
Dictyonema.
Didymograptus affinis, Nich.
Didymograptus bifidus, Hall (common).
Didymograptus extensus, Hall (common).
Didymograptus fasciculatus, Nich. (1 specimen).
Didymograptus filiformis, Tullberg.
Didymograptus gracilis, Törnquist.
Didymograptus nanus, Lapw. (common).
Didymograptus nicholsoni, Lapw.
A Dendrograptid.
Glyptograptus dentatus, Brongn. (1 specimen).
Tetragraptus amii, Lapw. MS.
Tetragraptus fruticosus, Hall.
Tetragraptus pendens, Elles (three specimens).
Tetragraptus quadribrachiatus, Hall.
Tetragraptus serra, Brongn.
Thamnograptus sp.
? *Trichograptus fragilis*, Nich. (common).

Miss Elles considers that this assemblage proves that these beds belong to the upper part of the zone of *Didymograptus extensus*. In our previous paper[1] we quoted Miss Elles as assigning the graptolitic fauna of the Treanlaur stream near Tourmakeady to about the *Didymograptus-hirundo* horizon, that is, to a slightly higher horizon than that of the Lettereeneen beds. Stratigraphical considerations, however, render it very probable that the two sets of beds are approximately on the same horizon, and Miss Elles informs us that the fossil evidence is not inimical to this view; she further points out that the *Didymograptus bifidus* which is abundant at both these localities is a small and early mutation of the form characteristic of the *bifidus* zone proper.

In addition to the main outcrop of these beds, Bands 4 & 3 and part of Band 2 are repeated by a strike-fault running close to the top of the ridge on its northern side. But, although fragments of black chert litter the ground along the line where Band 3 occurs, no actual exposures are here seen, either of the chert or of the graptolitic beds.

The coarse tuff or breccia in Band 3 is a noteworthy rock. The fragments, which sometimes have a length of about 2 inches, show a pure white on a weathered surface, and the contrast between this and the black matrix in which they are embedded renders the rock very conspicuous. Under the microscope, the fragments are seen to consist of quartz-felsite and the matrix to be very felspathic and quartzose.

Sections of cherts and fine, more or less silicified tuffs, from several points along the line of outcrop of Band 3, disclosed the presence of radiolaria similar to those described by us from the Tourmakeady district.

(2) On the southern slopes of Greenaun Hill.—This area, which has a visible length of about a third of a mile, is almost continuous with that just described. It is bounded by faults on all sides, except on the southern one, where it is covered up by peat and drift. The rocks are finely exposed in certain cuttings due to the making of the new road from Cappaghduff West to Barnahowna. The most noteworthy feature of these exposures is the extraordinary amount of disturbance which the rocks show, the chert bands being puckered and disrupted in a manner that can be better illustrated by photographs (see fig. 1, p. 257) than by descriptions.

All the rock-types described as occurring in the district farther to the west can be noted here, and the intimate association of the cherts and tuffs is very well seen, the cherts clearly owing their origin to the silicification of beds of very fine tuff. The chert bands reach a considerable thickness, one being at least 3½ feet thick; but it is possible that, in some cases, the apparent thickness may be due to the crumpling together of several bands and the squeezing out of intervening beds. No graptolites were found in this area.

[1] Quart. Journ. Geol. Soc. vol. lxv (1909) p. 108.

(3) Between the two principal masses of felsite.—Here is a triangular area of Mount Partry Beds, bounded by faults on every side. The rocks are ill-exposed (except in some small water-courses), and consist mainly of coarse grit, but cherts are also to be seen.

Fig. 1.—*Tuffs and banded cherts of Arenig age, exposed in a road-cutting south-west of Greenaun. The rocks are much disturbed.*

(*b*) The Shangort and Tourmakeady Beds.

As in the Tourmakeady district, the Shangort Beds consist of a series of more or less gritty tuffs enclosing calcareous bands of variable character comparable with those described as the Tourmakeady Beds in our previous paper. The Glensaul succession, however, differs from that in the Tourmakeady district in the much more frequent occurrence of very coarse breccias, and in the considerable development of well-marked calcareous bands, which sometimes pass into nearly pure limestones, but are, as a rule, highly calcareous grits or gritty tuffs, differing from some of the

Shangort Beds in the Tourmakeady district only in their relatively more calcareous character.

The lithological distinction which we found it convenient to draw in the Tourmakeady district between the Shangort and the Tourmakeady Beds scarcely holds in the Glensaul district, and we consequently describe the two sets of deposits together.

The succession of these rocks is as follows, in descending order:—

	Thickness in feet.
(4) Variable grits and tuffs with graptolitic beds and many calcareous bands, principally of limestone breccia, and a thick series of coarse tuffs or breccias	?
(3) Felsite of Greenaun and Tonaglanna	1100
(2) Grits and tuffs	470
(1) Coarse breccia of Lettereeneen	75

The cross-faults which traverse the district divide it into three portions. In the eastern (or Greenaun and Garranagerra) portion, the most complete series of the grits and tuffs overlying the felsite occurs; but the associated calcareous bands are little developed, and the series underlying the felsite is imperfectly seen.

In the middle portion, tuffs which we consider to be the equivalents of those overlying the felsite are well exposed, though here part of the felsite and the tuffs underlying it are entirely faulted out. It is in this portion of the area that the finest development of the calcareous rocks occurs.

In the western (or Tonaglanna and Lettereeneen) portion, nothing is seen of the rocks overlying the felsite; but there is a fine development of the rocks lying between it and the Mount Partry Beds. The following exposures of these beds have been studied by us.

(1) The Garranagerra and Greenaun exposures.—The rocks underlying the Greenaun felsite are seen in scattered exposures all along the southern face of the hill. About a third of a mile to the east of the summit, the succession is in descending order:—

		Thickness in feet.
(3) Coarse grit	about	20
(2) Gritty tuff		420
Gap covered by peat		240
(1) Very coarse tuff or breccia	seen	40

The gritty tuff is similar to the Shangort Beds prevalent in the Tourmakeady district, and to those immediately to be described which occur on the northern slopes of the Lettereeneen ridge, where they underlie a thin band of coarse grits and overlie a coarse breccia, both these rocks being exactly similar to those occurring in the area under consideration.

The very coarse tuff is only seen in one isolated exposure about a third of a mile east-south-east of the summit of Greenaun, and is composed of large fragments of felsite, some of them amygdaloidal. No fossils were found in any of these beds. North-west of the

Greenaun felsite, and overlying it, is a fine section, showing the following succession, in descending order :—

	Thickness in feet.
(3) Calcareous gritty tuff, with some small patches of limestone breccia and one of graptolitic beds	180
(2) Very coarse tuff or breccia, with impersistent bands of fine tuff	750
(1) Tuff, coarse and fine, with two calcareous bands and one patch of graptolitic beds	150

All these rocks dip regularly in a north-westerly or north-north-westerly direction. Band 1 consists of tuff, containing fragments (chiefly of felsite) reaching the length of an inch or more. For much of its outcrop it is ill-exposed, being often covered by peat; but at its western end, near the fault, it is finely seen. Here it includes a band of limestone (97),[1] while a second band extending westwards from the bed of a stream half a mile farther east underlies a graptolitic bed (148).

The second of these bands is of limestone breccia exactly similar in character to those present in the Tourmakeady district,—that is, consisting of angular fragments of limestone and of felsite embedded in a matrix of calcareous grit. There is no evidence of crushing in connexion with this deposit.

The first-mentioned deposit (97) is of quite a different character, consisting of blocks or wisps of limestone mingled with crushed and twisted masses of shale, the whole giving the clearest possible evidence of strong disturbance. This deposit occurs along a marked line of fault, and doubtless represents what was once a series of beds of limestone and shale now converted into a mass of fault-breccia. The limestone of these blocks is red, grey, or white, and of crystalline or horny texture. From some of these, and especially from those consisting of red crystalline limestone, we obtained the following fossils :—

Camerella cf. *cuneatella*, Dav. (very common).
Camerella sp.
Lingula sp.
Orthis obtusa, Pander.
Orthis parva, Pander.
Plectambonites sericea, Sow.
Porambonites sp.
Holopella sp.
Trochonema aff. *umbilicatum*, Hall.
Subulites elongatus, Ang.
Bronteopsis sp.
Cheirurus sp.
Bathyurellus sp.
Illænus weaveri, Reed.
Illænus sp.
Remopleurides sp.
Telephus hibernicus, Reed.

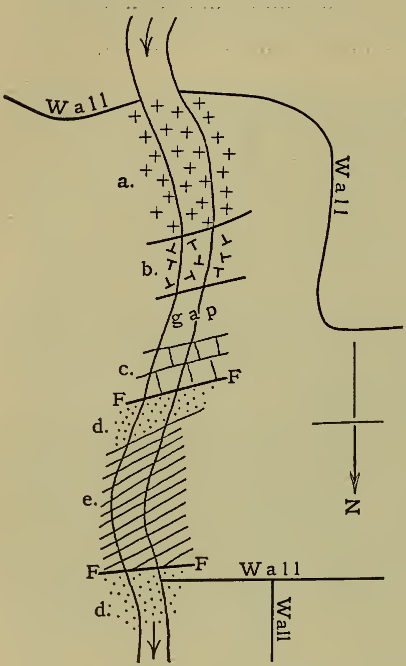
The section at the spot numbered 148 merits a further description, as it is the only important place where we found graptolitic beds interbedded among the ashy and calcareous series (Shangort and Tourmakeady Beds).

The rocks are exposed in the bed of a streamlet which, flowing northwards from the felsite forming the Greenaun ridge, enters the Glensaul river south of Garranagerra. The main felsite mass

[1] These numerals in parentheses indicate the localities where specimens were collected, and are shown on the map (Pl. XX).

gives rise to a little waterfall, and below this is an exposure of a nodular felsite of a peculiar character. Then, after a slight gap, comes the limestone breccia, above mentioned. This is seen in the stream-bed, and is easily traceable over the fields to the west for a distance of 100 yards or more. Then follow gritty tuffs apparently striking with the limestone breccia, that is, west-south-westwards; and next come very fine, dark, argillaceous tuffs, which occupy the stream for a distance of a little over 20 yards. These dip north-north-westwards at 75° to 80°, their junction with the gritty tuffs showing disturbance. They contain rounded bodies, which comparison with the better-preserved examples from other parts of the area shows to be almost certainly radiolaria; and the following graptolites were found in them:—*Didymograptus extensus*, Hall, *D. gibberulus*, Nich. (several well-preserved specimens), *D. hirundo*, Salt., and *D. nitidus*, Hall. These indicate the zone of *Didymograptus hirundo*. They are succeeded by more gritty tuffs (Shangort Beds), the junction with which is not very clear.

Fig. 2.—*Plan of part of a stream half a mile south of Garranagerra.*



[The length shown is about 100 yards.]

a = Main felsite mass of Greenaun.
b = Nodular felsite.
c = Limestone breccia.
d = Gritty tuff.
e = Fine dark argillaceous tuff, with graptolites and radiolaria.
F = Fault.

As regards its appearance in the field, Band 2 (see fig. 3, p. 261), the coarse tuff or breccia, is perhaps the most remarkable deposit of the district. It consists of a fine ashy quartzose matrix, throughout which are closely scattered blocks of felsite reaching a length of 8 inches or more. These usually have weathered more rapidly than the matrix in which they are embedded. At one point near the river, about 200 yards north-north-west of Glensaul School, the rock becomes a conglomerate rather than a breccia. Band 3 is seen immediately west of the footbridge, and consists of calcareous gritty tuff exactly like the prevalent type of Shangort Beds in the Tourmakeady area, except that it is rather more calcareous when fresh. We obtained the following fossils at the spot marked (62):—

Orthis obtusa (?), Pander.
Orthis sp.
Rafinesquina imbrex, var. *semi-globosina*, Dav.
Plectambonites quinquecostata (?), M'Coy.
Plectambonites sericea, Sow.
Porambonites sp.
Cystidean (? *Echinosphæra* sp.).
Bathyurus aff. *nero*, Billings.
Bathyurus cf. *timon*, Billings.
Bathyurellus glensaulensis, sp. nov.
Nileus armadillo, Dalm.
Illænus sp.
Megalaspis (?) sp.
Remopleurides sp.
Cheirurus cf. *clavifrons*, Dalm.
Cheirurus aff. *ornatus*, Dalm.
Pliomera pseudoarticulata, Portl.
Pliomera cf. *barrandei*, Billings.
Encrinurus octocostatus, sp. nov.
Cybele sp.
Phacops (Chasmops) aff. *odini*, Eichw.
Harpes sp.
Platyceras (?) sp.

Fig. 3.—*Coarse volcanic breccia (Shangort Beds) north-east of Glensaul School. The fragments tend to weather more quickly than the matrix.*

Although this deposit is the highest in the district from which we obtained any fossils, except poorly preserved graptolites, the fauna, as pointed out by Mr. Reed in his Palæontological Notes (p. 271), is rather of an Arenig than of a Llandeilo type, and indicates that the entire gritty, ashy, and calcareous series (Shangort and Tourmakeady Beds) of both the Glensaul and the Tourmakeady districts represents a somewhat lower horizon than we believed to be the case at the time when our paper on the Tourmakeady district was published.

A small band of limestone breccia overlies this fossiliferous deposit, running for a short distance west-north-westwards from under the footbridge; and two other small patches occur near the bend of the stream, about 200 yards to the west.

Exactly at this bend, and again at a spot about 50 yards below the bridge, thinly-bedded, black and grey, cherty beds are seen. In the latter patch (397) a few badly preserved graptolites were found. These were determined by Miss Elles to be *Glyptograptus dentatus* (Brongn.) and possibly *Didymograptus extensus* (Nich.). Both patches show considerable disturbance.

(2) The exposures between Tonaglanna and Glensaul School.—In this area there is a far finer development of the calcareous beds than anywhere else in the district. The successive bands of tuff, described as occurring in the Greenaun and Garranagerra area, are not here very clearly distinguishable, although coarse tuff occurs along the margin of the felsite mass which (as seen in the map, Pl. XX) is faulted northwards from the Greenaun felsite. West of this, and immediately north of the triangular patch of Mount Partry Beds faulted in to the west of the felsite, occurs an interesting development of calcareous rocks well exposed in certain old quarries. The upper part of this calcareous series consists of limestone breccia; below this, however, comes a broken-up mass of limestone which we do not regard as limestone breccia, that is, as a rock produced by explosive action, but as a limestone shattered by earth-movement, like the one already described at (97). This limestone (155) is highly fossiliferous, and we obtained from it the following species:—

Hyolithes aff. *dispar*, Holm.
Orthis cf. *balclatchiensis*, Dav.
Orthis obtusa (var.), Pander.
Orthis parva, Pander.
Plectambonites sericea, Sow.
Plectambonites (?) grayæ, Dav.
Christiania youngiana, Dav.
Porambonites sp.
Lingula sp.
Crinoid stems.
Illænus weaveri, Reed.
Illænus sp.
Niobe sp.
Sphærocoryphe sp.
Orthoceras (?) sp.
Trochonema sp.
Lophospira sp.
Cyclonema sp.
Liospira sp.
Loxonema (?) sp.

On the same line of strike, a short distance to the north-east, is a small patch of dolomitized limestone not broken up in any way.

North-east of this exposure occur three more or less continuous bands of limestone breccia, striking in a north-north-easterly direction. They are surrounded by tuff, in the main fine and gritty, but sometimes becoming coarse. Farther west a less continuous fourth band of limestone breccia may be traced.

Throughout this part of the area the prevalent rocks are coarse breccias, probably corresponding to Band 3 in the Greenaun and Garranagerra area, although the fragments weather differently, tending to stand out from the matrix rather than to weather more rapidly than it. Farther north, in the neighbourhood of the road and river, come highly calcareous gritty tuffs passing at times into nearly pure grey limestones. The tuffs correspond exactly to those forming Band 3 in the Greenaun and Garranagerra region. The following fossils were found here in the limestone bands:—*Orthis testudinaria*, Dalm., and *Streptis affinis*, Reed; in the more easterly band at 353, and a little farther north-east, *Calymene* sp., *Pliomera* sp., *Orthis testudinaria*, Dalm., and a Meristellid; in the more westerly band at 361 we found *Nileus armadillo*, Dalm., *Cheirurus (?)* sp., *Orthis* sp., *Plectambonites sericea*, Sow.; and in the bed of the stream at 354, along the same line of strike a few yards to the north-east, *Illænus* sp., *Lingula brevis (?)*, and *Siphonotreta (?)* sp.

Throughout this central area neither the tuffs, whether fine or coarse, nor the limestone breccias show any trace of bedding, and in consequence their dip and their thickness are not ascertainable. The limestone-breccia bands, however, give the strike, and the limestone exposed in the Glensaul river-banks has the prevalent north-north-westerly dip of the great majority of the rocks of the district.

It is definitely stated in the Geological Survey Memoir that the limestone bands are bent into anticlinal curves[1]; and, if this be so, the four limestone-breccia bands shown in the map might be all merely repetitions of one or two bands, but of this we are unable to obtain any evidence.

The breccia is almost entirely made up of angular fragments of white and grey limestone, but fragments of felsite and of bright red chert also occur.

(3) The Tonaglanna and Lettereeneen exposures.—No Shangort or Tourmakeady Beds are seen in this area overlying the felsite. Underlying it is a fine section, showing the following bands in descending order:—

	Thickness in feet.
(4) Coarse grit	20
(3) Gritty tuff, with cherty bands towards the base	520
(2) Coarse breccia	75
(1) Fine banded tuff	55

By far the most conspicuous band is the coarse breccia which forms the summit of the ridge stretching north-eastwards from the

[1] Explan. of Sheets 73, 74 (in part), 83, & 84, Mem. Geol. Surv. Ireland, 1876, p. 67.

Fig. 4.—*Section (I on the map, Pl. XX) from Garranagerra to Greenaun.*

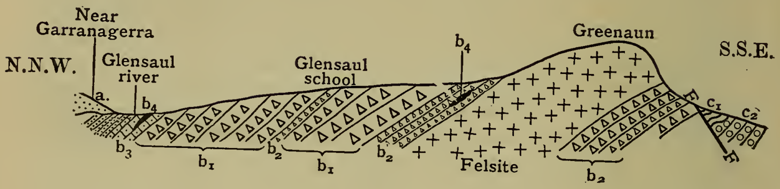


Fig. 5.—*Section (II on the map, Pl. XX) from Glensaul to the ridge west of Greenaun.*

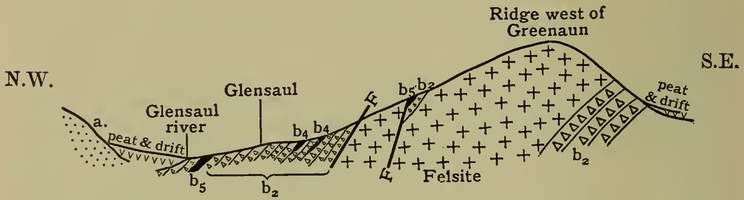
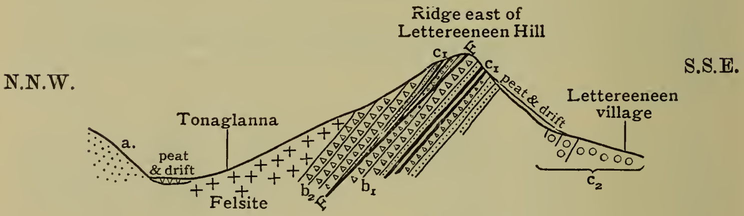


Fig. 6.—*Section (III on the map, Pl. XX) from Tonaglanna to the ridge east of Lettereeneen Hill.*



a = ? Bala Beds.

b = Shangort and Tourmakeady Beds (Arenig).
- b_1 = coarse tuff.
- b_2 = fine tuff.
- b_3 = calcareous tuff.
- b_4 = limestone breccia.
- b_5 = limestone brecciated by earth-movement.

c = Mount Partry Beds (Arenig).
- c_1 = cherts, fine grits and tuffs.
- c_2 = coarse conglomerate.

[Scale: 4 inches = 1 mile.]

top of Lettereeneen, and is finely exposed in many large ice-worn surfaces. As has been already mentioned when dealing with the Mount Partry Beds, a strike-fault repeats their upper part and the base of the Shangort Beds; but the series, when repeated by the fault, does not show by any means so fine a development of the coarse breccia as that forming the crest of the hill. The blocks in the coarse breccia consist of felsite, and the matrix has the character of a gritty ash.

Bands 1 & 3 do not require any special description, but Band 4 is a coarser rock and more definitely a grit than is generally met with in the Shangort Beds of the district: it resembles that underlying the felsite of the Greenaun ridge.

III. Table of Fossils from the Shangort and Tourmakeady Beds.

Names of Genera and Species.	Brecciated limestone, half a mile south-south-west of Glensaul School (97).	Brecciated limestone, a third of a mile south-east of Tonaglanna (155).	Ashy & gritty limestone & calcareous grit, 440 yards west-south-west of Glensaul School (353).	Ashy & gritty limestone & calcareous grit, half a mile west-south-west of Glensaul School (361).	Ashy & gritty limestone by foot-bridge a quarter of a mile south-south-west of Garranagerra (62).
Camerella cf. *cuneatella*, Dav.	+				
Camerella thomsoni, Dav.	+	...	...	...	+
Christiania youngiana, Dav.	...	+			
Lingula sp.	+	+	...	+	
Lingula brevis, Portl. (?)	...	...	...	+	
Indeterminable Meristellid	...	...	+		
Orbiculoidea (?) sp.					
Orthis sp.	+	...	...	+	+
Orthis cf. *balclatchiensis*, Dav.	...	+			
Orthis obtusa, Pander (var.)	+	+	...	...	+
Orthis parva, Pander	+	+			
Orthis testudinaria, Dalm.	...	...	+		
Plectambonites (?) grayæ, Dav.	...	+			
Plectambonites quinquecostata (?), M'Coy.	...	...	...	...	+
Plectambonites sericea, Sow.	+	+	...	+	+
Porambonites sp.	+	+	...	...	+
Rafinesquina imbrex, var. *semiglobosina*, Dav.	...	...	...	...	+
Siphonotreta (?) sp.	...	...	...	+	
Streptis affinis, Reed	...	...	+		
Bathyurellus glensaulensis, sp. nov.	...	...	...	...	+
Bathyurellus sp.	+				
Bathyurus aff. *nero*, Billings	...	...	..	...	+

Table of Fossils (*continued*).

Names of Genera and Species.	Brecciated limestone, half a mile south-south-west of Glensaul School (97).	Brecciated limestone, a third of a mile south-east of Tonaglanna (155).	Ashy & gritty limestone & calcareous grit, 440 yards west-south-west of Glensaul School (353).	Ashy & gritty limestone & calcareous grit, half a mile west-south-west of Glensaul School (361).	Ashy & gritty limestone by foot-bridge a quarter of a mile south-south-west of Garranagerra (62).
Bathyurus cf. *timon*, Billings	...	...	...	...	+
Bronteopsis sp.	+				
Calymene sp. (aff. *nivalis*, Salter)	...	...	+		
Calymene sp.	...	...	+		
Cheirurus cf. *clavifrons*, Dalm.	...	...	...	...	+
Cheirurus aff. *ornatus*, Dalm.	...	...	...	...	+
Cheirurus (Pseudosphærexochus) sp. ...	+				
Cheirurus sp.	...	...	...	+	
Cybele sp.	...	...	...	...	+
Encrinurus octocostatus, sp. nov.	...	...	...	...	+
Harpes sp.	...	...	...	...	+
Illænus weaveri, Reed	+	+			
Illænus sp.	+	+	...	+	+
Megalaspis (?) sp.	...	...	...	...	+
Nileus armadillo, Dalm.	...	...	...	+	+
Niobe sp.	...	+			
Phacops (Chasmops) aff. *odini*, Eichw. .	...	...	...	...	+
Pliomera cf. *barrandei*, Billings	...	...	...	...	+
Pliomera pseudoarticulata, Portl..........	...	...	...	...	+
Pliomera sp.	...	...	+		
Remopleurides sp.	+	...	...	...	+
Sphærocoryphe sp.	...	+			
Telephus hibernicus, Reed	+				
Crinoid stems................................	...	+			
Cystidean (? *Echinosphæra* sp.)	...	...	...	...	+
Cyclonema sp.	...	+			
Holopella sp.	+				
Liospira sp.	...	+			
Lophospira sp.	...	+			
Loxonema (?) sp.	...	+			
Platyceras (?) sp.	...	...	...	...	+
Trochonema aff. *umbilicatum* (Hall) ...	+				
Trochonema sp.	...	+			
Hyolithes aff. *dispar*, Holm...............	...	+			
Subulites elongatus, Ang. (?)	+				
Orthoceras (?) sp.	...	+			

IV. The Field-Relations of the Crystalline Igneous Rocks.

(*a*) The Main Felsite Mass.

In both the Glensaul and the Tourmakeady districts felsites are by far the most important igneous rocks: while in the latter district, however, they not only occur in extensive masses, but also in numerous minor intrusions, in the former, besides those forming the large masses near Tonaglanna and Greenaun, only two small patches are met with. The latter mass has its western portion shifted slightly northwards by a fault; and, though the Tonaglanna mass is separated by sedimentary beds from the Greenaun mass, there can be no doubt that all these portions were originally one continuous intrusion. Each has a width of about 450 yards and a thickness, judging by the dip of the adjacent beds, of about 1100 feet. The rock is almost everywhere very uniform in appearance, having a more or less brown groundmass, through which are scattered numerous conspicuous crystals of quartz and small dark irregular patches representing pseudomorphs after pyroxenes.

As regards its structure, and especially in the size and prominence of the quartz phenocrysts, this felsite bears a much greater resemblance to the intrusive felsites of the Tourmakeady district than to those which we there regard as contemporaneous flows; and for this, and for other reasons, the probabilities are strongly in favour of its being also an intruded rock.

But while the chief intrusive felsites of the Tourmakeady district are clearly of the nature of bosses bearing no relation to the lie of the strata, the felsite in the Glensaul district is evidently a sill in the main following the bedding, although at one point near its south-western border the Greenaun felsite mass appears to break across the bedding of the Shangort Beds.

(*b*) The Small Felsite Intrusions.

(1) We have already described the occurrence, almost due north of Greenaun summit, of a stream which runs northwards off the felsite mass and exposes a band of limestone breccia and some graptolitic beds. Between the main felsite mass and the limestone breccia a small exposure of a green nodular felsite is seen in the stream-bed: this may be intruded into the Shangort tuffs.

(2) Immediately south of the road from Glensaul School to Tonaglanna, and about half way between the two places, is a small exposure of a light green felsite. Its specific gravity is 2·66.

(3) About 250 yards to the east of this intrusion is another small mass of a pale-grey quartz-felsite. Owing to surface-deposits, its extent is not clear. Specific gravity = 2·69.

V. Petrographical Details.

Owing to the close resemblance which the Glensaul rocks bear to those of Tourmakeady, which we have already described, a brief reference to their principal characteristics will here suffice.

(*a*) The Felsites.

(1) The main felsite mass.—The rocks of this mass are everywhere singularly uniform in character. In a hand-specimen they are brown in colour, and as a rule show prominent quartz phenocrysts. The specific gravity of eleven of these rocks was taken, and ranged from 2·64 to 2·71, the average being 2·68. The ground-mass is always imperfectly spherulitic, and the large and numerous quartz phenocrysts are strongly corroded by it. The other minerals present are felspar, in a much weathered state; rhombic pyroxene, replaced by green pseudomorphs; and magnetite. The presence of the two last-named minerals in considerable quantities is the most noteworthy feature of the rock.

(2) The small felsite intrusions.—The only one of these that requires any special description is the peculiar nodular rock from near the boundary of the main felsite mass due south of Garranagerra. This rock is exactly similar to that from stream F, in the Tourmakeady district, described on p. 134 of our previous paper. The nodules consist of white quartz.

The other small intrusions resemble the main mass in petrographical characters.

(*b*) The Tuffs.

These may be divided into: (1) tuffs belonging to the Shangort and Tourmakeady Beds, and (2) tuffs belonging to the Mount Partry Beds.

(1) Tuffs belonging to the Shangort and Tourmakeady Beds.—These include (α) fine gritty tuffs; (β) limestone breccias; and (γ) coarse felsite breccias.

(α) The constituent elements of the fine tuffs are:—

(1) Lapilli, commonly of felsite, which often show a semi-spherulitic character.
(2) Quartz grains. } also derived from the felsite.
(3) Broken felspar crystals. } also derived from the felsite.
(4) A calcareous matrix.

These elements are variously combined in different varieties of tuff, but the prevalent type consists principally of felsite lapilli and quartz grains, sometimes with a little calcareous matrix. By the increase in the proportion of quartz grains the gritty tuffs pass gradually into grits, and by the increase in the calcareous matrix into ashy or gritty limestones.

(β & γ) The characters of these rocks, as observed in the field, have been described already, and little need be said about their microscopical characters. The matrix of the coarse felsite breccia is identical in character with the finer type of tuff, and consists in the main of quartz grains and of small felsite fragments. The same constituents are present in the matrix of the limestone breccia associated with abundant calcareous material.

(2) The most noteworthy point about the tuffs from the Mount Partry Beds is the tendency to silicification which many of them show.

VI. Comparison between the Glensaul and Tourmakeady Areas.

The two areas are very closely related geologically, nearly all the rock-types of Glensaul being common to the two. There are, however, some interesting differences. Of the Mount Partry Beds the coarse conglomerate, coarse and fine grits, graptolitic beds, and radiolarian cherts are common to the two districts; but the tuff presents some differences, as the conspicuous band associated with the cherts in the Glensaul district does not occur in that of Tourmakeady. The dominant type of Shangort Beds, that is, gritty more or less calcareous tuff, is the same in the two districts; but at Glensaul it shows a greater development of coarse breccias than near Tourmakeady, and there is also a greater tendency for the Shangort Beds to pass locally into relatively pure limestone. In addition to the type of calcareous deposit just referred to, the peculiar limestone breccias, which occur so frequently but so sporadically in the Tourmakeady district, are equally well seen in that of Glensaul, and tend to form relatively definite bands following the strike of the other rocks. We believe that the theory which we adopted to explain the formation of these beds in the Tourmakeady district, namely, that they are due to the disruption of limestone bands by explosive action, is applicable to those found at Glensaul.

The most abundant fossils in the Glensaul district were obtained, however, from limestone masses shattered, as we believe, not by explosive action but by earth-movements along lines of fault.

The conglomerates and grits of ? Bala age which bound the Tourmakeady district on the west are also found along the western border of the Glensaul district, but we have not studied them.

The crystalline igneous rocks are represented almost solely by the felsites of Tonaglanna and Greenaun, which are clearly parts of the same mass. The rocks agree closely with the intrusive felsites of the Tourmakeady district in petrographical character, and may be regarded with considerable confidence as forming a great sill intruded in the Shangort Beds. Three other small felsite intrusions occur, but the Glensaul district differs markedly from that of Tourmakeady in the absence of frequent small intrusions of felsite, dolerite, hornblende-lamprophyre, and fine-grained andesitic rocks or spilites.

VII. General Succession of the Strata, and Conclusions.

The general succession of the rocks in the Glensaul district is as follows, in descending order :—

	Thickness in feet.
3. ? Bala Beds. Conglomerates and sandstones. These beds have not been studied.	
(Break.)	
2. Shangort and Tourmakeady Beds.	
(8) Calcareous gritty tuff of no great coarseness, sometimes becoming so calcareous as to pass into fairly pure limestone, enclosing also bands and patches of limestone-breccia, and, more rarely, bands of highly fossiliferous limestone, which in some cases has been shattered by earth-movements	?
(7) Very coarse tuff or breccia, mainly composed of felsite fragments, and associated with it are impersistent bands of fine tuff	750
(6) Tuff, coarse and fine, with occasional patches of calcareous beds, and at one point a graptolitic bed indicating the zone of *Didymograptus hirundo*	150
(5) Great felsite sill of Tonaglanna and Greenaun ...... about	1100
(4) Coarse grit	20
(3) Gritty tuff........ varying in thickness from	520–620
(2) Coarse tuff or breccia, mainly composed of felsite fragments.	75
(1) Fine banded tuff	55
1. Mount Partry Beds.	
(4) Coarse grits	150
(3) Fine grits and tuffs associated with black chert, graptolitic beds, and a prominent band of coarse tuff or breccia about 30 feet thick. The graptolites indicate the upper part of the zone of *Didymograptus extensus*	? 150
(2) Coarse grits	110
(1) Coarse conglomerates .... (seen) about	600

The succession includes the upper part of the zone of *Didymograptus extensus*, to which the Mount Partry Beds are referable; the zone of *Didymograptus hirundo*, to which it appears that the lower part of the Shangort and Tourmakeady Beds may be assigned; and an overlying series, perhaps also to be included in the *Didymograptus-hirundo* Zone, but more probably representing that of *D. bifidus* and possibly including part of that of *D. murchisoni*.

In conclusion, we wish to tender our most sincere thanks to Miss G. L. Elles, D.Sc., for examining our graptolites; to Mr. F. R. C. Reed, M.A., F.G.S., for studying the other fossils from the district; and also to the Director of the Geological Survey of Ireland for the loan of maps.

VIII. Palæontological Notes. By F. R. C. Reed.

The fossils from this district which have been submitted to me for determination are mostly poor and fragmentary. They occur in two main types of rocks: namely (i) a hard, coarsely crystalline, reddish limestone (97, 155), and (ii) a rotten, gritty, calcareous ash (62). The specimens from the limestones marked 97 & 155 apparently belong to the same horizon and come from the same bed at different localities, for the rocks are lithologically identical and the faunas are indistinguishable. This horizon may be unhesitatingly correlated with the limestone of the Tourmakeady Beds described on a previous occasion. The more abundant material and newly discovered members of the fauna from these Glensaul localities necessitate a slight revision of my views as to the age of the limestone, and the additional evidence now available points to a somewhat lower horizon than was previously considered to be indicated. In fact, it appears that we must now correlate it with the Scandinavian equivalent of the English Arenig, that is, with the main mass of the *Orthoceras* Limestone. My previous reluctance to place the beds so low was due to the insufficiency of the evidence derived from the fossils; but now there does not appear to exist sufficient ground for refusing to admit that the sediment accumulating here in Arenig times was temporarily of a calcareous nature, and that the fauna which flourished during that interval in the West of Ireland was closely similar to that of the Scandinavian seas, where identical physical conditions of sedimentation prevailed. The completely different facies of the fauna, compared with that of the argillaceous beds which were being simultaneously formed in Wales, may be attributed to physical factors, such as the purity of the water and the absence from it of terrigenous material.

The fauna from the deposit marked 62, which is a rock practically identical with the common type of the Shangort Beds, points to the same general conclusions as to its age and relations. The presence of *Nileus armadillo* may be regarded as especially important, since this species occurs only in the *expansus* stage ($B_2\,b$) in the Baltic Provinces, although in Sweden it ranges up into the Cystidean Limestone and in Norway into Étage 4. But the variety *depressus*, which most resembles our form, is particularly characteristic of the *expansus* stage. The presence of a species of *Chasmops* in these beds (62) is surprising, and would not seem to warrant us in ascribing the beds to as low a stratigraphical horizon as might otherwise be given to them; for Schmidt states that, in the Baltic Provinces, the earliest member of the genus *Chasmops* occurs in the *Echinosphærites* Limestone (C_1), which he considers to be equivalent to the uppermost *Orthoceras* Limestone of Sweden (as developed in Öland and Westrogothia), and to the lower part of the *Chasmops* Limestone of the same regions. We can explain its occurrence by regarding the Swedish *Orthoceras*-Limestone fauna, or a certain portion of it, as having lived on later in the West of Ireland, just as, for instance, the Lower Devonian fauna did in the

Hamilton Beds of North America; or we may interpret the facts as indicating that *Chasmops* appeared at an earlier date in the western than in the eastern parts of its faunal province.

The slight intermixture of forms belonging to more than one horizon of the Baltic Province (as limited by Frech) may partly be due to different rates of migration of the various elements of the fauna, some moving more slowly than others. But there can be no doubt that the general faunistic facies of the Glensaul, Tourmakeady, and Shangort Beds is Scandinavian, and that the whole assemblage of species indicates the lower part of the Ordovician.

In what manner this Irish fauna was separated during its existence from that of the British seas is a matter of speculation; but we need not call into existence a rock-barrier or land-mass to account for the difference in character. It is also noteworthy that members of the westernmost part of the Atlantic Province made their way into this Irish sea: for *Bathyurellus* and *Bathyurus* are typically Canadian genera, and have not previously been recorded from the British Isles or from any part of Europe.

ILLÆNUS WEAVERI, Reed.

In my previous description [1] of this species no mention was made of terrace-lines across the posterior portion of the middle shield; but, in the numerous specimens from limestones 97 & 155, they are well preserved, and twelve to fourteen nearly continuous, gently arched, fairly regular and equidistant, raised, thread-like lines are seen to cross the glabella between the axial furrows, and extend forwards over an area of about a third of the length of the head-shield. The terrace-lines in *I. esmarki*, Schloth., to which this species has been compared, are more strongly curved and set more widely apart.

NIOBE sp. (Pl. XXII, figs. 3 *a* & 3 *b*.)

An imperfect fragment of a pygidium which occurs in the limestone of Glensaul (155) deserves special notice, as it must be referred to the genus *Niobe*.

It seems to resemble in general characters *Niobe insignis*, Linrs.[2], although the number of pleuræ on the lateral lobes is less, being only four. Prof. Brögger [3] regards Billings's *Asaphus morrisii*,[4] from Newfoundland, as the American representative of this Norwegian species. The small species *Niobe obsoleta*, Linrs., may be compared.

[1] Quart. Journ. Geol. Soc. vol. lxv (1909) p. 142 & pl. vi, figs. 1–3.

[2] J. G. O. Linnarsson, 'Om Vestergotlands Cambriska & Siluriska Aflagringar' K. Svenska Vetensk. Akad. Handl. vol. viii, no. 2 (1869) p. 75 & pl. ii, fig. 36; W. C. Brögger, 'Die Silurischen Etagen 2 & 3' Christiania, 1882, p. 66 & pl. iv, figs. 1 *a–d*.

[3] 'Verbreitung der *Euloma-Niobe* Fauna' Nyt Mag. Naturvidensk. vol. xxxvi 1898) p. 226.

[4] E. Billings, 'Palæozoic Fossils of Canada' vol. i (1865) p. 272 & fig. 257.

In *N. emarginula*, Ang., as figured by Brögger[1], a similar ornamentation of the test occurs. The other Russian[2] and Scandinavian species are less closely allied to it.

NILEUS ARMADILLO, Dalman. (Pl. XXII, figs. 1, 2 *a* & 2 *b*.)

There is one head-shield from the deposit marked 62 in a fairly perfect state of preservation, showing the entire glabella, the eye-lobes, and the facial sutures, which may be referred without hesitation to the species *Nileus armadillo*, Dalman.[3] It especially resembles the specimen figured by Schmidt[4] from the Baltic Provinces, the faint median keel and tubercle on the glabella being distinct. Prof. Brögger[5] mentions that, in examples of the variety *depressus* without the test, there is often visible a small tubercle on a raised keel. Our specimen which shows these features is also without the test, and thus agrees in all these respects. The other typical characters of the head-shield of *N. armadillo* are sufficiently exhibited. The species occurs typically in the *Orthoceras* and Cystidean Limestones of Scandinavia and in the *expansus* stage ($B_2 b$) in the Baltic Provinces.

The impression from the Shangort Beds, previously described as *Symphysurus (?)* or *Nileus*,[6] may be assigned to the same species, as our new specimen possesses all the missing features which rendered the identification of this other fossil doubtful.

Our specimen measures as follows: length of glabella = 14·5 millimetres, width of the same between the eyes = 13·0 mm.

A pygidium from the limestone (361), measuring 12 mm. in length and 21 mm. in width, may also be referred to *Nileus armadillo*. It possesses the shape and characters of the form figured by F. Schmidt[7] from Stage $B_2 b$ in the Baltic Provinces, which agrees closely with the variety *depressus*, Sars & Bœck. The broad axis is of faint elevation, but distinctly defined and of an obtusely conical shape, and it shows traces of three or four rings on its surface. The border is rather broad, weakly concave, but not marked off by a definite furrow from the rest of the lateral lobes. The surface of the shell seems to be smooth.

Dimensions.—Length of pygidium = 12 millimetres; width of the same = 21 mm.; length of axis = 7 mm.; width of the same = 7 mm.

[1] 'Die Silurischen Etagen 2 & 3' Christiania, 1882, p. 68 & pl. vii, fig. 7 *a*; pl. viii, fig. 7; pl. xii, fig. 13.
[2] F. Schmidt, 'Rev. Ostbalt. Silur. Trilob.' pt. v, Lief. 2, Mem. Acad. Imp. Sci. St. Petersb. ser. 8, vol. xii, no. 8 (1901) pp. 98–110.
[3] Dalman, 'Palæad.' 1828, p. 49 & pl. iv, figs. 3 *a*–3 *e*.
[4] F. Schmidt, 'Rev. Ostbalt. Silur. Trilob.' pt. v, Lief. 3, Mem. Acad. Imp. Sci. St. Petersb. ser. 8, vol. xiv, no. 10 (1904) p. 64 & pl. viii, fig. 13.
[5] 'Die Silurischen Etagen 2 & 3' Christiania, 1882, p. 62 & pl. vii, fig. 6 *a*.
[6] F. R. C. Reed, Quart. Journ. Geol. Soc. vol. lxv (1909) p. 150 & pl. vi, fig. 12.
[7] F. Schmidt, *op. supra cit.* pl. viii, figs. 17 & 18.

Bathyurellus glensaulensis, sp. nov. (Pl. XXI, figs. 1 *a*–3 *b*.)

Head-shield convex, semioval to parabolic, with genal angles produced back into stout pointed spines. Border strongly concave and slightly upturned, broad in front, narrowing to genal angles, without definite marginal furrow. Glabella cylindro-conical, with nearly parallel sides and with an obtusely-pointed anterior end, rising above the cheeks with a gentle independent convexity, smooth, without lateral furrows, in length equal to about two-thirds that of the head-shield and in width to about a quarter of its width. Axial furrows well marked, narrow, not deeply impressed, continuous round the front of the glabella. Occipital furrow straight, narrow, of the same strength as the axial furrows, marking off a broad, flattened, simple, band-like occipital segment, in width equal to about a sixth of the length of the glabella. Eye-lobes large, semicircular, a little more than a third of the length of the glabella, situated rather far back at less than their own length from the posterior margin of the head-shield, with a breadth equal to about a quarter of the width of the glabella. Facial sutures with the anterior branch curving strongly outwards in front of the eye, and then forwards and slightly inwards to cut the margin of the head-shield at an acute angle at the level of the front end of the glabella, and at a distance from it equal to more than double its width. Posterior branch of the facial sutures short, curving backwards and outwards to cut the posterior margin acutely at a distance about half way out to the lateral edge of the head-shield. Anterior wings of fixed cheeks broad, convex, uniting in a wide preglabellar area in front, and arching down steeply into a broad concave border. Posterior wing of fixed cheek small. Neck-ring flattened, of moderate width, marked off by a faint neck-furrow which disappears at the facial suture. Free cheeks large, elongated, triangular, convex, with the posterior outer angle produced backwards and tapering rather slowly into a long genal point; border concave, broad, narrowing and dying out before the genal point. Eye rising steeply from the cheek, constricted at the base, semilunate, rounded, convex, with its surface composed of eighty to ninety diagonal rows of minute lenses, each row containing about twenty lenses. Surface of occipital segment ornamented by small, broken, somewhat sinuous, imbricating lamellæ, arched sharply forward in the middle.

Dimensions.—Length of head-shield = 18 millimetres; width of middle shield between the anterior ends of the facial sutures = 22 mm.; width of the same between the eyes = 12 mm.; length of glabella = 11 mm.; width of the same at the base = 7 mm.

This interesting trilobite is represented in the collection by two head-shields, one of which is fairly perfect, and by two free cheeks. All the specimens come from the gritty tuff marked 62.

In general shape the head is like that of *Bathyurellus formosus*, Billings,[1] from the Quebec Group of Newfoundland, but the course of the facial sutures is more like those in *B. expansus*, Billings,[2]

[1] 'Palæozoic Fossils of Canada' vol. i (1865) p. 266 & fig. 250.

[2] *Ibid.* p. 318 & fig. 306.

from Stanbridge. We may also compare *B. brevispinus*[1] from the Chazy Limestone, but its genal angles are less produced. The genus has not been previously recorded from the British Isles.

BATHYURUS cf. TIMON, Billings. (Pl. XXI, fig. 5.)

There is one fairly perfect pygidium from the tuff (62), which may be compared with *Bathyurus timon*, Billings,[2] of the Quebec Group, Port aux Choix (Newfoundland).

It had a similar shape before distortion, and measures 19 millimetres in length and 27 mm. in width; the axis, pleural lobes, number of segments, and ornamentation seem to show no conspicuous points of difference from the Canadian species.

The genus *Bathyurus* has been recorded from Argentina by Prof. E. Kayser,[3] and recently by Mr. E. Blackwelder[4] from the Middle Yangtse region in China, associated with a typical Lower Ordovician fauna; but it has not been previously found in the British Isles.

BATHYURUS aff. NERO, Billings. (Pl. XXI, figs. 4 *a* & 4 *b*.)

One small imperfect head-shield from the tuff (62) with a glabella 6 millimetres long, 4·5 mm. wide, and with the head measuring 8 mm. in width across the eyes, is referable to the genus *Bathyurus*.

In the shape of the glabella and in the tuberculation it resembles *Bathyurus strenuus*, Billings,[5] but the eyes are set closer in, and have a marginal band. The position of the eyes against the sides of the glabella more vividly recalls *B. perspicator*, Billings.[6] We may especially compare the head of *B. nero*, Billings,[7] which has a tuberculated glabella and occipital ring almost identical with those seen in our specimen, but the fixed cheeks are not known. In *B. angelini*,[8] Billings, from the Chazy Limestone, the position of the eyes and the shape of the glabella are similar; but the eyes seem to be larger and are set farther back than in this Glensaul specimen. It may also be compared with *B. spiniger* (Hall),[9] particularly with regard to the structure of the palpebral lobes, but they are situated farther back in the American species, and the occipital ring has an axial spine. *B. extans* (Hall)[10] is also allied, though less closely. Both the latter occur in the Trenton Beds.

[1] Raymond, Ann. Carnegie Mus. vol. iii (1905) no. 2, p. 337 & pl. x, figs. 13–15.

[2] 'Palæozoic Fossils of Canada' vol. i (1865) p. 261 & fig. 244.

[3] Palæontographica, Suppl. iii, pt. 2 (1876) pp. 10–12 & pl. ii, figs. 5–8.

[4] Bailey Willis (& others), 'Research in China' vol. i (1907) pt. i, p. 271.

[5] 'Palæozoic Fossils of Canada' vol. i (1865) p. 204 & fig. 188.

[6] *Ibid.* p. 205 & fig. 191.

[7] *Ibid.* p. 260 & figs. 243 *a*–243 *b*.

[8] Raymond, Ann. Carnegie Mus. vol. iii (1905) no. 2, p. 335 & fig. 1.

[9] J. Hall, 'Palæont. New York.' vol. i (1847) p. 241 & pl. lxiv, fig. 5; and J. M. Clarke, 'Lower Silurian Trilobites of Minnesota' (vol. iii, pt. 2, Final Rep. Geol. Nat. Hist. Surv. Minn.) 1893–97, p. 723 & fig. 38.

[10] J. M. Clarke, *op. supra cit.* p. 722, fig. 37 & references.

PLIOMERA PSEUDOARTICULATA, Portl. (Pl. XXII, figs. 5 & 6.)

The head-shield of *Pliomera pseudoarticulata*, Portl., has never been described, and apparently no head has been found on any occasion in definite connexion with the pygidium on which this species was founded. There is one head-shield from the tuff (62), which does not resemble that of *Pl. fischeri*, Eichw., or *Pl. actinura*, Dalm., nor any of the British species described, but appears to be more similar to *Pl. westoni* (Billings)[1] of the Quebec Group. The glabella is moderately convex, subquadrate, and subpentagonal, the anterior end being strongly arched forwards and almost angulated in the middle instead of truncate; the sides are parallel, and the first, second, and third pairs of lateral furrows are equidistant, slightly oblique and parallel, and in length about a quarter of the width of the glabella; the posterior pair, which is rather nearer the occipital furrow than it is to the second lateral furrow, is slightly arched backwards; the anterior furrows are mere elongated pits at the anterior end of the glabella in front of the lateral angles, are separated by about two-thirds of its width, and become very weak before reaching the axial furrows. The occipital ring is not well preserved, but the furrow is slightly arched forwards. The axial furrows are narrow, though strong and deep. The fixed cheeks are large and subtriangular with a gently convex surface, are about one and a quarter times the width of the glabella, and are arched down on each side. The genal angle is obtuse and rounded, and the marginal and neck-furrows, which unite in a sharp curve, are of uniform strength, and mark off a prominent, rounded, convex neck-segment and border. The surface of the cheek is coarsely pitted; the eyes are large and situated opposite the second lateral lobes, at a distance from the glabella equal to about a third of its width. The anterior branch of the facial suture is not well preserved; but the posterior branch is seen to have the typical course, curving out in a sigmoidal fashion behind the eye and running out almost parallel to the posterior margin of the head-shield to cut the lateral edge in front of the genal angle.

Dimensions.—Length of head-shield = 20 millimetres; width of the same = 52 mm.; length of glabella = 17 mm.; width of the same = 16 mm.

Pliomera mathesii, Ang.,[2] as well as the above mentioned *Pl. westoni* (Billings), seems more nearly allied to this form than *Pl. fischeri* or *Pl. actinura*, on account of the shape of the glabella. From the occurrence in the Shangort Beds[3] of a precisely similar type of head-shield (fig. 6), in association with an undoubted pygidium of *Pl. pseudoarticulata*, we may probably refer this head-shield to this species.

[1] 'Palæozoic Fossils of Canada' vol. i (1865) p. 321 & fig. 307 *a*.
[2] N. P. Angelin, 'Palæontologia Scandinavica' 1854, p. 35 & pl. xxii, fig. 1.
[3] C. I. Gardiner, S. H. Reynolds, & F. R. C. Reed, Quart. Journ. Geol. Soc. vol. lxv (1909) p. 125.

ENCRINURUS OCTOCOSTATUS, sp. nov. (Pl. XXII, figs. 4 *a* & 4 *b*.)

The species of *Encrinurus* described by me from 'the gritty ash (322) a third of a mile south-south-west of Shangort,'[1] in the Shangort Beds, is represented by a well-preserved pygidium from the gritty tuff (62) showing the characters described. But it should be added that the posterior end of the axis is not very well defined in this species, the axial furrows dying out before the tip, and the last two pairs of pleuræ bending round behind and merging into it without any distinct furrows between them. The length of the specimen figured here is 9·5 millimetres, and its width at the front end about the same. The first two and the last two axial rings have been destroyed in this example, but the tip of the pygidium is unusually well preserved. If this species is a new one, as it seems to be, the name *E. octocostatus* may be applied to it. An imperfect free cheek from the same bed (62) possibly belongs to the same species; the border is strongly convex, rounded and ornamented with rather distant, small tubercles, and is marked off from the rest of the cheek by a deep, rounded, marginal furrow. The cheek is moderately convex, ornamented with large, coarse, conspicuous tubercles, and bears a tall conical eye on a short stalk.

PHACOPS (CHASMOPS) aff. ODINI, Eichwald.

There are two pygidia in the collection from the tuff (62) which seem closely allied to *Ph. odini*, Eichw., or may be identical with it. One is nearly perfect, and measures 16 millimetres in length and 23 to 24 mm. in breadth; it shows ten to twelve rings on the axis and eight or nine pleuræ on the lateral lobes. The axis is conical, tapering rather rapidly at about 25° or 30°; the rings are well defined, and show slight lateral swellings. The pleuræ of the dependent, and strongly arched, lateral lobes show the usual characters; there is no distinct impressed line or furrow, but traces of a row of punctæ can be made out on their surface. The proportions of this pygidium and the number of rings on the axis and of pleuræ on the lateral lobes agree very closely with *Ph. odini* as described by F. Schmidt,[2] who remarks that the pygidium of this species may be compared with that of the Scandinavian *Ph. conophthalma*, of which there are believed to be British examples.[3] The punctæ on the pleuræ recall *Ph. amphora*, Salter,[4] from the Llandeilo, but this has more numerous segments.

ORTHIS OBTUSA (Pander), var.

The small abundant species of *Orthis* which occurs in the limestone (155) may be regarded as a variety of *Orthis obtusa*[5]

[1] F. R. C. Reed, Quart. Journ. Geol. Soc. vol. lxv (1909) p. 147.
[2] 'Rev. Ostbalt. Silur. Trilob.' pt. i, Mem. Acad. Imp. Sci. St. Petersb. ser. 7, vol. xxx, no. 1 (1881) p. 99 & pl. ii, figs. 1–13; pl. xi, fig. 16?; pl. xv, fig. 30.
[3] J. W. Salter, 'Monogr. Brit. Trilob.' (Palæont. Soc. 1864–83) p. 40.
[4] *Ibid.* p. 42 & pl. iv, fig. 16.
[5] C. H. Pander, 'Beitr. Geogn. Russ. Reich.' St. Petersburg, 1830 p. 87 & pl. xxvi. fig. 7.

(Pander) with rather coarser ribs than usual. *O. obtusa* occurs in the *Orthoceras* Limestone and in the Cystidean Limestone. As C. Gagel[1] mentions, three to five of the median ribs on the pedicle-valve are often stronger than the others.

ORTHIS PARVA (Pander).

This species[2] is fairly common in the limestone (97) and (155). In the list of the fossils from the Tourmakeady Beds it was erroneously entered as *O. elegantula*, but the better material now available allows the correction to be made, as the beds in the two places are identical. *O. parva* is a common species in Stage B in the Baltic Provinces of Russia.

CAMERELLA cf. CUNEATELLA, Davidson.

A small and abundant brachiopod from the limestone (97), measuring from 6 to 7 millimetres in length, may be compared with the Scottish species described by Thomas Davidson[3] as *Rhynchonella cuneatella*, from the Balclatchie (Llandeilo) conglomerate of Ayrshire. The triangular shape is the same, but the marginal folds, eight or nine in number, are more numerous, and the beak is not preserved. A fine longitudinal striation also appears to be present. The Scandinavian and Russian species '*Rhynchonella*' *digitata*[4] (M. v. Leuchtb.), from the *expansus* beds, may be more closely allied to our form, which is also scarcely distinguishable from some specimens of *Camarella thomsoni*, Dav., but probably it is a new species. None of the specimens, unfortunately, are well preserved.

EXPLANATION OF PLATES XX–XXII.

PLATE XX.

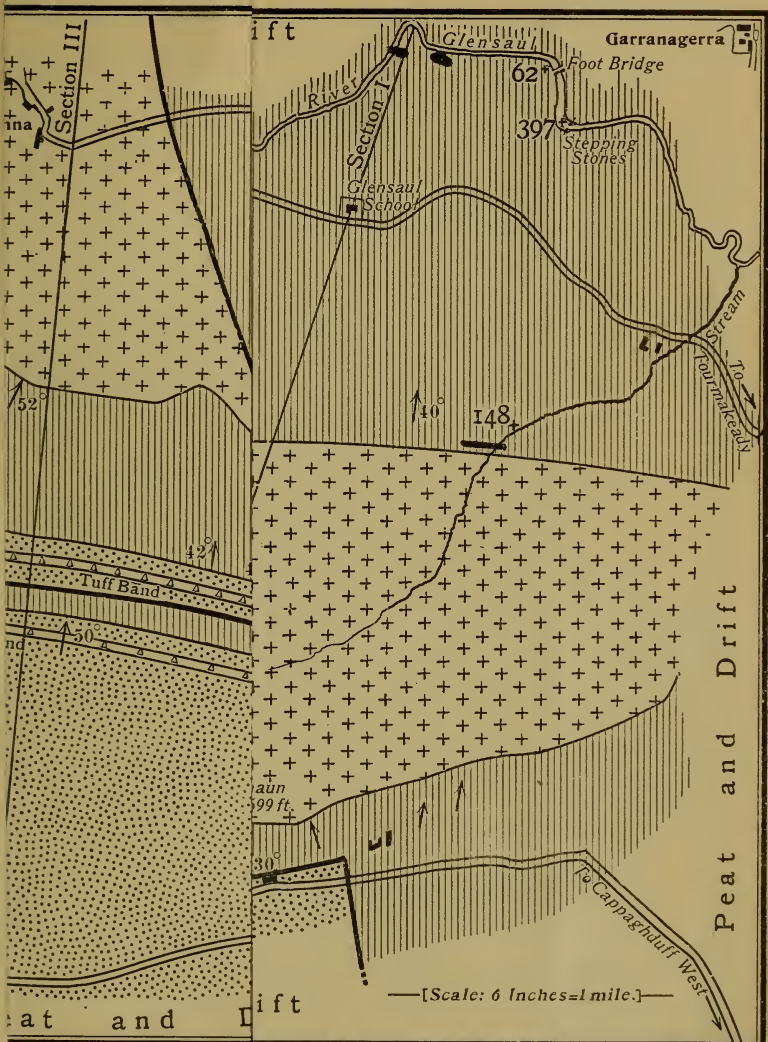
Map of the igneous and associated sedimentary rocks of the Glensaul district, Co. Galway, on the scale of 6 inches to the mile.

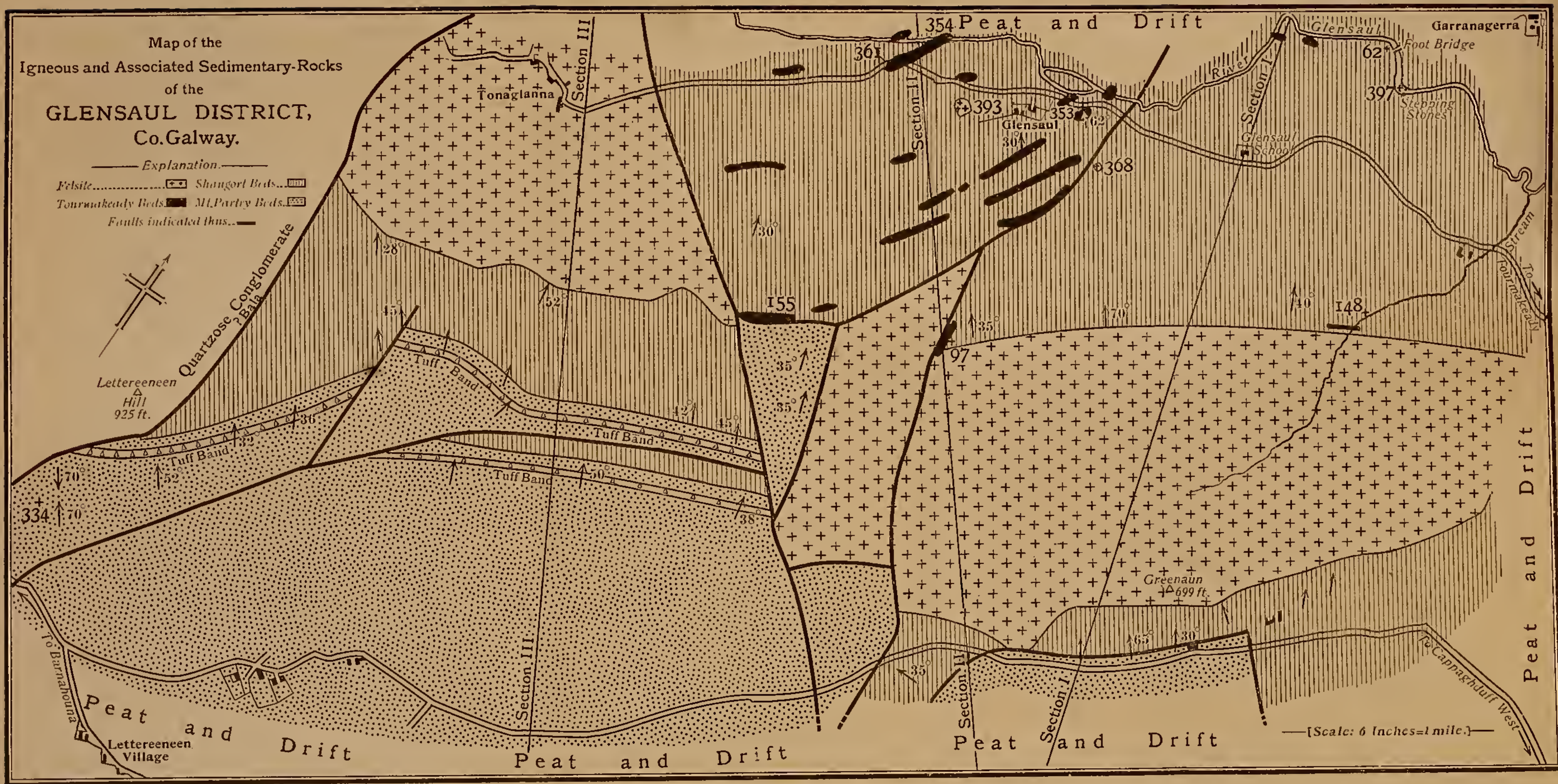
PLATE XXI.

[All the specimens figured in this plate are from locality 62.]

Fig. 1 *a*. *Bathyurellus glensaulensis*, sp. nov. Anterior portion of head-shield. × 2.
1 *b*. Do. Side view of the same specimen. × 2.
2 *a*. Do. Middle shield, nearly perfect. × 2.
2 *b*. Do. Side view of the same specimen. × 2.
3 *a*. Do. Free cheek. × 2.
3 *b*. Do. Eye of the same specimen. × 6.
4 *a*. *Bathyurus* aff. *nero*, Billings. Middle shield. × 3.
4 *b*. Do. Side view of the same specimen. × 3.
5. *Bathyurus* cf. *timon*, Billings. Pygidium. × 2.

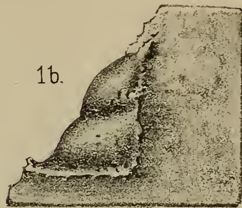
[1] 'Brachiop. Cambr. Silur. Geschiebe,' Beitr. Naturk. Preuss., Phys.-Œk. Gesellsch. Königsberg, 1890, p. 33 & pl. ii, fig. 23.
[2] 'Beitr. Geogn. Russ. Reich.' St. Petersburg, 1830, p. 83 & pl. xxvi, fig. 10.
[3] 'Monogr. Brit. Foss. Brach.' vol. v (Palæont. Soc. 1882–84) p. 200 & pl. x, fig. 11.
[4] W. C. Brögger, 'Die Silurischen Etagen 2 & 3' Christiania, 1882, p. 52 & pl. xi, figs. 2 *a*–2 *c*.


Section III
ift
Glensaul
River
Garranagerra
Foot Bridge
62
397
Stepping Stones
Section I
Glensaul School
Stream
To Tourmakeady
40°
148
52°
42°
Tuff Band
50°
30°
To Cappaghduff West
Peat and Drift
[Scale: 6 Inches=1 mile.]
ift

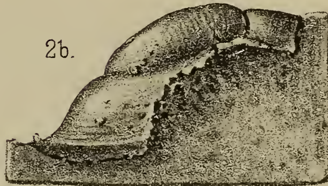


Map of the
Igneous and Associated Sedimentary-Rocks
of the
GLENSAUL DISTRICT,
Co. Galway.
Explanation.
Felsite
Shangort Beds
Tourmakeady Beds
Mt. Partry Beds
Faults indicated thus
Peat and Drift
Tonaglanna
Section III
Section II
Section I
Glensaul
Glensaul School
River
Garranagerra
Foot Bridge
Stepping Stones
Stream
To Tourmakeady
Quartzose Conglomerate ? Bala
Lettereeneen Hill 925 ft.
Tuff Band
Greenaun 699 ft.
To Barnahouna
Lettereeneen Village
To Cappaghduff West
[Scale: 6 Inches=1 mile.]
354
361
393
353
368
397
62
155
148
97
334

1a.



1b.



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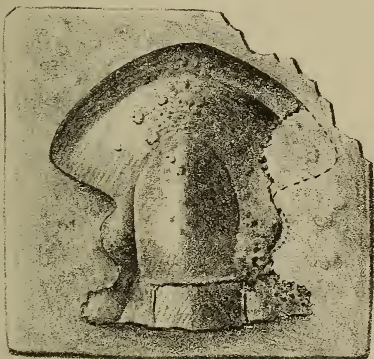

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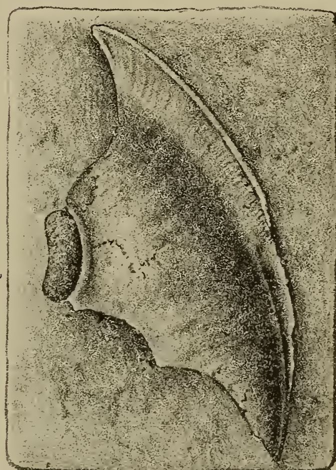
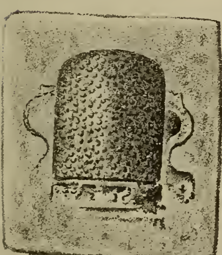


3a

3b.



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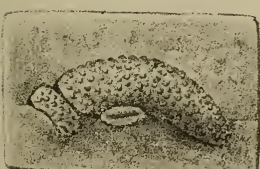

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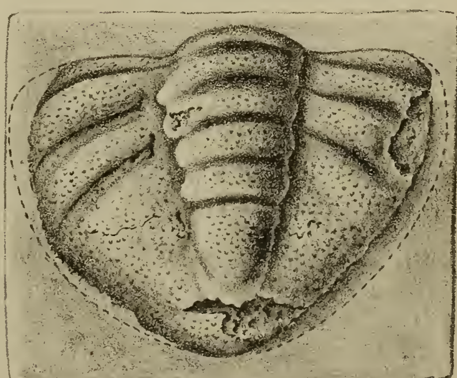
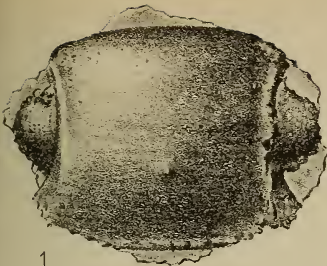


5.

J. Green del.

West, Newman imp.

TRILOBITES FROM THE GLENSAUL DISTRICT.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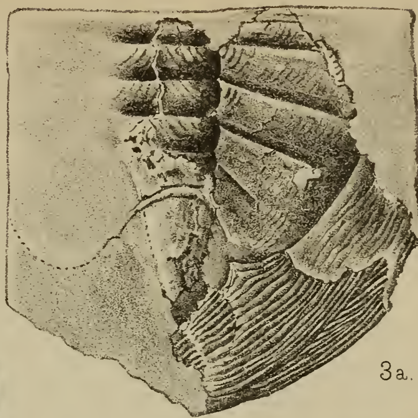
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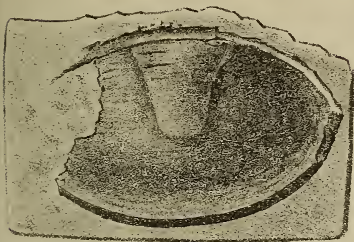
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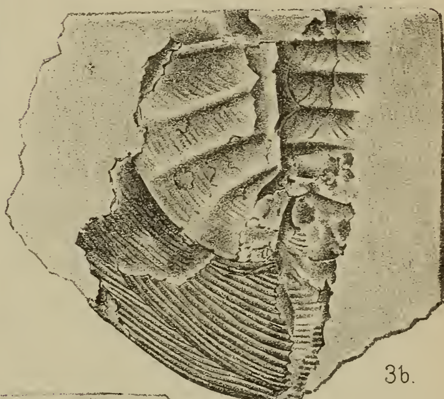
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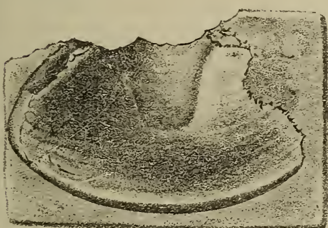
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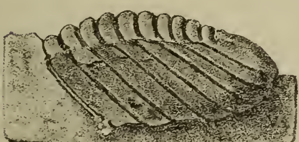
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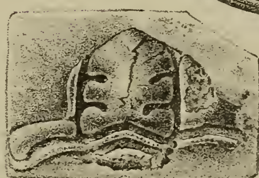
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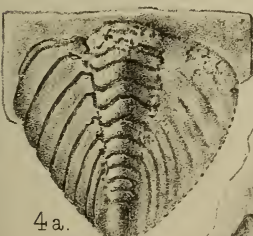
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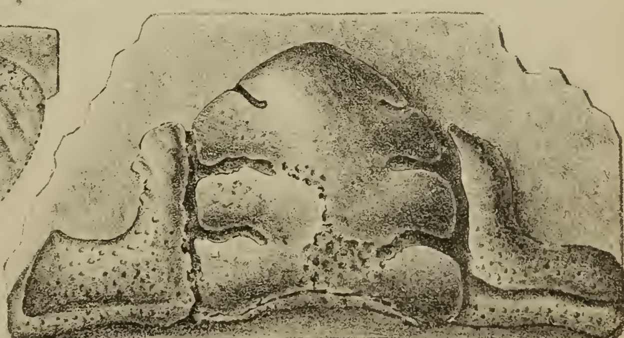
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J. Green del. West, Newman imp.

TRILOBITES FROM THE GLENSAUL DISTRICT.

Plate XXII.

Fig. 1. *Nileus armadillo*, Dalman. Middle shield. × 2. Locality 62.
2 *a*. Do. Pygidium, internal cast. × 2. Locality 361.
2 *b*. Do. Pygidium, interior of the test of the same specimen. × 2.
3 *a*. *Niobe* sp. Imperfect pygidium. × 2. Locality 155.
3 *b*. Do. Interior of the test of the same specimen. × 2.
4 *a*. *Encrinurus octocostatus*, sp. nov. Pygidium. × 3. Locality 62.
4 *b*. Do. Side view of the same specimen. × 3.
5. *Pliomera pseudoarticulata* (Portlock). Middle shield. × 2. Locality 62.
6. Do. Young individual, from Shangort. × 2.

Discussion.

The President remarked that there seemed nothing improbable in the supposed inclusion of fragments of contemporary limestone in the volcanic breccias. The tuffs which were deposited in the formation of Monte Nuovo contained shells and fragments from the adjacent sea-bottom, and recent formations of calcareous sand were involved in the volcanic ejectamenta of Anchor Head, Hawaii.

Mr. H. H. Thomas congratulated the Authors on a piece of work which would prove of considerable interest to students of British stratigraphy. He was relieved to find that the Tourmakeady and Shangort Beds had been removed from the Llandeilo Series, and placed in the Arenig: for, not only was the *Didymograptus-extensus* Zone a horizon of widespread volcanic activity in the neighbouring country of Wales, but the fauna of the Tourmakeady and Shangort Beds had little in common with that of the calcareous beds of the Welsh Llandeilo. It was, therefore, much more satisfactory to find that this highly interesting fauna was not an anomalous fauna of Llandeilo age, but dependent on a calcareous facies of the *extensus* beds, which in South Wales are wholly argillaceous and arenaceous.

The speaker regretted that 'dependent' graptolites allied to *Didymograptus bifidus* were found associated with the zone-form of *D. extensus*: for the separation of the *Tetragraptus* Beds from the Llanvirn Series of Hicks, always a task of some difficulty, would now be far from easy, unless fossils and exposures were exceedingly numerous. It was fortunate, however, that in South Wales 'dependent' species of *Didymograptus* were restricted to the Llanvirn Series, and that *D. extensus* was confined to its own zone.

With reference to the intrusive felsite, he asked whether the Authors held any views as to the original nature of the rhombic pyroxene which was represented by pseudomorphs; also whether there were any felspar phenocrysts, and whether it had been possible to determine to what species they belonged.

Mr. G. W. Young remarked that, in the uppermost section exhibited, the felsite mass formed a prominent hill, while in the bottom section, taken about a mile away, it occupied the floor of a deep valley. He asked for an explanation.

Prof. E. W. Skeats said that, while unfamiliar with the area described by the Authors, he was much interested in their description of the association of cherts with tuffs and igneous rocks in the Arenig Series, and in their demonstration that some of the cherts were silicified tuffs. A similar association of diabase, tuffs, and cherts occurred at Heathcote and other areas in Victoria. Many of the banded cherts from Heathcote could not be distinguished from the cherts exhibited by the Authors.

Mr. Gardiner expressed the thanks of the Authors for the reception accorded to their paper. In reply to Mr. Thomas, he pointed out that, although the lowest graptolitic horizon was undoubtedly referable to the *Didymograptus-extensus* Zone, the highest one contained only a few graptolites—from which no exact conclusion could be drawn. The Authors, therefore, merely put forward the suggestion that these beds might belong, either to the *D.-hirundo* Zone, or to higher beds.

With regard to the reason why the felsite sill formed a hill-crest at one end and a valley-floor at the other end of the area, he pointed out that these rocks had been exposed to more than one period of denudation. The ? Bala conglomerate, which was full of fragments of felsite and of chert, doubtless extended at one time over the whole area. The trend of the present river-system might, therefore, be regarded as being due to causes other than the occurrence of the felsite in particular spots.

10. *The* Metallogeny *of the* British Isles. By Alexander Moncrieff Finlayson, M.Sc., F.G.S. (Read December 15th, 1909.)

[Plate XXIII—Map.]

Contents.

I. Introduction.

The recent development of the geographical method of studying ore-deposits is due to Prof. L. de Launay, who first pointed out its application in 1897. His later works on this plan include examinations of the ore-deposits of Africa, Italy, and Siberia.[1] His object is to delineate the various regional types of ores, and to show their intimate genetic relation with tectonics and with petrographic provinces, the regional types being termed 'metallogenetic provinces'. The same method has been applied by Dr. J. Malcolm Maclaren in his 'auriferous provinces'.[2] We have thus, in the science of ore-deposits, the application of methods analogous to those exemplified in Suess's 'Antlitz der Erde,'—methods which aim at correlating detached observations, and bringing our knowledge of the ore-deposits of an area into relation with our knowledge of its geological structure.

In the present paper an endeavour is made to work out the distribution of ore-deposits in the British Isles, and to determine the relationship of the ores to the tectonics of the country, and to the distribution of igneous rocks therein. Prof. de Launay's nomenclature has been followed, and I wish here to express my thanks to him for his kindness in corresponding with me on the subject.

The modern analytical classifications of ore-deposits, while nominally on a genetic basis, involve, as subdivisions, factors of varying importance—genesis, form, mineralogy, and structure. The essential and accidental features are liable to be confused, and the latter unduly emphasized. Further, there is a tendency to make the deposits, which show every conceivable gradation from one to another, fit into the subdivisions of the classification. Indeed,

[1] 'Sur les Types Régionaux de Gîtes Métallifères' C. R. Acad. Sci. Paris, vol. cxxx (1900) p. 743; 'Les Richesses Minérales de l'Afrique' Paris, 1903 (Abstract in Rev. Gén. des Sciences, vol. xiii, 1902, p. 1075): 'La Métallogénie de l'Italie' Xème Congrès Géol. Internat. (Mexico, 1906) vol. ii, p. 555; and 'La Métallogénie de l'Asie Russe' Ann. des Mines, ser. 10, vol. xv (1909) pp. 220 & 303.

[2] 'Gold' London, 1908, pp. 43 *et seqq.*

it is open to question whether, in the realm of ore-deposits as in that of petrography, a truly natural classification is yet attainable, at least on an analytical basis. The following classification of British ores is based mainly on the system evolved by W. H. Weed,[1] the subdivision of the veins, however, being adapted from that of the Freiberg school of mineralogists:—

I. Igneous (magmatic segregations).
 (*a*) Dykes and veins: Grainsgill wolfram-pegmatites. Carn Chuinneag tin-bearing magnetite.
 (*b*) Disseminations: Molybdenite in granites.

II. Igneous emanations.
 Contact-metamorphic: Loch Fyne nickeliferous pyrrhotite.

III. Fumarolic deposits: Zeolitic copper-ores in the Carboniferous lavas of Renfrewshire and Dumbartonshire.

IV. Gas-aqueous deposits. (Veins.)

A. Veins of oxide-ores.

(1) Spathic iron-ore veins: Cumberland.
(2) Red hæmatite veins.
(3) Manganese-ore veins: Merionethshire.
(4) Tin veins: Cornwall.

B. Veins of sulphide-ores.

(5) Copper veins.
 Tourmaline-copper: Cornwall.
 Quartz-copper: Coniston.
 Spathic copper: Exton.
(6) Silver-lead and zinc veins.
 Quartz-lead: Cardiganshire.
 Spathic lead: Flintshire.
 Barytic lead: Shropshire.
(7) Rich (noble) silver-ore veins.
 Silver-quartz: —— ?
 Silver-calcspar: Hilderston, Alva.
 Silver-copper: Cornwall.
 Silver-cobalt: Hilderston.
(8) Gold veins.
 Gold-copper and pyritic quartz: Merionethshire.
(9) Antimony-veins: Knipes, Dumfriesshire.
(10) Cobalt, nickel, and bismuth veins: occur locally in Cornwall, the Lake District, Hilderston, Killarney, etc.

V. Metamorphic deposits.
 Fahlbands of the Scottish Highlands.

The value of such a classification lies in the fact that it crystallizes views on genesis and on matters of detail; but, taken alone, it gives an incomplete survey of the ore-deposits, and it must therefore be supplemented by a study of the metallogeny as a whole, in order to bring the ore-deposits into their natural position in the geological record.

II. Epochs of Sub-Crustal and Igneous Activity in the British Area.

The complete history of the area, and its gradual evolution through periods of depression and sedimentation on the one hand, and periods of uplift and folding with igneous intrusions on the

[1] 'The Classification of Ore-Deposits: a Proposal & a Discussion' Eng. & Min. Journ. New York, 1903.

other, have been sufficiently worked out to give a basis for the determination of the metallogenetic epochs. It is necessary here, however, to pass over the minor periods of crust-movement with their attendant vulcanicity. Thus the complex events of pre-Cambrian time may be regarded as condensed into the disturbances and intrusions immediately preceding the Cambrian subsidence. Likewise the several Palæozoic epochs of vulcanicity will be represented by the two major periods: that is, Caledonian and Hercynian. With this understanding, the major epochs of disturbance in the geological evolution of the British area are as follows:—

1. Pre-Cambrian (Huronian of Marcel Bertrand [1]).
2. Post-Silurian (Caledonian).
3. Post-Carboniferous (Hercynian).
4. Post-Cretaceous and early Tertiary.

To the pre-Cambrian Epoch belong the older granites and gneisses, with their associated rocks, which accompanied the folding and uplift of the pre-Cambrian rocks of the Highlands. The Caledonian Epoch, with the elevation and folding of the Lower Palæozoic formations, was marked by the intrusion of a widely distributed series of granite masses, forming a defined petrographic province, and including the 'newer granites' of the Scottish Highlands and the Grampians, the Galloway and other granites of the Southern Uplands, the granites of the Lake District and the Isle of Man, the Newry and Leinster granites, the Donegal and Galway granites, and probably the hornblende-granite of Leicestershire. The Hercynian Epoch was marked by uplift and disturbance of the Devono-Carboniferous as well as the older rocks, while intrusions of this age are exposed in the Cornish area. Finally, the uplift at the beginning of the Tertiary was followed by an outburst of vulcanicity, with its centre in the north-west of the area.

III. Metallogenetic Epochs in the British Area.

It is now necessary to consider each of these epochs in turn, in order to examine the evidence as to the age and relations of the various groups of ore-deposits in the area.

Pre-Cambrian Epoch.—A deposit belonging to this division is the tin-bearing magnetite occurring as a segregation in the Archæan granite-gneiss of Carn Chuinneag (Ross-shire).[2] Its content of tin oxide (up to 17 per cent.) marks it as an unusual if not a unique mineralogical occurrence, but genetically it belongs to the type of the magnetic iron-ore segregations of Scandinavia and of the Adirondacks. There are doubtless other deposits in the metamorphic complex of the Scottish Highlands which should be referred to the pre-Cambrian, but our knowledge of the scattered ore-occurrences of this area is very incomplete.

[1] 'Sur la Distribution Géographique des Roches Éruptives en Europe' Bull. Soc. Géol. France, ser. 3, vol. xvi (1888) p. 576.
[2] 'Summary of Progress Geol. Surv.' for 1903 (1904) p. 58.

Caledonian Epoch.—The ores of this epoch are likewise confined chiefly to the Scottish Highlands. The Caledonian granitic intrusions are widely developed in this area, and the ores are often intimately related to these igneous rocks. The common occurrences of molybdenite in the Caledonian granites are an example. The segregations of chromite in the serpentine at Unst, in the Shetlands, are Caledonian or older. The deposits of nickeliferous pyrrhotite and chalcopyrite at Glen Esochossan and Craignure, Loch Fyne, adjoining felsite and quartz-porphyry, are border-segregations or contact-deposits of Caledonian age.[1] The pyritous schists, and fahlbands carrying complex sulphides, which are developed around Loch Tay,[2] in the Cowal district, Loch Fyne, and elsewhere, also probably belong here.[3] Lastly, the alluvial gold of various localities in the Highlands, notably the Helmsdale district in Sutherland, and parts of Forfarshire and Perthshire, has been derived from veins in the older rocks, which veins appear to belong to the Caledonian Epoch. Most of the deposits of the Highland area, in short, are provisionally referred to the Caledonian, but clear evidence of their age is not always forthcoming. Some of the fahlbands may be older, while there are many occurrences of normal lead and copper veins in the area which are probably Hercynian, including those of Strontian, in Argyllshire, and of Islay. The deposits here referred to the Caledonian are, however, of the 'Scandinavian' facies, typically represented by the segregations of oxide and sulphide ores, the pyritic masses, and the fahlbands, of Norway and Sweden, all of which are, in general, of Caledonian age.

In the Lake District the wolfram-bearing pegmatites in the Grainsgill greisen belong to this epoch,[4] and a few unimportant occurrences of molybdenite and chalcopyrite, associated with tourmaline, represent this phase in the Caledonian granites of Donegal.

Lastly, the belt of pyritic masses in the Avoca district (County Wicklow), together with that of Parys Mountain (Anglesey), is probably of Caledonian age. The deposits occupy zones of shearing and crushing in Ordovician slates and phyllites, and are intimately related to a well-marked province of varied intrusive sills and dykes of Caledonian age, adjoining the granitic mass of Leinster on the west. The entire development of igneous rocks and associated earth-movements in this area dates from post-Silurian times, and the pyritic ores were probably concentrated, in the first place, by magmatic differentiation accompanying the igneous outbursts and subcrustal stresses, being afterwards deposited by replacement along shear-zones and fault-slip planes. Structurally and genetically, the Avoca masses are in every way analogous to the cupriferous deposits of the Huelva district in Southern Spain, which are likewise intimately related to a complex series of crust-movements and igneous intrusions.

[1] J. B. Hill, 'Geology of Mid-Argyll' Mem. Geol. Surv. 1905, p. 151.
[2] C. H. Gustav Thost, Quart. Journ. Geol. Soc. vol. xvi (1860) p. 422.
[3] J. B. Hill, *loc. supra cit.*; and W. Gunn (& others), 'Geology of Cowal' Mem. Geol. Surv. 1897, p. 287.
[4] A. M. Finlayson, Geol. Mag. dec. v, vol. iii (1910) p. 19.

Hercynian Epoch.—This epoch is by far the most important in the area, since it is believed to embrace all the ore-deposits not included in the two preceding divisions. The corresponding metallogenetic province may be subdivided into three distinct subprovinces or regions, based on differences in geological structure. These groups are a Southern or Armorican, embracing the fragments of the old Armorican Mountains in Southern Ireland and the South-West of England; a Northern, including all the other areas of Palæozoic rocks in England and Wales, Southern Scotland, and most of Ireland; and an Eastern region, embracing the Mesozoic area of Central and South-Eastern England. It is, of course, not intended to suggest that there is any essential difference in the tectonics of these three areas. The subdivisions, which are tabulated in the classification set out on a later page, are made for convenience of description, and in order to emphasize the geographical and geological relations of the different groups of ore-deposits.

The Southern district, both in respect of its geological structure and of its ore-deposits, is marked off on the whole from the districts to the north of it. The ores comprise the abundant copper, lead, and zinc veins in the counties of Kerry, Cork, and Waterford, the deposits in the Mendip and Quantock Hills of Somerset, and the tin-copper ores of Cornwall and Devon, with the associated lead and zinc ores. The chief features of this Armorican region are the marked local development of tin, and the general abundance of copper. Like the geological structure of the region in which they occur, the ore-deposits have Continental affinities. It is a peculiar circumstance that the highly disturbed district of Pembrokeshire, which in Palæozoic times was more than once a theatre of igneous activity, and was involved in the Armorican movements, should be barren of ore-deposits.

The Northern region may be subdivided on a basis of geological and geographical continuity between its various fragments. Thus, taking first the areas of Lower Palæozoic rocks, the Southern Uplands, the Lake District, the Isle of Man, and North-Eastern Ireland constitute an ore-bearing unit. This area is characterized in general by veins of lead and zinc ores, with copper in places, some antimony, and traces of cobalt ore; while gold occurs in the Southern Uplands, and has been recorded also from the Lake District. It will be observed that the Caledonian granites are abundantly developed in all these districts. A second unit comprises the North-West and West of Ireland, chiefly the counties of Donegal, Mayo, and Galway. The ores here are similarly lead, zinc, and copper; while the Caledonian granite is again prominent in Donegal and Galway. A third unit, well-defined, embraces Northern and Central Wales, Anglesey, and the South-East of Ireland. This area differs somewhat from the other two: while lead and zinc ores are still abundant, copper is much more prominent, especially in Carnarvonshire, and there is also the well-marked gold-belt of Merionethshire. Finally, antimony, nickel, and cobalt are rare or absent. A marked feature is the localization of these copper and gold districts. The pyritic masses of Wicklow and Anglesey, in this area, are considered, as pointed out above, to belong to the older Caledonian Epoch.

Turning to areas of Upper Palæozoic rocks, still in the Northern province, we have a second group of units, separated on geological and geographical considerations. The Midland Valley of Scotland is characterized by the silver-ore veins of Alva in Stirlingshire and of Hilderston in Linlithgowshire, and by the zeolitic copper deposits in the Carboniferous lavas of Renfrewshire and Dumbartonshire. The Pennine Range, extending through the North of England down to Derbyshire, is another unit, characterized by lead and zinc ores throughout its whole extent, while fluorspar, barytes, and copper ores are sporadically distributed. A third unit is made up of the Carboniferous Limestone area of Flintshire and Denbighshire, also yielding lead and zinc ores, but very little fluorspar or barytes. The Northern province is completed by the central Carboniferous plain of Ireland, containing scattered occurrences of lead, zinc, and copper ores.

The Eastern region is marked by occurrences of blende, galena, and other ores in trifling quantities in the Keuper, Lias, and Lower Oolite of several counties, and, more especially, by the bedded cupriferous deposits of Alderley Edge and Mottram St. Andrews in Cheshire. Similar deposits are also known in the Peckforton Hills north of Whitchurch, at Grinshill near Shrewsbury, and in the neighbourhood of West Felton, Oswestry. They are the British representatives of the copper-bearing Triassic rocks of New Mexico and Arizona, the Kupferschiefer of Mansfeld, and the lead-bearing sandstones (Bunter) of Commern and Mechernich. The ore-occurrences of the Eastern district cannot be satisfactorily explained as due to sedimentation. They represent the highest zone of Hercynian ore-deposition in the British area, and indicate that the Hercynian metallogenetic epoch extended well into the Mesozoic Era. The absence of fissures to serve as trunk-channels and the impoverishment, dilution, and dissipation of the solutions in this uppermost zone, account for the paucity of ores.

It is necessary to consider the evidence for placing all the ores here enumerated in the Hercynian, more especially as many of the areas are essentially Caledonian in their geological structure. Evidence is to be obtained from a consideration both of the vein-fissures and of the ores contained in them.

With regard to the former, the vein-fissures of certain districts are known to be post-Carboniferous or pre-Triassic, notably those in the older rocks of the Lake District[1] and of North Wales.[2] In the Isle of Man the fissures are later than the pre-Carboniferous disturbances,[3] and are probably contemporaneous with those of the

[1] A. Harker, Quart. Journ. Geol. Soc. vol. li (1895) p. 126.

[2] A. C. Ramsay, 'Geology of North Wales' Mem. Geol. Surv. 2nd ed. (1881) pp. 200–203, 264, 301; and A. Harker, 'The Bala Volcanic Series of Caernarvonshire' Cambridge, 1889, p. 115.

[3] G. W. Lamplugh, 'Geology of the Isle of Man' Mem. Geol. Surv. 1903, p. 488.

Lake District, to which the island is structurally related. The vein-fissures of Merionethshire and Shropshire are independent of the Caledonian folds which are so well developed in these areas. They generally strike across the folds, and are clearly of later date. The same is true of Cardiganshire: Prof. O. T. Jones has pointed out, for example, that the transverse vein-fissures around Pont Erwyd cut across the older Caledonian folds, while the strike-faults associated with these folds are barren of ores.[1] In the Leadhills, the ores occur similarly in a set of conjugate fissures which strike transversely to the axis of a Caledonian fold. In the Carboniferous Limestone districts we find conjugate fissure-systems structurally related to the post-Carboniferous compression of these areas, and probably due to the stresses then set up. In none of these Carboniferous areas do the vein-fissures extend up into adjoining Triassic strata. In Ireland, for example, the vein-fissures, both in the older and in the younger Palæozoic rocks, are chiefly concentrated in those districts which were folded and compressed during the Hercynian disturbances, notably in the western, eastern, and southern districts. In the central plain of Ireland, where folding was gentle and fissuring slight, there is an obvious paucity of veins, even if we make allowance for the extensive masking by drift in many places. The dependence of ore-deposits on post-Carboniferous folding and consequent fissuring is thus strikingly shown in Ireland. On the whole, then, the evidence indicates that the vein-fissures of these different areas are closely related, as regards both their age and their origin, to the Hercynian earth-movements; while the fissures in many districts of Caledonian movements are unrelated to, and later than, the Caledonian structures.

As regards the ores, their primary deposition cannot have been far removed from the date of formation of the fissures. The fissuring, indeed, is an index of much subterranean energy at this period, while the practical absence of ores from Mesozoic strata clearly points to the fact that the bulk of the ore-deposition took place prior to the consolidation and elevation of these strata. Further, the general community of the Hercynian type of lead, zinc, and copper ores throughout the whole region, suggests that all the deposits are of the same age. Conclusive evidence is obtained from those areas where a type or group of veins is continuous from older into adjoining younger rocks. Thus, in the Lake District, the barytic lead-veins in the Skiddaw Slates at Thornthwaite, and in the Borrowdale Ashes at Greenside, are repeated when we pass eastwards into the Carboniferous tract of Dufton Fell and Alston Moor. Similarly, in Flintshire and in the Minera district of Denbighshire, there are lead-veins in the Wenlock Shales immediately to the west of the Carboniferous vein-districts. In the Isle of Man there are veins of one and the same type in the Manx Slates, in the Caledonian granite of Foxdale, and in the Carboniferous

[1] 'The Hartfell-Valentian Succession in the District around Plynlimon & Pont Erwyd' Quart. Journ. Geol. Soc. vol. lxv (1909) p. 527.

Limestone of Castletown. This association is also well seen around Lough Corrib (Galway), where there is a group of lead-copper veins occurring indifferently both in the Older Palæozoic slates and in the Carboniferous Limestone. It is not conceivable, in any of these examples, that the veins in such adjacent districts can be of different ages. Recorded instances of individual veins passing from the Carboniferous Limestone into older rocks are not common, as such veins generally become barren when they leave the limestone and have not been explored further. The Pant-y-Buarth vein, however, in the Carboniferous Limestone of Flintshire, was traced into the Wenlock Shales on the west,[1] as was also the Old Vein at Minera in Denbighshire. Shafts sunk on a copper-vein at Great Orme's Head seem also to have followed the vein down from Carboniferous Limestone into Ordovician or Silurian slates.[2]

In conclusion, it will be seen that all the available evidence points in one direction, namely, that the vein-fissures are post-Carboniferous and pre-Triassic, while the period of ore-deposition, as indicated by the various examples given, also belongs to this general epoch. This evidence, collected in all the typical vein-districts throughout the British area, is considered to justify the conclusion that all the deposits cited are of Hercynian age.

It is evident that the ore-deposits here grouped together as Hercynian are closely related to the various Hercynian deposits of Western and Central Europe. Thus the fragments of the Variscan Mountains contain the ore-deposits of the Harz and of Freiberg and other important Saxon localities. The Armorican chain of Britanny, Belgium, and Westphalia, and the Central Plateau of France are marked by similar ore-deposits; while the Spanish Meseta is another Hercynian fragment, richly metalliferous, especially in lead and zinc ores and in copper ores. Veins of tin, copper, silver-lead, and zinc ores are characteristic of the Hercynian metallogeny of Europe,[3] and the British ores here considered form a portion of this great series.

Before leaving the Hercynian Epoch, it should be pointed out that there is a suggestion of relationship between the widespread petrographic province of Caledonian granites and the similarly widespread metallogenetic province of Hercynian ores. The relationship is not very intimate, but there is no other series of igneous intrusions in the British area the distribution of which is in any way comparable with the distribution of the Hercynian ore-deposits. It is curious that, except in the Cornish area, the Hercynian deposits are unaccompanied by genetically related igneous rocks. There is, however, little doubt that the Hercynian ores have been primarily derived from magmatic sources; and, judging from the foregoing considerations, it seems probable that the magmatic

1 A. Strahan, 'Geology of Flint, Mold, & Ruthin' Mem. Geol. Surv. 1890, p. 188.

2 A. C. Ramsay, 'Geology of North Wales' Mem. Geol. Surv. 2nd ed. (1881) p. 308.

3 L. de Launay, C. R. Acad. Sci. Paris, vol. cxxx (1900) p. 745.

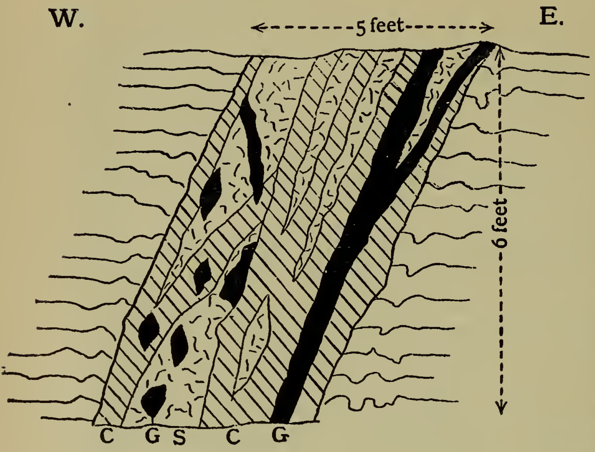
sources of the Caledonian granites and of the Hercynian ore-deposits respectively were closely related.

Tertiary Epoch.—The Tertiary metallogenetic province of Europe is conterminous with the Tertiary arcs of folding and intrusion around the Mediterranean area.[1] The auriferous deposits of Hungary and Transylvania and the ore-deposits of Italy are typical examples. The Tertiary Epoch of igneous activity in the north-west of the British area, however, does not appear to have been accompanied by ore-deposition. These Tertiary eruptions were largely of basic rocks, a type seldom accompanied by important ore-deposits in Tertiary times,[2] while they did not give rise anywhere to thermal after-effects of any significance. Again, where Tertiary intrusions occur in the British area, they are unaccompanied by ore-deposits genetically related to them. Further, the distribution of Tertiary eruptives is local, and bears no relation to the distribution of ores. The Tertiary volcanic rocks, indeed, are concentrated in the least metalliferous portion of the kingdom. Lastly, none of the British ore-deposits have any of the features of the Tertiary facies, as exemplified in the andesitic and related goldfields.

It has, however, been claimed or suggested that certain of the ore-deposits here classed as Hercynian are the result of the earth-movements and vulcanicity of the Tertiary Epoch. The late J. G. Goodchild emphasized the comb-structures and crystal-filled cavities in lead-veins in the North of England as a proof that no disturbance of the vein-fissures has occurred since ore-deposition; and, as the Tertiary volcanic period was the last phase of widespread disturbance, he inferred that the ore-deposition followed these disturbances.[3] These features of the veins, however, are accidental rather than essential. Since the primary deposition the ores, particularly in the limestone districts, have undergone much solution, rearrangement, and redeposition by circulating waters. Many of these crystallized ores in solution-cavities are of comparatively recent date, and are properly classified as secondary alterations. The evidence of such structures in the veins is, therefore, inconclusive and of little value as regards the age of primary ore-deposition. Similarly, the plumosite of Foxdale, the delicate habit of which has been taken as an indication of the absence of movement since its formation in the vein,[4] is probably also a product of secondary enrichment. The fact of movement since primary ore-deposition is clearly proved by the occurrence of brecciated vein-fillings, illustrated in figs. 1, 2, & 3 (pp. 290, 291). These diagrams, made during the present investigation, show typical vein-structures in the

[1] L. de Launay, *loc. supra cit.*
[2] Malcolm Maclaren, 'Gold' London, 1908, p. 77.
[3] 'Mode of Occurrence & Genesis of Metalliferous Deposits' Proc. Geol. Assoc. vol. xi (1888–90) pp. 45–69.
[4] G. W. Lamplugh, 'Geology of the Isle of Man' Mem. Geol. Surv. 1903, p. 503.

Fig. 1.—*Section of Brow Vein, Leadhills; 70-fathom level, January 1909.*

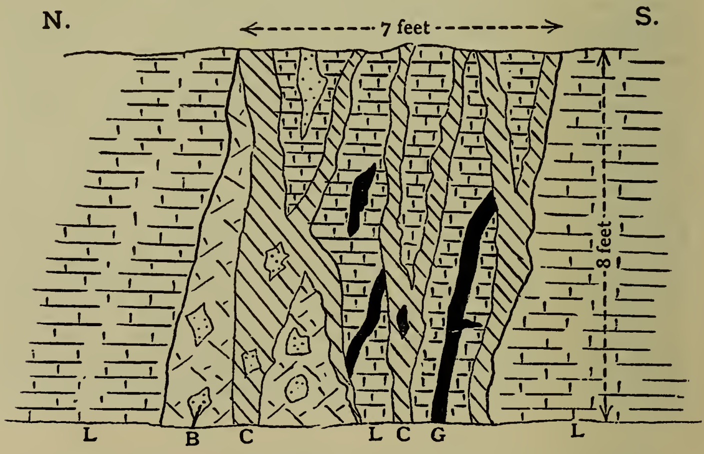


[C = Calcite; G = Galena; S = Crushed slate.]

deeper levels of some mines, where circulating waters have not re-arranged the ores or formed later 'pipes' and 'flats.' The primary ores, galena and blende, have been broken up by movement and re-cemented by calcite or quartz.

Mr. G. W. Lamplugh has shown that certain basaltic dykes in the Isle of Man, which are probably of Tertiary age, lie alongside lead-veins in such a manner that the ores as now found must have been deposited after, and probably in consequence of, the intrusion of the dykes.[1] In these cases there is no evident genetic relationship between the dykes and the ores, while the

Fig. 2.—*Section of Rampgill Vein, Nenthead, in the Great Limestone; main level east, December 1908.*



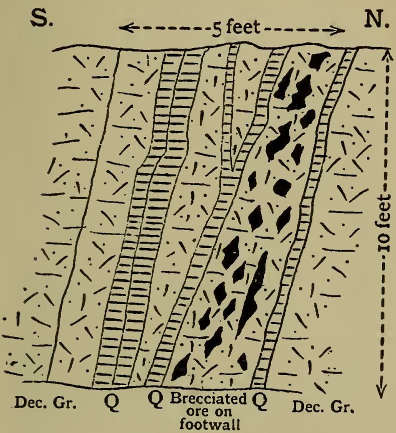
[L = Limestone; B = Blende; C = Calcite; G = Galena.]

larger and more productive veins of the Isle of Man are unrelated to such dykes, and the veins where the phenomenon was observed

[1] 'Geology of the Isle of Man' Mem. Geol. Surv. 1903, pp. 488–89.

are small and carry insignificant quantities of ore. It is most probable, therefore, that the invasion of the dykes was accompanied by heated waters and resulted in an invigorated underground circulation, by means of which the ores, which had long previously been deposited in the veins, were taken into solution, re-arranged, and re-deposited in their present position alongside of or impregnating the dykes. The phenomenon is, then, of secondary origin.

Fig. 3.—*Section of Foxdale Vein, 320-fathom stopes east, January 1909.*



[Dec. Gr. = Decomposed granite; Q = Quartz-veins; the black patches represent galena.]

Lastly, Mr. J. B. Hill and Mr. J. H. Collins have concluded that the lead and zinc veins of Cornwall and Devon are of Tertiary age.[1] The chief reasons advanced for this conclusion are that the vein-fissures trend north and south, parallel to faults and dykes of Tertiary age in the Scottish Highlands, and that certain north-and-south faults in the east of Devon extend into and cut the Chalk.[2] This, however, only proves that post-Cretaceous movement has occurred along the fissures, which latter may be much older. These fissures, moreover, are not ore-bearing. It is clear that the lead and zinc veins of the district are younger than the tin-copper veins which they intersect. This is indicated by the differences in vein-filling rather than by the displacement of the one set of fissures by the other. At the same time, the orientation of the two sets of fissures and their relation to the tectonics of the area indicate that both sets have probably been formed by and during the Armorican stresses. Both sets of fissures, in short, form a conjugate system, and, if not contemporaneous, they are at all events not widely different in age. The ore-deposits of Cornwall and Devon are believed to be all of Armorican age, but deposited as two successive phases, namely, an earlier tin-copper phase and a later lead-zinc phase, appearing when the eruptive after-effects were less intense.

[1] J. B. Hill, 'Plutonic & other Intrusive Rocks of West Cornwall in their Relation to the Mineral Ores' Trans. Roy. Geol. Soc. Cornwall, vol. xii (1901–1905) p. 599; J. H. Collins, chapt. v of the 'Origin & Development of Ore-Deposits in the West of England' Journ. Roy. Inst. Cornwall, vol. xiii, pt. 2 (1896) pp. 283 *et seqq.*

[2] H. T. De la Beche, 'Geology of Cornwall, Devon, & West Somerset' Mem. Geol. Surv. 1839, p. 311.

None of the evidence for Tertiary ore-deposition in the British area appears convincing, and it is concluded that the manifestations of Tertiary vulcanicity and earth-movement in the area were unaccompanied by the formation of ore-deposits.

IV. Classification of the British Ore-Deposits.

The accompanying table (p. 293) embodies the classification of the ores here considered, according to their epochs and provinces, while the geographical subdivisions of the Hercynian Province are also set out in detail. In the various provinces there may occur deposits belonging to a different epoch from that to which the characteristic ores of these provinces belong. Thus, the Caledonian Province of the Scottish Highlands includes some deposits belonging to the younger Hercynian Epoch. Again, the wolfram-bearing pegmatites of Grainsgill, belonging to the Caledonian Epoch, are in a district of typical Hercynian ores. To such occurrences may be applied the terms metallogenetic outlier or inlier, according as they belong to a younger or older epoch than the ores characteristic of the area where they occur. It should be mentioned here that the North-West of Ireland, although its ores are probably of Hercynian age, is mapped as a part of the Caledonian Province (Pl. XXIII), since it is geologically related to the Highlands of Scotland. Similarly, the South-East of Ireland, although containing the Wicklow pyritic masses of Caledonian age, is mapped as Hercynian, in order to link it up with the allied districts of Northern and Central Wales, where the veins are of Hercynian age. In other words, the pyritic deposits of Wicklow, considered in relation to the Welsh ores and to those of Central Ireland, are a metallogenetic inlier.

V. Conclusions.

Zones of ore-deposition.—The West of England gives much insight into the nature of the Hercynian ore-formation. It appears highly probable that this local development of tin-ore, with its accompanying pneumatolysis, is an index of the horizon of ore-deposition, and an indication of what we should find at greater depths in other Hercynian districts, namely, deep-seated intrusions with ores intimately related to them. As we pass up, we find copper and gold in the intermediate zones, and lead and zinc in the higher zones. The Cornish area thus seems to afford the key to the deep-seated conditions which prevailed throughout the region during the Hercynian Epoch. The occurrence in the Cornish area of gold and of ores of nickel, cobalt, silver, arsenic, and antimony should also be noted as throwing light on the occurrence and derivation of these metals in other districts, that is, in higher zones. A consideration of the data revealed in Cornwall, in the Lower Palæozoic rocks, and in the Upper Palæozoic rocks respectively, leads to the following conclusions as to the sequence of ores in successive vertical zones.

METALLOGENETIC CLASSIFICATION OF BRITISH ORE-DEPOSITS. (See Map, Pl. XXIII.)

Metallogenetic Epoch.	Metallogenetic Provinces and Sub-Provinces.			Types of Ore-Deposits.
1. HURONIAN or PRE-CAMBRIAN.	Scottish Highlands (locally).			Magmatic segregations (so far as known).
2. CALEDONIAN	Scottish Highlands; local occurrences elsewhere.			Magmatic segregations, pegmatites, pyritic deposits, fahlbands, gold.
3. HERCYNIAN	a. Northern Region.	1. In Lower Palæozoic Rocks.	Southern Uplands, Lake District, Isle of Man, North-East of Ireland.	Veins of copper, gold, silver-lead, and zinc ores.
			North-West and West of Ireland.	
			Northern and Central Wales, Anglesey, South-East of Ireland.	
		2. In Upper Palæozoic Rocks.	Midland Valley of Scotland.	Veins of silver-lead and zinc ores, with fluorspar, barytes, and some copper ores.
			Pennine Chain.	
			Flintshire.	
			Central Plain of Ireland.	
	b. Southern (Armorican) Region		South of Ireland & S.W. England.	Tin-copper ores; copper and lead-zinc ores.
	c. Eastern Region		Central & South-Eastern plain of England.	Traces of copper, lead, and zinc ores.

The Hercynian Epoch of ore-deposition was ushered in by earth-movements and deep-seated intrusions, the latter being exposed only in Cornwall and Devon. The igneous masses, on cooling, gave off gas-aqueous emanations which rose into the fissures, carrying with them in solution the various ores which had been segregated from the magma. There were first deposited, in the deepest zones and in close proximity to the intrusions, ores such as cassiterite, with chalcopyrite, pneumatolytic minerals, and some of the rare metals. As the solutions rose higher, they were largely depleted of tin with its special solvents and carriers. Gold and silver, chalcopyrite, pyrite, arsenopyrite, and pyrrhotite, with some galena and blende, were then deposited. Gradually the solutions were robbed of the less soluble ores, and carried a preponderance of the more mobile lead and zinc ores, which attained a maximum development in the Carboniferous Limestone zone. As the solutions circulated in still higher zones, they became impoverished and diluted by admixture with descending surface-waters, and the scattered ore-occurrences in the Lower Mesozoic rocks represent the last stage in the sequence of events which began at the end of the Carboniferous.

The zones of deposition of the ores, as deduced from an examination of the British occurrences, are, then, as follows:—

1. The deep pneumatolytic zone, with tin, tungsten, etc., and some copper.
2. The intermediate zone, with copper, gold, and some lead and zinc.
3. The upper zone, containing chiefly lead and zinc.

The conception of successive vertical zones of ore-deposition has been elaborated by other workers along different lines. Mr. Waldemar Lindgren has mapped out the zones by a consideration of the physical conditions attending deposition at different depths,[1] and Mr. J. E. Spurr has obtained similar results from an examination of the relations between 'petrographic and metallographic provinces.'[2] His classification is given below:—

'1. The pegmatite zone, containing tin, molybdenum, tungsten, etc.
2. The free gold-auriferous pyrite zone.
3. The cupriferous pyrite zone.
4. The galena-blende (galena usually argentiferous) zone.
5. The zone of silver and also much gold, usually associated with metals which combine with them to make substances which are highly mobile, and account for the relatively elevated position of the zone, *i. e.* antimony, bismuth, arsenic, tellurium, and selenium.'

This last zone is not represented in the British area. Otherwise it will be seen that Mr. Spurr's subdivisions are quite applicable to the British Hercynian province, and are in general agreement with the subdivisions deduced from an examination of this province by itself.

[1] 'Economic Geology,' vol. ii (1907) p. 105.
[2] *Ibid.* p. 781.

Magmatic differentiation and ore-deposition.—The local distribution of certain ores, such as the gold ores of Merionethshire, the pyritic deposits of Wicklow and Anglesey, the silver-cobalt ores of Alva and Hilderston, and other similar occurrences, is very striking when considering the geographical distribution of the metals. While some of such peculiarities may result from selective chemical affinity and from influences due to the country-rock, it is clear that there is a much more important and more general cause at work. The heterogeneous distribution of ores in the rocks of the earth's crust cannot be accounted for by assuming an originally heterogeneous distribution of metals beneath. It is agreed that the ultimate source of all heavy metals is in igneous magmas, and further, the differentiation of certain metals with certain types of plutonic rocks has long been recognized. It follows that the distribution of ores, as now found, is an index to the former distribution of metals in the magmatic sources beneath, a distribution brought about by progressive differentiation of these magmas, with correspondiug differentiation and segregation of the heavy metals.

We are here brought into touch with a feature emphasized by Mr. J. E. Spurr, namely, the relations observed between petrographic provinces and provinces of ore-deposits.[1] This feature, which is illustrated to some extent in the British area, clearly indicates that the differentiation of igneous rocks and that of ores have been closely involved. That petrographic provinces with a certain individuality are accompanied by metallogenetic provinces with a corresponding individuality is illustrated in many regions. I may instance the pyritic deposits of Huelva, Norway, and Wicklow; the nickeliferous pyrrhotites of Norway and of Sudbury; the Tertiary goldfields of Hungary and of the Pacific belt; and the ancient goldfields of Gondwanaland (Erythræan Province of Dr. Maclaren).[2] Each of these types has its characteristic assemblage of igneous rocks, and generally also its characteristic tectonic structure due to certain definite sub-crustal processes.

It is clearly evident that the differentiation and concentration of ores, as reflected in such cases, has been intimately bound up with the differentiation of magmas, and hence has been dependent, throughout geological time, on epochs of intense crust-movement. To these circumstances is due the occurrence and recurrence of defined metallogenetic epochs, corresponding with widespread epochs of crust-movement and igneous activity. The facts of magmatic differentiation in relation to ore-deposition on the one hand, and to tectonic processes on the other, are clearly indicated. The full and complete explanation of these facts is a labour for the future, and must wait upon further knowledge of the processes involved, and of their relation to the earth's history.

[1] J. E. Spurr, *loc. supra cit.*

[2] Trans. Inst. Min. & Met. vol. xvi (1906–1907) p. 15.

EXPLANATION OF PLATE XXIII.

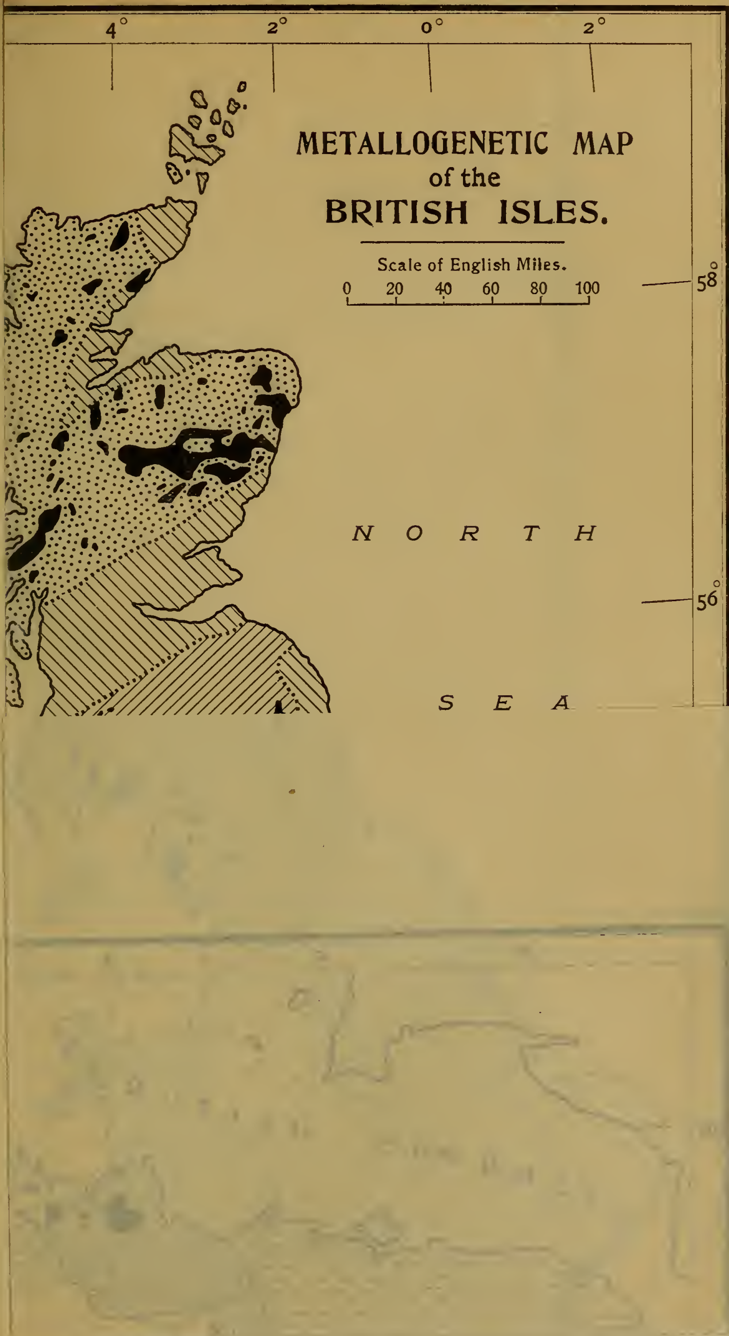
Metallogenetic map of the British Isles, on the scale of 80 miles to the inch.

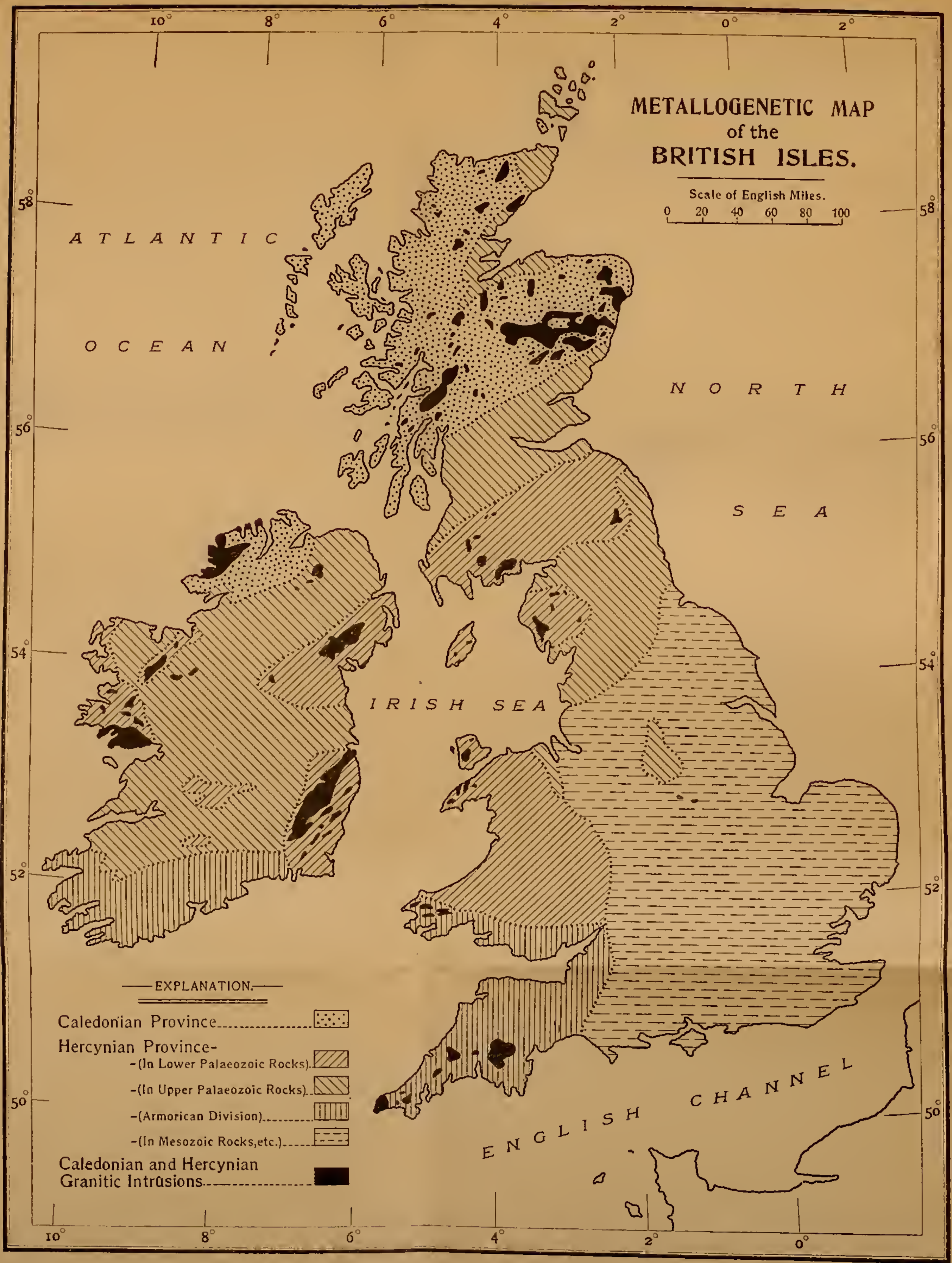
Discussion.

The President (Prof. W. J. Sollas) remarked that the chief novelty in the Author's communication was to be found in the asserted Armorican age of many ore-deposits hitherto regarded as Caledonian, and expressed the opinion that the evidence was hardly equal to the burden laid upon it. In Glendalough, lead-veins occurred in association with Caledonian granite; and, pending further investigation, it still seemed probable that most of the Wicklow veins were of Caledonian age. Apart from the rare outstanding instances discussed by the Author, the absence of metallic deposits around Tertiary granite in the British Isles had always seemed a very remarkable fact.

Prof. Watts stated that, although he had always associated many of the chief metalliferous deposits in Britain with the Caledonian movement, he had been reluctantly compelled to accept the evidence adduced by the Author that the bulk of it was associated with the Hercynian movement. The Author had visited all the principal mining localities in the country, and had based his conclusions partly on evidence gathered on the spot and partly on published accounts of the mines.

Mr. D. A. Macalister complimented the Author, and referred to his establishment of a connexion between Hercynian movements and the metalliferous lode-deposits of this country. It was difficult to assign fissuring to a particular period, and, as it was certain that fissuring and faulting along Armorican lines of folding had taken place as late as Tertiary times, he asked the Author what limits he would put to fissuring in this direction definitely connected with the Armorican movement. It appeared best to restrict the term to the time during which the movements were actually bringing about their orogenic effects. The termination of the Hercynian and Variscan movements in Central Europe and in the Armorican of France and South-Western Britain was marked by intrusions of granite, some of which gave rise to tin and copper deposits. Since the intrusion of granite in Cornwall and Devon there had been no disturbances, except those of fissuring and slight overthrusting. The tin and copper lodes were roughly parallel with the folding of the sediments, but as they traversed the granite and were filled with minerals of pneumatolytic origin, they were evidently confined to the period immediately following the consolidation of the granite or to Armorican-movement times. But in the case of the lead-lodes there were three points which negatived a similar conclusion—(*a*) They traversed the Armorican folding at right angles; (*b*) the minerals were genetically distinct from those formed by pneumatolysis; and (*c*) they were of later age than the tin and copper lodes. The only grounds for putting them in the Armorican period would be that no mountain-building movements had occurred in


4°
2°
0°
2°
METALLOGENETIC MAP
of the
BRITISH ISLES.
Scale of English Miles.
0 20 40 60 80 100
58°
N O R T H
56°
S E A


METALLOGENETIC MAP
of the
BRITISH ISLES.
Scale of English Miles.
0 20 40 60 80 100
ATLANTIC
OCEAN
NORTH
SEA
IRISH SEA
ENGLISH CHANNEL
EXPLANATION.
Caledonian Province
Hercynian Province-
-(In Lower Palaeozoic Rocks)
-(In Upper Palaeozoic Rocks)
-(Armorican Division)
-(In Mesozoic Rocks,etc.)
Caledonian and Hercynian Granitic Intrusions
10°
8°
6°
4°
2°
0°
58°
56°
54°
52°
50°

these islands since Armorican-movement times. As the Armorican movement ceased in, at latest, Permian times, the lead-lodes of Cornwall were probably formed by regional strain of the plateau-type, in association with the oscillating subsidences which followed the Armorican movement, and lasted until Tertiary times. These movements were typified in Skye, and were possibly homotaxial with the Alpine mountain-building movement of Southern Europe and also anterior to it. Tin ores were found near the igneous rocks, while lead ores were formed not only at a greater distance but at a later time, as the Author apparently admitted in explaining the connexion of the ores. The selective capacity of lead ores for certain rocks caused the speaker to hesitate in accepting all the Author's views.

Mr. Postlethwaite said that he was best acquainted with the ore-deposits of the Lake District, which belonged partly to the post-Silurian and partly to the post-Carboniferous age. The lead ore found in the Crossfell range and in the Alston District, besides the deposits of hæmatite in Western Cumberland and Furness, belonged to the latter date; while the lead and zinc ores found in the older Ordovician rocks were of the former age. The vein-fissures in the older rocks had been formed and filled before the extensive denudation of the Lake District had begun. Deposits of ore, or remnants of those deposits, were found on mountain-tops, notably at Old Brandlehow, Barrow, and Greenside Mines.

Mr. T. Crook congratulated the Author, but was surprised that he had assigned so little active ore-deposition to the Caledonian period. The visible effects of Caledonian movements on the orogeny of these islands were not less conspicuous than those of the Hercynian; while, both as regarded extent of intrusion and severity of movement, the former decidedly excelled the latter. Further, the Caledonian movements probably covered a longer period of time than those of the Hercynian. Therefore, according to the view that periods of crust-movement synchronize with those of ore-deposition, it seemed necessary to infer that the Caledonian changes were probably accompanied by more productive results than the Author admitted in his paper. The evidence available for assigning Hercynian age to ore-occurrences in rocks which had been affected by Caledonian movements seemed to be largely inconclusive. The Caledonian areas had been subjected to much more extensive denudation than the Hercynian; and consequently, existing records of such ore-formations as might have accompanied the Caledonian, were not so nearly complete as those for the Hercynian, movements.

Mr. Lamplugh said that the Author had correctly diagnosed the state of the evidence in the Isle of Man. In a few cases it was clear that the ores had attained their present position after the intrusion of the Tertiary dykes, but evidence of this kind was exceptional and not general. If these cases were disposed of by presuming them to be due to secondary migration of ore within the lode, there was very little evidence in the other lodes, including the main lodes of the island, either for or against the Author's classification. It was necessary to recognize, however, that in some cases there might be a wide difference between the age of the fissure and the age of its metalliferous contents.

The Author thanked the Fellows for their reception and criticisms of his paper. In reply to the President, to Prof. Watts, and to Mr. Crook, who found difficulties in his view that all the vein-groups that he had enumerated were of Hercynian and not Caledonian age, he admitted that his conclusions were a generalization from particular examples. But the community of vein-type throughout the whole area, the frequent extension of a group of veins from a district of Carboniferous Limestone into an adjoining district of older rocks affected by the Caledonian movements, and the tracing of individual veins from Carboniferous to Lower Palæozoic rocks, seemed to lead to no other conclusion than that the Hercynian was the great epoch of ore-deposition in the region, always excepting the area of the Scottish Highlands. It was a significant fact that the great province of Caledonian granites was almost unaccompanied by closely-related ore-deposits in Britain. Ore-deposition seemed to have been delayed until the next great tectonic epoch, when, strangely enough, there was, except in the Cornish area, a marked poverty of plutonic intrusives (exposed). Mr. Macalister's remarks suggested questions of the paragenesis of the two groups of ores in Cornwall and Devon. The Author had not studied this problem, but it must be considered in determining more exactly the relations of the chief vein-types in that area. In the meantime he interpreted ore-deposition in Cornwall and Devon as belonging to one epoch (Armorican or Hercynian), the ores being deposited, however, in two or more cycles.

In reply to Mr. Lamplugh, who emphasized the importance of drawing a time-distinction frequently between the formation and the filling of fissures, the Author said that it was recognized that the arrangement of ores in the veins was being continually modified; but their primary deposition, he felt, must have been closely connected, in most cases, with the fissure-formation. The latter indicated great subterranean energy, which must have been a factor in the concentration and transport of ores in the deeper zones. Further, there was, between the Hercynian and the Tertiary, no period in Britain where a deep-seated agency was manifested, which could have effected the transport and deposition of ores in depth. The plumosite at Foxdale, the habit of which indicated absence of movement since its formation, was, he believed, either a product of secondary enrichment, or the result of local re-arrangements following on the Tertiary disturbances within the area of the Isle of Man.

11. PROBLEMS *of* ORE-DEPOSITION *in the* LEAD *and* ZINC VEINS *of* GREAT BRITAIN. By ALEXANDER MONCRIEFF FINLAYSON, M.Sc., F.G.S. (Read January 26th, 1910.)

CONTENTS.

I. INTRODUCTION.

THE lead and zinc districts of Great Britain afford good opportunities for the study of these ores, owing to the variety of types met with and the advanced state of mining. Unfortunately, however, many interesting districts have been exhausted and abandoned, with the inevitable loss of much valuable information, which was not secured when the mines were in operation. As Franz Posepny has truly remarked,

'Mining, indeed, constantly furnishes fresh evidences in new openings, but it destroys the old at the same time; and if these are not preserved for science before it is too late, they are lost for ever.' [1]

The Geological Survey memoirs, however, have in some cases preserved many data which could not otherwise be obtained. The present work has been carried out on the basis of personal field-work in all the chief districts, coupled with laboratory work at the Imperial College of Science and Technology, where all the analyses tabulated in this paper were made.

The lead and zinc veins of Britain are chiefly of the spathic and barytic types of Freiberg mineralogists. Calcite is the predominant gangue, while fluorspar, barytes, and quartz are also abundant. Zeolites occur locally, as at Strontian in Argyllshire, and at Glendalough (Wicklow). The galena is argentiferous to a varying degree, and rich silver-ores have been mined at Hilderston (Linlithgowshire), at Alva (Stirlingshire), and in parts of Cornwall. These veins, though small and unimportant, are of the Joachimsthal and Annaberg type. The country-rock of the veins embraces nearly all the Palæozoic formations, from pre-Cambrian gneiss to the Carboniferous Limestone.

[1] 'The Genesis of Ore-Deposits' Amer. Inst. Min. Eng. 2nd ed. (1902) p. 3 (reprinted from vol. xxiii of the Trans.).

II. Source of the Ores.

Since the days when the lateral-secretion theory was first propounded by Sandberger, deposits of lead and zinc ores have afforded much scope for investigation of the source of the metals. In Great Britain there are two general types: namely, veins in the Carboniferous Limestone, and veins in the older slates and granites. Concerning the latter type, there is no clear ground for argument; the ores have obviously been derived from a deep source, probably from deep-seated igneous masses. Attention is, therefore, here confined to the source of the ores in the limestone districts.

Fluorine.—Four samples of limestone were analysed by the method of W. F. Hillebrand,[1] with the following results:—

Locality.	*Fluorine percentage.*
Halkyn (Flintshire)	0·21
Matlock (Derbyshire)	0·11
Nenthead (Cumberland)	0·04
Rookhope (Durham)	0·13

Duplicate analyses of these specimens yielded sometimes discordant results, due probably to imperfections in the method of assay, as pointed out by Hillebrand; but the results leave no doubt as to the presence of small quantities of fluorine in the limestones. The constituent has probably been derived from seaweeds or other organic matter in the original sediments, or from the fluorine-bearing calcium phosphate of shells.

It is highly improbable, however, that this can be the source of the fluorine in the vein-fluorspar. The quantities present are extremely small, and the occurrence of fluorine in the rocks bears no relation to the occurrence of fluorspar in the veins. The occurrence and mineralogical relations of the fluorspar indicate that fluorine has been one of the original elements in the vein-solutions. The presence of fluorine is believed to indicate, in short, a deep-seated origin, dating probably from processes of magmatic extraction.

Lead and Zinc.—In searching for these constituents, a series of rocks was examined, the material being ground very fine. Quantities of from 30 to 100 grams were taken, and analysed by methods previously used by W. F. Hillebrand[2] and by James D. Robertson.[3] The following table gives the results:—

[1] 'Analysis of Silicate & Carbonate Rocks' Bull. U.S. Geol. Surv. No. 305 (1907) p. 157.

[2] 'Geology & Mining Industry of Leadville, Colorado' Monogr. xii, U.S. Geol. Surv. 1886, p. 591.

[3] Geol. Surv. Missouri, vol. vii (1894) pp. 479, 740.

Rock.	*Locality.*	*Lead.*	*Zinc.*
		Per cent.	Per cent.
Granite	Foxdale.	·004	·005
Granite	Threlkeld.	·003	·011
Granite	Glendalough.	·004	·001
Granite	Dartmoor.	·002	·002
Diabase (Whin Sill)	Rotherhope.	·003	·0005
Diabase (Toadstone)	Darleydale.	·001	·001
Volcanic ash	Conway.	·0025	not found.
Volcanic ash	Greenside.	·006	·002
Slate	Leadhills.	·001	not found.
Limestone	Halkyn.	·0005	·0015
Limestone	Matlock.	·001	·0005
Limestone	Alston.	·0015	·001

The results were verified as far as possible by blank experiments, and by tests of the reagents used; while some duplicate analyses made indicated that the figures were generally correct to within 30 per cent. of the amount stated. The results correspond with those of W. F. Hillebrand on the Leadville porphyries, where the average amount of lead oxide was determined to be 0·002 per cent.[1] Similarly, J. D. Robertson, in the Archæan rocks of Missouri, records 0·004 per cent. of lead and 0·009 per cent. of zinc.[2] The foregoing analyses, like those of Luther Wagoner for gold and silver in rocks at San Francisco,[3] show a higher percentage of metals in the igneous than in the sedimentary rocks, suggesting the conclusion that the metals in the latter rocks have been derived by denudation of the older igneous and crystalline rocks.

A consideration of the areas which were basins of deposition in Britain during the Carboniferous Limestone epoch shows that these basins received the drainage from the older rocks, and gives some ground for the belief that the traces of metals found in the limestones by analysis have been derived from the older rocks and deposited contemporaneously with the limestones. Thence, it is only a step to assume that the ores of the veins have been concentrated by circulating waters from the disseminated metals in the limestones. There are several objections to this view, and these may be tabulated as follows:—

(1) Analyses were made of specimens of limestone from the Vieille Montagne Company's mine at Nenthead. The specimens were taken along a cross-cut, at varying distances from the vein and along one and the same stratum—the Great Limestone. The results were as follows:—

[1] *Loc. supra. cit.* [2] *Loc. supra. cit.*
[3] Trans. Amer. Inst. Min. Eng. vol. xxxi (1901) p. 808.

No.	Position of Sample.	Lead.	Zinc.
		Per cent.	Per cent.
1	Limestone in the vein.	·012	·040
2	Do. on the vein-wall.	·025	·015
3	Do. 10 feet from the vein.	·015	·030
4	Do. 20 " "	·001	·004
5	Do. 40 " "	·002	·001
6	Do. 70 " "	·0005	·001

There is no uniform variation in passing from the vein into the country-rock, but the analyses clearly show a much higher metal-content in the limestone adjoining the vein than in the rock farther away. A similar phenomenon has been recorded by J. S. Curtis at Eureka (Nevada),[1] and the difference is certainly due to impregnation of the adjacent rock by the vein-solutions.

(2) A strong objection to the lateral-secretion theory is the close similarity in all respects between veins in limestone, in granite, and in older slates, especially in adjoining districts. Thus the veins in the limestone districts of Alston Moor and Dufton Fell are exactly similar mineralogically to the veins in the slates and ash-beds of the Lake District. Again, in the Isle of Man there are veins in granite extending into the adjoining slates, numerous veins in the slates themselves, and veins in the Carboniferous Limestone at Castletown. It is not conceivable that the ores of these different veins can have different sources of origin.

(3) In the United States, where this problem has been very fully investigated, there are two general types of lead and zinc-ore deposits: firstly the silver-lead or 'hard-lead' ores, typified at Leadville, Aspen, Rico, Tintic, Cœur d'Alène, and Eureka; and secondly the 'soft-lead' and zinc-ores of the Mississippi and Missouri districts, including Wisconsin, the Ozark district, South-Eastern Missouri, and Northern Arkansas. The general conclusions in regard to these two types are that the silver-lead ores are of deep-seated origin, while the ores of the Missouri type have been concentrated in most cases from a disseminated condition in the same formation or in one adjoining that in which they are now found. The essential features of the deposits of this type, the sedigenetic deposits of H. F. Bain,[2] are their sporadic occurrence, the absence of defined veins, the non-persistent and shallow character of the deposits, and the generally negligible silver-content of the galena.

Comparing the British occurrences with these conditions, the veins of the limestone areas occur typically in strong fault-fissures, altogether distinct from the shallow non-persistent deposits of Wisconsin.

[1] 'Silver-Lead Deposits of Eureka, Nevada' Monogr. vii, U.S. Geol. Surv. 1884, p. 85.
[2] 'Economic Geology' vol. i (1906) p. 331.

The silver-content of the galena (4 to 15 ozs. per ton) is much higher than that of sedigenetic ores, and the restriction of the ore in the veins to certain horizons is clearly due to the influence of different strata on ore-deposition, and not to any greater abundance of disseminated metals in these strata. The ore-deposits are totally unrelated to drainage-lines, topographic slopes, synclinal basins, or other features such as are often found to be determining factors in the occurrence of the American deposits.[1] These features were examined during the present investigation in North Derbyshire, with the aid of the geological and topographical maps, but the results were negative or inconclusive. On the other hand, both in that district and in Flintshire, the deposits show a tendency to concentrate beneath anticlinal arches, especially when these are or have been covered by a 'blanket' of impervious shales. Further, the localization of ores in certain tracts, which might suggest a greater original abundance of disseminated metals in these tracts, is not at all marked in the British limestone districts; and, when it does occur, it is seen to be dependent on the localization of fissures or on the presence of strata favourable to ore-deposition.

It is, therefore, concluded that the lead and zinc ores in the limestone districts, like those in the older slates and granites, have been brought into the fissures by solutions ascending from deep-seated sources, at a period subsequent to the deposition of the rocks.

It should here be noted that some limestone areas, particularly North Derbyshire, are characterized by abundant small and scattered deposits of ore occupying solution-cavities and enlarged joint-planes ('flats' and 'pipes'), the galena having generally a very low silver-content. These deposits are comparable in all respects to the sedigenetic type, and are probably the result of later re-arrangement and concentration by circulating waters—the ores found in them being derived chiefly from the ores previously deposited in the adjoining veins, and possibly to some extent from the traces of disseminated metals in the surrounding rocks.

Barium.—The most noteworthy feature in the occurrence of barytes in these veins is its irregular distribution. Thus it is abundant in the Leadhills, the Lake District, Shropshire, and North Derbyshire, while it is rare in the Isle of Man, Flintshire, Cardiganshire, and Devon. The importance of barium as a minor constituent in the rocks of the earth's crust is now widely recognized, and its original source is generally considered to be in the felspars and micas of the igneous rocks.[2] It is most probable, therefore, that the barium minerals in the veins were concentrated in the first place by magmatic processes, along with lead, zinc, and fluorine, and that the barium was similarly brought to its present position by solutions ascending from deep-seated igneous rocks.

[1] H. F. Bain, 'Zinc & Lead Deposits of the Upper Mississippi Valley' Bull. U.S. Geol. Surv. No. 294 (1906) pp. 66–70.

[2] F. W. Clarke, 'The Data of Geochemistry' Bull. U.S. Geol. Surv. No. 330 (1908) p. 14.

III. The Vein-Solutions.

The composition of the vein-solutions on the one hand and their source on the other are cognate subjects, and may therefore be considered under the same head.

Nature of the solutions.—A clue to the chemical composition of the vein-solutions is given in the first place by the hydrothermal alteration of the wall-rocks, an examination of which was made during this investigation. A series of analyses, tabulated below, was made of fresh and altered rocks from five different localities:—

	A_1.	A_2.	B_1.	B_2.	C_1.	C_2.	D_1.	D_2.	E_1.	E_2.
H_2O	2·05	2·35	1·04	1·21	1·95	1·65	0·89	1·24	2·12	2·48
SiO_2	64·45	60·42	75·64	80·67	50·46	62·29	75·46	65·68	2·34	15·25
Al_2O_3	13·31	13·45	8·79	6·23	13·89	12·27	12·68	13·49	0·57	0·61
TiO_2	0·51	0·33	0·68	0·65	2·26	1·13	...	...	...	...
Fe_2O_3	2·32	1·42	3·24	0·19	3·69	1·29	0·85	0·56	0·65	0·42
FeO	3·62	1·23	1·61	0·45	9·02	8·65	0·34	0·28	...	...
CaO	5·73	7·24	1·09	2·48	8·81	3·29	1·21	6·28	51·18	42·83
MgO	3·24	1·15	0·28	0·21	5·03	2·45	1·68	0·31	1·24	5·37
K_2O	2·21	3·35	2·31	2·45	1·33	2·66	5·46	5·85	...	...
Na_2O	1·55	0·94	3·67	1·38	2·85	0·23	2·48	0·13	...	...
MnO	0·24	0·40	0·46	0·35	0·22	0·27	...	...	...	...
P_2O_5	..	...	...	...	0·37	0·32	...	...	...	...
CO_2	1·24	8·73	0·31	3·24	0·19	4·34	nil	5·28	42·27	32·66
FeS_2	...	...	1·05	1·33	...	...	...	...	...	...
Totals	100·47	101·01	100·17	100·84	100·07	100·84	101·05	99·10	100·37	99·62
Specific gravities.	2·564	2·490	2·522	2·318	2·853	2·648	2·621	3·213	...	...

A_1: Leadhills slate, fresh.
A_2: Do. do. altered.
B_1: Conway volcanic ash, fresh.
B_2: Do. do. do. altered.
C_1: Whin Sill diabase, fresh.
C_2: Do. do. altered.
D_1: Foxdale granite, fresh.
D_2: Do. do. altered.
E_1: Halkyn limestone, fresh.
E_2: Do. do. altered.

It will be seen from the foregoing analyses that the different rocks show much variation in the changes of constituents. The Leadhills slate (A_1 & A_2) shows a loss of iron oxides, balanced by an increase in lime, potash, and carbon dioxide. Under the microscope the altered slate shows a great development of dusty sericite, with some secondary calcite and siderite. The alterations in this rock have been sericitization and carbonatization.

The rhyolitic ash from Trecastell, Conway (B_1 & B_2), shows some loss of alumina as well as of iron oxides and soda, with an increase in lime, potash, carbon dioxide, and silica. The fresh rock contains abundant orthoclase and plagioclase phenocrysts, and much secondary quartz-mosaic. The altered rock shows further silicification, while the felspars are replaced by sericite and calcite aggregates.

The Whin Sill (C_1 & C_2) was examined at Rotherhope, near Alston, where it is intersected by a vein now being worked. The unaltered rock consists largely of andesine-labradorite and ophitic augite, with a good deal of magnetite and ilmenite. Near the vein much secondary quartz and sericite has been produced, with patches of secondary carbonates. The augite is altered to pale-green chlorite, with separation of magnetite. On the vein-walls the rock is white and granular, and is transformed to an aggregate of siderite, sericite, and quartz. Ilmenite alters first to leucoxene, and this, together with magnetite, changes largely to siderite, which occurs in abundant greyish-brown patches. The rest of the rock is composed of granular secondary quartz and much finely divided sericite, while fresh apatite needles are scattered through it. As seen from the analyses, the principal chemical changes have been a loss of titanium and ferric oxides and a gain in silica, potash, and carbon dioxide. Taking the major constituents, and recalculating the analyses, we obtain the following approximate mineralogical compositions:—

C_1 (fresh).		C_2 (altered).	
Augite	34·86	Siderite	14·42
Magnetite and ilmenite	9·92	Sericite	32·58
Plagioclase (andesine)	52·69	Quartz	49·29
Apatite	0·74	Apatite	0·74
Totals	98·21		97·03

The intense changes in this rock have been essentially mineralogical, there being no marked percentage loss of bases in the altered rock.

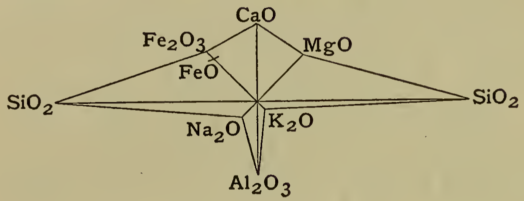
The Foxdale granite also shows very considerable alteration. The fresh rock is a binary granite, containing orthoclase and oligoclase, with some microcline, muscovite, and frequently biotite, and abundant quartz. Adjoining the Foxdale vein the rock is pulverulent and earthy, and of a greenish-yellow colour. It crumbles readily, and swells on the addition of water. Under the microscope the quartz and muscovite are seen to be unchanged, but the felspars are completely altered to aggregates of sericite. Patches of calcite are frequent, and fine mosaics of secondary quartz sometimes replace felspar phenocrysts. Biotite is first bleached, and later altered to pale-green chlorite with separation of magnetite. The analyses (D_1 & D_2) show a loss of silica, iron oxides, magnesia, and soda, and a concentration of lime, potash, and carbon dioxide. The changes are in general comparable with those in the other rocks just described, and are in many respects similar to the alteration of the gneiss which carries the silver-lead veins of Freiberg, except for the great loss of constituents in the altered rock at Freiberg.[1]

The specific gravities tabulated on p. 304 show that the altered rocks have in general a reduced specific gravity. This, without marked loss of constituents, is in accordance with the alteration to a less dense mineral aggregate. The marked increase in specific gravity of the altered granite of Foxdale (D_2) indicates greater porosity, a property which is revealed by its tendency to swell and disintegrate when exposed in the mine-workings. The accompanying diagrams (fig. 1, p. 306), constructed on W. H. Hobbs's

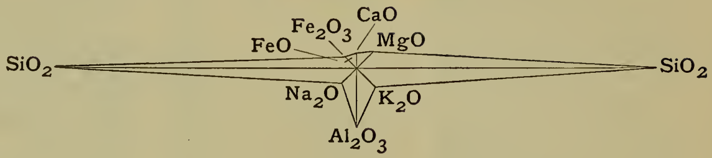
[1] Th. Scheerer, Zeitschr. Deutsch. Geol. Gesellsch. vol. xiv (1862) p. 87; and A. Stelzner, Neues Jahrb. vol. i (1884) p. 271.

Fig. 1.—*Diagrams illustrating the composition of fresh and altered country-rock.*

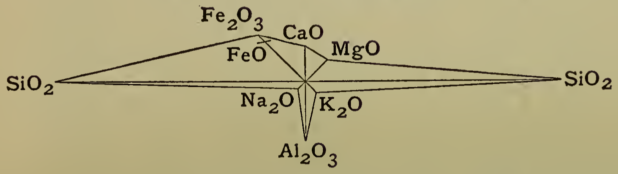
A. Whin Sill diabase (fresh).



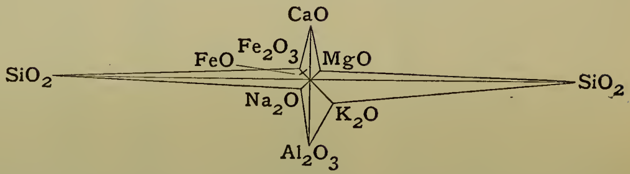
C. Foxdale granite (fresh).



B. Whin Sill diabase (altered).



D. Foxdale granite (altered).



[Scale : ·01 in molecular ratio = ·025 inch.]

modification of Brögger's method,[1] illustrate the changes in composition of two of the types analysed.

The limestones have been affected in a manner altogether different from the silicate-rocks. The analyses (E_1 & E_2) show that the wall-rock alteration has here been silicification and dolomitization. Microscopic examination of the altered limestone reveals the development of abundant quartz grains, either in aggregates or as scattered crystals in the limestone, while small rhombohedra of dolomite are sometimes distinguishable.

The want of uniformity in the changes observed in the different rock-types examined is essentially due to the different mineral and chemical composition of the rocks themselves, which must have greatly affected the results. Thus, a solution low in alkalies would tend to extract potash or soda from a rock rich in these constituents, while the same solution would have a reverse effect on limestone. Such causes, bringing into operation the principle of relative mass of interacting constituents, must make the conditions complex, and prevent uniform changes in a wide district of varied country-rocks.

As a general rule, it appears that in the silicate-rocks the characteristic changes have been a concentration of potash, lime, and carbon dioxide, and a leaching of silica, iron oxides, magnesia, and soda, the mineralogical effects being sericitization and carbonatization. In the carbonate-rocks silica has been generally introduced, and some of the lime has been replaced by magnesia, the changes here being, in other words, silicification and dolomitization. The results are in accordance with the pioneer researches of Waldemar Lindgren.[2] The processes of alteration indicate that the vein-forming solutions carried carbonates of the alkalies (chiefly potash) and of the alkaline earths (chiefly lime). This conclusion is supported by the great preponderance of calcite as a gangue-mineral in the veins.

The chemical composition of the solutions is indicated in the second place by the minerals which they carried. The lead and zinc may have been transported, either as sulphides dissolved in alkaline sulphides, or as oxidized salts (carbonates or sulphates) dissolved in alkaline bicarbonates. The conclusions just reached suggest the latter hypothesis; but, on this view, it is very difficult to account for the presence of the sulphides in the veins, since organic matter is not generally a prominent constituent of the rocks, and there are no other strong reducing agents present which could have effected the wholesale reduction of oxidized salts of the metals to the sulphides. The great quantity of sulphide-ore in the veins seems to imply that the carriers of the metals must have been alkaline sulphides, the efficiency of which as solvents of the metallic sulphides has been shown by Prof. C. Dœlter[3] and others.

[1] W. H. Hobbs, 'Suggestions regarding Classification of the Igneous Rocks' Journ. Geol. Chicago, vol. viii (1900) p. 1.

[2] 'Metasomatic Processes in Fissure-Veins' Trans. Amer. Inst. Min. Eng. vol. xxx (1900–1901) p. 578.

[3] Tschermak's Min. Petrogr. Mittheil. n. s. vol. xi (1890) p. 319.

Barium, on the other hand, would be readily carried as the carbonate, dissolved in excess of carbon dioxide, the change to barytes being effected during deposition by reaction with alkaline sulphides and by oxidation. In this connexion the relations of the sulphate and carbonate of barium in the veins are important. These two minerals are seldom closely associated in the veins, one generally occurring to the exclusion of the other. Further, there is no evidence, except in local cases, of change from the one form into the other. The carbonate (witherite), as at Fallowfield and Settlingstones, generally appears as a direct metasomatic replacement of limestone; while the sulphate (barytes) occurs usually as a compact fissure-filling. Prof. Clowes has suggested that barytes, as a cement in sandstone, has been formed *in situ* by interaction between barium carbonate and soluble sulphates.[1] Herr G. Lattermann has described a deposit of barytes at Lautenthal in the Harz, which has been formed by the interaction of sulphate-bearing mine-waters with spring-water carrying barium chloride.[2] Mr. C. W. Dickson has shown that it forms by reaction between bicarbonated solutions of barium and oxidizing sulphides.[3] This last case is most probable for the barytes in the British districts. The formation of the sulphate seems to be, in every case, brought about during deposition.

Fluorine was doubtless the chief agent in the primary processes of magmatic extraction, forming volatile fluorides or fluosilicates of the metals. As the solutions ascended, and became cooled and diluted, these compounds would be hydrolysed, with the formation of new combinations and release of the fluorine, which was ultimately fixed by combination with calcium.

Summing up, it appears that the vein-solutions carried, in addition to fluorine and volatile fluorides, chiefly alkaline and earthy carbonates, which transported barium in solution and effected the observed alteration of the wall-rock; also alkaline sulphides, which transported the lead and zinc as sulphides.

Source of the solutions.—The conclusion that all the ores are of deep-seated origin, as well as the depth to which the veins extend, indicates that the waters were, in the first place, 'juvenile,' being probably hydrothermal after-effects of deep-seated igneous disturbances and intrusions. This is supported by the occurrence of fluorine; the processes at considerable depth were probably pneumatolytic in nature. Further, it is not likely that meteoric waters played any conspicuous part in the primary ore-deposition in the slate and granite districts.

In limestone areas, however, the conditions are different, and a consideration of the facts strongly suggests that underground atmospheric waters, mingling with the 'juvenile' waters, have played an important part in ore-deposition. The facts are as follows:—

(1) The ores are almost universally distributed throughout the

[1] Proc. Roy. Soc. vol. xlvi (1889–90) p. 368.
[2] Jahrb. K. Preuss. Geol. Landesanst. 1888–89, p. 259.
[3] School of Mines Quarterly, vol. xxiii (1902) p. 366.

British limestone districts, a fact which is difficult of explanation on the assumption of aqueous emanations direct from magmas.

(2) The ore frequently fails at comparatively shallow depths. The vertical range of the ores is, indeed, comparable to the depth of the present underground circulation.

(3) The silver-content of the galena in limestone-districts is frequently much lower than in areas of the older rocks. This, taken in conjunction with the known fact that the silver-value of galena is reduced by prolonged solvent action of water or dilute solutions, indicates that the ores have undergone much more transport in these districts than in the slate and granite areas.

(4) Extensive circulation is further put in evidence by the structure of the deposits. The pipes, flats, and enlarged vein-fissures which are typical of all the limestone-districts are clearly the result of circulation by meteoric waters, and the rich deposits of ore found in them have probably been formed by the same agency, since, in many cases, the deposition of ore has been intimately related to the formation of the cavities. Circulation furnishes the key to ore-deposition in the limestone districts, and it seems improbable that this circulation was effected so uniformly over large areas by juvenile springs.

(5) It is most probable that the main epoch of deposition of all the lead and zinc ores of Britain was Permo-Triassic, a period when the rocks were elevated and fissured, the climate was dry, and erosion was rapid. These conditions were eminently favourable to a deep circulation of atmospheric waters.

(6) The importance of the underground circulation is indicated by the occurrence of underground waters at the present day. The springs in North Derbyshire are a good example: the Buxton spring-water has a temperature of 82° F., indicating an undoubtedly deep circulation. This water carries traces of lead and fluorine.[1] Further evidence comes from Flintshire, where the Halkyn drainage-adit, unwatering the mines on Halkyn Mountain to a depth of 250 feet below the summit of the mountain, delivers a million gallons of water per day, and St. Winifred's Well, at Holywell, is estimated to yield 4400 gallons of water per minute.[2] A sample of water taken from the Halkyn drainage-adit was analysed for lead in the course of this work. and found to carry from 0·01 to 0·03 grains of lead oxide per gallon. The temperature of the water was 52° F., and the solid contents (chiefly carbonates and chlorides) amounted to 30 grains per gallon.

(7) Lastly, there is the well-known fact that the toadstones of North Derbyshire and the Whin Sill of Northumberland and adjacent counties generally limit the downward extent of the productive parts of veins which cut these rocks. There is in this a further suggestion that the ores were to a large extent deposited by underground waters circulating only above these impervious layers.

[1] 'Geology of North Derbyshire' Mem. Geol. Surv. 2nd ed. (1887) p. 115.

[2] A. Strahan, 'Geology of Flint, Mold, & Ruthin' Mem. Geol. Surv. 1890, p. 222.

In conclusion, while the vein-solutions were at first and predominantly of truly deep-seated origin, it seems necessary to recognize that underground waters of meteoric origin must have played an important part in the distribution and final deposition of the ores in the upper strata of the limestone-tracts.

IV. Metasomatic Processes.

The relative part played by replacement on the one hand, and by the filling of fissures on the other hand, is variable, but on the whole the latter process has been dominant in the districts examined. The vein-structures generally show the characters due to filling, except where local silicification and carbonization have occurred. Replacement has played a minor part in the formation of the important deposits which have yielded the bulk of the ores. Interesting metasomatic processes are, however, seen under the microscope.

Fig. 2.—*Replacement of limestone by quartz and galena: Halkyn Mine (Flintshire).*

[The quartz appears as scattered grains (white), closely followed by granular galena (black), which gradually replaces the rock, enclosing residual plates of recrystallized calcite and quartz-grains. (Transmitted light: × 50.)]

Specimens of limestone from veins at Halkyn show, first, recrystallization with the formation of veinlets and coarse plates of calcite. This has been followed by the introduction of galena, blende, and quartz, all replacing the calcite. The formation of scattered quartz-granules is characteristic, the quartz being most abundant where sulphides are forming. Blende occurs in irregular rounded grains. Galena appears first in small crystals, uniting into strings which penetrate the calcite. These gradually form a network, and finally a solid mass of granular ore, enclosing a few residual patches of calcite (fig. 2). The silicification appears to be an accompaniment of the formation of the sulphides, and the absence, in the latter, of defined crystal outlines, such as appear when they are deposited in open cavities, is very characteristic.

The rhyolitic breccia at Trecastell, Conway, shows similar processes. It is generally much silicified, cavities and cracks in the rock being filled by coarse quartz crystals, while a fine-grained quartz-mosaic replaces the mass of the rock (fig. 3). Galena and blende occur in the breccia, both replacing quartz, and appearing as irregular rounded grains, which may grow to a considerable size. The galena tends to wrap round the fragments of rhyolite, which act as nuclei (fig. 4, p. 312). The rhyolite is gradually replaced by a quartz-mosaic, and this in turn by galena (fig. 5, p. 312), the replacement of quartz by the ore following closely on the silicification.

Fig. 3.—*Metasomatic quartz, forming a fine-grained mosaic, accompanied by quartz filling a cavity, with comb-structure: Trecastell Mine, Conway. (Transmitted light: × 50.)*

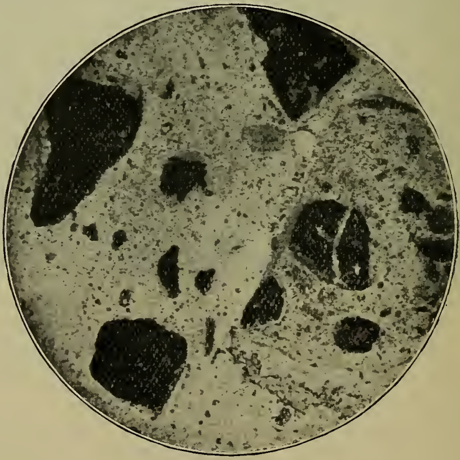
The replacement of limestone by fluorspar was observed in several specimens from the Mill Close Mine (North Derbyshire). One section showed a dark organic limestone, almost completely replaced by coarse-grained colourless fluorspar. The fluorspar has sharp crystal-faces where it abuts against the limestone, and small crystals of fluorspar in the limestone itself are also generally well formed. The process consists in a general aggregation of small crystals until the whole of the limestone is replaced, the fluorspar individuals frequently growing on one another in crystallographic continuity. The fluorspar is often followed by galena, with its usual granular structure, replacing both the fluorspar and the residual limestone. In the former it appears first as grains and strings on the edges and along cleavage-planes of the fluorspar, gradually forming larger masses.

Other specimens from the same mine show replacement of fluorspar by quartz. The quartz appears first along cracks and cleavage-planes, and gradually spreads into the fluorspar as a mosaic. One specimen shows a granular fluorspar formed by replacement of an organic limestone, patches of organic matter being

Fig. 4.—*Rhyolitic breccia, showing replacement by galena.*

[The galena is seen enveloping a residual fragment of the rock: Trecastell Mine. (Transmitted light: × 50.)]

Fig. 5.—*Rhyolitic breccia, Trecastell Mine.*



[The galena has here replaced spherulitic portions of the breccia, which had been previously silicified. (Transmitted light: × 35.)]

scattered through the secondary mineral. The fluorspar has been followed by quartz, which occurs as scattered grains or aggregates, and at times the quartz crystals form pseudomorphs after cubic fluorspar.

Specimens from Rotherhope show a mass of crystallized fluorspar, the cracks in which are occupied by infiltrated quartz. Strings of galena have advanced into the fluorspar by replacement of the quartz, and also by further replacement of the fluorspar. The replacement of fluorspar by galena is also seen in specimens from other districts ; the reverse change was not observed.

The characteristic metasomatic processes seen under the microscope are, then, as follows :—

1. Replacement of limestone by fluorspar.
2. Do. of limestone by galena.
3. Do. of fluorspar by galena.
4. Do. of limestone and fluorspar by quartz.
5. Do. of limestone by blende.

Galena is much more active than blende in processes of replacement. Quartz and calcite do not replace the sulphides to any extent, but quartz freely replaces both calcite and fluorspar.

The metasomatic formation of fluorspar is a striking feature. While the greater part of this mineral has probably been deposited in open spaces, its practical restriction to limestones or calcareous rocks clearly indicates that the calcium has for the most part been derived from the country-rock, the mineral being deposited at times by direct replacement, and at other times after more or less transport.

It is important to observe that galena always follows fluorspar in replacement, a fact which is of value in determining the order of deposition of the vein-minerals.

V. Paragenesis.

The relations and order of deposition of the ores are easily studied in the field, more especially in banded comby veins and in solution-cavities. The results, however, are frequently conflicting and inconclusive, and the relations may differ in different districts, while anomalous orders of deposition are to be seen in one and the same vein. These anomalies are due to the complex history of the ores in the limestone-districts and to continued re-arrangement and redeposition by circulating waters since the ores were first transported from a deep-seated source. The problems cannot be satisfactorily approached from field-evidence alone, the relations of the ores in cavity-fillings being often notoriously unreliable. Calcite and quartz show no definite order: they have been deposited both before and after the sulphides, and their relations to the other minerals are therefore variable. In this connexion, mention should be made of some brecciated ores found in several mines. At Foxdale the main vein in the lowest levels is frequently brecciated, the ore consisting of rounded or angular fragments of fine-grained galena, together with decomposed granite, cemented by calcite and quartz. The Brow vein at Leadhills shows a similar breccia in places. The Rampgill vein at Nenthead contains sometimes a filling of crushed limestone with both galena and blende, cemented by strings of calcite. Other interesting specimens are seen at the Trecastell Mine, Conway. Some of these show fragments of volcanic ash with a selvage of galena, constituting typical 'ring-ore.' On the other hand, some fragments of brecciated ash contain strings of galena cut off at the edges of the fragments, the whole being cemented by calcite. There is here evidence of ore-deposition both before and after the brecciation of the vein-stone.

Chalcopyrite generally occurs enclosed in or wrapped round by galena or blende, and has evidently been one of the first sulphides deposited. Pyrite, on the other hand, has generally been later than galena and blende. It is quite a subordinate constituent, and occurs as small crystals in vughs or cavities, deposited on any or all of the other ores. Fluorspar shows variable relations in the field. It commonly occurs as the inner lining of flats and pipes; at times it forms alternating crusts with galena, and it is again often enveloped by calcite and quartz. The relations of barytes are not very definite. It commonly occurs by itself, unaccompanied by much galena or blende—hence the dictum of the miners at the Leadhills and elsewhere that barytes ' poisons ' the veins for other ores. This relation, which holds good in many districts, strongly suggests that barytes and galena were closely connected in order of deposition, the physical conditions favourable to the deposition of barytes being prejudicial to the formation of the sulphides.

The examination of thin sections enables the relations of fluorspar to be determined, as has been pointed out in the last section (§ IV) dealing with replacement. As a general rule, fluorspar is observed replacing limestone, and this is succeeded by galena replacing the fluorspar. The priority of the fluorspar is thus clearly indicated. Specimens from the Mill Close Mine show strings of galena penetrating a mass of crystallized fluorspar, while veinlets of fluorspar are crossed by later veinlets of galena. Other specimens show strings of blende penetrating fluorspar. The relations of fluorspar and chalcopyrite were not directly observed, but it is probable that the chalcopyrite is the older, as the fluorspar has been deposited in intimate relation with the galena and blende. That fluorspar should be one of the earlier minerals formed in the primary deposition appears from the fact that the mobile fluorine in the solutions, released at greater depths from combination with the metals, must have been a very potent constituent, and one of the first to form stable combinations whenever temperature became low enough for its combinations to persist. It may be pointed out in objection that fluorspar often forms the inside crust in flats and pipes, but the two cases are not strictly comparable. We have, in the one case, direct formation of fluorspar by replacement of limestone, and, in the other, crystallization in cavities as the last stage in a series of complex processes, involving much rearrangement of the ores.

The relations of the opaque minerals are most satisfactorily determined by metallographic methods, as recently applied to ores by Dr. W. D. Campbell[1] and Mr. C. W. Knight. In the present investigation the specimens were polished on a series of emery discs, and finally on washed rouge or tripoli. The examinations under low powers were made with a petrographical microscope fitted with a vertical illuminator over the objective, light being supplied by a 220-volt Nernst lamp. For higher powers a Zeiss metallurgical microscope was used, kindly placed at my disposal by Prof. W. A. Carlyle, in the Metallurgical Department of the Imperial College

Fig. 6.—*Etching figures on 'cubical' galena, oriented at right angles to the direction of polishing. (Reflected light: × 200.)*

of Science & Technology. The lenses used were apochromats of 12, 4, and 2-millimetre focal lengths, and the linear magnification ranged from 120 to 700. Of the sulphides examined, the soft galena polishes with a very smooth surface, and gives characteristic etching-pits under the pressure of rubbing. The etching-figures are triangular in outline (fig. 6). Their orientation is unaffected by the direction of rubbing, depending wholly on the

[1] 'The Microscopic Examination of Opaque Minerals' Economic Geology, vol. i (1906) p. 751.

Fig. 7.—*Crystal of chalcopyrite (with scratched surface), enveloped by blende (dark) and galena (white): Nenthead Mine, Allendale. (Reflected light: × 200.)*

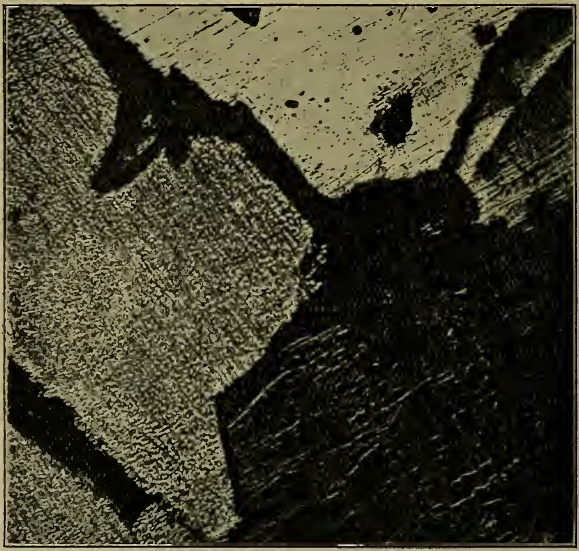
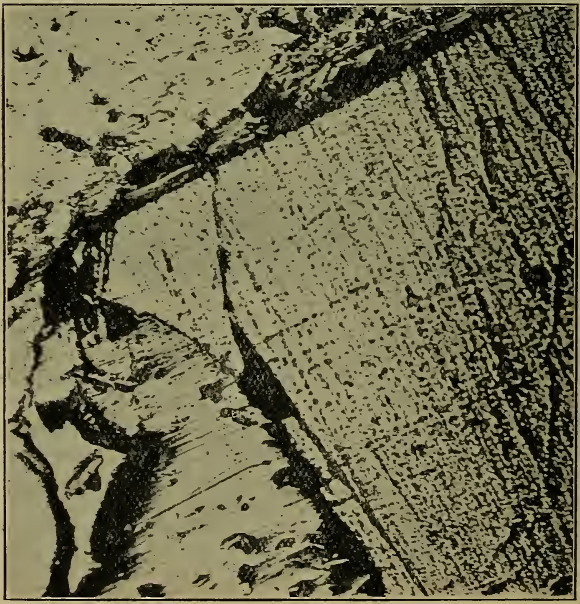
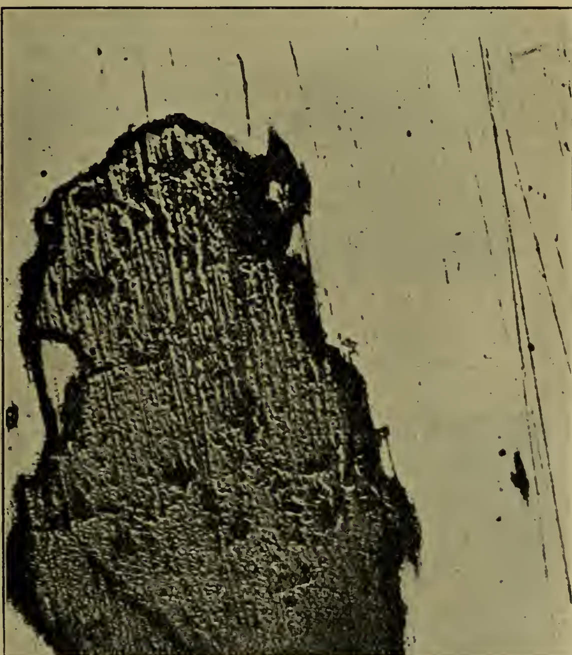


Fig. 8.—*Crystal of chalcopyrite enveloped by galena: Leadhills Mine, Lanarkshire. (Reflected light: × 200.)*



position of the plane of the specimen with respect to the crystal symmetry. The orientation of different groups of figures on a surface thus indicates the different crystal individuals in the specimen. The figures develop best in cubical galena. Banded or 'steel-grained' ores frequently do not etch without the use of reagents. The blende polishes with a rougher surface, more or less pitted, and grey to brown in colour, while, owing to its greater hardness, it stands up in slight relief above the galena. It does not etch with polishing, and its borders in contact with galena are

Fig. 9.—*Blende, with rough-pitted surface, enclosed in galena: Halkyn Mine, Flintshire. (Reflected light: × 200.)*



frequently rounded or corroded. The chalcopyrite has a rougher surface and a bright yellow colour. It generally shows good crystal outlines, and, like blende, polishes in relief, an effect easily produced by finishing the specimen on parchment or on fairly thick broadcloth.

Examination of a number of specimens showed that chalcopyrite generally occurs well crystallized and wrapped round by galena or blende (figs. 7 & 8, p. 316). The blende is also generally enclosed in galena (fig. 9). These relations are characteristic, not only of typical British ores, but also of ores from some New South Wales and Queensland localities. The general order of deposition of the

Fig. 10.—*Strings of native silver in galena, following the cleavage planes of the galena crystals: Nentsbury Mine, Alston. (Reflected light: × 200.)*

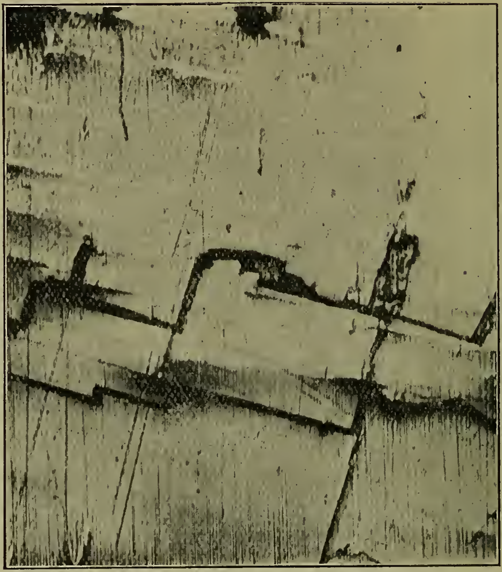
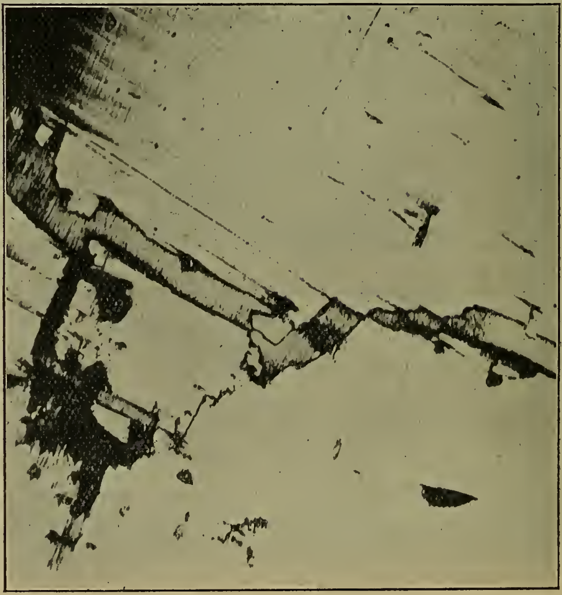


Fig. 11.—*Strings of native silver in galena: Foxdale Mine, Isle of Man. (Reflected light: × 400.)*



sulphides, then, has been: chalcopyrite, blende, galena. The distinct crystallization of chalcopyrite suggests that some time elapsed between the arrival of this ore and of the other two, which are more intimately related and sometimes intergrown. Venules of galena penetrating blende are commonly seen in ore from Trecastell, Conway. Specimens from veins on Carrock Fell exhibit crystals of chalcopyrite enclosed in and wrapped round by galena. Specimens from the Coniston copper-mine show chalcopyrite embedded in quartz, while blende occurs deposited on both chalcopyrite and quartz, and finally arsenopyrite occurs as groups of crystals deposited on cavities in the blende. The 'bluestone' or granular lead-zinc ore of Parys Mountain (Anglesey) and of Avoca (Wicklow) consists of an intergrowth of galena and blende enclosing earlier crystals of chalcopyrite. The general relations of the chief sulphides appear to be fairly well established by these observations. It should be noted that, while galena is generally later than blende in primary ore, the relations may be reversed where the ore has undergone secondary alteration. Thus, some specimens from superficial parts of the Nenthead mine show galena traversed by blende filling irregular cracks and corrosion-cavities.

The silver-content of galena was also investigated by observation of polished ores. Specimens of galena taken from deep levels, unaffected by secondary alteration, showed no silver or silver-compound in any case, even under the highest powers. The galena showed no heterogeneity on etching with various reagents, and the cleavage-planes were not occupied by any extraneous ore. It therefore appears that the silver in these ores exists either in an excessively fine state of dissemination or as a sulphide in intimate isomorphous combination with the galena, a combination which would not be resolved by etching. Specimens of argentiferous galena taken from higher levels, within reach of underground waters, however, showed in several cases strings of greyish-white native silver, running along cleavage-cracks in the galena. The silver occurs generally in straight threads intersecting one another along the cleavage-planes (figs. 10 & 11, p. 318), and stands up in slight relief above the surrounding galena. A similar occurrence, it may be noted, has been recorded by T. L. Phipson in galena from the Phœnix Mine (Cornwall).[1] There is little doubt that this development of native silver is the result of secondary concentration by descending surface-waters, the silver being taken into solution during oxidation of the galena near the surface, and redeposited in the ore at lower levels. These observations appear to have some bearing on ore-dressing problems. Thus, the occurrence of native silver in secondary ore would explain the partial removal of the silver by amalgamation in some experiments of M. Roswag,[2] and would also account for the notable loss of silver in the dressing of many ores, the fine silver going off in the slimes.[3] On the other

[1] C. R. Acad. Sci. Paris, vol. lxxviii (1874) p. 563.
[2] L. de Launay, 'L'Argent' Paris, 1896, p. 47.
[3] W. F. A. Thomae, 'The Zeehan & Dundas Silver-Field, Tasmania' Trans. Inst. Min. & Met. vol. iv (1895–96) p. 60.

hand, where no silver was removed by amalgamation in Roswag's experiments, and where ore-dressing does not affect the silver-value of the ore, it is probable that the silver exists in its primary state of combination with the galena.

In conclusion, the general order of deposition of the vein-minerals, exclusive of calcite and quartz, may be stated as follows :—

1. Chalcopyrite.
2. Fluorspar.
3. Blende. } Barytes.
4. Galena. }
5. Pyrite and arsenopyrite.

It may be mentioned, for comparison, that a common order of deposition in the Upper Mississippi district has been: blende, galena, marcasite.[1]

These conclusions are generally supported by the vertical distribution of ore in the veins. Chalcopyrite generally occurs in the deeper parts of the veins, with galena above, as at Ecton in Staffordshire.[2] Similarly, in the Alston Moor district, chalcopyrite is chiefly found in the 'Copper Hazles' between the Upper Scar and Tynebottom Limestones, which are on a much lower horizon than the lead and zinc ores of the Great Limestone and adjoining strata. Blende replaces galena in the deeper levels of several British mines, as is also the case at Freiberg below 1600 feet.[3] A similar vertical succession has been recorded in the Castle Mountain and Elkhorn districts (Montana).[4] The silver-content of galena becomes distinctly poorer in the deep levels of Foxdale, Leadhills, and other mines. This is in agreement with the observations of A. W. Stelzner and F. Kolbeck at Freiberg,[5] and of Zirkler in the Upper Harz.[6] Finally, fluorspar is chiefly confined to the upper horizons of the veins. This has been pointed out by Mr. C. B. Wedd in North Derbyshire,[7] and the same phenomenon is seen in the Weardale and Alston Moor districts, where it is confined to the upper 300 feet of the metalliferous strata of the Carboniferous Limestone Series. This feature of the occurrence of fluorspar, which is apparently at variance with the fact that fluorspar is one of the earlier minerals deposited, is probably due to the instability of the mineral at high temperatures, since it is decomposed by superheated steam,[8] and could not therefore exist at greater depths.

[1] C. R. Van Hise, 'A Treatise on Metamorphism' Monogr. xlvii, U.S. Geol. Surv. 1904, p. 1145.

[2] 'Geology of North Derbyshire' Mem. Geol. Surv. 2nd ed. (1887) p. 158.

[3] R. Beck, 'The Nature of Ore-Deposits' (transl. W. H. Weed) New York, 1905, p. 362.

[4] W. H. Weed & L. V. Pirsson, 'Geology of the Castle Mountain Mining District, Montana' Bull. U.S. Geol. Surv. No. 139, 1896; W. H. Weed, 'Geology & Ore-Deposits of the Elkhorn Mining District, Jefferson Co., Montana' 22nd Ann. Rep. U.S. Geol. Surv. pt. ii (1900–01) p. 503.

[5] R. Beck, *op. supra cit.* p. 362.

[6] 'Ueber die Gangnehältnisse der Grube Bergmannstrost bei Clausthal' 'Glückauf' Essen, 1897, p. 84.

[7] 'The Fluorspar Deposits of Derbyshire' Trans. Inst. Min. Eng. vol. xxxv (1908) pp. 517–21.

[8] *Ibid.* p. 525; also Henry Watts, 'Dictionary of Chemistry' London. vol. i (1863) p. 718.

In general, then, the vertical succession of ores in the veins is in agreement with their paragenetic relations determined above, relations which are likewise supported by the relative solubilities of the sulphides as determined by Prof. C. Dœlter and G. A. Binder.[1]

VI. Influence of the Country-Rock on Ore-Deposition.

The effect of different strata on the distribution of ore in the veins is strikingly shown in many districts. Each area, however, has its own features, determined by local circumstances, and what may be the general rule in one district, sometimes fails in its application to another district. It must be pointed out that enrichments at vein-intersections, accompanied by vertical or pitching shoots of ore, are frequent. These have not been specially investigated in this work, as, owing to the inaccessibility of so many of the old mines and workings, there are not sufficient opportunities to make extended observations. The general facts and principles governing the effect of the country-rock are here summarized, followed by an account of some experiments dealing with the chemical aspect of the problem.

Veins in the older Palæozoic slates and associated rocks show similar features throughout. Where, as is generally the case, strata of different character succeed one another vertically, the relative abundance of ore is dependent on the character of the fissure, and this, in turn, has been determined by the physical properties of the different strata which it intersects. At the Leadhills, the fissures are well defined and the ore good in the grit-beds of the Glenkiln-Hartfell Series, while impoverishment occurs when the fissures pinch or scatter in the associated shale-beds. The same relation holds in the Shelve district of Shropshire, where, by the alternation of slates and shales, there have been formed typical ore-horizons in the slates, separated by unproductive stretches in the shales,[2] a condition analogous to that described by Mr. C. W. Purington from San Juan (Colorado).[3] Similar features occur in the Isle of Man[4]; while in Cardiganshire, the softer shale-beds, the 'metalliferous slates' of Walter Keeping,[5] are more favourable strata than the hard and resistant grits.[6] In the Lake district the fissures in the firm Borrowdale ash-beds, as at Greenside and Coniston, are more regular, and the ore more evenly distributed, than in the softer Skiddaw Slates, where, as at Thornthwaite and Threlkeld, the veins are irregular and patchy. In all these and similar cases the essential factor has been the nature of the fissure or circulation-channel, which is best defined in those strata that admit of the cleanest fissuring. The effect is a relative one:

[1] Tschermak's Min. Petrol. Mitth. n. s. vol. xi (1890) p. 319, & vol. xii (1891) p. 332.
[2] D. C. Davies, 'Metalliferous Minerals & Mining' London, 1901, p. 222.
[3] 'Economic Geology' vol. i (1906) p. 129.
[4] G. W. Lamplugh, 'Geology of the Isle of Man' Mem. Geol. Surv. 1903, p. 491.
[5] Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 141.
[6] W. W. Smyth, Mem. Geol. Surv. vol. ii. pt. 2 (1848) p. 655.

for, while resistant beds may be most favourable in one district, the fissuring may be concentrated in the softer beds in another area. The influence of the country-rock has been due, in these cases, to its physical character, not to its chemical composition.

In limestone areas the effects are more complex, since they depend on both physical and chemical characters. The influence of the former is well seen in the pinching and dissipation of the fissures in the soft shales of Flintshire and North Derbyshire, and likewise in the hard igneous rocks of Derbyshire and Northumberland. The most favourable beds for fissuring have been the limestones and cherts, beds intermediate in strength between the shales and the igneous rocks. The effect of porosity is also well illustrated, as both the impervious shales and igneous rocks have impeded circulation, the ores being concentrated in the intervening horizons of porous calcareous beds. The chemical influence of the rocks has been important, as seen in the concentration of ore in the calcareous and dolomitic beds. These effects are discussed in connexion with the subjoined experimental results.

Deposition of metals from solution.—In order to obtain information concerning ore-deposition in the presence of different rocks, a series of tests was carried out to compare the quantities of lead and zinc deposited from solutions of their salts by various solid materials. The solutions used were lead nitrate and zinc sulphate of corresponding strength. The solid materials were as follows:—

1. Washed kaolin.
2. Calcareous grit, Leadhills. ($CaO=10{\cdot}5$ per cent.)
3. Cherty limestone, Halkyn. ($CaCO_3=70{\cdot}45$; $SiO_2=20{\cdot}25$ per cent.)
4. Shell limestone, Alston. ($CaCO_3=90{\cdot}50$ per cent.; Organic matter $=6{\cdot}60$.)
5. Magnesian limestone. ($MgCO_3=36$ per cent.)
6. Crystalline dolomite.
7. Crystalline calcite.
8. 'Curly' shale, Broxburn. (Hydrocarbon $=22{\cdot}85$; Fixed carbon $=4{\cdot}43$; ash $=71{\cdot}25$ per cent.)
9. Burnt shale, Broxburn. ($C=5{\cdot}38$; $SiO_2=56{\cdot}00$; $Al_2O_3=31{\cdot}20$; $Fe_2O_3=2{\cdot}84$; $SO_3=5{\cdot}06$ per cent.)
10. Coke, Broxburn. ($C=95$ per cent.)
11. Solid paraffin, Broxburn. (Heavy hydrocarbons.)

The materials were ground to a uniform degree of fineness, and amounts of 10 grams were placed in stoppered jars with 50 cubic centimetres of the solutions. The jars were left for 4 or 5 days at ordinary room-temperatures, with periodical shaking. The solutions, which had been previously standardized, were then filtered off and analysed, to determine the loss of metals in each case. The exact degree of fineness of the powder beyond a certain point makes little difference to the result, provided the solid presents a sufficient surface to the solution to enable it to exert the maximum effect. Again, prolonged contact does not result in corresponding effect, most of the deposition taking place during the first and second days. The percentage results of the tests are recorded in the following table:—

Solution.	Extraction of metal by:—										
	1. Kaolin.	2. Calcareous grit.	3. Cherty limestone.	4. Shell limestone.	5. Magnesian limestone.	6. Dolomite.	7. Calcite.	8. 'Curly' shale.	9. Burnt shale.	10. Coke.	11. Paraffin.
Lead (Nitrate)	24·50%	70·85	91·55	92·64	70·21	71·34	90·88	42·50	44·45	40·16	39·38
Zinc (Sulphate) ...	9·25	52·46	85·65	82·57	50·89	54·31	83·29	22·37	21·49	24·53	25·26

It will be seen, first, that lead is deposited more freely, in every case, than zinc. The chemical influence of the rock is evidently more important in the case of lead, a conclusion which is supported by microscopic and field-observations.

With regard to the influence of the different substances, it appears that the silicate, kaolin, is the least active of all, while the carbonates are the most active. In the case of all the carbonates (Nos. 2 to 7), thick deposits of lead and zinc carbonates were formed in the bottom of the jars, binding the powders into a firm cement, while much lime had gone into solution. In these cases the deposition was effected by replacement of the rock-material by the metal. At the same time, it is to be observed that lime is much more effective than magnesia in these laboratory tests, an effect probably due to its greater solubility during replacement. In the veins, on the other hand, dolomitic limestones are the more favourable beds as a rule, especially for the deposition of secondary calamine. This has been ascribed to the greater porosity of the dolomitic rock.[1] The discordance between the experimental results and the facts of observation in the field is probably due to the elimination, in the former case, of the physical element of porosity by fine grinding. Further, the much longer time-factor and the more dilute solutions in nature would greatly modify the results.

Turning to the carbonaceous substances (Nos. 8 to 11), it is seen that the extraction of metals by these is very much lower than by the carbonates. In considering this fact, it must be borne in mind that time, concentration, temperature, and composition of solutions were not comparable with the conditions which existed during ore-deposition. The variation of these factors makes it very difficult to apply the experimental results in explanation of natural phenomena. In particular the solutions in nature were alkaline carbonates and sulphides, whereas those here used were acid sulphates and carbonates. The lower influence of the organic matter as here shown is probably due to its more refractory nature, which rendered it less amenable to replacement. The replacement of calcareous substances, in short, is more effective under the conditions of these experiments than the reducing influence of organic matter on the oxidized salts of the metals. In the case of vein-solutions containing metallic sulphides dissolved in alkaline sulphides, however, the influence of organic matter was probably more important. At the same time, it is probable that organic

[1] H. F. Bain, 'Lead & Zinc Deposits of the Ozark Region' 22nd Ann. Rep. U.S. Geol. Surv. (1901) pt. ii, p. 128.

matter is a less active precipitant of lead and zinc than of the gold and silver, which are extremely sensitive to its influence, as shown by the experiments of Mr. T. A. Rickard,[1] and emphasized in an important paper by Dr. W. P. Jenney.[2] Further, the influence of different materials must vary greatly according to the metals carried in solution. In this connexion may be mentioned a striking case of selective deposition recorded from Ku Shau Tzu (Mongolia) by J. A. Church.[3] Here the veins carry galena in the limestones, and native silver and tetrahedrite in the overlying shales. In general, the influence of organic matter seems to be most marked in the case of those metals the compounds of which are least stable; while it is less active in the presence of those basic metals which form more stable compounds.

The form in which the metals were deposited was not examined in the case of the silicate and the shales. Mr. E. C. Sullivan, in a long series of experiments on the deposition of various metals by natural silicates,[4] has shown that the principle of adsorption, advocated by Dr. E. Kohler,[5] does not generally apply, and that, in each instance, an equivalent quantity of base from the silicate passes into solution, in exchange for the metal deposited. Even with the most refractory silicates, this exchange or replacement of bases was found to take place, while it was also observed that the small quantities of metals deposited went into combination as silicates, an exact parallel with the formation of the carbonates in the above-described experiments. Ore-deposition thus resolves itself, in all cases, into a process of osmosis, there being no simple precipitation of metals without an exchange. This has been previously maintained on theoretical grounds by H. P. Gillette.[6]

VII. Secondary Alteration.

The greatest depths to which mining extends in the British lead and zinc districts are at Foxdale (2010 feet) and at Laxey (1800 feet), in the Isle of Man. At these depths, the ore is becoming poorer, and it is probable that the limit of ore-deposition does not greatly exceed 2500 feet beneath the surface in any of the districts considered. This range is comparable to that of other well-known lead and zinc fields, such as Freiberg (2134 feet), the Upper Harz (2788 feet), Linares (2000 feet), and Eureka, Nevada (3000 feet). Since the formation of the veins, great denudation, amounting to an average of 2000 feet vertical, has taken place. Thus it appears that nearly one-half of the original height of the veins has been shorn off by denudation.

Accompanying this denudation there has been much secondary

[1] 'The Enterprise Mine, Rico, Colorado' Trans. Amer. Inst. Min. Eng. vol. xxvi (1896-97) p. 978.

[2] 'The Chemistry of Ore-Deposition' *Ibid.* vol. xxxiii (1903) p. 445.

[3] *Ibid.* vol. xxxiii (1903) p. 1065.

[4] 'Interaction between Minerals & Water-Solutions' Bull. U.S. Geol. Surv. No. 312, 1907.

[5] 'Adsorptionsprozesse als Faktoren der Lagerstättenbildung & Lithogenesis' Zeitschr. f. prakt. Geol. vol. xi (1903) p. 49.

[6] 'Osmosis as a Factor in Ore-Formation' Trans. Amer. Inst. Min. Eng. vol. xxxiv (1904) p. 710.

alteration and enrichment of the upper parts of the veins, expressed in the formation of a superficial zone of oxidization, succeeded by a zone of cementation, which finally passes down into the zone of unaltered ores. The secondary changes which have taken place indicate that the chemical processes of solution and cementation have proceeded more rapidly than the physical processes of denudation.

In the zone of oxidation, above the permanent ground water-level, secondary oxidized compounds are abundant, and have received considerable notice, especially at the Leadhills and at Caldbeck Fells. In the cementation-zone beneath, Prof. C. R. Van Hise's conception of a second concentration by descending waters, as distinguished from the first concentration by ascending waters,[1] is well illustrated in the limestone districts. The characteristic solution-cavities, that is, 'pipes' and 'flats,' in limestone are clearly the work of descending waters, and they have been more or less filled with ores and gangue-minerals by the same agency. The flats in the Flintshire area frequently contain masses of galena embedded in loose sand derived from the disintegration of calcareous sandstone, while pipes are often similarly filled with more or less detrital matter. In the Halkyn vein, at a depth of 600 feet, a large cavity over 20 feet in width and 60 feet high has been dissolved out along the vein-fissure by underground waters at a point of vein-intersection, with complete removal of both ores and gangue. The depth of effect of the waters is similarly indicated by the remarkable occurrence, in some Flintshire veins, of tree-trunks to a depth of 600 feet.[2] Sulphides have been abundantly redeposited below the ground water-level, and the many crystallizations of galena and blende in vughs and cavities are largely of secondary origin; while fluorspar has probably also been re-arranged at the same time. The depth to which secondary processes have extended varies between 600 and 1000 feet, according to the permeability and extent of fissuring of the rocks. That much of this work was accomplished before the Glacial Period is evident from the occurrence, in some districts, of pre-Glacial clays containing galena and cerussite, which fill hollows and pipes in the rock. The 'gravel-ore' of Talargoch and other parts of Flintshire,[3] containing waterworn fragments of galena and earthy cerussite in a matrix of pre-Glacial clay and sand, is a further remnant of the earlier denudation processes.

One of the most important effects of descending waters has been the enrichment of galena by silver in the upper horizons. The appearance of native silver in the more argentiferous galena, already described, is the result of secondary concentration. At Hilderston, in Linlithgowshire, niccolite in the veins was argentiferous to a depth of 70 feet, below which it quickly became

[1] C. R. Van Hise, 'A Treatise on Metamorphism' Monogr. xlvii, U.S. Geol. Surv. 1904, pp. 1144–58.

[2] A. Strahan, 'Geology of Flint, Mold, & Ruthin' Mem. Geol. Surv. 1890, pp. 178, 190.

[3] A. Strahan, 'Geology of Rhyl, Abergele, & Colwyn' Mem. Geol. Surv. 1885, p. 47.

impoverished.[1] Another occurrence which is probably of secondary origin, is that of the plumosite and argentiferous tetrahedrite at Foxdale, which were found in vughy and cellular portions of the lode at depths of 600 feet,[2] and have not been met with in the deeper workings.

An equally important secondary process has been the depletion of blende from the upper parts of the veins by conversion into soluble sulphate, and its subsequent deposition as calamine by the replacement of limestone or dolomite. Calamine has been a common ore in Flintshire veins to a depth of 200 feet, while it has been the chief zinc-ore mined in North Derbyshire. The calamine-deposits of the Mendip Hills in Somerset,[3] and of the Silvermines district in Tipperary,[4] have been formed by the removal of the blende from the adjacent lead-veins, and the deposition of calamine by replacement of the dolomite beds in which the deposits occur. They are analogous to the calamine deposits of Upper Silesia, South-Western New Mexico, and Virginia.

VIII. Summary.

The natural history of the ores in the districts here discussed may now be summarized.

The fluorine and heavy metals of the ores have been derived from a deep-seated source, probably in the first place by marginal segregation in underlying magmas. They were carried upwards chiefly by 'juvenile' waters emanating from these magmas, fluorine being an important constituent in the deeper zones. In the upper horizons of limestone districts, the underground circulation of meteoric waters has had an important effect on the distribution and deposition of the ores in the veins. The vein-solutions carried alkaline sulphides, which held the metals in solution as sulphides, and also alkaline and earthy carbonates. These latter compounds have effected sericitization and carbonatization in the adjoining country-rock, except in the case of limestones, where silicification and dolomitization took place near the vein-walls. The filling of spaces rather than replacement of rock has been the chief feature in the deposition of the ores, but the process of deposition has itself involved interchange of constituents between rock and solution, as expressed in the chemical alteration of the wall-rocks. The calcium of fluorspar has been very largely derived from the adjoining rocks. Of the vein-minerals, chalcopyrite was first deposited, followed by fluorspar, blende, galena, and pyrite in that order. Ore-deposition has persisted over a maximum vertical range of about 5000 feet, chalcopyrite and blende being characteristic of the lower horizons, galena and fluorspar of the upper. The country-rock has influenced ore-deposition, first by its physical character

[1] M. F. Heddle, 'Mineralogy of Scotland' Edinburgh, vol. i (1901) pp. 10–11.
[2] W. W. Smyth, Trans. Roy. Geol. Soc. Cornwall, vol. x (1887) p. 82.
[3] H. B. Woodward, 'Geology of East Somerset & the Bristol Coalfields' Mem. Geol. Surv. 1876, pp. 167 *et seqq.*
[4] Explan. of Sheet 134, Mem. Geol. Surv. Ireland, 1861, p. 31.

and porosity, and secondly by its chemical composition: limestones and dolomites being most favourable for the deposition of lead and zinc ores. Subsequent denudation, to the extent of nearly a half of the original height of the veins, has been accompanied by much secondary alteration, the chief secondary processes being the enrichment of silver and the depletion of blende in the upper parts of the veins, and the formation of metasomatic deposits of calamine. These secondary processes have been effective to depths of over 600 feet.

In connexion with these researches on British ore-deposits, I wish to express my warmest thanks to Prof. R. A. S. Redmayne, Chief Inspector of Mines, to Dr. John Horne, and to the managers of the different mines visited, for opportunities of doing field-work; and to Prof. W. W. Watts for his advice and criticism in the laboratory and in the preparation of the results.

Discussion.

Dr. D. Mawson remarked that the paper specially interested him, as he had just completed a detailed memoir dealing with the genesis of the Broken Hill Lode. The importance of this latter was witnessed by the fact that within the last twenty-five years, ore to the value of £60,000,000 had been won from it.

In the more important cases mentioned in the paper just read, the speaker was glad to hear that the Author regarded the genesis of the ore as arising from deep-seated sources. His (the speaker's) experience was confirmatory of the fact that the principal sulphidic lead-zinc ores of the world were primary depositions along lines of weakness, and originated from ascending, usually thermal, mineralized waters. The Broken Hill Lode was a case in point, in which he regarded the ore as an ultimate separation-product from a bathylitic igneous intrusion, and in this manner was of the nature of a pegmatite. The genetic connexion between pegmatites and certain ore-deposits had recently been firmly established, and to it special prominence had been given by Mr. Spurr.

Dr. Cullis congratulated the Author, and was inclined to support the contention that, while the minerals of those British lead-zinc lodes which are enclosed in limestone might possibly have been derived from the country rock, the contents of lodes in killas and other sedimentary rocks were of a more deep-seated origin, and probably originated from some underlying igneous source. The rapid diminution and disappearance of the lode-minerals in the surrounding country with departure from the lode, referred to by the Author, seemed to point to this conclusion; so also did the nature of the veinstones characteristic of lead-zinc veins—calcite, dolomite, quartz, fluorspar, and barytes. The first three of these could hardly be claimed to favour one of the two suggested modes of origin more than the other; but the last two, in view of the frequency of fluorine in the emanations of deep-seated igneous masses, and of barium in the lime-bearing felspars of igneous rocks, were strongly suggestive of an igneous origin. In claiming a deep-seated origin for the contents of these lodes, the Author would encounter certain difficulties, such as the fact that lead-zinc lodes are so very much more common in sedimentary than igneous rocks, and the further fact, that the lode-walls in such cases practically never show signs of any characteristic alteration.

Prof. W. W. Watts congratulated the Author on the outcome of a large amount of work in the field and in the laboratory. So far as his own experience went, he had been unable to establish the presence of barium in felspars in an area containing many veins of barytes.

The President (Prof. W. J. Sollas) expressed his satisfaction at the advocacy of what seemed to him the common-sense view of lode-deposits. He did not think that the theory of lateral secretion had ever taken root in British geology, and the observations of the Author (so far as they went) were opposed to it. The order of deposition of minerals was a difficult subject, and afforded room for much subjective determination. In the Carboniferous Limestone of the North of England it had been supposed that some lodes were filled in by descending solutions. This was not impossible, if lakes supplied by hot springs had extended over the limestone. Barytes was associated with galena in lodes traversing killas, and the probability was that both barium and lead had been supplied by the same magma.

The Author thanked the speakers, and in reply said that the lead and zinc ores of the Mississippi and Missouri districts were admitted by many workers to have been concentrated from a disseminated condition: it seemed advisable, therefore, to examine carefully any limestone district characterized by lead ores with a low silver-content. In regard to the order of deposition of the sulphides, his experience had always been that the chalcopyrite occurred in well-formed crystals enclosed in and wrapped round by galena or blende. This was the case in ores from Conway, Coniston, and Wicklow, where the 'bluestone' found with the pyritic ores enclosed occasional crystals of chalcopyrite. Ores from other parts of the world showed the same relations, including galena- and blende-bearing specimens from the pyritic masses of Southern Spain. He had not in this paper considered the possible application of the hypothesis of deposition of the ores *per descensum*.

He agreed with Dr. Cullis that fluorine indicated a deep-seated origin, at least in the districts studied; and with another speaker that it was frequently difficult to apply the results of artificial laboratory experiments in explanation of the natural phenomena.

He was much interested in Dr. Mawson's observations on Broken Hill. He had lately examined some Broken Hill ores by metallographic methods, which indicated that the garnet and rhodonite had been more or less granulated and re-cemented by later galena and blende. This agreed with the observations of Prof. R. Beck: and the deposition of the sulphides at Broken Hill appeared to be the last of the complex series of disturbances which had affected that area.

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Vol. LXVI. AUGUST 23RD, 1910. **No. 263.**
PART 3.

THE

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OF THE

GEOLOGICAL SOCIETY.

EDITED BY

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[With Eleven Plates, illustrating Papers by Dr. L. Moysey, Mr. F. P. Mennell, Miss H. Drew & Miss I. L. Slater, Mr. J. B. Scrivenor, and Prof. E. W. Skeats.]

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Session 1910–1911.

1910.

Wednesday,	November	9*—23*
„	December	7 —21*

1911.

Wednesday,	January	11*—25*
„	February (Anniversary, Friday, Feb. 17th)	8*—22*
„	March	8*—22
„	April	5*—26
„	May	10*—24
„	June	14*

[*Business will commence at Eight o'Clock precisely.*]

The dates marked with an asterisk are those on which the Council w me

12. *On* PALÆOXYRIS *and other* ALLIED FOSSILS *from the* DERBYSHIRE *and* NOTTINGHAMSHIRE COALFIELD. By LEWIS MOYSEY, B.A., M.B., B.C., F.G.S. (Read March 23rd, 1910.)

[PLATES XXIV–XXVII.]

IN a more or less careful examination of this coalfield, with a view to the compilation of a comprehensive catalogue of its flora, so many specimens of *Palæoxyris* have been found that it seems to me advisable to record such facts as the new material affords in relation to their structure. To the solution of the problem as to their true nature, however, this mass of material gives, unfortunately, no clue.

These curious organisms have been known for many years, and have been the subject of many papers and controversies; notably a paper by Dr. R. Kidston,[1] giving a very careful description and figures of such species as were known to him from British rocks, to which he added a complete bibliography up to 1885.

The first recorded specimen from British Carboniferous rocks was found in Coalbrookdale.[2] It is figured as *Carpolites helicteroides*, and was supposed to be a fruit.

A. Brongniart,[3] however, in 1828 had described an allied fossil under the name of *Palæoxyris regularis*—this name having been given, owing to its supposed resemblance to the inflorescence of the recent *Xyris*. Prestl[4] described them from the New Red Sandstone (? Rhætic) of Bamberg. A. Schenk,[5] in 1867, called attention to the resemblance of these organisms to the egg-cases of fishes, comparing them with those of certain Elasmobranchs; but he did not consider the resemblance close enough to warrant their transference to the animal kingdom. Later, however, in 1888,[6] having had further opportunities for comparison, he advocated the view that they are egg-cases, and most observers of the present day have adopted this opinion.

Lesquereux,[7] in 1870, described three species of *Palæoxyris* from

[1] Proc. Roy. Phys. Soc. Edinb. vol. ix (1885) pp. 54–65 & pl. i.

[2] J. Morris, in Prestwich's 'Geology of Coalbrookdale' Trans. Geol. Soc. ser. 2, vol. v, pt. iii (1840) pl. xxxviii, figs. 12 & 12*a*, with explanation of figs.

[3] Ann. Sci. Nat. vol. xv, p. 456 & pl. xx, fig. 1; and 'Prodrôme Hist. Végét. Foss.' pp. 137, 190.

[4] K. Sternberg, 'Versuch einer Geogn.-Botan. Darstellung der Flora der Vorwelt' Fasc. vii–viii (1838) p. 189 & pl. lix, figs. 10–11.

[5] 'Fossile Flora der Grenzschichten des Keupers & Lias Frankens' pp. 204, 205.

[6] 'Die Fossilen Pflanzenreste' 1888, p. 188; see also A. G. Nathorst, 'Om *Spirangium*, &c.' Öfversigt af Kongl. Svensk. Vetensk.-Akad. Förhandl. vol. xxxvi, No. 3 (1879) p. 81.

[7] Geol. Surv. Illinois, vol. iv, pp. 464–67.

the Coal Measures of Illinois. Under *P. prendeli* he figured two specimens (*op. cit.* pl. xxvii, figs. 10 & 12), one of which, judging from the figure, should be placed under *Palæoxyris helicteroides* (Morris). Another, *Palæoxyris corrugata* (*loc. cit.* fig. 13), might easily be a distorted specimen of either *P. prendeli* or *P. helicteroides*. His *Palæoxyris appendiculata* (*loc. cit.* fig. 11) is probably *P. carbonaria*, Schimper. Should this be so, his three forms would then be the same as the species most commonly met with in the European Coal Measures, thus showing a remarkably wide distribution in space of identical species of a certainly rare fossil.

The same author, in the 'Coal Flora of Pennsylvania,' [1] notes the discovery of other examples in that coalfield; but he makes use of the old figures in illustration of them, adding, however, a figure and description of another species, *Spirangium multiplicatum*,[2] from an example which is in a very bad state of preservation.

Since that date there has been, apparently, no literature on the subject, except a short note by Mr. W. H. Sutcliffe on *Palæoxyris prendeli*.[3] Many examples (about twenty-two) have been obtained from Shipley Manor Claypit, near Ilkeston, Derbyshire (horizon: Top Hard Coal), where has also been found an extraordinary number of other fossils, both vegetable and animal. There is, however, reason to think that the Derbyshire Coalfield in general is very prolific in these organisms, as they have been found in ironstone nodules from many claypits scattered all over the district. But they seem to be confined to the upper beds of the Middle Coal Measures, none having, so far, been discovered below the Deep Soft Coal. This may be due, in some measure, to lack of opportunity to search for them, as very few openings in the lower part of the Middle Coal Measures are to be found in this district—the majority of the brick-pits being opened in the clays in the immediate vicinity of the Top Hard Coal. A careful search in the beds in the neighbourhood of the Kilburn Coal (that is, the lowest beds of the Middle Coal Measures) has failed to reveal any. In other districts, however, Dr. Kidston has obtained *Palæoxyris helicteroides* in the Lower Coal Measures of Scotland; Mr. Walter Baldwin, of Rochdale, has found an uncompressed example of *Palæoxyris* sp. in the Millstone Grit; and two specimens of *Palæoxyris prendeli* have lately been obtained from the Sparth Bottoms Claypit, Rochdale (horizon: Arley Mine Coal = lower beds of the Middle Coal Measures).

There are four other localities in the Derbyshire and Nottinghamshire coalfield where *Palæoxyris* is very plentiful:—(1) Meadow Lane Claypit, Alfreton (horizon: Waterloo Coal), where several have been found in a small opening, which is practically barren of other fossils; (2) Brindsley Claypit, Eastwood, Nottinghamshire (horizon: Combe Coal, above the Top Hard Coal); (3) Newthorpe Claypit, near Eastwood (horizon: well below the Top Hard Coal);

[1] 2nd Geol. Surv. Penn. Rep. Progress P, vol. ii (1880) p. 519 & pl. lxxv, figs. 13–15 *a*.

[2] *Ibid.* fig. 11.

[3] 'Lancashire Naturalist' July 1909.

(4) Digby Claypit,[1] Kimberley, Nottinghamshire (horizon: Top Hard Coal), where over 130 specimens have been obtained, and where certain symmetrical, smooth-surfaced, ovoid nodules contain these organisms to the exclusion of all other fossils. Isolated examples have been obtained from Waingroves Claypit (horizon: Top Hard Coal); Nelson Street Claypit, Heanor, Derbyshire (horizon: Dunsil Coal); Loscoe Claypit, Heanor (horizon: Top Hard Coal); and from a small opening in the Great Northern Railway goods-yard, Eastwood.

The various species of *Palæoxyris* that have been found in the district are:—

Palæoxyris prendeli, Lesquereux.	Shipley, Newthorpe, and Brindsley.
Palæoxyris carbonaria, Schimper.	Brindsley and Digby.
Palæoxyris helicteroides (Morris).	Shipley, Digby, Brindsley, and Meadow Lane.
Palæoxyris (Vetacapsula) johnsoni, Kidston.	Shipley and Digby.

Palæoxyris helicteroides proves to be by far the commonest species. Of the 130 Digby specimens, all but two must, at present, be classed under the species *helicteroides*, in that they are characterized by a broad band or segment arranged in a spiral manner, alternating with one half its breadth. They differ markedly in size,[2] from 10·8 centimetres in length and 3 cm. in breadth, to about 3·5 cm. in length and 1 cm. in breadth. The great majority, however, maintain a fairly uniform size of 5·20 centimetres in length by 1·2 cm. in breadth.

Description of the Fossils.

Palæoxyris helicteroides (Morris). (Pl. XXIV, figs. 1–4.)

A fusiform thick-walled sac, prolonged upwards into a beak, downwards into a pedicle. Its walls are composed of spirally arranged, alternately broad and narrow bands. It is difficult to determine in compressed examples, such as all these are, the number of bands or segments which go to make up the spiral. There must obviously have been an even number; otherwise the alternation of broad and narrow bands would not occur (Dr. Kidston gives from six to seven bands). From a careful examination of many of the most perfect of these new specimens, it has been found that there were probably eight bands: four narrow, and four broad.

The fossil may be divided for description into three parts: (1) the pedicle, (2) the body, and (3) the beak.

The pedicle is of variable length, never showing any definite termination: its average length in the Digby specimens is 3·5 cm.

[1] See 'Geology of the Derbyshire & Notts Coalfield' Mem. Geol. Surv. 1908, p. 96, for description and figured section of this claypit.

[2] In all measurements the length of the pedicle is omitted, as it is obviously of variable length, only the body and beak being taken into account. The breadth is taken across the broadest part of the body.

It is a narrow hollow stalk, composed of spirally arranged segments, which expands somewhat suddenly into the body.

The body is thin-walled and fusiform: its walls are formed of the eight spirally arranged, alternately broad and narrow segments. Its lower third is more expanded than the rest, and shows a marked crumpling or deformity at this part (see Pl. XXIV, fig. 1, A) indicating that here was contained some body which has since disappeared. In fact, in the Digby specimens at least, there is a distinct cavity between the fossil and its counterpart in the lower third of the body, which is filled with a white powdery substance.

This substance has been in several instances subjected to microscopical examination, with and without chemical solvents; but, so far, nothing has been found that throws any light on its original nature. Chemically, this substance has been found to consist of ferrous carbonate.[1] A careful search for phosphates, the presence of which, it was thought, might point to the animal nature of the fossil, has yielded only a negative result. If these fossils are really egg-capsules, it is very unlikely that any relics of the embryo would be found, as in all probability they would be the spent egg-cases, drifted to their present position by currents; just as rarely, if ever, do we find the embryo skate still contained in the 'sailor's purses' of our coasts.

In the upper two-thirds the body tapers gradually to form a distinct though broad neck, from which arises the beak (Pl. XXIV, figs. 3 & 4). The beak, a conspicuous feature in these organisms, has not so far been adequately described—apparently, as the existing published figures of *Palæoxyris* seem to show, because no specimens have up till now been found exhibiting the beak in a perfect state. It is nearly as long as the body, measuring about 2·5 cm. in length, and is presumably of a somewhat more resistant nature, as, in a specimen showing a crushed and contorted body, the beak often appears uncrushed and complete (Pl. XXIV, fig. 3). It has a slight twist on itself, like that on the blade of a ship's propeller.

All the segments of the body enter into the formation of the beak, but they run parallel to the long axis of the fossil, having lost their spiral arrangement at the constriction of the neck. After expanding almost to the width of the body, the beak gradually tapers to a fine point. The beak was flattened, not circular in transverse section as was the body, but whether it contained a cavity or whether the corresponding segments were approximated together, forming a more or less rigid, slightly twisted, spear-shaped termination, it is impossible to say. There is a definite arrangement of the segments forming the beak. First, there is one narrow segment, gradually tapering to a point running up the centre of the beak; on either side of this are two broad segments, which, slightly expanding at first, begin gradually to

[1] I am indebted for the suggestion of this experiment and the carrying out of its details to Mr. R. D. Vernon, of Nottingham, to whom I would here tender my sincere thanks.

diminish in width; outside these on each side comes a narrow segment. The central narrow segment and the two broad segments are duplicated on the other side of the fossil, thus making up the eight segments of the body (Pl. XXIV, fig. 4).

PALÆOXYRIS PRENDELI, Lesquereux.[1] (Pl. XXV, figs. 1 & 2.)

Several specimens of this species have been found in the Shipley Manor and Newthorpe Claypits. One, especially well preserved, from Shipley, shows a spirally arranged pedicle of unknown length, which expands somewhat suddenly into a broad fusiform body about 2·5 cm. long, and 1·8 cm. broad, composed of four, equal, spirally arranged segments, 6 mm. wide (Dr. Kidston gives six to eight segments). The body shows the usual deformity in the lower third to a very slight degree, although other specimens show it markedly. The beak in this case is beautifully preserved, showing two of the segments, losing their spiral arrangement at the definitely constricted neck, and expanding into two broad alæ, which, taking on a double contour at their edges,[2] rapidly taper to a somewhat tumid point, the other two segments being presumably applied to these on the other side of the specimen. The beak has the propeller-like twist, as in *Palæoxyris helicteroides.* Dimensions of beak: 2·1 cm. in length by 1·35 cm. in breadth.

PALÆOXYRIS CARBONARIA, Schimper.[3]

One doubtful and very imperfect specimen was obtained from Brindsley Claypit, and two, contained in one nodule, from Digby. These specimens are too imperfect to add anything to our knowledge of the species.

PALÆOXYRIS (VETACAPSULA) JOHNSONI, Kidston.[4] (Pl. XXIV, fig. 5 & Pl. XXV, fig. 3.)

Two doubtful examples of this species have been found at Shipley, and one good example at Digby. The Digby specimen (Pl. XXIV, fig. 5) is about 5 cm. long (omitting the pedicle), and 2 cm. broad, its anterior termination being imperfect. Its body is more globular than in any of the preceding species, and is characterized by being made up of a number of very narrow bands, 38 having been counted across the broadest part of the fossil. There is very little evidence of a spiral arrangement of these bands; they apparently run parallel to the long axis of the fossil. In a specimen (Pl. XXV, fig. 3), kindly lent to me by Dr. Kidston, from the shale over the Thick Coal, near Bilston, Staffordshire (Westphalian Series), there is a slight twist in the arrangement of the

[1] Geol. Surv. Illinois, vol. iv (1870) p. 464 & pl. xxvii, fig. 12.

[2] It is possible that the double contour is due to the want of accuracy in the approximation of the corresponding segments on the opposite side of the fossil. There is also seen, on careful examination, the appearance of four segments in the upper tumid portion of the beak, as if they were surrounding an apical opening in the fossil (see Pl. XXV, fig. 2).

[3] Stiehler, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. ii (1850) p. 182 & pl. vii.

[4] Proc. Roy. Phys. Soc. Edin. vol. ix (1885) p. 63.

bands, but this might well be due to the state of preservation of the fossil. The body shows the usual deformity in its lower third, and gradually tapers upwards into the beak, which is imperfect in every specimen that has come to hand.

The absence of an evident spiral arrangement of the segments of this species affords a very marked distinction from the other species of *Palæoxyris*, and from the allied genus *Fayolia*, but brings it so near to the allied genus *Vetacapsula*, that it seems to me advisable to place the fossil in the latter genus, and I have therefore ventured to alter its name to *Vetacapsula johnsoni.*

The fine oblique lines mentioned by Dr. Kidston as ornamenting the segments of *Palæoxyris prendeli* have been noticed also on several specimens of *P. helicteroides.* They are generally best shown at the commencement of the body, and are so variable that they can safely be referred to some accident in mineralization. The fine parallel striæ, mentioned by Lesquereux, may also be due to the same cause. In most cases the segments appear smooth without any evidence of ornamentation, nor do they show any trace of carbonaceous matter on their surface.

The majority of the Shipley specimens are encrusted with *Spirorbis* sp., which is quite common on other fossils from the same locality. On several of the Digby specimens, however, small irregular bosses, and occasionally deeply excavated pits, have been found, for the most part upon the beak (Pl. XXIV, fig. 3, B). These bosses and depressions are presumably due to some parasitic organism, and are not normal to the fossil. It is curious to note that in the figure of *Carpolites helicteroides*,[1] given by Morris in Prestwich's 'Geology of Coalbrookdale,' there is shown a similar excrescence on one of the segments of the body of the fossil.

With regard to the mode of attachment of these fossils, Ettingshausen[2] has shown that they occur in a verticillate or umbellate manner. Schimper[3] gives a figure of *Spirangium jugleri*, Ettingshausen, in which at least nine examples are seen arising from a common centre; and, according to his figure, it is the shorter, broader, extremity that forms the point of attachment. In view, however, of the discovery of the distinct and, in many cases, perfect beak, and of the fact that the pedicle is always of variable length, and so far has not shown a definite termination, it is more probable that these organisms were attached by the pedicular end, and that the end which carried the beak was free. In those Derbyshire nodules that show two specimens, the fossils seem to lie at all angles to one another; in at least three instances they have been found to lie with their beaks approximating or even touching, but this may well be due to accidental juxtaposition.

[1] Trans. Geol. Soc. ser. 2, vol. v, pt. iii (1840) pl. xxxviii, fig. 12.

[2] 'Ueber *Palæobromelia*' Abhandl. d. K.K. Geol. Reichsanst. vol. i (1852) pt. iii, no. 1.

[3] 'Traité de Paléontologie Végétale' vol. ii (1872) p. 519 & (atlas) pl. lxxx, fig. 5 (*Spirangium jugleri*).

Vetacapsula.

(Pl. XXIV, fig. 5; Pl. XXV, figs. 3 & 4; & Pl. XXVI, fig. 1.)

A single example of a very rare fossil, evidently allied to *Palæoxyris*,—*Vetacapsula cooperi* (Mackie & Crocker),—was found at Newthorpe Claypit. Mr. E. J. Mackie[1] prints a very meagre description of his specimen, promising to give at a later date a more detailed account in conjunction with Mr. C. W. Crocker. No further description having been found, it is probable that Mr. Mackie did not go farther into the matter. A short note by the same author (*op. cit.* p. 216) reports the finding of a similar fossil in the Coal Measures of Dudley, by Mr. J. C. Capewell, and, incidentally, reveals the fact that the locality from which the type-specimen was obtained is not known, and that it is presumed to have come from the Coal Measures from the appearance of the ironstone nodule in which it was contained.

The woodcut accompanying the description is fairly clear. It shows a broad pedicle expanding into a more or less regular oval body, which tapers gradually at the upper end into what is presumably a beak, the apex of which, however, is not shown in the specimen. There is a crumpling or deformity at about the centre of the body, as in *Palæoxyris*. Mr. Mackie notices a vertical suture down the middle; this, however, may well be due to accidental crushing. His description, with measurements, is as follows:—

'*Vetacapsula Cooperi*—flower-bud or seed-vessel—length, 3 inches apex to base; width, as on stone, 1^5 inches—divided by a central vertical suture: ribbings $\frac{1}{10}$ inch broad in the middle, tapering at both ends, about 26? in each hemisphere.'

The Newthorpe specimen (Pl. XXV, fig. 4), exposed on the surface of a large flat ironstone-nodule, is very perfect. It shows a relatively broad pedicle, the terminal moiety of which is still embedded in the matrix, composed of fine bands running vertically in the long axis of the fossil. The pedicle expands suddenly into the body, thus forming a characteristic rounded shoulder in the contour of the body at its lower third, and imparting to the body, in its present compressed state, a shape somewhat like that of a conventional heart inverted. The body is about 4·7 cm. long and 5·6 cm. broad, and twenty-six segments can be counted across it. There is a crumpling or deformity of the segments in the lower third. The body gradually tapers into the beak, which is more than 5·5 cm. long; the actual termination of the beak is not shown, but appears to have been a sharp point.

The counting of the number of bands or segments which go to make up this organism is, in its compressed state, a matter of great difficulty. By making a plasticine model with a diameter exactly the width of the specimen on the stone, and marking on this

[1] 'Geol. & Nat. Hist. Repertory' vol. i (1865–67) pp. 79–80.

spaces equivalent to the width of the most perfect bands, that is, 3 mm., it is found that forty bands would be necessary to make up the fossil. This, however, must be a very rough estimate, owing to our ignorance concerning the true diameter of the fossil when uncompressed. The above-mentioned twenty-six segments counted on the specimen would agree closely enough with this estimate, if it be assumed that several segments, showing through from the opposite side, had been taken into account, as may very easily be the case. Each band or segment is smooth, without any sign of ornament, and each one tapers to enter into the beak above and the pedicle below. Here again no trace of carbonaceous material is found between the fossil and its counterpart.

Dr. Kidston has kindly lent me two specimens for description here. One, a plaster cast of a specimen from Coalbrookdale, the original of which is now in the British Museum (Natural History), agrees so exactly, in measurements and details, with the Newthorpe specimen, that there can be no question as to their identity. The other from Sparth Bottoms, Rochdale (horizon: Arley Mine Coal), obtained by Mr. W. H. Sutcliffe (Pl. XXVI, fig. 1) from an ironstone nodule, presents only a short broad pedicle, the lower part being truncated by the margin of the nodule. The body is more fusiform, there being no sudden expansion of the pedicle into the body, giving rise to a definite shoulder as in the other two specimens. The upper part of the body is still hidden in the matrix. There is a deformity situated in the lower half of the body, but nearer the middle line than in the other two specimens. The body is 2·5 cm. broad, and shows seventeen bands or segments, the most perfect of which are 1·75 mm. wide.

This specimen differs markedly in size and shape from the two preceding examples, but agrees closely in shape with Mackie's figure. It would be unwise, in the present uncertainty as to the nature of these fossils, to multiply species, and it would seem therefore best to include them all under the old specific name, until more light can be thrown on them by the discovery of further specimens.

There is, too, in Dr. Kidston's possession, a small specimen, collected by Mr. W. Hemingway from Brightside, Sheffield, from the rock below the Haigh Moor Coal, preserved on the surface of a piece of shale, which also bears a few pinnules of a Sphenopterid fern. This specimen shows a fusiform body 8 mm. broad, with about nine segments, the breadth of which is about 1 mm. The segments in this case show a slight tendency to a spiral arrangement, which, however, may be due to an accident in fossilization. This specimen had better be included under *Vetacapsula*.

Fayolia.

(Pl. XXVI, fig. 3 & Pl. XXVII, figs. 1–2.)

1884. *Fayolia*, Renault & Zeiller, C. R. Acad. Sci. Paris, vol. xcviii, p. 1391 (*Fayolia dentata* fig., *Fayolia grandis* fig.).
1884. *Fayolia*, Weiss, 'Steinkohlen-Calamarien' vol. ii, p. 203 (as *Gyrocalamus*, Weiss, vol. ii, p. 152).
1888. *Fayolia*, Renault & Zeiller, C. R. Acad. Sci. Paris, vol. cvii, p. 1022.
1888. *Fayolia*, Renault & Zeiller, 'Flore Fossile (Terrain Houiller de Commentry)' pt. i, p. 15 *et seqq*. (Bull. Soc. Industr. Minérale, St. Étienne).
1888. *Fayolia*, Schenk, 'Die Fossilen Pflanzenreste' p. 186.
1890. *Fayolia*, Renault & Zeiller, 'Flore Fossile (Terrain Houiller de Commentry)' App. to pt. i, pp. 369 *et seqq*. (Note rectificative).
1885. *Spiraxis*, Newberry, Ann. N. Y. Acad. Sci. vol. iii, p. 219.

In Shipley Claypit were found four examples of the genus *Fayolia*. Three of these are fragments of uncompressed examples; the other is compressed, and is in too imperfect a state of preservation for accurate determination.

These organisms were first found in the Commentry Coalfield by M. Fayol, and were described by Renault & Zeiller in 1884. Prof. Zeiller, in the 'Flore Fossile (Terrain Houiller de Commentry)', thus describes the genus :—

'Corps fusiformes ou cylindriques, effilés en pointe à leurs deux extrémités, portés au sommet d'un pédoncule, et formés de deux valves plus au moins concaves en dehors, soudées l'une à l'autre par leurs bords, contournées en hélice, et circonscrivant une cavité centrale. Valves marquées, un peu au dessus de leur ligne de suture, d'une file de petites cicatrices rondes ou elliptiques. Lignes de suture de ces valves portant chacune une collerette hélicoïdale étalée, à bord entier ou dentelé.' (Pp. 15–16.)

He then (pp. 22 *et seqq*.) describes two species :—

1884. Fayolia dentata, Renault & Zeiller, C. R. Acad. Sci. Paris, vol. xcviii, p. 1393 & p. 1392, fig. 1. Weiss, 'Steinkohl. Calam.' vol. ii, p. 204 & p. 203, fig. 1. Saporta, in A. d'Orbigny's 'Paléont. franç.: Végétaux, Terr. Jurass.' vol. iv, pp. 39, 40 & pl. iv, fig. 1.

Body fusiform, 8 to 16 cm. long, 15 to 25 mm. broad across the middle, carried on a smooth or finely striated pedicle, and composed of two concave valves 5 to 10 mm. wide, fused along their borders, and arranged in a spiral, showing six to seven turns of the spiral. Valves marked at 1 to 2 mm. above their fused borders by a row of small round scars ·75 to 1·5 mm. in diameter, and placed 1·5 to 3 mm. apart from centre to centre, sometimes carrying bent or straight spines with fine longitudinal striations 12 to 25 mm. long. The lines of suture of the valves are slightly raised, and carry a spiral collerette with a finely dentate or fringed margin from 5 to 6 mm. wide, apparently becoming free towards the apex of the fossil, and gradually diminishing in width to end in a vertical point and lose its dentate margin.

1884. Fayolia grandis, Renault & Zeiller, C. R. Acad. Sci. Paris, vol. xcviii, p. 1393 & fig. 2. Weiss, 'Steinkohl. Calam.' vol. ii, p. 204 & p. 203, fig. 2. Saporta, in A. d'Orbigny's 'Paléont. franç.: Végétaux, Terr. Jurass.' vol. iv, pp. 39, 40 & pl. iv, fig. 2.

1884. Possibly *Fayolia palatina*, Weiss, 'Steinkohl. Calam.' vol. ii, p. 204. (*Gyrocalamus palatinus*, *ibid*. p. 152 & pl. iv, figs. 3–4.)

Body cylindrical, narrowing to a point at the extremities, 3 to 4 cm. wide and more than 40 cm. long, formed of two slightly concave, finely striated valves, fused to one another along their borders, and forming a spiral with at least eight to ten turns. Valves showing, 5 to 6 mm. above their lines of suture, a row of circular or elliptical scars 2 to 4 mm. high, 2·3 mm. broad and 3·8 mm. apart. The line of suture of the valves, slightly projecting, carries a spiral spreading c o l l e r e t t e, 5 to 8 mm. broad, with an entire margin.

Prof. Zeiller then discusses the relationship of these organisms with *Palæoxyris*, and mentions the discovery in 1884 by Weiss of *Gyrocalamus palatinus* in the Lower Permian (Lebacher Beds) of Alben, north of Cusel.[1] This species he tentatively considers identical with his *Fayolia grandis*. He notices the discovery, in the Chemung Group (base of the Upper Devonian) of Southern New York and of Pennsylvania, of *Spiraxis major* and *Sp. randalli*, described by Newberry,[2] which he considers to be a badly preserved *Fayolia*. He expresses himself very guardedly as to their nature, believing them to belong to the vegetable kingdom.

In the second volume of the 'Flore Fossile (Terrain Houiller de Commentry),'[3] however, having been in communication with Schenk,[4] who in 1867 had called attention to the resemblance of *Palæoxyris* to the egg-cases of Elasmobranchs, and in 1888 had compared *Fayolia* with the same egg-cases, citing those of several tropical Rays, Zeiller, in an emendatory note, strongly upholds the animal nature of these organisms, comparing them with the egg-cases of *Cestracion philippi* and of the Chimæroid fishes.

C. E. Weiss in 1887 described another species—*Fayolia sterzeliana*,[5] from Borna near Chemnitz (horizon: Hainichen-Ebersdorfer Beds = Culm = Lower Coal Measures). This is distinguished from *Fayolia palatina* (or *F. grandis*) by its smaller size. The scars are smaller, 1 mm. instead of 4 mm. in diameter, and are placed closer together—where ten scars occur in 17·5 mm. on *Fayolia sterzeliana*, ten occur in 60 mm. on *F. palatina*. The valves are marked by fine weak spiral striations, which are absent in the other species. The scars are circular or slightly oval in form, and stand on a convex bar or ridge. The 'collerette' appears to have an entire margin.

FAYOLIA DENTATA, Seward.[6]

The only British specimen hitherto discovered was found by Mr. Best of Darlington in the Lower Coal-Measure sandstones of Stainton Quarries, Barnard Castle, in 1887, and was described by Prof. Seward in the 'Naturalist' as *Fayolia dentata*. The figure and description of this, however, differ from those of Zeiller's type specimen, in that the spine scars (seen for the most part on the impression, *op. cit.* fig. 1) are smaller, and more closely placed, agreeing in this respect more nearly with Weiss's *F. sterzeliana*, though a re-examination of the fossil would be necessary before

[1] This fossil was first named *Gyrocalamus* by Weiss; but later in the same book he changes the name to *Fayolia*, on seeing Reinault & Zeiller's account of *Fayolia* in the Comptes Rendus Acad. Sci. Paris.

[2] Ann. N. Y. Acad. Sci. vol. iii (1885) pp. 219–20 & pl. xviii, figs. 1–3.

[3] Vol. ii (1890) App. to pt. i, p. 369.

[4] 'Die Fossilen Pflanzenreste' 1888, p. 188.

[5] 'Ueber *Fayolia sterzeliana*, n. sp.' Jahrb. d. K. Preuss. Geol. Landesanst. 1887, p. 94 & pl. iv.

[6] 'Naturalist' 1894, p. 233 & pl. i, figs. 1–2.

seriously challenging Seward's specific name. This specimen is of especial interest, in that it shows that the cast of the fossil (*op. cit.* fig. 2) is *Spiraxis*; while the impression in the matrix is a typical *Fayolia*.

The materials from Shipley available for description are:—(1) Two fragments of a large uncompressed *Fayolia*, which are so alike, and were found so close together on the floor of the claypit, that there is great probability that they form parts of the same individual; with parts of their encasing nodules, which give an exact copy of the central fossil: (2) one fragment of a somewhat larger example, with its counterpart: (3) a nodule containing crushed and broken fragments of another example: and (4) the above-mentioned compressed specimen of a smaller *Fayolia*, evidently of a different species.

FAYOLIA CRENULATA, sp. nov.[1] (Pl. XXVI, figs. 2–3 & Pl. XXVII, fig. 1.)

The largest fragment (Pl. XXVI, fig. 3) consists of a flattened cylinder tapering gradually towards the base, the cross-section of which is more or less a perfect oval, 5·6 cm. wide at its upper part, 4·5 cm. wide at its base, and 11 cm. long, broken off transversely at each end and consequently showing no termination; composed of two finely striated valves 2·1 cm. broad, fused together along their edges, forming a spiral with two and a half turns. The line of fusion of the valves is marked by a coarse line, and 3 mm. above this occurs another coarse line; again, 8 mm. above the fused border occurs a row of circular scars 2 mm. in diameter and placed 4·6 mm. apart, so that ten scars can be counted in 38 mm. Just above the row of scars is seen a crenulate line of ornamentation with a marked double contour, each dip in the crenulation corresponding to a scar. This ornamentation will be discussed later, in relation to the 'collerette.' The whole area, from the line of fusion of the valves to the top of the crenulate margin, projects markedly from the plane of the cylinder. The striations on the valves, running exactly parallel to the turns of the spiral, are for the most part fine lines; but there are to be noticed coarser striations irregularly disposed (Pl. XXVII, fig. 1), two of which, however, usually run close together near the centre of the valve. The scars are not facets, but show an irregular broken surface, as if spines had been attached to them and had been broken off.

There is evidence of a distinct, membranous, finely striated 'collerette,' 12·75 to 15 mm. wide, arising from the line of junction of the valves, and making an angle of about 30° with the face of the fossil: its free crenulate margin gradually bending outwards to about a right angle. This 'collerette' can be clearly seen on some of the fragments of the encasing nodule, and also on the matrix in some places adhering to the fossil (Pl. XXVI, fig. 3, and Pl. XXVII, fig. 1, A). It seems impossible to explain the crenulate ornamentation just above the line of scars, without coming to the conclusion that there was another, probably more

[1] This specimen was informally brought before the Geological Society by Mr. E. T. Newton, F.R.S., in the autumn of 1904.

delicate 'collerette,' pierced by or possibly carrying the spines, arising from the second coarse striation, and more nearly applied to the cylindrical body, which has become impressed on the body during fossilization. That the ornament is not due to the application to the fossil of the first-mentioned 'collerette' is proved by the fact that the encasing nodule shows the 'collerette' with its crenulate margin, projecting at an angle from the body, and at the same time a corresponding portion of the fossil shows its crenulate ornamentation. It is worthy of note in this connexion that in Prof. Zeiller's figure of *Fayolia grandis* [1] an exactly similar ornamentation is shown, but is not mentioned in the text.

This specimen approaches nearer to *Fayolia grandis* (Renault & Zeiller) than to any other described species, agreeing fairly well in the size of the scars, their distance apart, and the dimensions of the 'collerette.' But the fact that it is much larger, that the fine striations appear to be more coarse than in the described species, and also that the 'collerette' possesses a crenulate margin, all seem to show that we are here dealing with a new species. The choice of a specific name naturally falls on *crenulata*: thus carrying on the same principle of differentiation as that adopted by Prof. Zeiller in his *Fayolia dentata*.

The fragment of an even larger specimen shows no special features worthy of notice, and agrees so exactly with the previously described specimen that there is no hesitation in ascribing it to the same species.

With regard to the nodule containing crushed fragments, however, the scars are placed much closer together, in fact they are almost touching. The margin of the 'collerette' appears to be entire, and the fine striations on the valves are less marked. The specimen rapidly diminishes both in width and in thickness, and is evidently a fragment of a specimen nearing its basal termination. It agrees closely with *Fayolia sterzeliana* (Weiss), but is in too fragmentary a condition for accurate determination.

The small compressed example shows several points of interest. It is spindle-shaped, 5 cm. long and 1·5 cm. broad, showing its apical termination in the form of a blunt point, while its basal end is truncated by the margin of the nodule. Its spine-scars are relatively large and are placed 1 mm. apart, so that four can be counted in the space of 10 mm. No details as to its 'collerette' can be distinguished, but near the apex on the left of the figure (Pl. XXVII, fig. 2) can be made out a sharp, finely striated, straight spine, 4·5 mm. long; a little farther away can be seen the point of another embedded in the matrix. The details of the fossil are obscured by the presence on the same nodule of a plant-stem, and the pinnule of a Sphenopterid fern. The fossil is in too imperfect a state of preservation for accurate specific determination, but agrees fairly closely with *Fayolia dentata*, Renault & Zeiller, and should provisionally be placed near that species.

[1] 'Flore Fossile (Terrain Houiller de Commentry)' pt. i (1888) pl. xlii, fig. 3.

Distribution of *Fayolia, Vetacapsula,* and *Palæoxyris* in time.

The genus *Fayolia* has been found as *Spiraxis major*, Newberry, in the Chemung Group of the State of New York, and as *Sp. randalli*, Newberry, in the same rocks in Pennsylvania. Stainier[1] describes *Sp. interstrialis* from the celebrated quarries of Isne-Sauvage (near the village of Les Isnes), opened up in the Upper Devonian (Psammites du Condroz). He correlates the beds from which the Belgian specimen was derived with those of Pennsylvania and the State of New York, as they both contain the same fauna. He thus states that the 'schistes de La Famenne' are absolutely identical with the Chemung Series. The genus, therefore, first appears in the Upper Devonian strata.

Weiss's *Fayolia sterzeliana* was obtained from the Ebersdorfer Beds in the German Culm, which is equivalent to the Lower Carboniferous or Dinantian Series. The Darlington specimen, *Fayolia dentata*, Seward, was found in the Lower Coal-Measure sandstones (Woodward) of Barnard Castle, while the Shipley specimens came from the Middle Coal Measures in the neighbourhood of the Top Hard Coal (Barnsley Coal of Yorkshire): both these horizons being comprised in the Westphalian division of the Carboniferous Period. The Commentry species were found in the beds above 'La Grande Couche,' but especially in the Tranchée de Forêt, 26 to 33 feet above that well-known coal-seam: these measures are of late Stephanian age.[2] The most recent specimen found up to now is *Fayolia palatina* (Weiss),[3] discovered in the Lebacher Beds of the Lower Permian. There is, however, a *Spiraxis bivalvis*, Ward,[4] noted from the Laramie Group (Upper Cretaceous) of Clear Creek (Montana), U.S.A. No description is given, but, from the figure, the specimen appears to be too imperfect for satisfactory determination; and it would be unwise to extend the range of the genus to so great an extent on such insufficient evidence.

Of the genus *Vetacapsula* no record of its discovery out of England has so far been obtained. The British Museum (Natural History) possesses three examples from near Dudley, including Mackie's type-specimen, and one from Coalbrookdale. The Museum of Practical Geology, Jermyn Street, possesses two specimens from Coalbrookdale: all, therefore, having been obtained from the Middle Coal Measures. Dr. Kidston's specimen comes from the lower beds of the Middle Coal Measures of Lancashire, and the Newthorpe example from the upper beds of the same Measures in Nottinghamshire. All these organisms, therefore, have been found in the Westphalian division of the Carboniferous Period.

[1] Bull. Soc. belge Géol. vol. viii (1894) Mém. p. 23 (fig.).
[2] W. Gibson, 'Geology of Coal & Coal-mining' 1908, p. 247.
[3] 'Steinkohlen-Calamarien' vol. ii (1884) p. 152 & pl. iv, figs. 3-4.
[4] 'Synopsis of the Flora of the Laramie Group' 6th Ann. Rep. U.S. Geol. Surv. (1884-85) p. 549 & pl. xxxi, fig. 3.

Palæoxyris, on the other hand, has existed through a long space of time, having been found in the Lanarkian Series (=Lower Coal Measures of Scotland), in the Middle Coal Measures of Rochdale, Dudley, Coalbrookdale, Yorkshire, and Derbyshire. Brongniart described *Palæoxyris* from the Grès bigarrés (Lower Trias); Schimper from the Rhætic of Bamberg; and Ettingshausen's specimens, described under the name of *Palæobromelia*, came from the Wealden of Deister. This genus therefore ranges from the middle of the Carboniferous Period to the lower portion of the Cretaceous; few genera have enjoyed so long a geological range.

Affinities.

As before mentioned, most modern observers are of the opinion that these organisms are the egg-cases of fishes.

In a recently published monograph on Chimæroid fishes,[1] Dr. Bashford Dean, remarking on the difficulty of obtaining full egg-cases of *Chimæra colliei* by dredging—probably owing to the fact that the eggs were deposited at depths (over 60 fathoms) where dredging was difficult, or in his case impossible,—states that he obtained from Discovery Bay, Puget Sound, a surprisingly large number of spent egg-cases in 6 fathoms of water, which had, presumably, been drifted from greater depths by currents. This fact suggests an explanation for the occurrence of so large a quantity of *Palæoxyris* in the limited area of Digby Claypit.

In discussing the fossil Chimæroid egg-cases, that author mentions a capsule of *Ischyodus*[2] from the 'Dogger Beds' (Jurassic) of Germany, which is a typical Chimæroid egg-case, comparable with those of the recent *Collorhynchus*. He dismisses *Fayolia*, *Palæoxyris*, and '*Spirangium*' as too imperfect and badly preserved, stating that they could equally well be the coprolites of fishes with spiral intestinal valves. He makes exception, however, in favour of a recently discovered '*Spirangium*' (*op. cit.* fig. 13, p. 28)—presumably because it is in a better state of preservation than most of the American examples. On this specimen he makes the following note:

> '*Spirangium*, H. E. Sauvage (1903), from Lithographic Stone, Lerida, Spain (Jurassic). If this prove a Chimæroid egg-case, it is remarkable in a feature suggesting the capsule of a Cestraciont—marginal webs arranged in spiral.'

In a note defining technical terms (*op. cit.* p. 28) he gives the following description of the capsule of *Chimæra colliei*:—

> 'In *Chimæra colliei* the parts of the young fish are found to have a definite relation to the egg-capsule. . . . . The capsule can therefore be referred to as containing a case for the embryo, which is always subdivided into snout sheath, trunk sheath, and tail sheath. The case has also a dorsal side, which bears anteriorly an opercular flap, which provides for the ultimate escape of the young; and a ventral side, which is usually more convex. [Other descriptive terms are] . . . . opercular ridges, overlapping, form together the

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[1] 'Chimæroid Fishes & their Development' 1906, p. 8.
[2] *Ibid.* fig. 14, p. 31 (after Jækel).

rims of the opercular flap. In their specialization these rims have sometimes protruding serrulæ, which interlock and form a close-set grating, which admits water for the respiration of the embryo, and which later breaks open to permit the young fish to escape from the capsule. . . . Ventilating apertures are also present at the sides of the tail sheath, and these may be termed the caudal pores.'

The figures of two recent Chimæroid egg-capsules are here reproduced from Dr. Bashford Dean's monograph (Pl. XXVII, figs. 3 & 4), from which it will be seen that the dart-like shape is the same, both in the recent capsules and in *Palæoxyris* and *Vetacapsula*, but no differentiation in head-, trunk-, and tail-sheath can be made out in the fossils. It is possible, however, that the 'beak' of *Palæoxyris* may be the equivalent of the opercular flap and its appendages.

It is not suggested here that these fossils are the egg-cases of actual Chimæroids. In fact, their spiral disposition suggests that they have some affinities with those of the Cestracionts. But, if Bashford Dean be right—and he brings forward some strong arguments in favour of his theory [1]—in his view that the Chimæroids are a highly specialized family, branching off from the Selachian stem near, or even within, the group of Palæozoic Cestracionts, and are not the lowly survivors of a primitive stock from which the Selachians arose (as has been formerly supposed): then it is possible to look upon these fossils as the capsules of a more generalized ancestor of both the Cestracionts and the Chimæroids, which combined in their egg-cases some of the characteristics of both.

In conclusion I would here wish to express my thanks to Dr. R. Kidston for the kindly help and advice which he has given me, and the trouble that he has taken in reviewing this paper; also for the loan of specimens and carefully collected notes, which have been invaluable for its production. I am further indebted to Mr. E. A. Newell Arber, to Dr. H. H. Swinnerton, to Dr. F. Oswald, and to Dr. Walcot Gibson, for much help and advice. Also to Mr. E. M. Mundy, of Shipley Manor, and to the manager of the Digby Brickworks, for the facilities which they have granted me for examining the ironstone nodules of their claypits.

EXPLANATION OF PLATES XXIV–XXVII.

PLATE XXIV.

Fig. 1. *Palæoxyris helicteroides* (Morris). Meadow Lane Claypit, Alfreton. Author's collection. Natural size.

2. *Palæoxyris helicteroides* (Morris). Digby Claypit, Kimberley. Two-thirds of the natural size. Author's collection.

3. *Palæoxyris helicteroides* (Morris). Digby Claypit, Kimberley. Two-thirds of the natural size. Showing parasitic bosses on the beak. Author's collection.

4. *Palæoxyris helicteroides* (Morris). Digby Claypit, Kimberley. Natural size. Showing the arrangement of segments in the beak. Author's collection.

5. *Palæoxyris* (*Vetacapsula*) *johnsoni*, Kidston. Two-thirds of the natural size. Author's collection.

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[1] *Op. cit.* p. 155.

Plate XXV.

Fig. 1. *Palæoxyris prendeli*, Lesquereux. Shipley Claypit (Derbyshire). Two-thirds of the natural size. Showing the beak and the arrangement of segments in the body. Author's collection.
2. The same enlarged, showing details of the beak.
3. *Palæoxyris* (*Vetacapsula*) *johnsoni*, Kidston. Bilston (Staffordshire). Natural size. Collection of Dr. R. Kidston, Stirling.
4. *Vetacapsula cooperi*, Mackie & Crocker. Newthorpe Claypit, Eastwood. Two-thirds of the natural size. Author's collection.

Plate XXVI.

Fig. 1. *Vetacapsula cooperi*, Mackie & Crocker. Sparth Bottoms (Lancashire). Natural size. From Dr. R. Kidston's collection, Stirling.
2. *Fayolia crenulata*, sp. nov. Portion of encasing nodule, showing crenulate 'collerette.'
3. *F. crenulata*, sp. nov. Shipley Claypit (Derbyshire). Natural size. Presented to the Museum of Practical Geology, Jermyn Street. [This figure has been accidentally reversed, its lower extremity being uppermost.]

Plate XXVII.

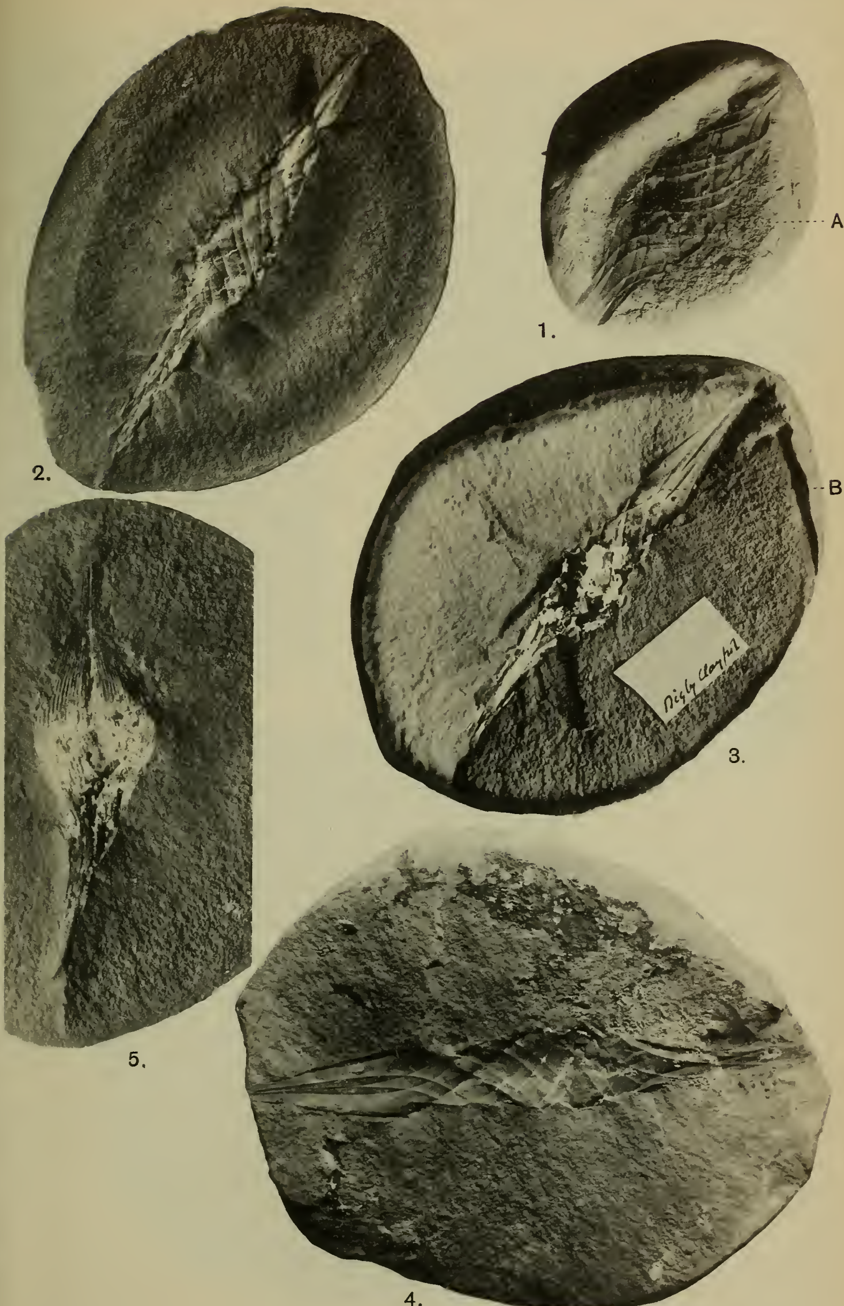
Fig. 1. Details of *Fayolia crenulata*. × 2.
2. *Fayolia* cf. *F. dentata*, Renault & Zeiller. Shipley (Derbyshire). About natural size. A compressed example, showing a finely striated spine. Presented to the Museum of Practical Geology, Jermyn Street.
3. Egg-capsule of *Chimæra phantasma*. Misaka (Japan). Ventral aspect, a third of the natural size. Copied from Bashford Dean's monograph on Chimæroids.
4. Egg-capsule of *Chimæra mitsukurii*. Misaka (Japan). Ventral aspect, a third of the natural size. Copied from the same monograph.

Discussion.

Dr. Henry Woodward, after referring to the many rare and interesting fossils obtained by the Author from the Coal Measures near Nottingham, expressed his opinion that the organisms, long known as *Palæoxyris*, were more probably egg-capsules of some species of Carboniferous fish, rather than a part of any plant—although found associated with various plant-remains and not occurring with those of fishes. He thought it very possible that (as is the habit of the living Salmonidæ) these Coal-Measure fishes might have entered the estuaries or the rivers, in order to deposit their ova or their egg-capsules, and have left these attached to vegetation, either floating or fixed. The superficially plant-like aspect of *Palæoxyris* might have been only a mimetic resemblance, and have served as a protective disguise for the young embryo.

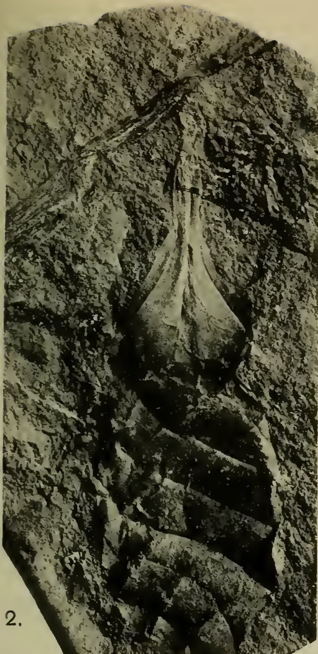
Dr. Walcot Gibson remarked that the results obtained by the Author were the outcome of long-continued and skilfully conducted work in the field and in the laboratory. The close association of marine organisms with plants in the Coal Measures of Derbyshire and Nottinghamshire could be explained by the proximity of swamps to the Carboniferous sea throughout the Coal-Measure Period.

Dr. Smith Woodward welcomed the new facts concerning the structure of *Palæoxyris* and allied fossils, but regretted that they



L.M. Photogr. — Bemrose Ltd., Collo., Derby.

PALÆOXYRIS AND VETACAPSULA.



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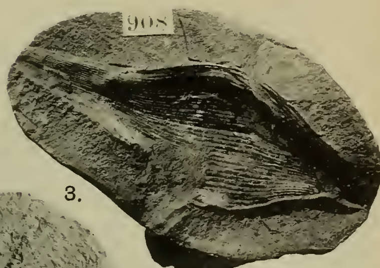

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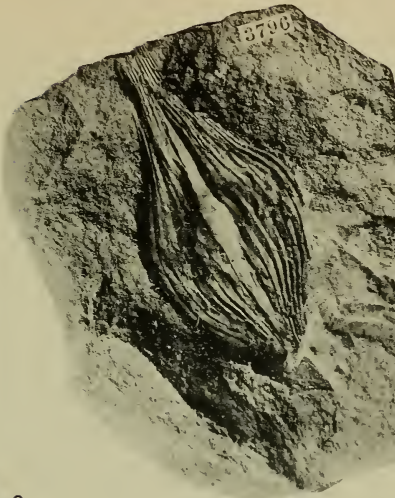
L.M. Photogr. *Bemrose Ltd., Collo., Derby.*

Palæoxyris and Vetacapsula.



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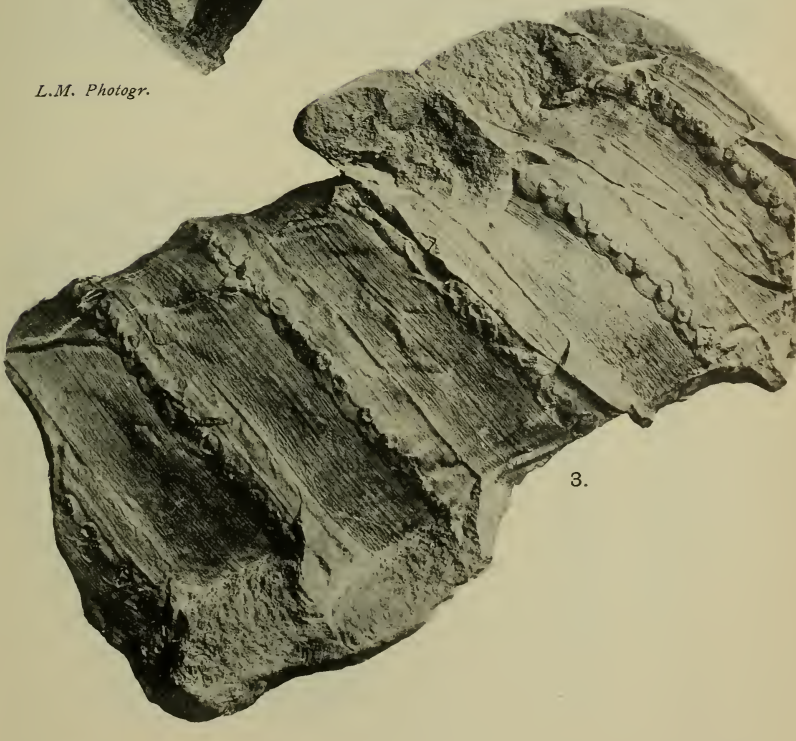

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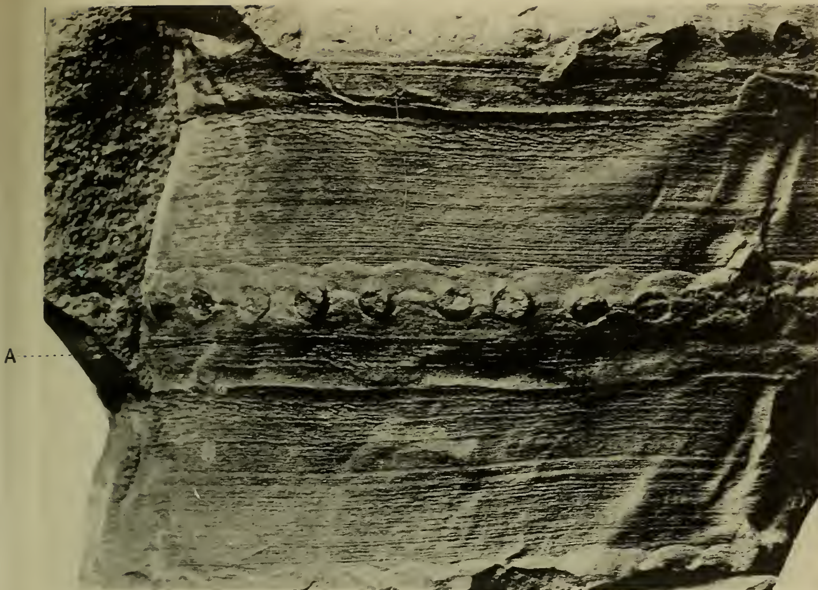
VETACAPSULA AND FAYOLIA.



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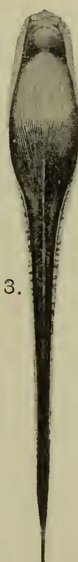

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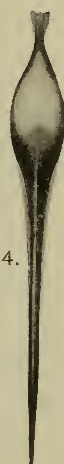

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L.M. Photogr.

Bemrose Ltd., Collo., Derby.

Fayolia and Chimæroid Capsules.

appeared still to leave the true nature of these organisms in doubt. He remarked on the wide geological range of such fossils, and asked the Author whether he had ever found them in the Coal-Measures in clusters like those described from the Wealden formation of the Continent. If they were the eggs of fishes, they must belong either to Elasmobranchs or to Chimæroids, of which traces were almost completely absent from the rocks in which *Palæoxyris* and allied fossils were found.

Dr. Martin Schmidt remarked on the analogy between the fruits of a certain species of mangrove, common in the Dutch East Indies, and the fossils described.

The President (Prof. W. W. Watts) pointed out that the apparent variation in size in the fossils exhibited was not in favour of the origin of *Palæoxyris* as an egg-capsule.

The Author, after thanking the Fellows for their kind reception of his paper, remarked, with reference to the observations of Dr. Henry Woodward, that the presence of plant-remains in the same nodule with the Shipley specimen appeared to him purely accidental, as every nodule from that claypit contained plant-remains. He could not quite endorse Dr. Gibson's contention that the clays from which these specimens came might have been marine, as there was no evidence of an associated marine fauna. He was very interested in Dr. Schmidt's observation concerning the fruit of the Bakao. He had noticed that these organisms had been found occurring in clusters, but the nature of the substance to which they were attached could not in any case be made out.

13. *An* Earthquake Model. By John William Evans, D.Sc., Ll.B., F.G.S. (Read June 15th, 1910.)

Some eighteen months ago, Mr. R. D. Oldham showed to this Society a model designed to explain the mechanism of the earth-movements at the time of the Californian earthquake of 1906 in the neighbourhood of the San Andreas Fault.[1] Though of great value in assisting us to realize the nature of the changes which then took place, it does not give prominence to the time-element so as to indicate the succession of events that led up to the earthquake shock; and it is to illustrate this aspect of the question that I have had the model constructed which forms the subject of the present paper.

It will be convenient for me, in the first place, to describe succinctly, from my own standpoint, the stages into which the conditions that precede an earthquake may be divided.

I shall on the present occasion put on one side earthquakes which are in the nature of landslips, as well as those which are the immediate result of the explosive action of the gases in igneous magmas, although there are authors who attribute to both of these modes of origin a greater importance and a more frequent occurrence than is usually accorded to them.

The typical earthquake, then, including great earthquakes like that of 1906, is, in my belief, the ultimate result of the slow relative movement of great masses of the earth's crust extending in most cases far beyond the area immediately affected by the shock. This differential creep may be in a horizontal, or in a vertical, or in any intermediate direction. As it proceeds, the intervening tract is subjected to stresses resulting in distortion or strain, so that a transverse line which was originally straight becomes curved. When the stress exceeds anywhere the limit of strength of the rocks, fracture will occur. This will relieve the stress, and if the adjoining portions of the rock have not lost their original elasticity through long subjection to the stress, they will swing back and resume their former relation to the mass with which they still remain connected.[2]

This motion of release appears to be identical with the molar displacement or 'mochleusis' of Mr. Oldham. It will obviously be greatest near the fault (except so far as it is affected by friction between the moving portions of the rock on opposite sides), and gradually diminish, as was the case in the earthquake above mentioned, as the distance from the fault increases.

Under the accelerating force of the elasticity of the rock the

[1] Quart. Journ. Geol. Soc. vol. lxv (1909) p. 1.

[2] I have assumed in my descriptions that there is only one fracture, and that the movements are everywhere parallel to it. In practice there will in most cases be smaller secondary fractures, especially near the surface, each with its local movements of release. The great length of the San Andreas Fault shows, however, that it is not of this secondary character.

movement will proceed with increasing velocity, until it meets with an obstacle or the position of equilibrium is passed. In the former case it will be brought to a standstill with a sudden jar made up of numerous short-period vibrations. In the latter it will either continue with diminishing velocity, until it is arrested by an obstacle in the manner already described ; or, what is probably a rare occurrence, the swing will be prolonged until the accumulation of negative acceleration due to the elasticity of the rock exactly cancels the velocity at the position of equilibrium. In either event it will return to this position, about which it will swing to and fro until it comes to rest under the influence of friction, which will of course profoundly affect all the movements that have been described.

It is, I believe, the short-period vibrations due to the sudden check of the fault-movement when an obstacle is encountered, which constitute the earthquake properly so called, and are the cause of its destructive action. The fracture which initiates the movement doubtless gives rise to minor vibrations, and the same is the case with the friction between the rocks as they brush past each other. To the latter action must also be attributed the grating or rumbling sounds which are often described as heralding a violent shock.

There still remains to be considered the question of the long-period vibrations which form the more important portion of the records of distant earthquakes, and are separated from the shorter vibrations that precede them by their inability to traverse the highly-compressed deeper portions of the earth's interior. They may very well be attributed to the backward and forward swing of the severed rocks about their position of equilibrium, although it is possible that in some cases they may represent beats due to the interference of vibrations of shorter period.

The strength of the earthquake will evidently depend largely on the degree in which the rock has retained its elasticity. If the creep be very slow, the rock may be able to adjust itself to the new conditions, and there will be no fracture and no shock. A similar result may ensue, if the rocks are at a high temperature or under great pressure. If, on the other hand, they are more or less incoherent, they will possess no elasticity, and fracture may occur without a shock ensuing. In the same manner movement may occur without shock along a pre-existing fault, the sides of which do not adhere to each other. In these cases, however, the movement will probably be of the same slow character as that of the main rock-masses on each side of the fault.

The model which I have designed to illustrate these principles has been constructed by my cousin, Mr. Frederic J. Bakewell, electrical and mechanical engineer, to whom I am much indebted for his ingenuity and resource in overcoming the difficulties that presented themselves.

It consists of two vertical rectangular frames (f_1 & f_2 in the photographs—figs. 1, 2, & 3, p. 348) mounted side by side on a common

Fig. 1.—*Original configuration. before slow relative movement.*

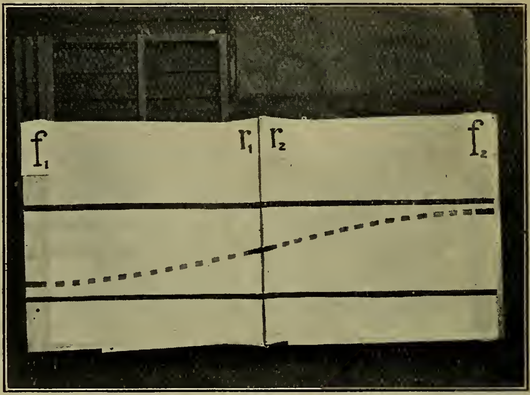
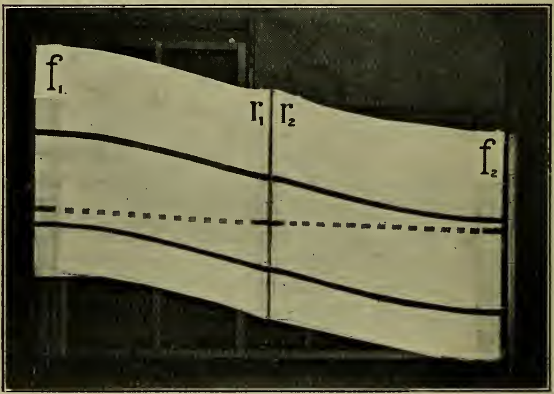
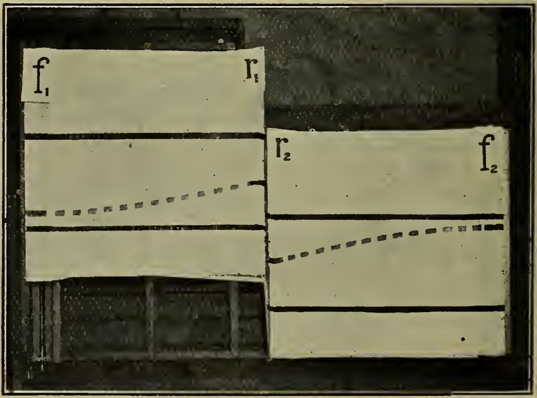


Fig. 2.—*Configuration after slow relative movement, immediately before fracture and earthquake.*



[The interrupted line is now supposed to be drawn as a straight line.]

Fig. 3.—*Configuration after earthquake.*



support. That on the left (f_1) is capable of being moved upwards[1] by the action of a screw. The other on the right (f_2) can move a short distance to the left. To each of these frames a number of steel strips are attached at one end. These are covered with a thin flexible silk membrane, which shares their movements. The free ends of the steel strips attached to each frame are pivoted in a movable vertical rod. The two rods r_1, r_2, one for each frame, are at first closely connected by an interlacing loop of string, so that a continuous surface is obtained which comprises both membranes, as shown in fig. 1 (p. 348). It represents the whole region before the commencement of the creep. It is seen to be traversed by continuous horizontal straight lines as well as by an interrupted curved line, the meaning of which will appear immediately.

The screw is now turned so that the frame f_1 moves upwards into the position shown in fig. 2, when the lines which were formerly straight and horizontal become curved in a sigmoid manner, the curvature being reversed where they traverse the vertical rods. This position represents the conditions after the slow creep has progressed until the limit of the strength of the rocks has been just reached, so that fracture is on the point of taking place. The interrupted line now stretches straight across, horizontally, from side to side. It may represent straight roads or fences transverse to the fault made in the period immediately preceding the earthquake.

The 'fracture' is effected by cutting the string. This releases the two rods, which at once fly apart, r_1 upwards and r_2 downwards. Shortly after they have passed the position of equilibrium they are brought to a stop by the collision of two metallic masses attached to them, which are thrown into rapid vibration and sound the corresponding notes. As they are not quite in unison, distinct beats are heard. At the same time, the rods swing back and vibrate with a comparatively slow period about the position of equilibrium. The model finally comes to rest in the position shown in fig. 3, where the interrupted line which was straight in fig. 2 has become curved in fig. 3, resembling very closely the lines drawn as a result of the geodetic observations taken since the Californian earthquake.[2] At the same time, the ends of the lines are seen to be turned back by the friction between the two sides of the fissure.

If the model is to be considered as a representation of the course of events in connexion with the Californian earthquake, the slow motion of the left-hand frame expresses a gradual creep of the bed of the Pacific to the north-west relatively to the North American continent, giving rise to a region of strain in the neighbourhood of the coast-line, which increases until fracture occurs in the San Andreas Fault.

[1] Namely, upwards in the photograph. The model works best, however, when the frames are horizontal.

[2] R. D. Oldham, Quart. Journ. Geol. Soc. vol. lxv (1909) fig. 2, p. 4.

Such a movement may be explained without difficulty, on the hypothesis that the earth as a whole is subject to powerful tangential compression. This view has, it is true, been called in question, on the ground that contraction of the earth's interior due to cooling is insufficient to account for the folding and overthrusts which can be shown to have taken place. It must be remembered, however, that the interior must also diminish in volume as a result of volcanic eruptions and loss of water and other materials from springs of intra-telluric origin. At the same time, the crust is always expanding in consequence of the gradual hydration of its crystalline rocks, which probably constitute by far the greater portion of its mass, by water both of intra-telluric and of atmospheric origin.[1] Not only does this take place in the great tracts of the fundamental gneiss, but every intrusive boss or dyke must exercise expansive action as its alteration proceeds.[2]

The Pacific coast of North America constitutes a line of weakness connected with the folding that gave rise to the coastal ranges. In the extreme north of the Pacific, in the neighbourhood of the Aleutian Islands, this changes from a south-east and north-west to an east-and-west direction. In North America, on the other hand, there is no transverse—that is to say, east-and-west—line of weakness in the north, but to the southward we have one stretching through the Antilles and Mexico. Similar relations prevail on the Asiatic side. Accordingly, as the crust adjusts itself by folding and thrusts where it is weakest, a northward movement of the bed of the North Pacific relatively to both North America and Asia may be expected to take place. This is, in fact, what occurs, for a relative movement to the north can be shown to have taken place not only on the west side of the great Californian fault in 1906, but also on the east side of the well-known Neotale fault in Japan at the time of the great earthquake of 1891.

This gradual northward movement of the North Pacific relatively to the continents on either side must be accompanied by intense folding and thrusting in the neighbourhood of the Aleutian Islands; and immediately to the south of these is one of the most active earthquake-tracts of which we have any knowledge. At the same time, the lines of weakness on the borders of the continents must be affected to some extent in a similar manner. It is true that in the case of the earthquake of 1906 the movement was mainly longitudinal parallel to the coast, but there were not wanting indications of a certain amount of overthrusting of the continental over the marine area.

[1] It is probable that pneumatolytic action in general usually causes expansion: for instance, in the conversion of a granite into a greisen.

[2] I need not say that there are other causes, such as tidal action and changes in rock-temperature, which may in places be responsible for variations of tangential pressure or the local occurrence of conditions of tension, and the latter undoubtedly also appear in the course of the development of great flexures in the earth's crust.

I have not attempted in the model to illustrate movement of more than one description at the same time. The same model may, however, be employed to illustrate an earthquake connected with a fault in which the vertical movement is the more important, whether it be an incident of the folding due to the compression of the earth's crust, or of the rise of mountain-ranges as a result of the removal of material from their summits and slopes and its accumulation on the adjoining plains or sea-bed.

We are told that, after the earthquake of 1822, the shore-line of Chile was found to be raised. This probably represents a rise by its own elasticity of the tract under strain on the landward side of the fault when released by fracture. The temporary withdrawal of the sea, which so often accompanies an earthquake on that coast, has been attributed to a depression of the sea-bottom. This may represent the corresponding movement in the contrary direction on the other—seaward—side of the fault.

There is another point of some importance which is illustrated by the model. When the left-hand frame f_1 is moved upwards by means of the screw, the strips of steel are not only bent but are subjected to tensional force, so that it would be impossible to keep the vertical rods together if it were not for the lateral play allowed to the right-hand frame f_2, which permits of its approximating to the other. In Nature, the distortion giving rise to such a tensile force is not so marked; for the gradual movement of one portion of the earth's crust relatively to the other is usually small, compared with the width of the tract of ground between them that suffers deformation: but it must have an important influence in determining the occurrence of fracture in a region of strain, as rocks offer but feeble resistance to tension. In areas where the earth's crust is in a state of tension and normal faulting occurs, the tendency to fracture will be greater and faults more numerous. On the other hand, in regions characterized by reversed faults where tangential compression is present, this will play the same part as the movement of the right-hand frame, and tend to diminish the tendency to fracture, so that it will only be when movements are very considerable or take place with comparative rapidity that faults will result: in other cases they will be replaced by folds. The same region may, of course, be at one time affected by compression and at another by tension.

On these principles it is easy to understand why normal faults should be more frequent than reversed faults, despite the fact that we have every reason to believe that conditions involving pressure more commonly prevail than those resulting in tension.

Discussion.

Mr. R. D. Oldham said that the model was certainly very instructive, so far as it reproduced the effects observed after the Californian earthquake; but, with regard to the cause of the earthquake so little was known, and the impossibility of reproducing the conditions in Nature was so obvious, that no model could convey information or prove anything. The Author had adopted and illustrated a theory which was generally accepted, but which the speaker himself had found reason to abandon for the supposition that great earthquakes are as a rule due to the sudden development of strain, or what might be crudely described as an explosion, rather than the sudden relief by fracture of a slowly accumulating strain. This, however, did not affect the use of the Author's model as an illustration of the deformation which may be the result of an earthquake.

The Author said that he was strongly opposed to the views of the school of seismologists, to which Mr. Oldham had, it seemed, now given his adherence, who thought that the great earthquakes represented explosions of igneous material in the earth's crust (misslungene Ausbruchsversuche, to use the expressive phrase of Branca). Such earthquakes as were known to be due to explosive volcanic action were local in character, and had little effect on distant seismographs. Important earthquakes like the Californian earthquake of 1906, as well as the majority of the smaller disturbances, appeared to be closely related to lines of tectonic weakness, and it was reasonable to suppose that they were incidents of the readjustment of the earth's crust, which is always proceeding, though more active in some periods than in others.

He would like to add that a sudden explosion of an imprisoned magma could only occur in the neighbourhood of the surface. It was dynamically impossible under the pressure of a great thickness of superincumbent strata.

14. *The* Geological Structure *of* Southern Rhodesia.

By Frederic Philip Mennell, F.G.S. (Read December 15th, 1909.)

[Plate XXVIII—Geological Map.]

Contents.

I. Introductory.

The region popularly denominated 'South Africa' is usually considered as extending from the Cape to the Zambezi River, and the latter is also the dividing-line between Northern and Southern Rhodesia. The South African area is made up principally of sedimentary rocks, which include an unbroken stratigraphical sequence from the base of the Devonian up to the Jurassic System. Even at the Cape, however, inliers of older rocks are exposed, which cannot, as palæontological evidence is lacking, be ascribed with certainty to any particular period. These 'Pre-Cape' rocks become increasingly important as the Transvaal border is approached; and in the southern part of that province we find, developed along the denuded axis of a great anticline, those ancient strata of the 'Transvaal System' which include the gold-bearing 'banket.'

These old rocks have been subdivided into a number of separate groups, each of great thickness and all probably of Archæan age. They still present a comparatively normal sedimentary facies however, and it is only in places, towards the north, that we find areas of crystalline schists, associated, as usual, with huge granite masses. In fact, it is only near the Rhodesian border that we enter upon that great region of metamorphic schists which appears to occupy most of the central portion of the African continent. So limited is the distribution of unaltered stratified rocks over the greater part of this area that Mr. J. A. Chalmers & Dr. F. H. Hatch, in publishing the first brief references to the geology of Rhodesia,[1] could only record, after a by no means insignificant amount of travel, that sediments are 'said to occur.' The present writer, with more extended opportunities of investigation, has been led to compare the sediments with the drift-deposits of England,[2] and the

[1] Geol. Mag. dec. iv, vol. ii (1895) p. 195.
[2] 'Geology of Southern Rhodesia' 1904 (Spec. Rep. No. 2, Rhod. Mus.) p. 25.

beds themselves, owing chiefly to their inaccessible and unhealthy situations, are still very imperfectly known. The main interest of the Rhodesian region, from a geological point of view, consists in the fact that it is the first part to be examined in any detail of what may be termed the Laurentian area of Africa, which is probably as large and as interesting as that of North America itself.

During the past eight years I have spent practically the whole of the time that I could snatch from official duties in field-work among the Rhodesian rocks, supplemented by examination of them under the microscope. A number of previous papers have dealt with certain of the observations made, but the present communication is the first that embodies the results of the actual mapping of any considerable portion of the country. It will, of course, be realized that a region possessing all the complexity of the Scottish Highlands, and many times as extensive, will need far more detailed study before our knowledge of its problems can be considered at all complete. At the same time, certain generalizations can be made, some of them bearing on questions of fundamental importance in Archæan geology. A brief account is also given here of the sedimentary rocks of the area and of the igneous rocks which form so important a feature of the country.

II. The Metamorphic Rocks.

The oldest rocks of Rhodesia comprise almost every conceivable lithological type, and exhibit nearly every possible degree of alteration. It would be fruitless to attempt their minute subdivision or even to endeavour to define the areas occupied by the main types. It is only possible at present to point out certain facts which have gradually been ascertained by study in the field and under the microscope, and afford an obvious basis for working out the structural features of the whole country.

(1) The Hornblendic Rocks.

First of all, attention may be drawn to the great development of hornblendic rocks. Mica-schists, of which we hear so much elsewhere, are almost unknown; indeed, I have never been able to collect as much as a single specimen resembling those so well developed, for example, in the neighbourhood of Salcombe in Devon, which I examined shortly before leaving England. One finds, moreover, few of the intensely sheared rocks of such a district, except very locally—a few yards, for instance, on each side of a gold-reef, where a well-foliated chlorite-schist may be produced from a massive epidiorite.

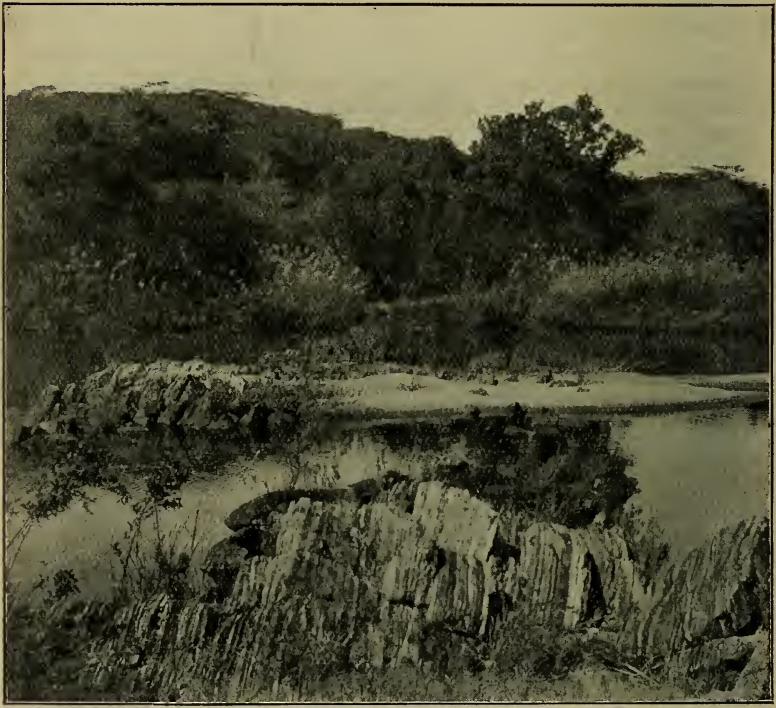
It is the massive epidiorites and amphibolites, like those upon which Bulawayo is built, that constitute one of the most striking features of the greater part of the metamorphic areas. They can only be called 'schists' by convention, as they rarely show any signs of foliation; and one is strongly tempted to abandon the term 'dynamic' as applied to the type of metamorphism which they exhibit. 'Static' would seem a more appropriate term, and there is certainly no evidence of any intense differential movement during the evolution of the processes which imparted to most of the Rhodesian rocks their present characters.

Among the hornblendic rocks under consideration, and certain other types associated with them, there are probably two distinct classes. It may be surmised that some of them are representatives of the 'Basement Schists,' upon which the altered sediments, presently to be described, were originally laid down. On the other hand, many, indeed most of them, are probably among the youngest members of the metamorphic series, evidently representing igneous intrusions of various types, chiefly basic. Some retain very perfectly an original ophitic structure, despite uralitization, etc. (for instance, Rifle Kopje, near Bulawayo; Red Hills, Victoria district). In other cases they occur as well-marked dykes among the altered sediments, as, for example, in the Conglomerate Series in the bed of the Hunyani River at Lomagundi. Where this is not the case there is only analogy of structure to go upon. It is worth noting that, as they are altered intrusions, and therefore came up from below, they may simulate any age prior to their real one. They do, in fact, often exhibit a relation to the other rocks which would lead to their classification as older than those if their intrusive character were not realized. Although of different ages, all these rocks are clearly older than the great granite masses, by which, indeed, the whole of the members of the metamorphic series are alike invaded.

(2) The 'Banded Ironstones.'

Perhaps the most striking and anomalous to the European eye are the rocks locally known as 'Banded Ironstones,' a term which may lack precision, but is so well understood that it would be a pity to eliminate it from scientific literature. These rocks are well developed south-east of Bulawayo, where they verge upon the town; but their most conspicuous development is along the eastern border of the province of Matabeleland, from Gwelo to the Umniati River. Each separate exposure may be either only a few or many hundred feet thick; but in numerous cases the intercalated beds must be regarded as also belonging to the same general series. The southern equivalents or analogues of the Banded Ironstones have been variously referred to as 'magnetic quartzites,' 'banded jaspers,' 'hæmatite-schists,' 'striped cherts,' 'calico rock,' etc., and these names will serve as an indication of their lithological characters. Although by no means uniform, they must unquestionably represent a series consisting largely of fine mechanical sediments. Their conspicuous banding may be attributed chiefly to recrystallization under pressure, and is not necessarily an indication of the original direction of bedding. Although the rock is always to some extent ferruginous, the iron content may be very low and that of the different layers may vary extremely. Some parts are of a jaspery or chert-like nature, while other portions are nearly pure iron-oxide: usually hæmatite, but not infrequently magnetite, and occasionally limonite. The series exactly resembles

Outcrop of 'Banded Ironstone' in the bed of the Sebakwe River, near the Globe & Phœnix Mine.



the great iron-bearing group of the Lake Superior region, and may one day be of equal value on account of its metallic contents. Even now its economic importance is by no means inconsiderable, as several of the largest auriferous deposits in the country are impregnations in the Banded Ironstone Series.

If any proofs were needed of the sedimentary origin of these beds, such proofs might be derived from their composition, their widespread and continuous distribution over the country, and their relations with the surrounding rocks. They also occasionally include slaty beds (as, for instance, near Malungwane Hills); while, as contact-alteration products, one may observe minerals such as andalusite and sillimanite (fibrolite). The latter occurs at Hillside, near Bulawayo. Salisbury, the capital of Southern Rhodesia, is situated on the Banded Ironstone Series, and andalusite (or rather, perhaps, chiastolite)-schist underlies most of the eastern part of the town near the granite; while the more typical, less altered rock crops out at the 'Kopje' to the westward.

It is interesting to note that in the Transvaal there is a thick succession of unaltered shaly beds known as the Pretoria Series.[1] Though possibly themselves of Archæan age, they are quite soft and of normal appearance for the most part, but in places they become highly ferruginous and can scarcely be discriminated from the Rhodesian Banded Ironstones.[2] The latter are also absolutely indistinguishable from parts of the Lower Witwatersrand Beds of which, indeed, they may be exact equivalents, although this vexed question need not be entered into here.

A peculiar structural feature of the Banded Ironstones may be briefly touched upon. The banding is usually vertical or nearly so, and runs in straight and parallel lines. Intercalated, however, among an apparently normal sequence of these beds, there will often be found extraordinarily contorted layers, not usually exceeding a foot or so in thickness. Remarkable examples of this may be seen near Bulawayo and Salisbury; but especial mention must be made of a magnificent section on the banks of the Sebakwe River, about a mile east of the Globe & Phœnix pumping-station (see fig., p. 356). The contorted portions there merge into crush-breccias, and the phenomena do not appear to indicate shearing, but rather concertina-like folding due to lateral pressure. The way in which these intensely hard and resistant rocks have usually yielded, without breaking, to the forces acting upon them, is sufficient evidence of the depth at which the movements must have taken place.

(3) The Conglomerates.

The next set of rocks to which attention may be drawn is the Conglomerate Series. This comprises a succession of beds, apparently of enormous thickness, but probably much folded. Near Bulawayo they could scarcely be estimated as less than 10,000 feet thick, supposing them to be a normal sequence. It is in the somewhat remote Lomagundi district that these beds have attracted most attention, owing to the important occurrences of gold among them, and they are universally known as the Rhodesian 'banket.' I have had occasion to make a minute study of these beds in the course of two lengthy visits to the district, and have recently paid

[1] I have to express my indebtedness to Mr. H. Kynaston, Director of the Transvaal Geological Survey, for kindly conducting me over some of the exposures of these rocks in 1908.

[2] Compare also the Canadian slates and ironstones of Lower Devonian age in Nova Scotia, Ann. Rep. Canad. Geol. Surv. for 1904 (1905), pt. A, p. 300.

a third visit in company with Mr. A. E. V. Zealley, A.R.C.S. It may be stated that the beds extend east and west for many miles with a northerly dip of about 65°, and that they apparently exhibit a perfectly normal sequence.[1] There are three main bands of conglomerate splendidly exposed in the bed of the Hunyani River, and of these only the lowest is gold-bearing, which confirms the inference that they are really distinct. The lower part of the series, containing these conglomerate bands, is about 500 feet thick, but the total thickness, including the intercalated volcanic beds, is many thousands of feet, up to the base of the overlying limestones. In the west the series rests upon the Banded Ironstones, themselves auriferous at the Golden Kopje (Montrose Mine). At the Eldorado Mine, however, the conglomerates have apparently overlapped onto the Basement Schists, and there is no ironstone exposed between the former and the granite mass about 3 miles to the south. Banded-Ironstone pebbles are nevertheless abundant in places, although granite, granophyre, and quartz are more common as a rule. The granite, it must be remembered, is not derived from the neighbouring masses seen at the present day, which are intrusive.

In the Abercorn district, also in Northern Mashonaland, and possibly on the same line of strike as the Lomagundi rocks, a thick series of grits with occasional pebble-bands may be the equivalents of the beds already described, although they differ in general appearance. They also dip northwards and have the Banded Ironstone on the south, though one misses the overlying limestone of Lomagundi. Much attention has recently been drawn to these beds, by reason of rich gold-discoveries in them, and they strike along the Mazoe Valley in the direction of Simuna, where gold was discovered many years ago in the quartzites of the series. These rocks are microscopically very like the 'Moine Gneisses' of the Scottish Highlands,[2] although in the field they do not present the same bedded appearance. In the Sebakwe district similar conglomerates occur interfolded with the Banded Ironstones, of which they contain very numerous pebbles. The rock of the Riverlea Mine, which has been worked for gold for some years, is identical in almost every respect with that of the recent Abercorn discoveries. The Belingwe conglomerates are exceedingly like those of the Rand, but appear to contain very little gold, though they have been prospected.

Generally speaking, it may be asserted that the conglomerates and associated rocks form a connected series, and belong to a single period. That they must be of considerable thickness seems demonstrated by the fact that at Lomagundi there is no reduplication of the gold-bearing horizon on which the 'Eldorado' and 'Rowdy Boys' mines are situated, or of certain other bands with well-marked lithological characters. The latter feature may also be noted in the Bulawayo district.

[1] See J. W. Gregory, Addresses, etc. Rep. Brit. Assoc. 1905 (Johannesburg) p. 398 & S.A. Assoc. Adv. Sci. 1905, vol. ii, p. 103 etc.

[2] See G. Barrow, Quart. Journ. Geol. Soc. vol. lx (1904) p. 400, etc.

In common with all the other members of the metamorphic group, the great granite-masses have an intrusive relation to the conglomerates, while the epidiorites may also occur as obvious dykes in the series, as, for example, in the bed of the Hunyani River and at the Eldorado Mine, in both of which cases the dykes are nearly vertical and cut the beds almost at right angles. In no case, moreover, have fragments of the ordinary epidiorites been found among the pebbles at any of the numerous localities that I have visited. Banded Ironstone pebbles, on the other hand, are nearly always to be found, and often predominate over any others, as at the Riverlea Mine. Discordances in the direction of strike, as well as overlaps, point likewise to an unconformity between the Banded Ironstones and the Conglomerate Series. A very interesting point was revealed by the microscopic study of a series of pebbles collected at Lomagundi. As already noted, although the present-day exposures of granite are later than these beds, yet granite pebbles are extremely numerous at many localities. They differ from the intrusive granites in several features, notably in never showing microcline, which is usually the dominant felspar and is only locally rare or absent from the intrusive granites. 'Elvan'-like pebbles are also abundant: they indicate that a contact-zone was being denuded, certain actinolite-schists, etc., no doubt representing some of the contact-altered rocks. The Banded Ironstone pebbles are interesting, as showing that the rock had evidently assumed its present features when the Conglomerates were being laid down. Further than this, a specimen after being sliced showed one of the characteristic types of contact-alteration often seen round our normal granites, being changed to a coarsely granular aggregate of magnetite, quartz, and secondary hornblende. It is to be presumed, therefore, that even this early granite which furnished the pebbles was intrusive in the Banded Ironstone Series. It is possible, as I have already suggested,[1] that the gneissic rocks of the Surprise Mine in the Selukwe district may represent a granite of this age, but, if so, it has largely lost its original characters. All supposed records of granites earlier than the schists have been based on errors of observation, just as has become increasingly evident every year in Canada.

The volcanic rocks associated with the Lomagundi conglomerates have been mentioned incidentally above, but have not been examined microscopically. They undoubtedly often represent ancient lavas, and occur nearly at every point where the Conglomerates are developed. They are often highly amygdaloidal, the cavities being filled with calcite, quartz (representing, probably, original chalcedony or agate), or even with felspar, no doubt replacing various zeolites. I have a collection of a variety of types made in 1907 at Belingwe, between the Dobi River and the Native

[1] 'Geology of Southern Rhodesia' 1904 (Spec. Rep. No. 2, Rhod. Mus.) p. 11.

Commissioner's house, and I have also several specimens from Gatling Hill, not far away. Though always uralitized, etc., the structures of these rocks are marvellously well preserved, and there is no difficulty in recognizing their original character. The following may be noted as represented among my slides:—Perlitic and spherulitic rhyolite, porphyritic rhyolite, rhyolite-tuff (two varieties), porphyritic trachyte (two varieties), trachytic tuff, porphyritic andesite, altered enstatite-basalt, epidotic tuff. The most interesting is, perhaps, the first-named, from Gatling Hill, which has large spherulites, about a quarter of an inch in diameter, while the intervening originally glassy areas show well-developed systems of perlitic cracks.

It may be noted that, about 12 miles south of Bulawayo, the upper beds of the Conglomerate Series contain fragments of these rocks, thus emphasizing the contemporaneous nature of the latter as regards the lower beds. It should be stated that the well-rounded and miscellaneous character of the fragments, which also include granite, etc., besides the lavas, prevents these beds from being regarded as tuffs. The true tuffs of the series do not present a markedly fragmental appearance, either in hand-specimens or in the field.

(4) The Crystalline Limestones.

North of the Conglomerate Series, and overlying it, at Lomagundi, occurs a thick series of limestones which range east and west for at least 30 or 40 miles. They are well developed near Sinoia, where there is a magnificent series of caves, leading into a huge swallow-hole with an underground pool of deep-blue water, which presents a most extraordinary spectacle. As a term for convenient reference, the name of this locality may therefore be applied to these beds. I have traced this belt through the Alaska Copper-Mine, past Magonde's Kraal, about 30 miles west of Eldorado Mine. The rock, which is usually massive, white, and finely crystalline, is some thousands of feet thick. Near the caves there is a gritty bed close to the top of the limestone, which is succeeded by perhaps 100 feet of reddish slate, and then by quartzite. The limestone is somewhat dolomitic; and extensive, but little developed, deposits of copper and silver-lead ores occur in association with it.

Other occurrences of limestones, which may or may not be paralleled with the Sinoia rock, are found in various parts of the country, and are probably much more important than at present appears, owing to their more rapid weathering as compared with the associated rocks. Thus a thin band of limestone seems to be interbedded with the Conglomerates on the 'Rowdy Boys' claims, close to the Hunyani River. I have also found a large limestone pebble at the fourth level of the Eldorado Mine, whence it would appear that there have been limestones older, as well as younger, than the Conglomerates. A rather dark, coarsely crystalline limestone occurs at Chishawasha, near Salisbury, where it is burnt for lime, and farther east on Watson's Farm. At Concession Hill, near Hartley, a grey limestone occurs in contact with the Banded Ironstones, and the same is the case north of Belingwe. The dolomites of the Gaika Mine (Sebakwe) and of the Tebekwe Mine (Selukwe) are both alteration-products of serpentine, the latter retaining the microscopic structure of an olivine-derived serpentine in a most remarkable manner. In the Gwanda district a dark-blue to grey limestone with chert-bands occurs south of the Antenor mine, and runs in the direction of the Colleen Bawn Mine about 12 miles away, where it is well exposed. East of the Colleen Bawn, where the limestone is about 150 feet thick, it is invaded by the granite and is sometimes very coarsely crystalline, besides showing development of hornblende, mica, chlorite, scapolite, sphene, magnetite, etc. Indeed, the band of amphibolite between it and the normal granite is no doubt a reaction-product of the two rocks. Near the Bucks Reef Company's battery, the same limestone, which has here taken a sharp turn to the south, is converted into a granular aggregate of green augite, apparently by an ordinary dolerite dyke, although the Pandangwe granite mass is not far off. At the Colleen Bawn Mine itself, graphite occurs in quantity, a feature also noted at the Bushman Mine in Bechuanaland, and at a granite-limestone contact, not far from the Rhodesian border. This seems clearly due to the insolubility of carbonaceous matter in a highly siliceous magma, so that in the process of absorption by an invading granite the organic matter would tend to accumulate along the margin of the granite in the form of graphite. This process would also account for the streaks of graphite met with in a marginal modification of the granite of the Victoria district.

About 12 miles south-east of Bulawayo, where the rocks have an approximately north-and-south strike, there are several exposures of limestone, apparently a single band repeated several times by folding and faulting. Thus, proceeding from Claremont Farm across the Tuli Road, and then on past the Talisman Mine, one meets successively from east to west: limestone, banded ironstone, conglomerate, limestone, conglomerate, schists, banded ironstone, limestone, and, finally, a great intrusion of hornblende-porphyrite. It is easy to draw sections to account for such a sequence in various ways, but to interpret the true relations of the rocks is quite another matter. Dips afford no assistance, as they are always vertical, or nearly so: that is, to all appearance; although, if mining operations necessitate following down a particular band of rock, its true dip is rarely found to be so steep. Thus hundreds of feet of sinking have shown the inclination of the Banded Ironstones at the Antelope Mine to be about 60° northwards. In many cases the apparent dip is not bedding, or even foliation, but merely a close jointing allied to cleavage.

To sum up regarding the relations of the various limestones, it may be said that the Sinoia Series seems unquestionably younger than the Conglomerates; whereas the other occurrences may indicate quite different ages, and certainly seem at times to point to close association with the Banded Ironstones.

III. The Granite Masses, and their Relations with the Metamorphic Rocks.[1]

As will be gathered from a glance at the map accompanying this paper (Pl. XXVIII), the granite masses occupy a much larger area than all the metamorphic rocks combined. They are, moreover, equally prominent on the north and on the east of the area mapped, indeed throughout nearly the whole of tropical Africa. It is no matter for surprise, therefore, that Mr. J. A. Chalmers & Dr. F. H. Hatch originally regarded the schists as representing altered intrusions into the granite.[2] The unfamiliar aspect of the contact-phenomena in an area of crystalline schists also no doubt contributed to this erroneous conclusion. A detailed examination of any contact-zone will, nevertheless, yield good evidence of the later origin of the granite.[3] 'Lit-par-lit' or interlaminar injection, is the characteristic feature of contacts, together with the production of 'mixed rocks' due to more or less complete absorption of schistose materials into the granite masses. It is frequently impossible to draw any good line of demarcation between granite and schists,[4] and in detailed mapping it would be necessary to colour separately certain areas as contact-zones. In the present instance, owing to the small scale of the map and the imperfection of our present knowledge, it has not been deemed advisable to attempt this, and a more or less conventional line has been drawn, indicating as far as possible predominance of granite on one side and of schists on the other. Some important areas of mixed rocks are, however, indicated on the map.

The difficulties of mapping are much increased by the great variability of the distribution of these rocks, even round a single plutonic mass. For instance, the northern contact of the small Heany mass is fairly sharp, and one passes abruptly from pure granite to pure schist. Its southern boundary is, however, extremely indefinite, and there is an area of mixed rocks in the Essexvale district more than equal in extent to the whole of the normal granite. The 'mixed rocks' in these cases comprise types that would often be classed as aplite, felsite, microgranite, gneiss, quartz-diorite, diorite, amphibolite, hornblende-granulite, pyroxene-granulite, eclogite, etc., but as few of these can have really crystallized freely from true fusion, the writer prefers to group them all together as granulites. They are characterized, as a rule, by a rather fine, evenly granular structure; also by the presence of quartz, and especially of microcline, in even the most basic types. It is these rocks that are the home of minerals like garnet, cordierite, fibrolite, kyanite, staurolite, corundum, spinel, etc. Tourmaline and topaz occur in certain of them, as, for example,

[1] Compare Addresses etc., Brit. & S.A. Assoc. Adv. Sci. 1905, vol. ii, pp. 23–37.

[2] Geol. Mag. dec. iv, vol. ii (1895) p. 197.

[3] See 1st Ann. Rep. Rhod. Mus. for 1902 (1903) p. 10; 'Geology of Southern Rhodesia' 1904 (Spec. Rep. No. 2, Rhod. Mus.) pp. 10–11; and Geol. Mag. dec. v, vol. iii (1906) p. 260.

[4] B. K. Emerson & J. H. Perry, Bull. U.S. Geol. Surv. No. 311 (1907) p. 46.

in the Essexvale area already mentioned. Epidote is also locally very abundant, and zoisite is sometimes seen.

It is, of course, these mixed rocks and the gneissic edges of the granites themselves that correspond with the original 'Lower Laurentian' or 'Fundamental Gneiss' of Canada and other regions. It is important, therefore, to notice the clearness of the evidence regarding their relations to the schistose rocks. After a little practice, it becomes easy to predict the nearness of the schists when travelling over granite and the approach of granite when travelling across the schists. In the case of the common epidiorites, for example, one notices that they usually become more foliated in character and that epidote often makes its appearance. Augite may be developed from the uralitic hornblende[1] and sphene from the ilmenite, the rock gradually merging into a coarse hornblendic or pyroxene-granulite. In the latter case enstatite is frequently present, in addition to augite.[2] Biotite and garnet may also appear, while patches and nodular masses of the so-called 'eclogite' may occur, as at Mbanji in the Wankie district. Where injection-processes are especially prominent, little veins of quartz and microcline (or other acid felspar) may be detected along the foliation-planes, as well as actual dykes of more or less normal granite, or of an aplitic or pegmatitic nature. These act as feeders to the processes of injection, and the absence of movement as an aid to the production of a gneissic or banded aspect in the adjacent granite is proved by the fact that these offshoots from it are rarely crushed or crumpled in any way. As the main granite mass is approached, interlaminar injection may give rise to the production of a typical 'banded gneiss,' the light bands being principally granitic in origin and the darker bands being composed of hornblende, etc. derived from the original epidiorite. Inside what may be considered as the granite boundary, patches and shreds or streaks of the basic material may be abundant. The whole character of the granite itself near by is often affected by the absorption of the material of which these remnants are visible. Thus, at nearly all contacts with hornblendic rocks, the granites are hornblende-bearing and rich in plagioclase. They also often show the rather unexpected feature of orthoclase co-existing with or entirely replacing microcline. All the really normal granites (that is, the interior portions of the great masses) are biotite-bearing and have microcline as the dominant felspar: they never contain hornblende or muscovite. The gneissic appearance of the edges of the granite masses has no connexion with shearing or crushing in the ordinary sense, although they often exhibit the most typical foliated and 'augen' structures. This is plainly shown by the entire absence of deformation in the minerals of first consolidation (as, for example, hornblende, biotite, and sphene); and also by the fact that the 'augen' of felspar have no tails of sheared material, being obviously either closely allied to true

[1] See W. F. Smeeth, Bull. Mysore Geol. Dept. No. 3, 1905.

[2] See F. D. Adams, Ann. Rep. Geol. Surv. Canada for 1895 (1897) pt. J, p. 75.

phenocrysts, or being of the nature of injected knots like those often seen among the schists near contacts. The granular quartz and felspar, which sometimes form a kind of ground-mass, show no strain-shadows or distortion of the twin-lamellæ. These more finely granular portions often merge into micropegmatite, an unmistakable indication of the igneous origin of the whole. Patches of micropegmatite (quartz + orthoclase or oligoclase) are frequently found included in the plates of microcline (Matopos, Jahonda, etc.): a fact which has an interesting bearing on theoretical problems, and conclusively proves that a 'eutectic' was not the final residuum of crystallization in these rocks, where the microcline generally shows a tendency to crystallize later than the quartz.

It may be remarked that the granite masses as a whole have a much less foliated character than is apparently the case in the Laurentian areas of Canada. There is seldom the slightest trace of a gneissic structure away from the margins of a mass. The only exception to this statement is where there has evidently been a synclinal fold in the originally overlying schists, now entirely removed by denudation, as, for instance, in the Mapane Flats, south of the Matopo Hills, where an east-and-west belt of mixed rocks occurs isolated on both sides by many miles of normal granite. In these gneissic rocks biotite is very abundant, and orthoclase replaces microcline; while dark bands of hornblende-pyroxene-granulite also occur.

It may be remarked that the rare mineral orthite, or allanite, often associated with epidote, occurs in most slides made from specimens of the Matopo granite and also in other masses.[1] It usually forms patchily coloured yellowish grains or crystals about a millimetre long, very feebly pleochroic, and having a double refraction not exceeding that of quartz. Sometimes, indeed, it is quite isotropic. Both the orthite and the epidote which sometimes surrounds it are frequently idiomorphic towards biotite (many Matopo localities) and also towards hornblende (near Zimbabwe Ruins), and have every appearance of being primary constituents, although one cannot avoid a suspicion that they may arise from some kind of leaching process during the cooling of the rocks. Orthite occurs in a granophyric (microgranitic) intrusion among the schists at the Morven Mine near the Bembezi River, the only instance with which I am acquainted outside the great granite masses. In a granite from Bumbuzi, near the Deka River, west of Wankies, garnet is abundant as well as orthite, an association which I have also seen in more than one rock from North-Eastern Rhodesia. Apart from the Matopos, the orthite seems usually confined to the marginal modifications of the granite masses. Altogether 15 per cent. of my slides contain the mineral, which has not hitherto been recorded from the granites of any other part of South Africa, although I have noticed it in a slice from a rock near the Shâshi River in the Tati district of Bechuanaland.

[1] See Geol. Mag. dec. iv, vol. x (1903) p. 347, & Rep. S.A. Assoc. Adv. Sci. 1903 (Cape Town) p. 284, with fig.

IV. The Unaltered Sedimentary Rocks.

The group of sediments that have now to be considered is a somewhat troublesome one to deal with. They do not occur (apart from certain outliers of the uppermost strata) anywhere in the more settled and accessible parts of the country, and, moreover, they afford few sections from which the relationships of the different divisions can be recognized. Most of the country is covered to a depth of many feet by loose sand resulting from the disintegration of the underlying rocks, so much so that one can travel for miles without seeing a stone. Moreover, owing to the absorbent nature of this sandy covering, there are practically no permanent water-courses over large areas, and this not only implies few exposures, but renders travel itself a matter of the utmost difficulty.

The first rough classification of these rocks was suggested by myself in the First Annual Report of the Rhodesia Museum (1902–03, p. 9). In this I proposed to recognize two main divisions: the Coal Series, and the beds above the Coal, or the Zambezi Series. Almost immediately afterwards, Mr. A. J. C. Molyneux, in a paper read before this Society, made a much more elaborate classification,[1] which may be summarized as follows:—

Zambezi Basin:—

	Thickness in feet.
Thaba-s'Induna Series	200
Forest Sandstones, with basalts	1000
Escarpment Grits	400
Upper Matobola Beds (with coal-bearing beds)	300
Bussé Series (local only ?)	300
Lower Matobola Beds (with coal-bearing beds)	200
Sijarira Series	2000

Limpopo Basin:—

Tuli Lavas.
Coal-bearing Beds.
(Unconformity.)
Samkoto Sandstones.

Before dealing with the characters and distribution of the rocks, it is necessary to discuss their classification. It may, first of all, be noted that no fossils except silicified wood are found in any of the beds, except in those associated with the coal. In the Upper Matobola Beds occurs *Palæomutela keyserlingi*, also found in the Permian of Russia and in the Middle Beaufort (*Dicynodon* Beds) of the Cape. In the Bussé Beds are found *Acrolepis molyneuxi* (a fish) and impressions of *Sigillaria* and *Calamites*. If, therefore, we accept the succession tabulated by Mr. Molyneux, the productive coal-measures at Sengwe are apparently on a considerably lower horizon than the Ecca Beds of the Cape, which are characterized by *Glossopteris*. The Coal Series at Wankies has yielded impressions of *Vertebraria*,[2] but this is from a higher horizon than the coal.

[1] Quart. Journ. Geol. Soc. vol. lix (1903) pp. 275 & 278.
[2] G. W. Lamplugh, *ibid.* vol. lxiii (1907) p. 176.

For the most part, therefore, we can, in discussing the relations of the beds, only rely on lithological considerations and the very scanty stratigraphical evidence, and we can scarcely adopt a detailed classification of them until after much more extended field observations than have so far been made. Mr. Lamplugh has already suggested [1] that the 'Sijarira Series' may be only the Matobola Beds in the vicinity of the fault which forms the boundary of the Victoria Falls basalts. This may be the case, but I think it more probable that the beds are Forest Sandstones overlapping the coal-beds in the north, as it is well recognized they do in the south, and with their relations complicated by faulting. This is strongly suggested by Mr. Molyneux's own description,[2] and such an overlap was actually recorded by the late Mr. C. E. Parsons, F.G.S.,[3] east of this area. Moreover, so far as the Limpopo basin is concerned, Mr. Molyneux has himself recently included the 'Samkoto Series' with the Forest Sandstones,[4] which renders it unnecessary here to do more than recall the fact. With regard to the 'Thaba-s'Induna Series,' it had already been pointed out by me that the white beds exposed at Taba-s'Induna are evidently the same as those seen underlying the red flaggy beds of what was subsequently termed the 'Forest Sandstone Series' at Pasipas Hill, about 12 miles north of Bulawayo.[5] So far as I have been able to judge from an examination of the ground near the Ifafe River, and from Mr. Parsons's more extensive observations farther north, there also appear to be no good grounds for separating the 'Escarpment Grits' from the Forest Sandstones. Apart from a slight anticline cut into by the Ifafe itself, the beds have a gentle northerly dip: and, as the ground rises considerably for a good many miles, higher and higher beds come on, until we reach the red sandstones and basaltic sheet of Sikonyaula's, which caps the edge of the drop where the grits are developed. If, therefore, we regard these last as a separate formation, nothing remains of the Forest Sandstone Series. The Matobola and Bussé Beds may be provisionally accepted as local subdivisions of the Sengwe coal-series; but, as they cannot be recognized at Wankies, the best-known and most important coalfield, and, moreover, the only one accessible under present conditions, it seems best not to attempt any general classification of the Coal Series until further evidence is available. The 'Boomka Flags' of Mr. Lamplugh are evidently the fine greenish tufaceous sandstones interbedded with the basalts at several localities, as, for example, near the Deka River, and near Sawmills siding, and may therefore be referred, as he evidently suspected, to the upper part of the Forest Sandstone Series.

As regards other formations, it was, I believe, first noticed by Mr. Parsons,[6] that in several borings for coal in the Mafungabusi

[1] Quart. Journ. Geol. Soc. vol. lxiii (1907) p. 181.
[2] *Ibid.* vol. lix (1903) p. 271.
[3] Proc. Rhod. Sci. Assoc. vol. iv (1904) p. 51.
[4] Rep. S.A. Assoc. Adv. Sci. for 1908, p. 108.
[5] 1st Ann. Rep. Rhod. Mus. for 1902 (1903) p. 9.
[6] Proc. Rhod. Sci. Assoc. vol. iv (1904) p. 50 & pl. v.

district, dark sandstones or quartzites were encountered, lying unconformably beneath the coal-beds. These have only a small outcrop, appearing as a ridge in the middle of the Coal Series. There are also beds in the southern parts of the Wankie district that appeared to me to be older than the Coal Series, although I was unable to obtain definite evidence of their relation to the latter. In the south-east of Mashonaland, however, the important cupriferous deposits of the Sabi Valley are largely impregnations in a series of sandstones and shales,[1] which are evidently older than the coal-beds developed not far away to the south. These include crumbly, white-weathering sandstones, which have below ground a dark quartzitic appearance, very like the beds mentioned as occurring at Mafungabusi. The associated shales are brown, grey, or purple, and the whole character of the beds is almost identical with that of the Waterberg Series (unfossiliferous) which underlies unconformably the coal-beds of the Transvaal. There need be little hesitation in correlating these shales and sandstones as of Waterberg age, for the latter are known to cross the Limpopo from the Northern Transvaal to the south-west of the area in question.

Turning to newer rocks, the unconsolidated sands and gravels of the Somabula Forest may be mentioned. These were first noticed by myself in 1904,[2] and afterwards more fully described in 1906.[3] They are obviously later than the Forest Sandstones, the inferences drawn from their lithological characters being fully confirmed by the presence of abundant agate fragments derived from the basalts of the Forest Sandstone Series. Pieces of the fibrous zeolite (either scolecite or mesolite), which is so characteristic of the Victoria Falls basalts, have also been noted. The sands of the Zambezi Valley, apparently wind-blown, may be the equivalents of the Somabula gravels, or of some part of the Forest Sandstone Series, which also contains much wind-blown material.

(*a*) The Older (? Waterberg) Sandstones.

It is scarcely possible to add much to the scanty information regarding these rocks already given in discussing the general question of classification. They probably cover a considerable extent of country in the Sabi basin and also farther west, but it is not possible to make any definite assertion on the point. North of the high plateau they are not well developed. The northern portion of Mashonaland is apparently devoid of sedimentary beds altogether, except possibly along the banks of the Zambezi, as I have been fairly close to its northern border in the Lomagundi and Mount Darwin districts without encountering any. Westward, however, the north of Matabeleland provides the most extensive sedimentary area of Rhodesia, and we find these beds exposed as already noted, protruding through the coal-beds between the Dimdimutwe and Gungwe

[1] 'Science in South Africa' 1905, p. 302.
[2] 'Geology of Southern Rhodesia' 1904 (Spec. Rep. No. 2, Rhod. Mus.) p. 17.
[3] Geol. Mag. dec. v, vol. iii (1906) pp. 459-62.

Rivers. They apparently occur also on the south side of the Wankie coal-area, which has, like the previously mentioned coalfield, the structure of a denuded anticline. It remains to be noticed that at the Umkondo Copper-Mine, near the Sabi River, these rocks contain a series of interbedded andesitic lavas. These are more altered than the basalts of the Forest Sandstone period, and their amygdules are often partly filled with epidote, a mineral never seen among those basalts. They are penetrated by dykes of beautifully fresh enstatite-dolerite, and sometimes, like the associated sandstones, contain copper-ore.

(*b*) The Coal Series.

As in the case of the underlying rocks, we have little precise information regarding the coal-beds. Their base and summit have never been defined, and as I am personally acquainted only with the Wankie Coalfield, I shall not attempt to enter into great detail concerning them. As already stated, they appear to be absent from Northern Mashonaland, although at Tete on the Zambezi, in Portuguese territory, there occur beds from which a strictly Carboniferous flora has been described by Prof. Zeiller.[1] In the south-east of Mashonaland, coal has been discovered about 12 miles south of the Umkondo Copper-Mine, and also close to the junction of the Lundi and Sabi Rivers. The beds also probably extend along the direction of the Limpopo River, though by no means in unbroken continuity, all through the south of the country as far as Tuli. It is in the north of Matabeleland that they exhibit their greatest development, forming the Wankie, Sengwe, Sebungwe, and Mafungabusi coalfields, of which the first-named is at present the only actual coal-producer. Sandstones are always the predominant feature of the series, although shaly beds are generally associated directly with the coal itself. There are, however, conglomerates and occasional concretionary limestones. It appears possible that in the Tuli district the Dwyka (Glacial) Conglomerate is present at the base of the series, as in the Cape Colony and in the Transvaal. It is probable that the rocks include representatives of the Beaufort and Ecca divisions of the 'Karroo System,' although the coal itself may be on a lower horizon than either. As a rule, the coal-bearing series appears to overlie directly the metamorphic rocks or the granite masses, but the beds nearly always emerge from beneath a covering of Forest Sandstone. They occur nowhere at a less distance than 100 miles from the axis of the plateau, and are generally nearer twice that distance, a fact which renders them far less important economically than would be the case if they were nearer the more settled districts. At present, wood is much more extensively used for fuel than coal.

[1] Annales des Mines, ser. 8, vol. iv (1883) pp. 594–98.

(*c*) The Forest Sandstones.

The predominantly arenaceous beds to which the name Forest Sandstone is here applied are much more extensively developed than the other Rhodesian sediments, and they are the only ones that occur on the high plateau which forms the backbone of Southern Rhodesia. The map indicates their distribution with considerable accuracy, although it has been impossible to distinguish the overlying Somabula gravels and sands over part of the area. It is also probable that the inliers of granite and schist are more numerous and extensive than is represented. At the same time there is little hope of the coal-bearing beds being exposed underneath the Forest Sandstone in any of the inliers, as the overlap of the latter on the schists and granites appears to commence very close to the known coalfields, as for instance at Mbanji, south of Wankies, and at Mafungabusi. It seems highly probable that there is an unconformity at the base of the series, but its true base has never been defined. All the exposures known to me which show its relation to older rocks are junctions with the metamorphic schists or with the granites. North of Bulawayo there are a number of such sections within 20 miles of the town.

Like the other sediments, the Forest Sandstones appear to be absent or but feebly developed to the north of Mashonaland. So soon as the Sanyati River is crossed, however, and one enters Matabeleland, they appear in force, and cover much of the country in the Mafungabusi and Sengwe districts. There is an outlier between the Jombi and Ifafe Rivers, consisting of red flaggy sandstones overlying pale gritty beds with bands of conglomerate near the base, the actual base being a bed of coarse felspathic grit resting upon granite. The main southern boundary runs along the Ifafe River, and then westward towards the Shangani junction. A long tongue, of which the tip is composed of Somabula gravels, etc., stretches out south-eastwards for many miles towards Gwelo, approaching within 10 miles of that town. About 5 miles north of Gwelo there appears to be an outlier 4 or 5 miles wide, trending in the direction of Enkeldoorn, between which town and Charter occurs the only outlier that is close to the axis of the plateau on its south side. Turning again to the main body, its boundary appears to run south-westwards after leaving the Shangani towards the Bubi, after crossing which it turns due eastwards again, until it meets the Bembezi nearly due north of Bulawayo. It then runs back south-eastwards again towards the Queen's Mine, about 3 miles west of which a long narrow tongue stretches to within a few miles of the Zambezi-Limpopo watershed, terminating in the Amanxele Hills, which consist of white sandstone capped by basalt. A very irregular course is then taken across the Koce and Umguza Rivers to within a few miles of the Khami at Pasipas, where the beds dip northwards at about 30° and consist of white massive sandstone, overlain by red flaggy beds. Outliers occur on the south at Umfazumiti Hill (white sandstone resting upon schists); near the

Umguza (sandstones overlying conglomerate and capped by basalt); at Forest Vale and the hill on the opposite side of the railway (false-bedded, white to pinkish or brownish sandstone resting upon granite). The most important outlier is, however, that marked by the conspicuous flat-topped hill known as Taba-s'Induna. This eminence has a basaltic capping, absent from the rest of the outlier. The basalt appears to be a lava-flow, and is of precisely similar character to that of the Amanxele Hills. It appears to occur at a lower horizon than usual, as the underlying beds are fine white sandstone, instead of the higher red flaggy beds. This white sandstone is without any sign of bedding-planes, and even shows a kind of spheroidal weathering in places. It resembles exactly the white beds of the Cave Sandstone (Jurassic) of Cape Colony. The lowest beds are apparently pinkish sandy shales resting upon schists. North of Pasipas (already mentioned) the Forest Sandstones run northwards without a break for nearly 150 miles. Beyond the Wankie Coalfield the sandstones themselves make little show; but the basalts, which are often seen farther south, here become of greater importance, and cover several thousand square miles around the Victoria Falls. They are often highly amygdaloidal, and are characterized by their glomeroporphyritic structure and by the absence of olivine.

(*d*) The Somabula Gravels and Sands.

The gravels and sands of the Somabula Forest, about 12 miles south-west of Gwelo, are of considerable interest for several reasons. They are the only beds resembling the gravels of the 'drift' deposits of England in their lithological characters; they afford the sole development, other than purely superficial deposits, of sediments overlying the Forest Sandstones; and they are, moreover, remarkable for the variety of gems and other interesting minerals which they yield.

These beds occur on a series of ridges near the apex of the main watershed of the country, and have a thickness, where not reduced by denudation, of about 150 feet. The uppermost beds are red and white sands, which have only occasionally survived on the crests of the ridges. Then come the gravels, composed of beautifully rounded pebbles in a matrix of sandy clay, often ferruginous. Vein-quartz is the commonest material among the pebbles, but a dark quartzite of unknown origin is also common. Sections show development of fibrolite in the interstitial material between the quartz-grains of this rock, so that it had evidently been subjected to contact metamorphism, and it is just possible that the source is the Banded Ironstone Series. Recognizable banded ironstone is fairly abundant, and so is agate from the basalts of the Forest Sandstone Series. The gravel has a maximum thickness of 40 or 50 feet. Below it come white micaceous sands, sometimes including clayey bands. The sands do not appear to contain many interesting minerals among their coarser material; but from the gravels are obtained diamond, ruby, sapphire, oriental amethyst, yellow chrysoberyl, catseye, alexandrite, beryl (aquamarine), blue and white topaz, etc. Of these gems only the diamond has so far been found *in situ* in Rhodesia, although common corundum is known from several localities, and the ordinary yellow topaz occurs at Essexvale, as already noted.

(*e*) Superficial Deposits.

In Rhodesia there are no drift deposits, like those of England, connected with the recent river-system. The coarse angular rock-débris seen in the beds of the rivers is very different from the alternations of gravels, sands, and brick-earth observed in Europe, besides being insignificant in amount. Even great rivers like the Zambezi and Limpopo are almost devoid of alluvial deposits. As if to make up for this, we have a variety of formations due largely to chemical action operating during the disintegration of the rocks upon which they rest. These comprise laterite, calcareous tufa (surface limestone), and compacted sands (surface 'quartzite'). None of these deposits appear to form actually on the surface of the ground; they are rather sub-surface in origin, accumulating under the soil. The iron or alumina of the laterite, the lime of the tufa, and the silica cementing the sands are obviously derived from the rise towards the surface, by capillarity, of solutions containing the substances named leached out of the decomposing silicates of the underlying rocks. Laterite is particularly widespread in its distribution, and may originate from rocks which seem little calculated to afford the necessary amounts of iron and alumina. I have described the features of the Rhodesian laterites in a recent paper,[1] and so they need not further detain us. The tufaceous limestones are usually found on the epidiorites and similar rocks of which the lime content is considerable. The decomposition of the ancient crystalline limestones, curiously enough, gives rise to deposits of a lateritic nature, instead of these tufas. The 'surface quartzites' are rare on the whole; but good examples, sometimes resembling very ancient rocks, may be seen close to Hillside near Bulawayo, and also in the Victoria Falls region. They frequently have a very cherty appearance, but are often quite conglomeratic in character, like so many of the laterites.

V. Various Igneous Rocks.

Besides the immense granite masses already mentioned, there are a great variety of igneous intrusions of later date. They are probably of very different ages, some being evidently connected with the volcanic activity of the Forest Sandstone period, and some certainly earlier. Perhaps the most remarkable of these rocks is the great mass of coarsely crystalline picrite extending for nearly the whole distance across Rhodesia from north to south, with an outcrop

[1] Geol. Mag. dec. v, vol. vi (1909) pp. 350-51.

about 4 miles wide as seen at Lomagundi, Selukwe, and Belingwe. It is almost certainly a gently inclined sheet injected along a line of weakness which is probably a thrust-plane, and it can be traced from the Umvukwe Hills on the east of the Ayrshire Mine in Northern Mashonaland, right away to the Umsingwane River at a point about 30 miles south of the West Nicholson Mine in Southern Matabeleland. It is predominantly an enstatite-rock, with only a very little felspar in places; but there are more acid varieties, as well as others rich in olivine and merging into almost pure olivine-rock. These specially basic types are usually more or less serpentinized, and often associated with chromite.

Probably allied in age and origin with this rock are the gabbros and the great dykes of ophitic dolerite found in many parts of the country, especially in its central portion. The gabbros usually contain enstatite, but not olivine, while the dolerites often contain the latter, besides merging into varieties rich in micropegmatite and therefore comparatively acid. Some of these are very like the well-known rock of Penmaenmawr. Certain intrusions of granophyre, such as the large boss at Gwelo Police Camp, are possibly to be classed with these rocks, although they may be offshoots from the granite masses. Very interesting in this connexion, and as bearing on certain theoretical problems, are the associations of dolerite with granophyre which has evidently been produced by the melting or injection of granite into which the dolerite is intrusive. Splendid examples of this may be seen near the Antelope Road, about 3 miles from the Matopo Station, and on a larger scale north of Kahlele's old kraal on the road from Fort Usher to Gwanda. There is every gradation between a typical granophyre and an obvious 'mixed rock' composed of phenocrysts or rather xenoliths of granitic quartz and felspar embedded in a doleritic ground-mass. In a similar way, a doleritic dyke near the railway-station at Bulawayo, which contains apparently original quartz, is seen at other points along its course to contain countless large and small xenoliths of half-melted quartz derived from a reef cropping out near by and dipping towards the dyke.

The intrusions associated with the Forest Sandstone basalts are of similar composition, although they can usually be distinguished microscopically from the lavas. They often show, like the latter, a glomeroporphyritic structure, and are never ophitic. I only know of two that show olivine, one from the Deka River (Wankie district), and another from Van Wyk's Vlei (Tuli district): the latter has conspicuous phenocrysts of olivine.

It only remains to mention the diamond-bearing rocks, of which Rhodesia, like the rest of South Africa, can now boast examples. Two occurrences of 'blue ground,' or 'kimberlite,' are known, about 5 miles apart, between the Bembezi and the Inkwekwezi Rivers, 35 to 40 miles north-east of Bulawayo. One seems to fill a large volcanic vent or 'pipe' of the usual type; the other was not sufficiently opened up at the time when I saw it for one to be able to do more than say that 'blue ground' undoubtedly exists and carries diamonds. The following remarks, therefore, apply to the locality nearest the Bembezi River, now known as the Colossus Mine. It appears to have an area of about 900 by 500 yards, and is thus the biggest known deposit of its kind, considerably exceeding in superficial area even the great Premier Mine in the Transvaal. The walls of the pipe are granite, except on the north, where dolerite and a green decomposed 'peridotite' occur. The 'blue ground' presents the usual features, having a serpentinized matrix with much calcite, and showing numerous rock-fragments and grains of minerals such as garnet, ilmenite, augite ('chrome-diopside') etc. The rock-fragments are chiefly granite and dolerite, derived from the walls; but there may also be noted inclusions of 'ultrabasic' rocks, among which are representatives of the 'eclogites' that have given rise to so much controversy. I have not yet been able to make a detailed study of these inclusions, but append brief descriptions of two leading types:—

A.—In hand-specimens, shows a dull-green cleavable mineral forming a kind of matrix, in which are embedded numerous small orange-coloured garnets. Under the microscope the garnets appear as colourless isotropic grains, with some tendency to crystal outline. Augite, colourless in section, occurs in somewhat greater amount, making up nearly all the rest of the rock, apart from a little yellowish, not very pleochroic mica, usually seen along the edges of the garnets, but never forming a complete rim.

B.—A dark, nearly black rock, showing occasional small pink garnets. Under the microscope it is seen to be a coarsely granular aggregate of olivine, enstatite, augite, garnet, and mica—in that order of abundance. The olivine is very fresh, with occasional lines of separated magnetite and very little yellowish or bluish serpentine. The enstatite is colourless, and most of the grains are somewhat elongated in the direction of the vertical axis, showing well-marked cleavage-traces, parallel to which extinction takes place. The augite is also quite colourless where unaltered, but most of it shows partial conversion into rather dirty-looking, but not distinctly coloured uralitic hornblende. Several garnets, from less than 1 millimetre to about 2 mm. across, are seen in the slice. They are colourless and quite isotropic, and are bordered wholly or in part by flakes of yellowish-brown mica. These latter have no definite orientation towards the garnet, the cleavage being tangential, radial, or at any angle. There is often a brownish band of alteration-products between the mica and garnet. There are rare flakes of the same mica away from the garnets.

Personally, I do not believe that the occurrence of diamonds has any connexion with the 'eclogites' or any other inclusions found in the various pipes.[1] The ordinary garnet of the 'blue ground' itself is always a deep red pyrope, quite different from those of the eclogites. Moreover, garnets are exceedingly rare at some localities, notably the large and rich Premier Mine of the Transvaal; and their abundance is no guarantee that diamonds are present, as witness so many 'blank pipes' all over South Africa. A notable amount of chromium seems to be characteristic of the garnets of 'blue ground.' The following analysis of material obtained by me from the Colossus

[1] See Rep. S.A. Assoc. Adv. Sci. 1908, pp. 105–106.

Mine was made by Mr. W. C. Hancock. An analysis of Kimberley pyrope is quoted for comparison.

	I. *Colossus Mine (Rhodesia).*	I A. *Kimberley (Cape Colony).*
SiO_2	40·43	41·34
Fe_2O_3	4·94	—
Al_2O_3	19·13	22·75
Cr_2O_3	2·12	2·96
FeO	8·66	12·12
MnO	0·12	0·36
CaO	4·44	5·17
MgO	20·33	16·20
Totals	100·17	100·90
Specific gravity =	3·72	

The Rhodesian garnet is therefore a more typical pyrope than that from the Kimberley pipe, although the general similarity in constitution is very close. It is naturally interesting to compare the composition of the garnets in the eclogite fragments with the pyrope; and as I am not aware that this has hitherto been done, I caused the following analyses to be made by Mr. Hancock, of material carefully picked out in the Mineralogical Laboratory at Cambridge from fragments of eclogites collected by myself. Analysis II shows the composition of the garnet of specimen *A* described above (p. 373), while Analysis III represents a more reddish garnet from some much smaller eclogite-fragments among the concentrates obtained in washing. It may be stated that, despite very exceptional opportunities, I have never succeeded in obtaining any eclogite showing garnets of the deep red colour of those common in an isolated state in the matrix itself, nor have I seen them in any of the numerous eclogite-fragments that I have examined from the Kimberley Mines.

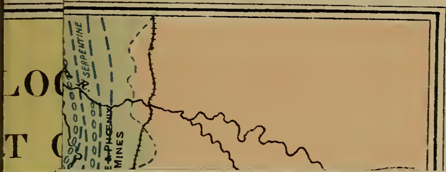
Analyses of garnets from eclogite.

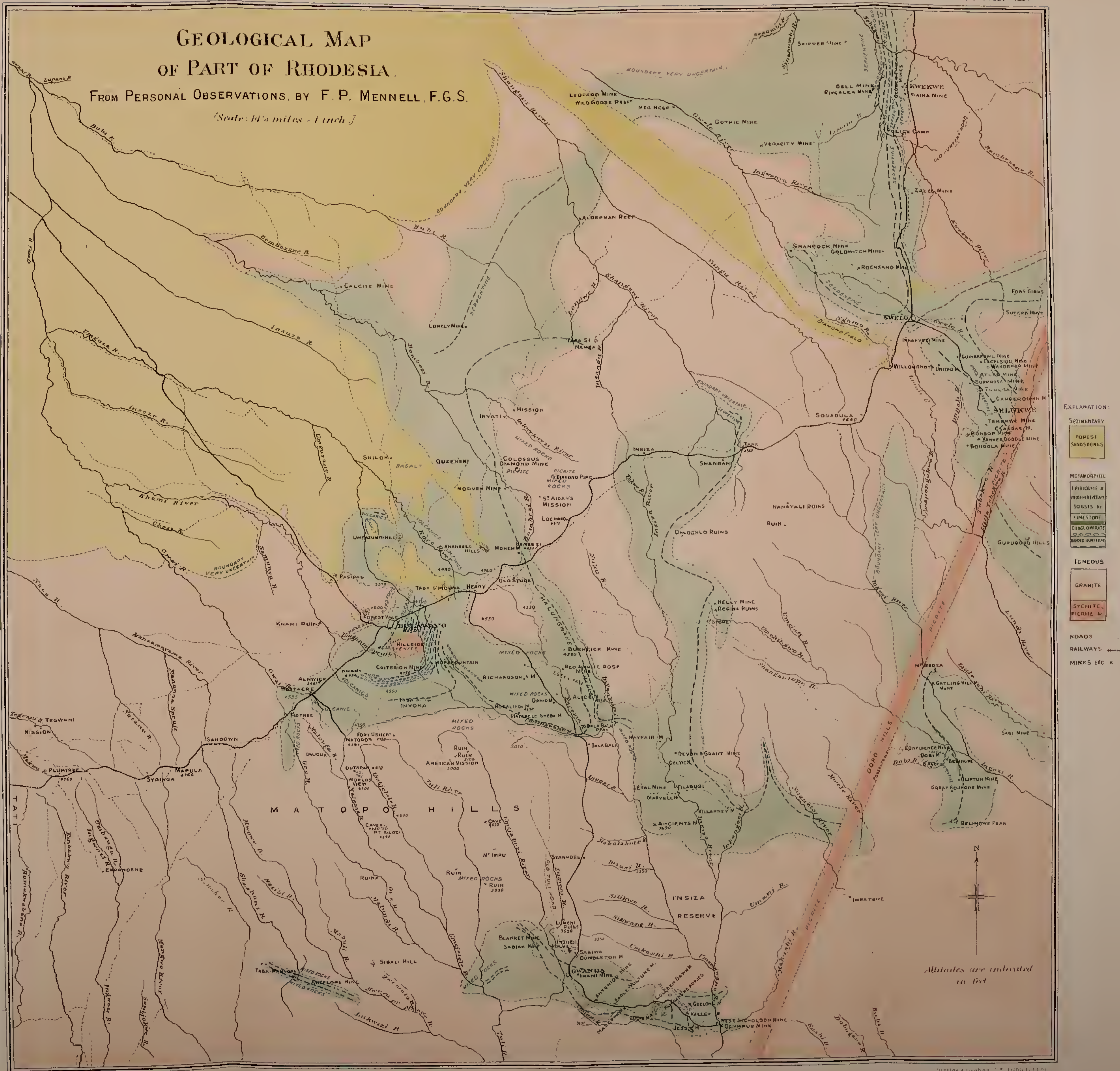
	II.	III.
SiO_2	40·44	39·87
Fe_2O_3	6·51	4·95
Al_2O_3	23·69	21·47
Cr_2O_3	0·32	0·26
FeO	11·38	8·10
MnO	0·60	0·23
CaO	9·86	12·32
MgO	7·72	12·89
Totals	100·52	100·09
Specific gravities =	3·75	3·64

It is not easy to pigeon-hole the above among the ordinary varieties of garnet, but it is evident that they differ markedly from the pyrope of the Colossus Mine.

Before passing from this subject, reference may be made to the composition of the augite, which, together with garnet and ilmenite,

l. Soc. Vol. LXVI, Pl. XXVIII.




GEOLOGICAL MAP
OF PART OF RHODESIA.
FROM PERSONAL OBSERVATIONS, BY F. P. MENNELL, F.G.S.
(Scale: 14½ miles = 1 inch.)
EXPLANATION:
SEDIMENTARY
FOREST SANDSTONES
METAMORPHIC
EPIDIORITE & UNDIFFERENTIATED SCHISTS &c
LIMESTONE
CONGLOMERATE
BANDED IRONSTONE
IGNEOUS
GRANITE
SYENITE, PICRITE &c
ROADS
RAILWAYS
MINES ETC
BULAWAYO
GWELO
SELUKWE
KWEKWE
MATOPO HILLS
INSIZA RESERVE
GWANDA
Altitudes are indicated in feet

makes up the characteristic concentrates of this and all other diamond pipes. It is of a deep green when fresh, and sometimes shows a well-marked parting parallel to {100}. This becomes so pronounced on weathering that the mineral might easily be mistaken for a mica.

Analysis of augite (chrome-diopside), Colossus Mine.

	IV.
SiO_2	53·93
Al_2O_3	1·90
Cr_2O_3	0·70
Fe_2O_3	5·97
FeO	2·67
CaO	13·11
MgO	20·08
H_2O	1·63
Total	99·99

The mineral is, therefore, a chrome-diopside, showing an exceptional freedom from alumina, and remarkable, moreover, for having magnesia, not merely in excess, but in large excess of the lime. I have to thank Dr. A. Hutchinson, F.G.S., for very kindly selecting material and arranging for the analysis of this and the previous specimens.

EXPLANATION OF PLATE XXVIII.

Geological map of part of Rhodesia, on the scale of 14½ miles to the inch.

[Acknowledgments are due to the Government of Southern Rhodesia for permitting the use of their farm map as a basis for the topography.]

15. Metamorphism *around the* Ross of Mull Granite.[1] By Thomas Owen Bosworth, B.A., B.Sc., F.G.S. (Read February 23rd, 1910.)

Contents.

I. The Granite and the Moine Gneisses.

(*a*) The Granite.

The western end of the Ross of Mull, which stretches out into the Atlantic, is a granite mass occupying some 20 square miles of land. On the north, west, and south this granite is exposed to the ocean waves, but along its eastern border it is seen in contact[2] with a series of typical Moine Schists, which form the next portion of this peninsula passing landwards.

The Ross of Mull granite is a muscovite-biotite-granite of coarse texture intruded into the Moine Schists and Gneisses. At the south-western corner of the Ross, opposite the island of Erraid, it gives place to a fairly coarse diorite, which also forms the Eilean a' Chalmain.[3] The granite was intruded probably before the diorite was cool, and the two rocks are there so intermixed that the drawing of any boundary-line between them is a purely arbitrary matter. Taken together, the facts summarized below lead to the conclusion that this granite is one of the 'Newer Granites,' as was formerly inferred by Prof. Judd[4]:—

(*a*) It resembles the newer granites in composition and association with diorite.
(*b*) It is unaffected by shearing.
(*c*) It is conspicuously later than the foliation and strain-slipping of the Moine Schists into which it has been intruded, producing contact-alteration.
(*d*) It is associated with sheets of mica-trap and vogesite, by which it is traversed. In one case,[5] an intrusive sheet $2\frac{1}{2}$ feet thick which cuts the Moine rocks is itself penetrated by strings and tongues of granite from an offshoot of the granite mass. This sheet is slightly foliated at the surfaces, but is probably younger than the normal epidiorites of the district.

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[1] Communicated by permission of the Director of H.M. Geological Survey.
[2] J. G. Goodchild, Geol. Mag. 1892, p. 447.
[3] Summary of Progress of Geol. Surv. for 1907, p. 66.
[4] Quart. Journ. Geol. Soc. vol. xxx (1874) pp. 244 & 290; see also Summary of Progress of Geol. Surv. for 1907, p. 66, & *ibid.* for 1908, p. 55.
[5] A quarter of a mile south of Rudha na Traighe-maoraich, on the shore of Loch na Lathaich.

[It has been pointed out by Mr. G. Barrow that the intricate line of junction with the gneisses is like those of the 'Older Granites'; but at the same time similar junctions (and also similar contact-alteration) are known around Newer Granites, notably the granites of the Glencoe district.[1]]

(*b*) The Moine Rocks.

The Moine rocks occupy an area of about 11 square miles, which is bounded on the west by the granite intrusion, on the north-east by the Bunessan Fault, which brings down the Tertiary plateau-basalts, and on the north and south by the sea.

These rocks are sharply folded, steeply inclined, and strike north-north-eastwards. They may be conveniently divided into

(1) a Psammitic Group, consisting chiefly of flaggy quartz-felspar granulites, with some thin beds of quartzose mica-schist; and

(2) a Pelitic Group, consisting chiefly of garnetiferous mica-schists (or gneisses) which are often coarse and quartzose, alternating with beds of fine, granulitic, micaceous quartzite and some thin bands of lime-silicate rock. Epidiorite sills occur among these gneisses.

The greater part of the ground is occupied by the rocks of Group 2, but those of Group 1 form the more easterly portion and also a very small tract in the extreme north-west of the Moine-rock area.

The following is a brief description of the rocks passed over, starting from the granite margin and travelling away from it eastwards across the outcrop of the Moine Gneisses. The traverse starts from the south-western corner of Loch na Lathaich along the coast-section to Bunessan, and thence inland along the old cliffs of the 100-foot raised beach, which extends up to and along the south side of Loch Assapol.

At the starting-point the granite is in contact with the psammitic Moine rocks, which here occupy a very small area between the road and the sea (see map, fig. 1, p. 378). These quartz-felspar granulites are similar to those of other districts, and probably represent original arkose and sandstone. In places (chiefly in the larger area in the south-eastern corner of the map) they are coarser than usual, and indications of drawn-out pebbles suggest that the rock was conglomeratic. The beds are parted by seams of quartzose mica-schist, which may represent thin beds of shale between the original sandstone. Near the granite the granulite contains ungranulitized porphyritic crystals of felspar (see p. 385).

Leaving the granulites, we pass eastwards across some beds of white quartzite on to the pelitic Moine rocks, which here are chiefly massive beds of coarsely-rumpled quartz-muscovite-biotite-gneiss. Alternating with these are fine granulitic micaceous quartzites, beds of dark, less quartzose mica-schist, and thin pale bands formed of calc-silicate minerals.

[1] C. T. Clough, H. B. Maufe, & E. B. Bailey, Quart. Journ. Geol. Soc. vol. lxv (1909) p. 611.

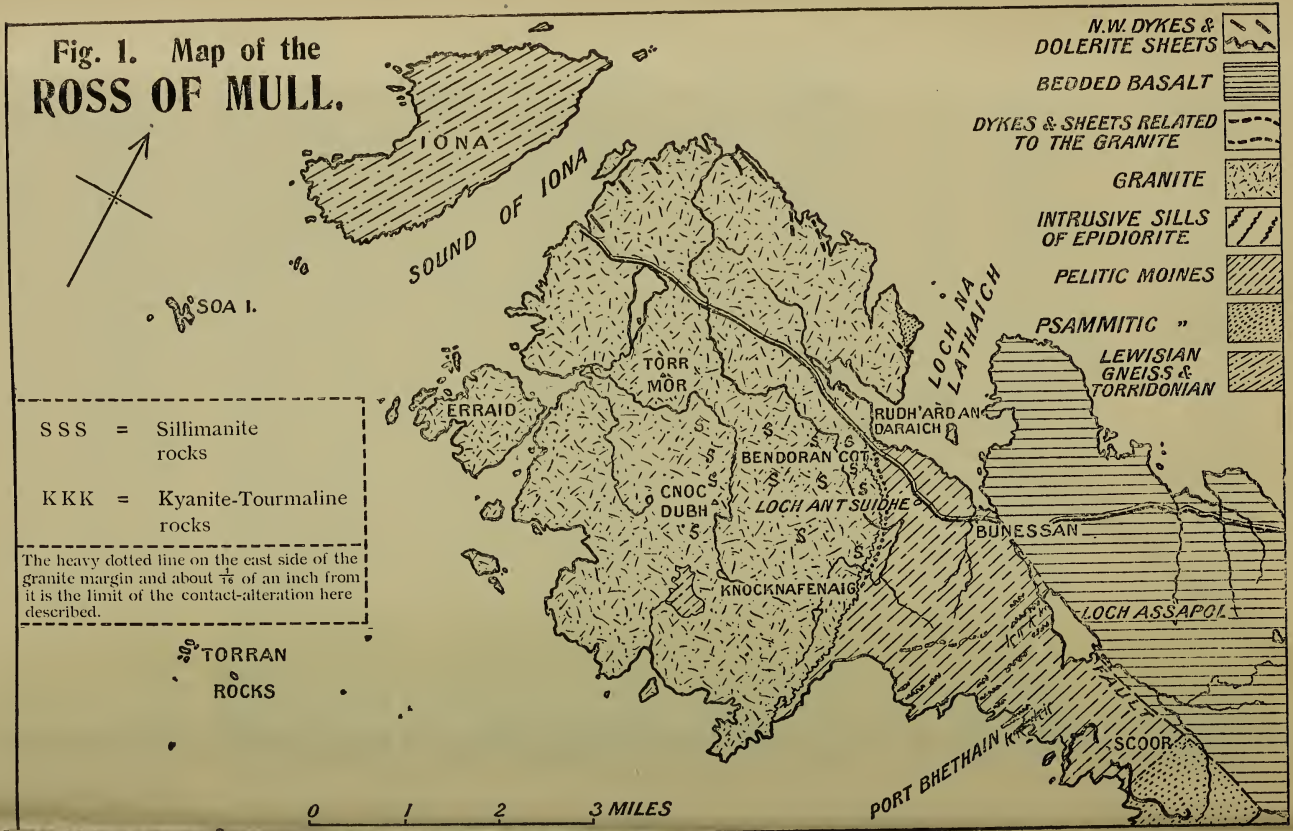

Fig. 1. Map of the ROSS OF MULL.

This series probably represents original shales, sandstones, and mudstones with thin calcareous bands. It is these pelitic gneisses which, followed along their strike up to the margin of the granite, are there found metamorphosed into the sillimanite-andalusite-cordierite-gneiss described in § III of this paper (p. 385).

Continuing the traverse, about halfway to Bunessan, the pelitic gneisses met with are less quartzose, and they are more finely divided into beds by alternation with the granulitic micaceous quartzites. Farther east, at about a quarter of a mile from Bunessan, near the pier, these quartzite beds become predominant; but on approaching Bunessan, and thence onwards, the mica-schist is again seen to be the more important member.

The bands of calc-silicate continue frequent, and are numerous between Bunessan and Loch Assapol. They are often about 1 inch thick and rarely exceed 6 inches, being sometimes lenticular, discontinuous, or nodular. Frequently the bands are faced on both sides with a thin layer of quartz, which in some cases is connected with veins. They are white rocks, consisting mainly of felspar, quartz, and calcite, spotted with large pink garnets and dark blades of hornblende; and, when treated with acid, they generally effervesce, especially in the central parts. These bands bear resemblance to the zoisite-amphibolites common in other areas,[1] and possibly represent impure limestones in the original sediments, which have been acted on by silica during the regional metamorphism.

Among the pelitic gneisses near Loch Assapol epidiorite bands are met with at frequent intervals. They are tough amphibolite-schists containing some felspar, quartz, mica, iron oxide, and, in most cases, abundant large garnets which stand out on the weathered surfaces. These old intrusions are rarely seen to transgress the bedding even to a slight extent, and evidently were sills.

It is in this tract that tourmaline, kyanite, and staurolite are found along the outcrop of two particular belts of rock, which are separated from the granite by the 2 miles of ordinary unaltered Moine rocks which have now been briefly described. An account of them is given in § IV of this paper (p. 391).

After a later quartz-porphyry sill has been passed over, and proceeding eastwards from Loch Assapol, the coarse quartzose type of pelitic gneiss is seen to become more conspicuous; ultimately white quartzite beds are again crossed, and the south-eastern tract of psammitic Moine rocks is reached.

Pegmatites.—Throughout the pelitic series which has just been described, veins of quartz and knots and patches of 'pegmatite' abound. These participate in the folding of the schists, and near the margin they are cut by the apophyses of the granite. They are further discussed in § IV (p. 391).

[1] Summary of Progress of Geol. Surv. for 1897, p. 41; *ibid.* 1900, p. 10; and *ibid.* 1902, p. 85; also 'Geology of Lower Strathspey' (Expl. of Sheet 85) Mem. Geol. Surv. 1902, p. 47.

II. Impregnation of the Pelitic Gneisses with Granite.[1]

(a) The Intrusion of the Granite.

The very intricate line of junction between the granite and the gneisses has a general trend which cuts obliquely across their strike in a north-and-south direction. The relations between the granite and the schists are of extreme complexity, veins and even isolated patches of granite occurring in the schist half a mile or more away from the generalized boundary-line; while masses and fragments of schist, of all sizes up to 200 or 300 yards in length, are found included plentifully in the midst of the granite area.

Fig. 2.—*Folded Moine Schists with granitic intrusions along the bedding, slightly swollen at the apex.*

T. O. B. 1908.

[The scale is a foot-rule. The white lines round the margin indicate the positions of some of the intrusions.]

These inclusions, which commonly retain their north-easterly strike, are most numerous in the eastern, southern, and central parts, but are comparatively scarce in the north and west. Near the junction they are often so abundant as to form massive injection-breccias.[2]

[1] The following account of the penetration of the schists by granite applies only to a narrow tract at the granite margin, not exceeding a few hundred yards in width.

[2] Good examples occur 40 yards south-west of Knock-na-fenaig and half a mile south-south-east of Bendoran Cottage (a mile and a quarter west of Bunessan).

The specific gravity of the inclusions is somewhat greater than that of the granite.

The absence of crushing, shearing, or any important faulting in the granite, together with the fact that the intrusion is newer than the structures in the schists, suggests that its present position is practically that in which it solidified.

Fig. 3.—*Granitic intrusions along the bedding and along the strain-slips.*

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[The stick in the picture is 6 inches long. Six of the white marks indicate some of the intrusions along the bedding, and one indicates the direction of those along the strain-slips.]

On the south-western shore of Loch na Lathaich, granulite is seen in several places beneath granite, lending some support to the view that the Ross of Mull granite is the bottom part of a large sill-like intrusion which rests upon the Moine Schists,[1] and contains inclusions derived from the floor.

[1] See E. H. Cunningham-Craig, Summary of Progress of Geol. Surv. for 1907, p. 66.

These granite patches overlying granulite, however, are very likely only offshoots from the main mass, and the line of junction with the schists is more readily interpreted as the lateral margin of a deep-rooted mass with countless tongues and protrusions issuing from it. It is here considered that the granite exposed in the Ross of Mull is the top of a great abyssal mass, over which the Moine rocks extended as a roof whose former height above the granite forming the present surface increased towards the north-west, and that the inclusions in the granite are fragments of this roof which have sunk in from above.

At the margin of the igneous mass injection of granite material among the schists has taken place in several ways :—

(1) Irregular veins and strings, possibly often along fissures and cracks.

(2) Injections along bedding.—These are very regular and uniform in thickness. The larger bands may be several feet thick, and the direction in which the granite flowed is shown by the bending of the mica-felts at the margins.

Much thinner bands are more common, and are sometimes so close together that a hand-specimen may show several; while often they are of such microscopic thinness, that they can only be recognized as granite from their field-relations.

How uniformly these bands may follow the bedding is seen in fig. 2 (p. 380). Here [1] the rocks have been steeply folded. Granite now occupies part of the core of the fold occurring to the left of the part photographed. Numerous bands of granite, many of them too thin to be visible in the picture, may be followed right round the fold. A slight thickening of each band at the apex suggests that the rock was sufficiently pliant for the intrusive matter to experience relief of pressure there.

(3) Injections along strain-slips.—The foliation-planes of the mica-schist (or muscovite-biotite gneiss) are often so rumpled that a set of parallel strain-slip planes has been produced crossing them. The structure is frequently on a large scale, with the planes an inch or more apart. On the coast the waves have sometimes broken the rocks repeatedly along them, producing parallel flat ledges on the cliffs. The granite also has taken advantage of these planes of weakness, and often the granite veins along the bedding are connected one with the other by a set of uniform injections along the strain-slips. This occurs to some extent in the rock figured above (fig. 2, p. 380), but a much better example may be seen almost exactly a third of a mile a little north of west of Loch-an-t-Suidhe. Here a large part of a hillside facing north is formed of a schist mass included in the granite. Along the bedding are numerous granite bands of various thicknesses, from a small fraction of an

[1] Locality about 200 yards west of Bendoran Cottage.

inch up to 4 inches; some close together and others as much as 6 inches apart (see fig. 3, p. 381).

The intervening beds of schist are crossed, at an angle of about 25°, by a set of injections along strain-slips connecting those along bedding. They are generally very thin white veins, in this case from, say, 0·02 to 0·10 inch thick, and about a sixth of an inch apart, but the dimensions vary considerably in different instances. The resulting rock is a gneiss with banding in two directions, of which a specimen is shown, of the natural size, in fig. 4 (p. 384).

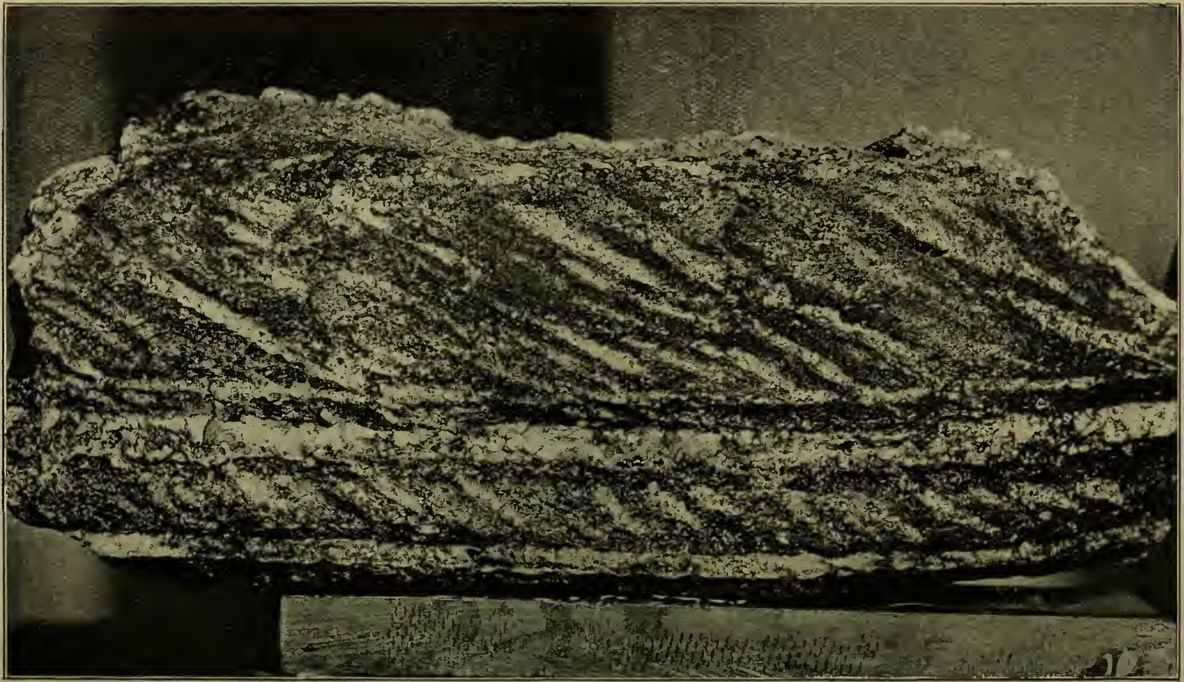
(4) Injection along foliation has taken place to varying degrees. Sometimes, as in the cases figured here, granitic matter has penetrated between the folia of mica only a little way from the margins of intrusions of the above kinds. Sometimes, especially in the coarsely-rumpled quartzose pelitic gneiss, the intrusions are definite separate veins, which may be traced for some distance along the structure. The rocks forming the hill behind Bendoran Cottage have been much affected in this way, but it is difficult to discriminate between the injected material and the layers of quartz and felspathic material belonging to the rock. Masses thus affected, however, seem to lose some of their schistose nature, and wear like the granite into rounded hillocks, rather than into the usual angular and jagged crags.

More commonly, the intrusions along foliation are in the finest strings, threads, and films, woven inseparably among the mica-felts. In extreme cases the invading granite is in large proportion in the rock, and has not only penetrated between the folia, but between the individual mica-plates. Some considerable masses of rock are permeated in this way. A good example may be seen by the shore about a fifth of a mile south-south-east of Rudh' Ard an Daraich, where a bed of quartzose biotite-gneiss, occurring in the quartz-felspar granulite series, has been converted into a rather pale compact rock weathering to a reddish colour, and somewhat resembling a granitoid gneiss.

Among blocks of schist included in the granite examples may be found in every stage of transformation. Some have sharp boundaries and are apparently unaltered, while others have been so permeated that only the faintest outlines or 'ghosts' can be discerned. Probably the identity of many has been completely lost, and here it may be observed that, although the normal granite contains but little mica, the marginal portions along the line of junction with the schists are comparatively rich in biotite.

In some places a curious rock has been produced in small quantity where very complete commingling of much schist material with the granite has taken place, the schistose texture being obliterated. It is speckled black and white, and contains a large proportion of biotite. The rock is of medium grain, but rather large white felspars, such as occur in the coarse granite, have crystallized out with almost porphyritic habit in this micaceous ground-mass. The best examples are 500 feet north-west of Bendoran Cottage and

Fig. 4.—*A specimen of the banded composite gneiss produced by injection.* (*Natural size.*)



R. L. 1909.

[There are four bands of granite along the bedding, shown horizontal in the figure: one is at the top of the specimen. These are connected by bands along strain-slips.]

1000 feet north-north-east of Knock-na-fenaig, at which latter place the rock is seen to contain sillimanite.

Similar felspathization (or else recrystallization) has been produced in the granulites: for, near the margin of the granite, well-formed ungranulitized porphyritic crystals of felspar are present in abundance.

Conclusion.—The facts just described show how readily pelitic schists may be impregnated with granitic matter in various ways, to form banded gneisses of more acid character; and possibly similar processes of igneous impregnation have been employed, again and again, on a grander scale, in the earlier stages of the conversion of ancient sediments from the schistose condition into the crystalline gneisses which underlie the oldest recognizable sedimentary rocks.[1]

III. Contact-Metamorphism of the Pelitic Gneisses.

In the cases which have been described above it is possible that some recrystallization occurred among the rocks invaded by the granite, but generally no minerals have been detected other than those proper either to the schist or to the granite.

There are, however, in many places near and within the granite, masses of pelitic gneiss which have undergone intense contact-metamorphism.

Distribution of the Contact-Altered Schist.

At the surface there is no continuous aureole of contact-altered schist such as can be mapped. This is partly because the rocks are greatly obscured by peat, and partly because beds of micaceous granulitic quartzite alternate with the beds of pelitic gneiss; and it is only where certain of these latter strike up to the granite that the sillimanite-rock is found. Most patches of this altered rock are actually within the granite area—some of them in the very middle of it (for instance, between Tòrr Mòr and Cnoc Dubh). Those patches which are outside occur close to the generalized boundary-line, where schist-masses and granite-veins are inextricably mixed. Some of the patches have been mapped on the 6-inch scale. On the accompanying map (fig. 1, p. 378) a heavy dotted line has been drawn: east of this line no schist, contact-altered as described below, has been found outside the granite mass.

Of the new minerals sillimanite is most abundant, and is visible in the field as pink or greenish fibrous prisms, sometimes exceeding an inch in length. Usually, except for the presence of these prisms, the rocks have a normal appearance, being coarse and often very quartzose 'muscovite-biotite-gneiss,' with or without

[1] See J. J. Sederholm, 'On Granite & Gneiss' (English summary), Bull. Comm. Géol. Finlande, No. 23, 1907.

garnet; but under the microscope they are seen to contain, besides the sillimanite, abundant cordierite, some andalusite, grains of green spinel, and a considerable amount of apatite (14160 & 14161).[1] Frequently they are, to some extent, penetrated by strings of granitic matter along the foliation; and sillimanite is specially clustered around the clots of intrusive matter, as though chemical

Fig. 5.—*Weathered surface of altered schist with knobs of sillimanite prisms. (The white stick lying in the foreground is 6 inches long.)*

T. O. B. 1908.

reaction had taken place there. There are good examples among the schist-masses included in the granite about $3\frac{1}{2}$ miles west-south-west of Bunessan, between Cnoc Dubh and Tòrr Mòr.

Differing from the above are other cases, notably around Bendoran Cottage, where the patches of altered schist have an unusual appearance, and the new minerals are in such quantity that it seems likely that extensive recrystallization occurred. The resulting rock

[1] These numerals refer to the numbers of the microscope slides preserved in the collections of the Geological Survey.

is a very tough, quartzose, muscovite-biotite-gneiss, with a close texture and leaden colour. The sillimanite occurs throughout the mass of the rock, and also in pale lenticular aggregates together with some andalusite and cordierite. These lenticles are biconvex, and commonly an inch or more in length and half an inch thick. They lie along the foliation, often several being near together, and there is a tendency for the rock to break along their convex boundaries, which are faced with biotite.

This rock is rendered conspicuous in the field by the weathering-out of the sillimanite aggregates in the form of rugged knobs projecting an inch or more from the surface (see fig. 5, p. 386). These knobs measure generally an inch or two across, and are about 2 inches apart. They consist of rough, fibrous, irregularly-terminated prisms, often crossing one another. Most of these are pink in colour, but some have a greenish tint. In size the prisms may exceed 1 inch by half an inch, but commonly they measure about a quarter by an eighth of an inch, and their roughness is probably due largely to the weathering away of other minerals from among them. Some quartz and small garnets are also present.

Sections of this rock, avoiding the lenticles, show it to consist of quartz, twinned and untwinned felspars, brown biotite, muscovites and some magnetite and garnet, together with a variable amount of apatite, cordierite, andalusite, fibrolite, and sillimanite prisms as described below, as well as green spinel.

The mutual relations of the common minerals are as usual in schists, the relative proportions varying in different bands, while the bands themselves are often coarsely rumpled. But the sillimanite, which occurs at intervals, takes precedence over all the other minerals, both for size and for perfection of crystal boundaries. Fig. 6 (p. 388) shows a part of slice 14126 magnified 18 diameters: the sillimanite is seen in cross-section in the central portion of the photograph.

Sections through the weathered-out knots, or the lenticles which give rise to them, show sillimanite as the principal constituent. There are also biotite, muscovite in large blades, patches of quartz, garnet, magnetite, and a little felspar. In the lenticles andalusite and cordierite are also plentiful, the former in one case [13971] being the chief constituent. Fig. 7 (p. 388) shows a portion of a weathered-out knob [14127], and fig. 8 (p. 389) a portion of a lenticle [14125]. In both of these sillimanite is the most conspicuous mineral.

This segregation and crystallization of aluminium silicates in such large proportion must have been accompanied by considerable chemical reaction and recrystallization among the original constituents of the rock.

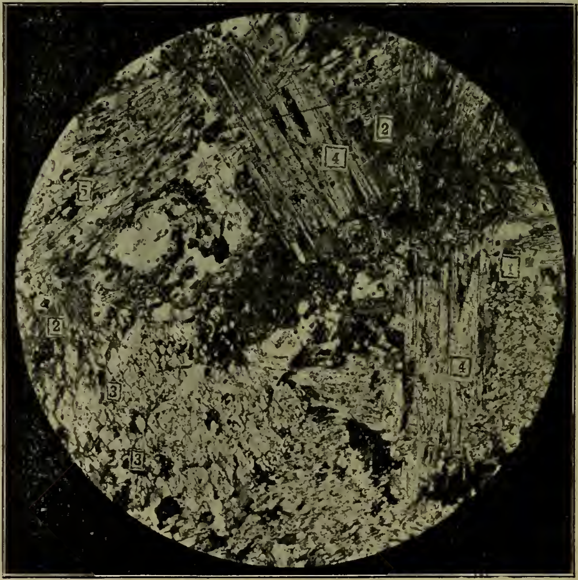
The sillimanite in these metamorphosed schists occurs in two ways:—

(1) Common fibrolite, present throughout the rock in felts, in bundles, and in groups of roughly-radiating fibres which penetrate the other minerals.
(2) In well-formed crystalline prisms.

Fig. 6.—*Section of contact-altered pelitic gneiss, showing two groups of sillimanite cross-sections near the centre of the field. Magnified 18 diameters* [*14126*].

T. C. H. 1909.

Fig. 7.—*Section of a weathered-out knob, magnified 18 diameters* [*14127*], *showing cross-sections and long sections of sillimanite.*



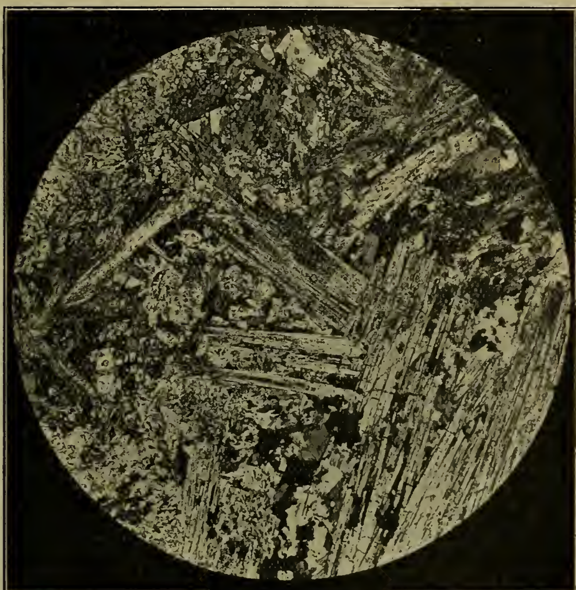
T. C. H. 1909.

[1=Quartz, biotite, etc.; 2=Fibrolite tufts; 3=Cross-sections of sillimanite; 4=Long sections of sillimanite; 5=Oblique sections of the same.]

As I do not find any record of this latter from the rocks of the Scottish Highlands, I venture to describe it further.

On examination of thin sections and of fragments obtained by crushing, it is seen that the stout prisms in the weathered-out knobs are not single crystals, but each is built up of a number of more slender crystalline prisms packed together with almost, but not quite exactly, the same optical orientation.

Fig. 8.—*Section of a lenticle, magnified 23 diameters [14125],*[1] *showing mainly long sections of sillimanite.*



Crystal fragments giving perfectly uniform extinction were obtained, measuring about an eightieth of an inch across. They are positive in character, and show well-marked cleavage-traces or a fibrous structure in the prism-zone and some irregular cross-fractures. In the rock-slices single crystals were observed measuring up to a quarter of an inch in length.

Parallel growths of andalusite with this mineral, as described by Prof. A. Lacroix,[2] also occur, appearing in section as longitudinal strips of andalusite between strips of sillimanite.

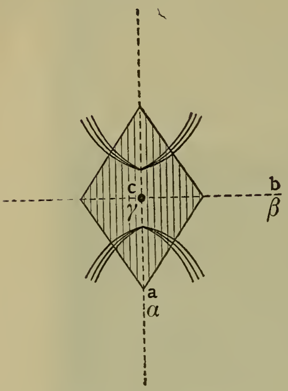
Wherever one of the rough stout prisms of sillimanite which

[1] For these three microphotographs (figs. 6–8) I am indebted to Mr. T. C. Hall, F.G.S., who took great trouble to rephotograph with the identical magnifications the exact fields shown in inferior photographs of my own perpetration.

[2] 'Minéralogie de la France & de ses Colonies' vol. i (1893) p. 42 & fig. 21.

occur in the knobs is cut across, a group of cross-sections of the component slender prisms is seen. Each of these crystal-prisms gives a 'diamond-shaped' cross-section; and they are set close together, with their corresponding sides approximately parallel or even in contact, so that the whole group behaves almost as a single crystal. The largest cross-section observed measures about ·01 inch across, and the angles are about 70° and 110°. No pinakoids are developed, but traces of a strong pinakoidal cleavage cross the sections parallel to the longer diagonal. This cleavage-plane is also the plane of the optic axes, for the cross-sections give good interference-figures, disposed as shown in the accompanying fig. 9. Hence this is the plane usually taken as (010) in sillimanite; and, accepting the figures $a : b = \cdot 970 : 1$, it follows that the longer diagonal in these crystals is along the a axis, and the prism here developed is of the form (2, 3, 0).

Fig. 9.



The interference-figure gives

$c = \gamma$; $a = \alpha$; $b = \beta$; and 2E = 45° approximately (measured with an eye-piece micrometer).

The crystals are thus positive, and have α and β very nearly equal. The interference-colour seen in the cross-sections is an extremely low grey. But γ is considerably greater, for in long sections the interference-colours are often of the second order. The refractive index γ is slightly greater than that of α-monobromonaphthalene (1·658). The crystals appear very clear, but with a quarter-inch objective they are in many cases seen to enclose grains of green spinel, sometimes in great numbers, together with some small particles of iron oxide.

The andalusite is associated with the sillimanite in smaller amount in the lenticles occurring in the rock, but it was not found on crushing up the weathered-out knobs, having possibly been weathered away. The crystals are often of large size [13971], and enclose some patches of quartz and numerous brown biotite-crystals; but they are not in the least clouded with small inclusions, being quite clear and of a strong pink colour in parts.

The cordierite, which is plentiful in most of the rock-sections, occurs in clear medium-sized grains, similar to the grains of quartz and felspar. It is generally in the mosaic with these minerals, and so closely resembles the quartz that it is with difficulty distinguished therefrom. The characteristic greenish pleochroic halos are present, but are very faint and not easily detected. Under a high-power objective very minute inclusions are seen to be numerous.

Much cordierite has been changed by weathering into golden-brown pinite. Grains seen in the early stages of this change are pale yellow, and show slight pleochroism.

The following remarks are quoted from a letter sent to me by Dr. J. S. Flett, F.G.S., when he had seen the slices of these rocks:—

'These are the most completely altered argillaceous rocks that I have ever seen from the Scottish Highlands. The association of minerals is the same as Dr. Teall[1] first described from Ben Cruachan, and Mr. Hinxman[2] found later at Netherly in Elgin, in Moine Schists at the edge of "Newer Granites." The included blocks in the Cornish granites contain the same group of minerals. The only British rock that I know which contains such large crystals of sillimanite is a specimen that Mr. Allan Dick has shown me from Croghan Domain, north of Phillipstown, Sheet 109, Ireland. This seems to be Slide 2734, described by Prof. Watts in his & McHenry's 'Guide to the Collections of Rocks & Fossils,' Geol. Surv. Ireland, 1898, pp. 38 & 39.'

IV. Kyanite and Tourmaline-Rocks ascribed to the Regional Metamorphism.

Mention has already been made of the abundant veins and patches of pegmatite which are conspicuously older than those connected with the granite, and participate in the folding of the pelitic Moine rocks (p. 379).

Around these quartz-pegmatite patches the pelitic gneiss is often particularly coarse and quartzose, the quartzo-felspathic streaks passing imperceptibly into the veins of 'pegmatite.' This streaky quartzose character appears often in places in a sporadic way among schists elsewhere containing but little quartz. There is, in fact, every gradation between 'pegmatite' veins and the ordinary quartz-felspathic streaks proper to some of the coarser pelitic gneisses.

Thus, although in these Moine gneisses the identity of the separate beds of sandstone, mudstone, etc. has been maintained, there has doubtless been some transfer of material from one part to another, especially in the case of silica, and it seems likely that these pegmatites are due to segregation of the more mobile constituents present in the original sediments rather than to intrusion of material from an underlying source.

Prisms of tourmaline may be found in many of these pegmatite patches throughout the area—pegmatites in no way connected with the granite; and in the two cases now to be described, the mineral occurs along with kyanite as a constituent of the pelitic gneiss.

In the first of these the kyanite occurs in the pelitic beds, within a belt of the Moine rocks about 80 yards wide and traceable along

[1] Summary of Progress of Geol. Surv. for 1898, p. 85, etc. Also 'Geology of the Country near Oban & Dalmally' (Expl. of Sheet 45) Mem. Geol. Surv. 1908, p. 143.

[2] J. S. Flett, 'Geology of Lower Strathspey' (Expl. of Sheet 85) Mem. Geol. Surv. 1902, p. 52.

the strike for nearly half a mile. The best exposure of this belt is at its northern end, opposite to and about 400 feet south-west from the foot of Loch Assapol, in the cliff of the 100-foot raised beach.

The rocks forming the cliff consist mainly of somewhat quartzose pelitic gneiss, alternating with fine, micaceous, granulitic quartzites and some thin bands of calc-silicates. There are also intrusive epidiorites.

At this place, in the central part of the belt are many quartz knots and pegmatite patches, often passing gradually into the pelitic gneiss. The composition of these pegmatites is variable, and some are peculiar—the following being three typical examples:—

(1) quartz and tourmaline;
(2) large crystals of kyanite and white felspar with some quartz;
(3) white felspar, tourmaline, and biotite.

The majority of the patches are only a foot or two across, but the largest is exposed along the strike for some 20 yards as a sheet about 3 feet thick forming a rock-face some 15 feet high, the beds here being almost vertical. The composition of this mass varies from place to place. A large portion consists of about three parts tourmaline and two parts white felspar, making a fairly homogeneous rock of coarse texture and slight schistosity.

Weathered surfaces show the tourmaline as lustrous prisms[1] sometimes an inch in length and half an inch thick; but, where the rock is broken, the tourmaline has an unusual appearance, its fractured surfaces being of a rough gritty nature and a dark olive-green colour.

In section (13976) it is seen to consist mainly of large tourmalines and felspars (mostly plagioclase of low extinction, but also some in which no twinning is visible). Quartz is present in a strained condition, and the tourmaline contains sometimes as much as half its bulk of quartz, in the shape of large angular inclusions with somewhat longitudinal arrangement, which probably are the cause of the roughness of the fracture. The felspar also includes much quartz. There is moreover brown biotite with deep pleochroic halos around inclusions, and stout prisms of rutile are very abundant in both tourmaline and felspar throughout.

In other portions of this pegmatite, black biotite makes up about half the rock, and where there is much quartz it has the appearance of a biotite-gneiss. In places large garnets are also present, as well as clots of clear quartz measuring up to 1 foot across. Near the margin kyanite occurs, and the rock passes into the tourmaline-bearing kyanite-gneiss which borders it on each side. A few yards away from the pegmatite the tourmaline becomes much less plentiful.

The kyanite-gneiss is a rather coarse rock composed of mica, felspar, and quartz, with abundant blue crystals of kyanite which lie along the bedding-planes and stand out conspicuously on the

[1] W. E. Koch, Trans. Geol. Soc. Glasgow, vol. vii (1881) p. 52; also figured in Heddle's 'Mineralogy of Scotland' vol. ii (1901) pl. lxxiii, fig. 1.

weathered faces. It is remarkable that, although the rock is rumpled, these crystals, which are of large size, sometimes 3 inches long, generally show few, if any, traces of disturbance.

In one instance, however, in a small pegmatite knot, a group of kyanite prisms was seen keeping a straight course for a length of 3 inches, then bending round by means of a series of fractures through about 130° and continuing in this direction for another inch. Crumpled mica occupies the inside of the bend (fig. 10). The original specimen is now in the Geological Survey Collection.

Fig. 10.—*Curved and fractured kyanite, natural size.*

R L. 1910.

In section (13970) this gneiss is seen to consist of coarse brown biotite, strained quartz, clear felspar (some with Carlsbad and albite twinning, but most of it showing none), large colourless garnets crowded with inclusions, rutile in stumpy prisms, and large clear kyanite.

The other occurrence of these two minerals is on the east side of Port Bhethain, a mile west-south-west of Scoor. The kyanite here is in thin pale prisms about half an inch long, in a schist of unusual appearance, consisting of dark mica with very little quartz and felspar, but containing well-shaped garnets often as big as a golf-ball.

Some parts of this rock, which are very schistose, contain a large amount of tourmaline, in lustrous black needles with parallel arrangement. But sometimes, where the rock is less schistose, both kyanite and tourmaline are large.

In addition to these minerals, thin sections show the presence of staurolite, abundant stumpy prisms of rutile, and also some indication of tufted needles of fibrolite enveloped in muscovite and fringing kyanite. There is only a small exposure of this rock, seen as a narrow strip for some 40 yards along the strike. It seems to be inseparable from a peculiar band of epidiorite. There is no remarkable amount of pegmatite here, and the granite is 2 miles distant.

Occurrence in other parts of the Highlands.

Tourmaline is common and widespread in the Highlands. In the Moine Rocks as a constituent of pelitic gneiss, besides the two instances in Mull, it has been noticed

(1) On the west side of Lake Luichart (Ross-shire), by Dr. Peach,[1] in a thin bed of mica-schist. Some specimens from this neighbourhood show stout prisms up to about half an inch in length, abundant in a garnetiferous quartz-muscovite-biotite schist of medium coarseness, in which knots and veins of quartz occur.

(2) Near Loch Hourn (Inverness-shire) by Mr. Clough.

(3) In the Strathfarrar district (Inverness-shire) by Mr. Hinxman. Some of these crystals are an inch or two long and an inch thick, in rather coarse quartzose muscovite-schist. Very large crystals occur here in pegmatite veins. In a letter Mr. Hinxman remarks that 'there is no evidence to connect the tourmaline of Glen Strathfarrar with any visible intrusion of granite.'

It is in the old pegmatite veins and patches that the tourmaline is most common: to quote only a few instances:—In the Moine Schists of Fannich Forest, Dr. Horne[2] found small pegmatite veins with prisms of tourmaline. In the Moine rocks of the Loch Fannich district, Mr. Pocock[3] mentioned pegmatites containing tourmaline crystals 4 or 5 inches long. Concerning these, Dr. Horne says in a letter

'We never connected these pegmatites with the Newer Granites, but regarded them as connected with the regional metamorphism.'

In the Moine rocks of Inverness-shire, Mr. Hinxman and Dr. Crampton find similar tourmaline-pegmatites.

In other Highland gneisses also tourmaline is common, Heddle[4] gives a long list of localities from which it is recorded, sometimes in quartz-veins and pegmatites, and sometimes in schists. Numerous specimens may be seen in the Heddle Collection in the

[1] Summary of Progress of Geol. Surv. for 1898.
[2] *Ibid.* p. 12. [3] *Ibid.* pp. 16 & 17.
[4] 'Mineralogy of Scotland' vol. ii (1901) pp. 74–75.

Royal Scottish Museum. Many of the localities are at a distance from Newer Granite intrusions.

In at least two instances tourmaline has been found in pelitic gneiss accompanied by kyanite, as in Mull, namely:—

(1) Glen Clova (Forfarshire).[1]

(2) Wood Wick, Unst (Shetland).[2] In this latter instance staurolite also is present. The specimens are dark garnetiferous biotite-gneiss containing abundantly kyanite and tourmaline.

Besides the foregoing occurrences tourmaline is, on the other hand, also well known in veins and pegmatites connected with plutonic intrusions, especially in the counties of Aberdeen and Banff[3]; but the facts here adduced plainly show that tourmaline is common in the Highlands, quite independent of the Newer Granites or other igneous masses.

The presence of the tourmaline is no indication that the old pegmatites are intrusions of extraneous material. After examination of the heavy mineral grains in a number of sedimentary rocks from various formations, it may be stated that tourmaline is almost invariably present in sediments. If the pegmatites be due to segregation during the regional metamorphism, they represent the most volatile fluid that the sediments could yield. Hence, in composition, they are likely to resemble the apophyses of granite, and they may well contain the tourmaline.[4]

Kyanite has not been recorded in Moine Gneisses elsewhere in the North and North-West Highlands, but it is well-known in other similar rocks, notably in the Lewisian Gneiss near Loch Maree; in Glen Urquhart (Inverness) in pelitic beds supposed to belong to the Lewisian Gneiss; and in the Lewisian Gneiss at Glenelg. In the 'East Central Highlands' it is plentiful in pelitic gneisses described by Mr. Barrow, and by him regarded as belonging to the Moine rocks, notably in the Glen Tilt[5] neighbourhood—in dark schists associated with the 'Main' or 'Blair Atholl' Limestone[6]—and in the 'Duchray Hill gneiss.[7] The kyanite in these extensive masses

[1] 'Mineralogy of Scotland' vol. ii (1901) p. 62.

[2] See specimens in the Heddle Collection, Royal Scottish Museum.

[3] See Heddle Collection, and also Heddle's 'Mineralogy of Scotland'; compare too the later Palæozoic granites of Galloway, Cornwall, and County Dublin.

[4] Since writing the above, I have received the following interesting note from Mr. Barrow:—'By far the greatest amount of schorl, if not the whole of it, as seen in altered sediments is due to aggregation of original clastic schorl. Minute needles of clastic schorl are often extremely abundant in the little-altered dark slates, along the Southern Highland border, especially in certain bands. Where these rocks occur in areas of higher crystalline metamorphism the schorl is aggregated, and now often forms patches or much larger needles easily seen by the unaided eye. In a fair number of cases this schorl is associated with quartz, forming small quartz-schorl segregations.'

[5] Quart. Journ. Geol. Soc. vol. xlix (1893) pp. 346–348 & map (pl. xv), also figs. 3 & 4 (pl. xvi).

[6] *Ibid.* vol. lx (1904) pp. 419, 420.

[7] Mem. Geol. Surv. (Expl. of Sheet 65) p. 101.

of gneiss, according to Mr. Barrow, is due to the thermal effects of intrusive gneisses among them or below.

In the 'Central Highland rocks' of Banffshire[1] kyanite is recorded from Glen Rinnes, from near Grantown-on-Spey and various other localities, in pelitic gneiss. Some of these are associated with epidiorite. In this connexion may be mentioned the kyanitic pseudomorphs after andalusite in the hornfels around the 'Inchbae augen-gneiss' (Ross-shire). Dr. Flett is of opinion that the andalusite first produced has been subsequently converted into kyanite by pressure. The kyanite is often accompanied by staurolite, and sometimes[2] by tourmaline, as in Mull (see p. 391).

Another common mode of occurrence of kyanite is in association with quartz in the old pegmatite knots and veins. Specimens from numerous localities may be seen in the Heddle Collection, and a number of localities are cited in Heddle's 'Mineralogy of Scotland' (vol. ii, 1901, p. 62).

Though, in some instances, the presence of kyanite may be more or less indirectly connected with older granites and epidiorite masses, in no case does its occurrence appear to be due to contact-alteration by Newer Granites or other unfoliated igneous intrusions.

In conclusion, it may be stated that where pelitic gneisses have undergone thermal metamorphism at the margin of the Newer Granites (see p. 385),[3] sillimanite, cordierite, and andalusite have been produced.[4] But kyanite, sometimes associated with tourmaline and staurolite in these rocks, is a product of the regional metamorphism, and it is often connected with the quartzose pegmatization of the pelitic gneiss, whether these pegmatites be segregations or intrusions from below.

Finally, I wish to acknowledge how greatly I am indebted to Dr. Horne, Mr. Clough, and Dr. Flett for their ever-ready advice and help; in particular to Mr. Clough for instruction and criticism in the field, and to Dr. Flett especially for notes on the cordierite and for his kindness in confirming many of my petrological observations.

[1] 'Geology of Lr. Strathspey' (Expl. of Sheet 85) Mem. Geol. Surv. 1902, p. 56.

[2] See p. 395.

[3] J. S. Flett, 'Geology of Lr. Strathspey' (Expl. of Sheet 85) Mem. Geol. Surv. 1902, p. 52; J. J. H. Teall, Sum. of Progress of Geol. Surv. for 1898, p. 85; also 'Geology of Oban & Dalmally' (Expl. of Sheet 45) Mem. Geol. Surv. 1908.

[4] These minerals are found also in gneisses which are not near Newer Granite. In the South-Eastern Highlands Mr. Barrow has described sillimanite-rocks occurring over a wide area, the boundary of which he has mapped for fully 100 miles. He finds the sillimanite in no way connected with Newer Granite intrusions: see Quart. Journ. Geol. Soc. vol. xlix (1893) p. 343 & pl. xv (map); also *ibid.* vol. lx (1904) p. 415.

Discussion.

The President (Prof. W. W. Watts) remarked that the paper was not only of great interest in itself, but it was an indication of the great interest which the members of the Geological Survey felt in their work, and a testimony to the freedom of thought and discussion which characterized that body. If the Author had succeeded in discriminating between the effects of regional and thermal metamorphism in the district under discussion, he would have made a most important contribution to knowledge.

Mr. G. Barrow congratulated the Author on his paper, and especially on the discovery of the sillimanite crystals, which were much finer than any that had been met with in the South-Eastern Highlands. In this area the speaker had traced the outer (southern) limit of the sillimanite-bearing gneisses for 100 miles. In them green spinels were quite common, and the gneisses, like those shown by the Author, were always far coarser in texture than the sillimanite-bearing rocks that occurred in the aureoles of metamorphism round any undoubted post-Torridon granite. He also congratulated the Author on the clearness with which he had unconsciously shown that the marginal phenomena of the granite were exactly those characteristic of the older Archæan granites, and never of the newer intrusions. Fortunately, geologists were able to satisfy themselves of the justice of this observation by examining on the ground the facts shown on the published 1-inch Geological Survey Maps of Scotland. In Sheet 66 the north-eastern margin of the great Kincardineshire granite, belonging to the newer group, cut across one of the more coherent patches of the older (Cairnshee) granite. The margin of the newer intrusion had a fine-grained and quickly-cooled edge, with no trace of veins or apophyses. The older rock here could rarely be mapped, although the whole country, along a belt fully 30 miles long, was flooded by it in the form of minute intrusions. The ground on which the junction between the two intrusions occurred was especially easy of access, and could be visited at any time.

The permeation of the granitic magma along both the folding-planes and the strain-slip cleavage was characteristic of the older Duchray Hill gneiss, shown on the published maps. In Sheet 56, on the east side of Glenshee, a large mass of diorite of Newer Granite age was seen clearly intrusive through the far older Duchray Hill gneiss. The junction was clear and bare on the south side of the diorite, and here again the strong contrast between the Archæan granite and the far newer one was well shown.

If the Author still claimed that this intrusion was of Newer Granite age and that it re-metamorphosed rocks previously altered, the speaker challenged him to publish on the official 1-inch map a line showing the outer limit of this new alteration. Long accounts had been published by the Geological Survey of Scotland of the new metamorphism produced by the Newer Granites in the Highlands; but no one had yet ventured to show the aureole of alteration on a published 1-inch map, as was always done in the case of the Devon and Cornish granites. In two cases at least, this aureole of alteration in the Highland rocks, due to new metamorphism by the Newer Granites, was perfectly well known. It did not extend more than 3 yards from the granite margin; and the new rocks produced showed no trace of foliation in the arrangement of their new minerals.

Dr. Teall congratulated the Author on having had so interesting a district to work in, and complimented him on the way in which he had presented the results of his observations to the Society. The speaker had himself observed in different parts of Scotland, especially in Caithness, examples of many of the phenomena of intrusion described by the Author; but he had rarely, if ever, seen them so well displayed as they evidently were in the Ross of Mull. The sillimanite-rocks were certainly finer than any that he had ever seen.

Referring to the previous speaker's remarks, Dr. Teall said that he was not particularly interested in the age of this granite. The granites of the Highlands belonged to different periods, and, given suitable conditions, any of them might have produced cordierite-sillimanite rocks. The terms older and newer as applied to the granites of the Highlands were not very definite. He presumed that the Author had some reason for using the latter term in this case.

Dr. Flett remarked that the Author had shown that, in the Ross of Mull, there was much evidence of a remarkable character bearing on some of the most important problems of Highland geology. The injection and permeation of the schists by the granite were very interesting, and must also be of an uncommon type, as, from the speaker's experience, junctions of this kind were very seldom met with at the margins of the Newer Granites. He hoped soon to have an opportunity of visiting these sections in the field, but the evidence now put before the Society, in photographs and in rock-specimens, had convinced him of the reality of the phenomena. The sillimanite-andalusite rocks in and around the granite were the most completely altered argillaceous sediments that the speaker had ever seen from the Highlands of Scotland, and he had little doubt that they were due to the contact-action of the Ross of Mull granite. It was certainly true that the Newer Granites often produced strikingly little contact-alteration, but instances were known where they had converted even the highly crystalline Moine Schists into cordierite-sillimanite-andalusite rocks. He would cite only one instance, which was discovered by Mr. Hinxman at Netherly (Elgin), and described in the Geological Survey Memoir on Lower Strathspey. There the pelitic Moine Schists were full of cordierite for a distance of a foot or two from the edge of the Netherly diorite, which was one of the basic apophyses of the Ben Rinnes and Hunt Hill granites.

The kyanite-tourmaline rocks, in the speaker's opinion, were even more interesting. They seemed to him to bear the stamp of thermal alteration, but kyanite had never been found in the Scottish Highlands under circumstances which would lead observers to conclude that it was due to the contact-action of Newer Granites. On the other hand, this mineral occurred not seldom in the vicinity of masses of the Older Granites or granitic gneisses. It was found, for example, in the Archæan inliers which appeared as infolds in the Moine Schists north of the Great Glen, and in the black schist of Banffshire and Aberdeenshire. In the metamorphic aureole of the Inchbae augen-gneiss, the pelitic Moine Schists had been converted into banded splintery hornfelses, which had for some reason resisted dynamic stresses, while the granite and the unaltered sediments had been converted into gneisses and schists. These hornfelses sometimes contained large crystals of andalusite, which still preserved their characteristic outlines, but had been changed to aggregates of kyanite. These pseudomorphs indicated that kyanite, which was the silicate of alumina that had the highest specific gravity and lowest molecular volume, tended to replace andalusite in rocks that had been subjected to great pressures.

Whatever doubts might be advanced regarding the origin of the sillimanite, cordierite, and green spinel in the enclosures of the Ross of Mull granite, there could be no question that these minerals had been produced in the pelitic Moine Schists of the Ross of Mull by the contact-action of Tertiary dolerite sills: for Mr. C. T. Clough had observed that, at the edge of these sills, the mica-schists had in some places been fused to a black glass, which was full of cordierite, sillimanite, and spinel.

Mr. E. B. Bailey, in speaking to the points raised by the first speaker, remarked upon the general petrographical resemblance of the Ross of Mull granite to the admitted Newer Granites of other parts of the Highlands. This resemblance was strengthened by the occurrence of lamprophyres and porphyrites in connexion with the Ross of Mull granite. It was very difficult, moreover, to reconcile the totally unsheared condition of the granite with the hypothesis that the intrusion was of pre-Cambrian age, considering that it lay only a very short distance to the east of the great Moine Thrust. The *à priori* objection to the attribution of the granite to a post-Cambrian date was based upon the nature of its margin and of the attendant contact-metamorphism. This objection lost much of its weight, in view of the very similar phenomena observed in connexion with the granites of the Glencoe district, of proved Old Red Sandstone age.

Dr. J. D. Falconer said that, in the course of the survey of Northern Nigeria, some facts had been ascertained, which had a certain bearing upon the matter under discussion. In Nigeria there were two sets of granitic intrusions, an earlier and a later, which had invaded a complex of crystalline igneous gneisses and gneisses of sedimentary origin. The later set consisted largely of soda-granites which showed sharp contacts and chilled margins. The earlier set included granites of a more ordinary biotitic and hornblendic character, which usually showed on the margins, or throughout, a variable degree of foliation and cataclastic deformation. The early granites never showed sharp contacts, but almost invariably produced injection-structures in the adjoining gneisses. The two sets of granites had evidently crystallized under very different conditions of temperature and pressure, and to these conditions might be ascribed the presence or absence of marginal injection-structures. The earlier granites had penetrated both the crystalline igneous gneisses and the gneisses of sedimentary origin, and had produced brecciation and injection-structures of a type similar to those now described by the Author. No evidence had been found of the production of true banded igneous gneisses, as the result of injection of sedimentary gneisses by granitic material. The transformation was theoretically possible, but it must take place at very great depths and under conditions of temperature and pressure widely different from those which prevailed during the intrusion of either the earlier or the later granites now exposed. The intrusion of the granites in Nigeria appeared to have been accompanied by little or no contact-metamorphism.

Dr. J. W. Evans thought that the extent and character of the metamorphism caused by granite intrusions depended greatly on the depth below the surface, which affected the pressure, the amount of volatile fluxes, and the duration of the action. Dr. Barrois had shown this to be the case in Britanny, where subsequent erosion had laid bare the junctions between intrusive granitic masses (which were believed to be of the same age) and the surrounding rocks to different depths in different localities. The speaker further laid stress on the importance of the study of the trimorphic minerals (andalusite, fibrolite or sillimanite, and kyanite), as indices of the pressure and temperature of metamorphism; and enquired what were the relations between the andalusite and the sillimanite in the metamorphic aureole, especially with regard to the order of crystallization. He also referred to the phenomenon of the felspathization of the metamorphosed rock, which Dr. Barrois believed to occur by means of osmotic action where the intrusion took place at great depths. Finally, he laid stress on the extreme fluidity that the intrusive magma must have possessed, to enable it to penetrate into the narrowest planes of division of the injected rock, and considered that this was evidence of the presence of a large amount of the elements of water and other volatile fluxes.

The Author thanked the Fellows present for their reception of his paper and for their criticisms; and, in reply to Mr. Barrow. said that, owing to the varied chemical composition of the different beds of Moine rocks, the intricacy of the schist-and-granite junction, and the obscuring of the ground by peat, there was no continuous aureole at the surface to be mapped. Patches of the sillimanite rock, however, had been indicated on the 6-inch maps. The kyanite-tourmaline rocks in Mull could not be regarded as connected with the granite. On the one hand were sillimanite, andalusite, and cordierite, developed in various bands of pelitic gneiss only where these were approached or invaded by the granite. On the other hand, kyanite, staurolite, and tourmaline were found only along the outcrop of two particular sets of beds, which were separated from the granite and the contact-altered rocks by 2 miles of ordinary unaltered Moine rocks (mainly pelitic gneiss), and in this pelitic gneiss none of the above-mentioned minerals had been found.

After thanking Dr. Teall for his kindly remarks, the Author said that the reasons for correlating the Ross of Mull granite intrusion with other granites, the later Palæozoic age of which was established, were: (1) its resemblance to them; (2) it was conspicuously later than the foliation of the Moine Gneisses; (3) the absence of shearing; and (4) it was traversed by similar sheets of mica-trap.

Referring to what Dr. Flett had said, the Author agreed that the kyanite-tourmaline rocks might be due to recrystallization, the extra heat being possibly derived from dynamic action or from intrusive matter. At one of the localities in Mull much pegmatite was associated with these minerals, but at the other locality there was no conspicuous amount of it. Pegmatite was commonly associated with these minerals in other districts. These old pegmatite patches were intimately related to the gneisses, and were often folded with them. There was every gradation from knots of true pegmatite to the ordinary quartzo-felspathic streaks which were present in the pelitic gneiss, and were frequently sporadic in their distribution. The Author had, however, left it for more experienced geologists to say whether these pegmatites were genuine intrusions from an independent deep-seated magma, or whether they were due to segregation during the regional metamorphism.

Felspathization, such as Dr. Evans had mentioned, did occur here. The peculiar rock, described as consisting of schist-material with porphyritic felspars, etc., was of this nature. The quartz-felspar granulites on the west side of Loch na Lathaich, near the granite also enclosed comparatively large well-formed felspars, which might be due either to recrystallization or to felspathization.

16. Notes *on the* Geology *of the* District *around* Llansawel (Carmarthenshire).

By Miss Helen Drew, M.A., and Miss Ida L. Slater, B.A. (Communicated by Dr. J. E. Marr, F.R.S., F.G.S. Read April 13th, 1910.)

[Plate XXIX—Geological Map.]

Contents.

I. Introduction.

In 1906 and 1907 respectively, we were the recipients of the Daniel Pidgeon Fund, and decided to undertake a piece of field-work among the Palæozoic rocks of Wales.

It was suggested to us that we should make the country north of Llandeilo the seat of our investigations, with the view of discovering, if possible, the junction between the rocks of Hartfell and those of Birkhill age. We knew that Lower Birkhill graptolites had been found at Pumpsaint, some 11 miles to the north of Llandeilo, and we therefore hoped that the intermediate country might furnish sufficient fossil evidence to give us this line of junction.

With this end in view, we first made our headquarters at Llandeilo, and studied the country north of that investigated by Mr. T. C. Cantrill and Mr. H. H. Thomas. However, we found that the same monotonous series of highly-cleaved unfossiliferous (?) shales, apparently of Upper Hartfell age, continued so persistently to the north as to give us no hope of a graptolitic succession there. While pursuing our way still farther north, in search of some change in the lithology, our attention was attracted by some large slabs of a hard blue mudstone, standing outside a smithy; on close inspection these showed unmistakable fragments of graptolites, preserved in pyrite. By the help of very vague directions, given in Welsh by the smith, we succeeded, after considerable difficulty, in locating the quarry from which the slabs had been brought. It is situated on the south side of the Llandovery-Lampeter Road, near a farm known as Bwlch Cefn Sarth, some 9½ miles north of Llandeilo, and 4½ miles east of the little village of Llansawel.

The graptolites obtained from this rock proved to be of Lower

Birkhill age, and this suggested to us that in the ground which we had traversed there must be a great deal of repetition in the highest Hartfell or in the lowest Birkhill Beds (or in both). We therefore thought it desirable to change our plans, and devote our energies to the establishment of a succession in the Silurian rocks, rather than to the discovery of a junction between them and rocks of Bala age. With this end in view we made Llansawel our centre, and now offer these notes as the result of our researches.

II. Historical Review.

Very little has been written on the geology of this 'most contorted and perplexing country,' as Sedgwick has called it. The Geological Survey Memoir on North Wales does not give more than the briefest reference to the district in question, and the only papers of real importance are two written by Sedgwick. In the first, entitled 'On the Classification of the Fossiliferous Slates of North Wales, &c.'[1] he describes very briefly a traverse from Aber Aeron through Lampeter and Pumpsaint by the old road to Llandovery. He thus touched the north of our district, and described the rocks as 'a long series of contorted slates and grits' (*op. cit.* p. 154). The traverse is admittedly only a general one, and no definite localities are given; so this paper is not as important, from our point of view, as the last of a set of three published eight years later, dealing with the base of the Llandovery.[2] Under the heading 'Conglomerates, Slates, & Sandstones of Dol Fan, &c.' (p. 480), he describes in general terms the rocks composing a wide stretch of country, extending from the south-west of Builth to the

'high rugged plateau near the watershed of the Cothi and the Towy. . . . [These form] a large and ill-defined group of slates and sandstones, sometimes passing into a coarse conglomerate. . . . This group is generally contorted and forming saddles with sides of high inclination; the conglomerates are not continuous, but breaking off and reappearing' (*op. cit.* p. 480).

These furnished only one fossil, a specimen of *Euomphalus tricinctus.*

Later in 1846 he took another traverse, from Llandovery to Pumpsaint, crossing similar rocks farther south, and from Bwlch Trebanau, 4 miles north-west of Llandovery, he records the following fossils:—

	Encrinite stems.	*Leptæna sericea.*
	Favosites.	*Orthis elegantula.*
	Turbinolopsis.	*Atrypa crassa.*
Found on a subsequent visit.	*Euomphalus tricinctus.*	*Calymene.*
	Euomphalus triporcatus.	

[1] Quart. Journ. Geol. Soc. vol. iii (1847) pp. 133–64.
[2] A. Sedgwick, 'On the Mayhill Sandstone & the Palæozoic System of England' Phil. Mag. ser. 4, vol. viii (1854) p. 472.

These were identified in the field by Salter, but unfortunately never reached Cambridge; Sedgwick states, however, that taken together they indicate a group below the Mayhill Sandstone, which is therefore Cambrian (*op. cit.* p. 481).

The Bwlch Trebanau Conglomerate falls just outside our area, but we believe it to be identical, and indeed continuous, with our Shon Nicholas Conglomerate. From this we were unfortunate in obtaining no identifiable fossils; but, in the absence of definite proof to the contrary, we consider it as basal Llandovery.

Sedgwick then records to the south, intimately associated with the conglomerates, but on a lower geological horizon,

'a very great development of rather earthy slates, and of arenaceous flagstones, sometimes coarse, and almost deserving the name of conglomerates: in which case they are often ferruginous' (*op. cit.* p. 481).

Fossils were obtained from many localities, and these gave a very characteristic Upper Bala horizon. These rocks we believe to be our Beili Tew Group.

III. General Geology.

The district is a hilly one, for the ground is everywhere as much as 300 feet above sea-level, rises often to 1000 feet, and sometimes to 1400 feet. One of the most noticeable features is the well-marked north-easterly and south-westerly trend of the hills. These run in parallel ridges broken by transverse valleys, containing small streams, flowing into the Cothi. This tributary of the Towy drains the whole district, and has carved out for itself a wide and flat-bottomed valley, filled with drift and alluvium. From Pumpsaint for about 3 miles the river flows in a southerly direction; it then bends round south-westwards, flowing parallel to the trend of the hills. (See map, Pl. XXIX.)

On the north-west the ground rises gradually to the main watershed between the Teifi and the Towy basins, but on the east the ridges are more broken up into isolated knobby crests.

The area is on the whole poor in rock-exposures, as the greater part consists of rich pasture and arable land. The underlying rock is therefore for the most part seen only in road-sections, in small quarries, in broken ground on the hill-tops, and in the stream-section of the Gorlech, for all the other streams flow in drift or alluvium.

In the area under consideration the rocks consist of a varied series of sediments with a remarkably uniform strike of E. 30° N. They include a coarse conglomerate, grits, shales, and hard blue mudstones. The last-named are the most prevalent, but it is a striking feature of the whole series that numerous gritty bands of varying thickness occur throughout. As we go north from Llandeilo, cleavage, which is hardly noticeable there, becomes rapidly more apparent, and all around Llansawel the rocks have suffered intensely, so that in some places they are reduced to splintery fragments, with no trace of bedding or fossils. This, together with the scarcity of exposures, has made it impossible for us to produce a complete stratigraphical map based on palæontological evidence, and we have been obliged to leave some of our boundaries conjectural.

We classify the succession as follows:—

C. Llansawel Group......	C_3. Pengelli Shales. C_2. Zone of *Monograptus communis*. C_1. Clynmarch or *cyphus* Grits and Shales.
B. Caio Group	B_2. Llathige Shales and Mudstones. B_1. Pen-y-ddinas Grits and Shon Nicholas Conglomerates.
A. Beili Tew Group	Beili Tew Grits and Shales.

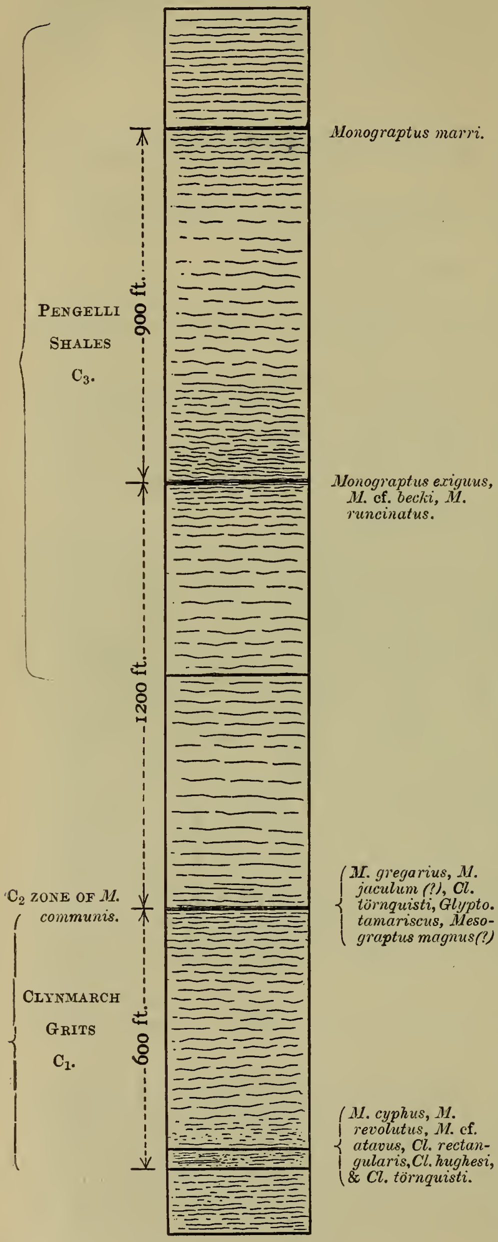
The series falls naturally into three groups, sharply marked off one from the other.

Our lowest or Beili Tew Group (A) is seen in Moelfre and the hills to the south, and in Banc Beili Tew. The most characteristic member is a very tough nodular shale, with no well-marked bedding and containing no fossils: there is also a considerable development of a sandy grit, with a conspicuous red-speckled weathering. This group we believe to be of Hartfell age.

Our second or Caio Group (B) derives its name from the village of Conwyl Caio, around which it is typically developed. The rocks of this group consist of tough dark-blue mudstones, shales, and at the base a coarse quartzose conglomerate, which makes a strong feature wherever it occurs. South-east of Llansawel there is a great development of a quartzitic grit, the relations of which to the conglomerate are not easy to determine, for the two are never found together. We believe it to be on much the same, or possibly on a slightly higher, horizon. These Caio Beds cannot be traced as a well-marked band across country, but extend over a distance of 3 miles across the strike, being repeated by a series of parallel folds, along the denuded crests of which the conglomerate occurs. The junction of this rock with the overlying shales and mudstones is often much faulted. The mudstones are characterized by a fauna of Diplograptids and Climacograptids only, and yield an assemblage characteristic of the *modestus* flags. From the conglomerate were obtained a few fragments of brachiopods and corals. In the grit we have failed to discover any fossils. We therefore believe that in this region the Llandovery period was ushered in by a shallow-water phase, which gave way rapidly to comparatively deep-sea conditions.

The highest group, which we name the Llansawel Group (C), consists of tough, dull-grey, cleaved shales, with softer black partings and interbedded grey banded grits. They have a uniform strike of E. 30° N., and their base forms a well-marked ridge north-west of Llansawel, extending for 5½ miles across country. This rise owes its existence to the occurrence among the shales of thick beds of hard sandy grit. These grits and associated shales provide one of

Fig. 1.—*Vertical section of the Llansawel Group, showing the relative positions of the more important graptolites.*



[Scale: 1 inch=500 feet.]

our best fossil horizons. They may be placed at the base of the zone of *Monograptus gregarius* of Prof. Lapworth, as they contain Monograptids of the *cyphus* type, in addition to *Mesograptus* and *Climacograptus.* On the north-west higher zones appear, and the upper beds roll continuously towards the rising ground of the watershed, and cover a wide extent of country.

To sum up, there are in this district three main groups, the mutual relations of which are beyond question. In the highest the sequence of the individual members is clear from the stratigraphy, and is confirmed by the palæontological evidence; in the second the maximum development of grits and conglomerates is certainly below that of the mudstones and shales.

The structure of the district is, at first sight, a simple one, owing to the monotonous north-westerly dip and north-easterly strike; but detailed mapping brings out unexpected complications in the distribution of the beds.

North and west of Llansawel the folding is simple, and has a Caledonian direction; the beds follow one another regularly, except for a certain amount of rolling in the upper part of the series, which causes a continual change in the direction of the dip. To the north-east, east, and south, on the contrary, the structure is complicated by a considerable amount of faulting; and we believe that these two regions are separated by one great fault (or a series of faults), the exact position of which is masked by the superficial deposits of the Cothi Valley. To the north the position of the break can be located to within a short distance, as the Clynmarch Grits are there seen striking directly into the Llathige Mudstones; and farther south its course probably follows closely that of the Cothi, ranging to the west of the high ground in Pen-y-ddinas and Banc Beili Tew.

In general, the direction of the faults is that of the axes of the folds, that is, north-east to south-west, but there are departures from this rule. The faulting chiefly occurs in the neighbourhood of the massive grits and conglomerates of the Caio Group. These have acted as resistant rigid bodies, and have first been folded and then broken under pressure from the north-west, the result being a series of faults, throwing alternately in opposite directions; and in every case the north-western limb of the fold appears to be faulted out.

IV. Detailed Description of the Beds.

(A) The Beili Tew Group.

The grits and shales characteristic of this group are well exposed in small quarries on the south-west side of Banc Beili Tew. Here the grits are typical; they are never massive, but alternate with the shales, which are often crushed up between them. This grit is easily distinguished from those of higher horizons. It is far less quartzitic, more sandy, and much more ferruginous, weathering very pale with red speckling; it contains unidentifiable organic fragments. The shales are very tough, and the bedding is in most cases obscured by concentric nodular banding. There is no sign of fossils, but from their position and lithological characters we believe the beds to be of pre-Birkhill, probably Hartfell, age.

(B) The Caio Group.

(B_1) The Shon Nicholas Conglomerate is well exposed along the crest of the ridge of that name, 3 miles east-south-east of Llansawel. Its conglomeratic nature is here very evident, the pebbles ranging in size from small grains to boulders 6 to 10 inches in diameter. The matrix is a tough grey grit, and the pebbles are mainly white quartz. These characters are not constant, as, on the next hill to the north (Banc Bwlch Cefn Sarth), the matrix is much more shaly; and, on Banc Goleugoed still farther north, the rock is virtually a grit, and the large pebbles are no longer evident. A few fragmentary fossils were obtained, but collecting was extremely difficult, owing to the toughness of the rock. On the hill-tops the conglomerate stands out as rugged bluffs, but where the weathered product collects, it forms a good red gravel.

The Pen-y-ddinas Grits are only seen to the south-east of Llansawel, where they form the greater part of the abrupt hill dominating the village, and the eastern extremity of Banc Beili Tew. This rock is a very hard grey quartzite, and occurs in massive beds, without interbedded shales. Its character is very uniform throughout the exposures; and we were unable to find the least trace of fossils.

The grit is never found in contact with the conglomerate, so that the relation of the one to the other is difficult to establish; but we believe them to be on much the same horizon, for the upper member of this group, the Llathige Shales and Mudstones (B_2), appears to follow directly on both grit and conglomerate. We were however, unfortunate in never obtaining fossils from the shales in the close neighbourhood of either of these coarse deposits, and we had therefore to rely upon the lithology.

(B_2) The Llathige Shales and Mudstones.—The quarry at Cae-gwyn, under the southern slopes of Shon Nicholas, has furnished probably the lowest graptolitic horizon that we have found in this district. The rock here consists of dark-grey shales, weathering to pale greenish and rusty tints, and thin well-bedded grits, banded and sandy, with the same rusty weathering. The slabs of grit are often characterized by a few large, scattered spherules of pyrite, which weather out brown. Cleavage is here hardly apparent, and the beds dip at 45° N. 10° W. This locality (L. 1 on the map, Pl. XXIX) has yielded several specimens of *Climacograptus normalis*, Lapw., and nothing else.

The mudstones have been largely quarried on the north-western face of Banc Bwlch Cefn Sarth, and the two most important sections are immediately south of the Pumpsaint-Llandovery-road, a quarry near the farm of Bwlch Cefn Sarth (L. 6), and another close to the farm of Llathige (L. 8). The rock is a compact blue mudstone, and is worked along the cleavage-planes in large massive slabs. The bedding is at a high angle: 70° at Bwlch Cefn Sarth and 90° at Llathige. In the first-mentioned quarry the graptolites are all preserved in pyrite, but are badly crushed by the cleavage; in the other, however, the fossils are much better preserved, and we obtained:—*Mesograptus modestus*, Lapw., *Climacograptus rectangularis*, M'Coy, and *Cl. normalis*. This assemblage forms a typical *modestus*-flag fauna.

A very similar rock is seen in the large quarry in Caio village; here the bedding is horizontal, and the cleavage at right angles to the bedding. The fossils obtained indicate the same horizon.

There are many exposures all around the old Roman levels and gold-mines of Pumpsaint. At two different points we have obtained fossils indicating again the zone of *Mesograptus modestus*, and probably the whole mass of rock is of much the same age.

In the northern part, where the workings are still carried on, there is evidence of a great amount of disturbance. The rocks are intensely cleaved, sharply folded into broken anticlines, and riddled in every direction with massive quartz-veins containing a large quantity of pyrite. The country rock is, when fresh, a tough blue mudstone, very similar to that in the Llathige quarry, but when weathered it splits into thin rusty splinters. From these cuttings no fossils were obtained.

A quarter of a mile to the south-west, at Ogof-y-Cawgiau, the rock is not so massive. Thin gritty bands are seen, and fossils are frequent (L. 5 on the map, Pl. XXIX). Dips of 15° north-westwards were noted, and the following fossils obtained:—*Mesograptus modestus* (small form), *Climacograptus medius*, and *Cl. rectangularis*. Some 300 yards to the south-west (L. 4) a shaly bed in the mudstones has furnished *Climacograptus törnquisti*, *Cl. rectangularis (?)*, and *Glyptograptus persculptus*.

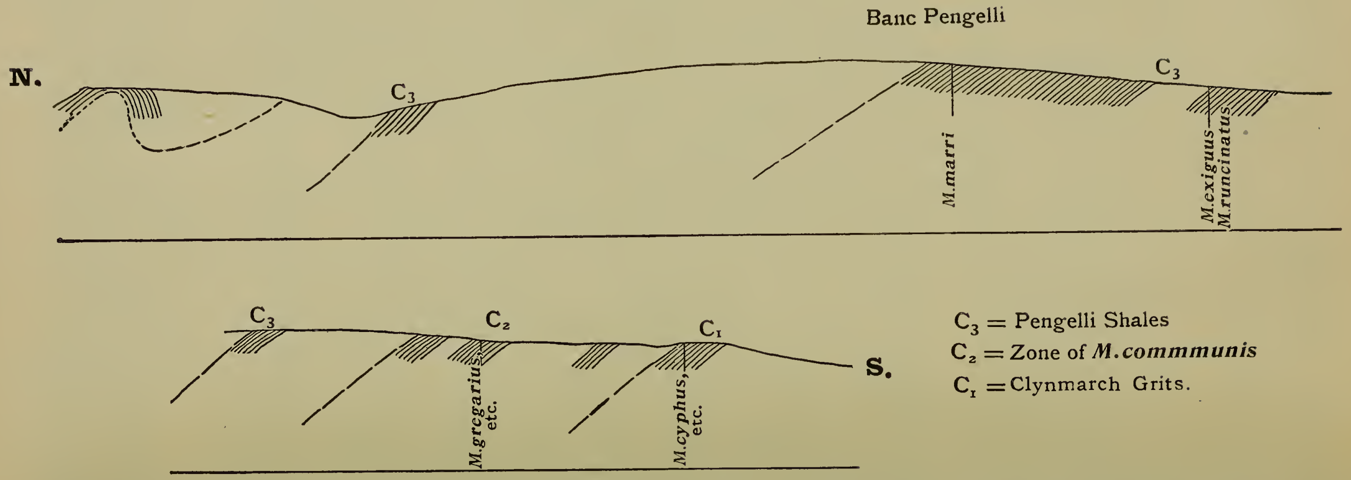
Half a mile south-south-west of Llansawel a tough, well-banded, grey and black shale is clearly exposed in a field-track (L. 3). The rock is seen dipping at an angle of 34° north, 25° west, and yielded *Mesograptus modestus*, *Climacograptus normalis*, and *Cl. medius*.

Just over a mile from Llansawel, along the Abergorlech road, a track leads off to Tre-glôg and Acheth, and here a considerable amount of rock is exposed; but, unfortunately, fossils were only found at one point, and these were in a very bad state of preservation. Around Tre-glôg, and in the track to Acheth-uchaf, the rock is a highly-cleaved soft and slightly nodular shale, with a very yellow or sometimes metallic weathering; and the fossils were obtained from a sandier bed, three quarters of an inch thick, by a gate a quarter of a mile from Tre-glôg (L. 2). The only form identified was *Climacograptus normalis*, Lapw. Beyond this bed the rock changes, and hard, blue-grey, banded mudstones are seen. Cleavage is still intense, and the weathering is a rusty brown. This is the nearest point to the *cyphus* grits where we have obtained exposures, and thus it was particularly desirable to find fossils. But we were entirely unable to do so, and the rock looked so unpromising that we believe it to be barren. From its position it should be in the neighbourhood of the zone of *Monograptus atavus* and *M. rheidolensis*, and the description of these beds in the Pont Erwyd district, with the change from soft shales weathering yellow to hard flags weathering brown, suggests the possibility of a lithological correlation. Also in the above-mentioned region *Climacograptus normalis* was almost the only fossil found in the lower beds of the zone of *Monograptus atavus*. However, this evidence for the age of the beds is very slender, and we do not feel that it is sufficient to enable us to separate them off from the Llathige Mudstone Series.

(C) The Llansawel Group.

(C_1).—The Llansawel Beds are best seen along the hill-road leading northwards from Llansawel to Lampeter. The road rises immediately on leaving the village, and the first exposure occurs in the bank 500 yards up. At this point the rise becomes more

Fig. 2.—*Section for a mile and a half up the mountain road to Lampeter, from a point 360 yards north of Bethel Chapel to 150 yards east of the road, showing the sequence in the Llansawel Group.*



[Scale: 6 inches = 1 mile.]

abrupt as rock emerges from drift. The beds consist of grey-black shales, much cleaved, and weathering into rusty, earthy fragments. Interbedded with them are grey, banded, gritty partings, a half to 1 inch thick; these become more conspicuous up the road, and just before the bend attain a thickness of 12 inches. This thickening of the grits is responsible for the well-marked ridge, already mentioned, which gives the only really continuous strike-line across the area. At this point, on the east side of the road, is a small quarry in grits and shales. There are quarries in the same beds at five other points within half a mile to the south-west, and another half a mile away to the north-east; the largest of these provides an excellent exposure of both grits and shales, 280 yards south-east of Clynmarch. The section is as follows:—

	Thickness in feet.
(3) Thinly bedded banded grits and sandy grey shales	—
(2) Blue-black shales, cleaved, metallic weathering, ripply bedding-surfaces	10 to 15
(1) Sandy micaceous grits, well bedded, with shaly partings .	30

This quarry has furnished the following graptolites:—*Monograptus cyphus*, *M. revolutus*, and *Climacograptus törnquisti*; while the quarry to the east of the road has yielded *Monograptus cyphus* and *Climacograptus rectangularis*.

These beds belong, therefore, to the zone of *M. cyphus*, and we have named them Clynmarch or *cyphus* Grits and Shales (C_1).

Continuing up the road, no more grits are seen, but shales are exposed at intervals in the road and in the bank. On the whole, these appear to be lighter, tougher, and bluer; but they are interbedded with softer black partings, which have yielded a few useful graptolites. Cleavage is still strongly marked, and the dip remains very constant, about 40° north 30° west.

(C_2).—Some 370 yards above the road-quarry were found (L. 14 in the map, Pl. XXIX) *Monograptus gregarius*, Lapw., *M. jaculum*, Lapw. (?), *Mesograptus magnus*, H. Lapw. (?), *Glyptograptus tamariscus*, Nich., and *Climacograptus törnquisti*, Elles & Wood.

Just above this a slight dip occurs in the road, suggesting the presence of softer beds. The small rise which follows is due to dark-grey, rather tough, shales from which no fossils were obtained.

(C_3).—About 300 yards farther on, the rock is a pale mudstone, and weathers to a pale grey with black stains. Rocks of this nature are exposed at intervals for the next 300 yards; and just beyond the road to the north-east the following fossils were obtained in a darker, more shaly bed (L. 15):—*Monograptus* cf. *becki*, *M. exiguus*, and *M. runcinatus*.

These rocks form the road-surface all up Banc Pengelli, and weather into raised hummocky masses; a quarter of a mile above L. 15 one specimen of *Monograptus marri* was obtained.

This series of tough pale rocks we have grouped together under the name of Pengelli Mudstones. For half a mile there are no exposures, and the rock is next seen in the bank where the road turns sharply down hill through a larch wood to a stream. Here its character is somewhat altered, the mudstones have become more massive, more thickly bedded, and slightly nodular, dull grey in colour, and weather yellow. No fossils were obtained. After a second stream has been crossed, the rocks are well seen in the roadside for 200 yards. Here once more grits come in, and with their appearance begins the rolling, so characteristic of these higher beds. The grits are grey and banded, reaching a maximum thickness of 3 inches. The interbedded shales are thin, flaky, dark grey, weathering to a yellow-brown. The cleavage practically coincides with the dip; but, despite this advantage, long search failed to reveal any fossils. The dip varies from 70° S. 20° E. to 48° N. 20° W. There is no change lithologically for nearly a mile, when a stream is crossed and the road rises. Near Cwm Dawe in the roadside are finely laminated blue-black and grey shales, splitting into fragments of papery thinness, with smooth black surfaces, marked by very noticeable concentric orange weathering; there is no trace of cleavage. The gritty bands still persist, and the dip still continually changes in direction. These beds furnished one specimen of *Monograptus marri*. The great distance across the strike, between the two localities yielding this fossil and no other, is easily accounted for by the rolling which sets in among these higher beds.

Confirmatory Sections.

(*a*) Section along Llanybyther Road.—The same series of rocks is crossed obliquely by the Llanybyther road, where is obtained confirmatory evidence of the sequence just described: as before, the section is very discontinuous, and fossil localities are even less frequent.

(C_1).—The first exposure is in the Clynmarch Grits, which are quarried just behind Sunnybank Farm. The character of the rock is absolutely similar to that in the other quarries on the north-east, and the fossils obtained were the same.

(C_3).—There is no further exposure until Cil Wenau is reached, three-quarters of a mile distant; here a considerable stretch of Pengelli Shales is exposed, with the same characteristics as those that were displayed along the Lampeter road, but for the appearance of thin grit bands. Where the road bends sharply northwestwards to Llethr-bledrig, one specimen of *Monograptus marri* was found in greyish shales, with little cleavage and orange weathering. Immediately north of this a dip of 52° south 20° east was observed, showing that the rolling comes in again, at about the same horizon as before.

Just beyond Rhyd-cymmerau the road divides into two. About 600 yards along the northern branch, and on the same line of strike up the steep hill on the west to Pant-glâs, flaky, thinly-bedded, uncleaved, orange-stained shales occur. No fossils were found, but lithologically the rock is identical with that seen near Cwm Dawe.

A little farther along the western road above Pant-glâs, grits become more numerous, and are interbedded with thin layers of black shales. Cleavage has once more appeared, and the shales are shivered up between the grit bands, giving a very characteristic appearance.

(*b*) Section on the Gorlech.—(C_1) Half a mile above Abergorlech the ridge of the Clynmarch Grits crosses the stream, making a sharp feature, and the rock has been quarried high up on the eastern slope, in the wood. The lithological characters are identical with those seen in the quarries of Clynmarch and Sunnybank, and the following fossils were obtained:—*Monograptus cyphus*, *M.* cf. *atavus*, O. T. Jones, *Climacograptus rectangularis*, *Cl. hughesi*, Nich., and *Orthograptus mutabilis (?)*.

(*c*) (C_1).—Nearly 2½ miles from Clynmarch, along the ridge to the north-east, the *cyphus* grits and shales are exposed again in a quarry in a wood, east of Cefn-telych. The beds dip 50° north-westwards, exhibit the characteristic lithology, and yield the typical fossils.

(C_3).—Two-thirds of a mile away to the north, high on the side of a hill, is a small quarry opened up in shales and thinly-bedded grits, the former uncleaved, smooth, and splitting up into thin laminæ. These beds (L. 16 on the map, Pl. XXIX) yielded graptolites in a very bad state of preservation; they have doubtfully been referred to *Monograptus marri*, *M. runcinatus*, and *M. galaensis (?)*. We therefore associate the beds with the Pengelli Shales.

V. Detailed Structure of the Outcrops of Conglomerate.

The complicated structure of this district is only brought out by detailed mapping. At the east of the Shon Nicholas ridge, where it is crossed by a mountain road, the conglomerate is exposed for 75 yards across the strike. A short distance to the south-west along the strike, a small subsidiary roll brings up the conglomerate again to the north-west of the main ridge. This small dome dies out in about 600 yards, beyond which the main outcrop widens, attaining its maximum width of 220 yards, three-quarters of a mile from the road mentioned above: at this point the direction of the dip is north 30° west. The base of the conglomerate is clearly marked by a well-defined feature, and at the western end of the hill is seen to swing round in accordance with the change of strike which sets in. The dips change first to north, then to south 60° east; while a north-westerly dip between them indicates a small secondary roll. The conglomerate outcrop also diminishes steadily in width and, after striking north-eastwards for a distance of 220 yards, ends

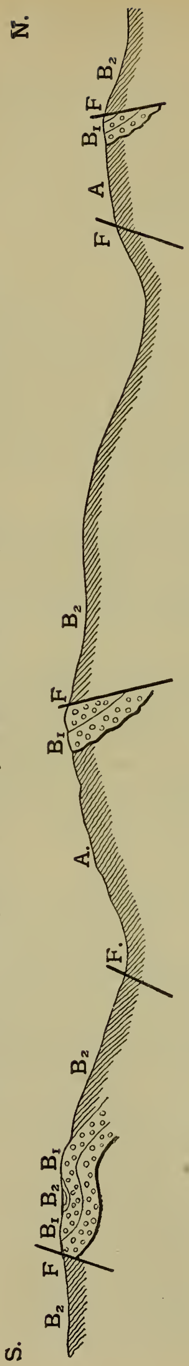


Fig. 3.—*Section across the conglomerate outcrops, from a point 150 yards north of Maes y Cwarau to a point a quarter of a mile south-south-west of the summit of Banc Goleugoed.* (*Scale: 6 inches = 1 mile.*)

[A = Beili Tew Group; B_1 = Pen-y-ddinas Grits; B_2 = Llathige Shales & Mudstones; F, F = Faults.]

abruptly against the Shon Nicholas Fault, ranging north-east and south-west, and throwing down higher beds against the conglomerate on the north-west.

South of the main outcrop the Llathige Shales of L. 1 appear to dip directly under the conglomerate. These shales owe their position to the Cae-gwyn Fault, which runs parallel to the Shon Nicholas Fault, but throws in the opposite direction, and cuts out the base of the conglomerate for part of its course.

Returning to the mountain-road mentioned on p. 413, the Llathige Shales are seen to follow the conglomerate in a natural sequence for a distance of 360 yards, at which point the tough concretionary Beili Tew Shales are brought on by the Shon Nicholas Fault, which is now throwing to the south. After 400 yards these apparently pass conformably under another small outcrop of the conglomerate: this forms a shallow syncline capping the southern crest of Banc Bwlch Cefn Sarth, and is cut off on the north by the Llathige Fault, introducing shales followed by the Llathige Mudstones exposed at L. 6.

Some 300 yards north of this point, the Bwlch Cefn Sarth Fault, with a downthrow to the south-east, repeats another small area of the Beili Tew Beds, capped by a small outcrop of conglomerate, on the crest of Banc Goleugoed; and a small patch of conglomerate crowns the little hill of Allt-y-Pigyn. Both the above are cut off on the north by the Goleugoed Fault, which throws them into contact with higher beds.

VI. Detailed Structure of Pen-y-ddinas and Banc Beili Tew.

In general, the structure here is that of two elongated domes, which have been dislocated by a number of faults. The dome is most complete in Pen-y-ddinas, where the rock is

Fig. 4.


MAP OF
PEN Y DDINAS
Scale of Yards
0 25 50 100
= 15 inches to 1 mile.
N.
700
25°
600
800
826
28°
30°
800
700
40°
42°
63°
90°
700
90°
45°
600
To Llansawel
To Talley
Altitudes are
indicated in feet.
B2. Llāthige Shales
& Mudstones.
B1. Pen-y-ddinas
Grits.
A. Grits & Shales.

mainly the tough grey quartzite named after that hill. This is followed by blue Llathige Mudstones, and underlain by Beili Tew Shales. On the south-west side the dome has been broken up by radial faults into a series of wedge-shaped masses, the Beili Tew Shales being exposed in the centre. One of these faults is marked by a massive quartz-vein. To the south-east the hill falls gently, and the grit is followed by blue Llathige Mudstones; but on the north-west there is a sudden change of slope, marking the position of a great fault, which ranges for at least a mile to the south-west across Banc Beili Tew and is probably continuous with the Bwlch Cefn Sarth Fault. This latter hill is mainly composed of rocks belonging to the Beili Tew Group; but in the north-eastern corner Pen-y-ddinas Grits occur, introduced by a series of three parallel step-faults at right angles to the direction of the hill. (See fig. 4, p. 415.)

VII. General Summary.

On the south there is a great development of grits and shales belonging to the Beili Tew Group, which we believe to be of Hartfell age.

The rocks of our Caio Group cover a wide area, and at many scattered localities we have obtained a fauna from which the genus *Monograptus* is entirely absent, while *Climacograptus* and *Diplograptus* are fairly frequent. We probably have here the representatives of the Lower Birkhill zones up to that of *Monograptus cyphus*. We have not, however, obtained sufficiently detailed palæontological evidence to elucidate the stratigraphical relationships of the different beds.

In our Llansawel Group we have the zone of *Monograptus cyphus* represented at the base, followed by the zone of *M. communis*. Above this are 1200 feet of rocks from which we have been unable to obtain any fossils, but they are presumably the equivalents of the highest zones of the Birkhill and the lowest zones of the Gala Shales. These barren beds are followed by 900 feet of rock yielding Lower Gala forms, and above this again is an enormous extent of rolling beds, which yield at distant intervals graptolites of much the same horizon. There is consequently no evidence that the overlap which occurs at the base of the Gala Beds in the Rhayader district extends to the Llansawel area.

VIII. Comparison with the Deposits of other British Areas.

The only areas with which we have thought it necessary to compare that of Llansawel are the neighbourhood of Rhayader described by Dr. H. Lapworth,[1] and that of Pont Erwyd dealt with in the recent paper of Prof. O. T. Jones.[2]

The general character of the deposits in these three districts appears to be closely similar, with a marked absence of calcareous

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 67.
[2] *Ibid.* vol. lxv (1909) p. 463.

rocks and predominance of shales, mudstones, and grits; but striking differences exist, and the Llansawel area seems to hold an intermediate position between the other two.

The Shon Nicholas Conglomerate and Pen-y-ddinas Grit which form so well marked a base to our Birkhill Series are absent altogether round Pont Erwyd, but are represented by the Cerig Gwynion Grit of Rhayader. The nature of this rock agrees very closely with that of our Pen-y-ddinas Grit, for it is described as

'a very dense, tough, hard quartzose grit or grauwacke. The colour varies from bluish-grey to greenish-grey.'[1]

In this respect, therefore, the district here described more closely resembles Rhayader. But there appears to be around Llansawel, as in Pont Erwyd, a complete passage from Lower to Upper Birkhill rocks, and the great Caban Conglomerate is entirely absent. Also, as far as we can see, there is no overlap at the base of the Gala rocks in Llansawel, but a complete passage up from Birkhill to Gala Shales, as in the Pont Erwyd district.

With regard to the detailed stratigraphy, there are many very close resemblances in lithology between the Llansawel district, and sometimes one, sometimes the other, of the Central Welsh areas under discussion. The Beili Tew Shales seem to agree very closely with the mudstones of the Drosgol Series, with the

'curious gnarled and knotted surface on weathering, which is connected with their internal structure, for a fresh fracture shows numerous dark laminæ twisted and contorted in a remarkable manner.'[2]

The characteristic grits in our *cyphus* zone, which cause a rise in ground wherever they occur, may be represented in the Rhayader district by the 'ferruginous sandy and green gritty beds'[3]; but in Pont Erwyd they seem to be entirely absent, and there the prominent feature is everywhere made by the pale mudstones of the *convolutus* zone, which are never conspicuous around Llansawel.

Lastly, the closest resemblance of all is seen between the upper part of the Pengelli Series and the higher part of the Rhayader Pale Shales, which are described as soft pale-grey shales, interbanded with grits, and weathering to a brilliant orange colour.[4] These shales are quite free from cleavage, and the graptolites are well preserved, whereas the Lower Pale Shales were highly cleaved. The resemblance is rendered even more complete by the fact that in the Rhayader district, as around Llansawel, folding and inversion sets in at this Upper Gala horizon. With regard to the faunal characteristics, it is quite impossible to institute a comparison. Only in the Llansawel Group is there a really clear stratigraphical succession, and here the characteristic graptolites occur in the same order as that in which they are found in other districts. For the

[1] H. Lapworth, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 95.
[2] O. T. Jones, *ibid.* vol. lxv (1909) p. 469.
[3] H. Lapworth, *op. supra cit.* p. 78.
[4] *Ibid.* p. 123.

rest, the few fossils found in scattered localities have been used as an indication of the zonal horizon, and not for the establishment of the sequence of graptolites; where there is an apparent anomaly in the assemblage of forms, as at L. 4, at which place *Climacograptus törnquisti* occurs with *Glyptograptus persculptus*, the preservation is so bad that the species is not to be relied upon.

In conclusion, we wish to express our thanks to those who have so kindly helped us: to Mr. H. H. Thomas, M.A., F.G.S., for very valuable encouragement and advice at the outset; to Miss G. L. Elles, D.Sc., for the identification of all our graptolites; and more especially to Prof. O. T. Jones, M.A., F.G.S., who is really responsible for the existence of this paper, for, without his encouragement and assistance on one or two critical occasions during the progress of the work, we should have been sorely tempted to abandon it in despair, and leave this perplexing district to others more fitted to cope with its problems.

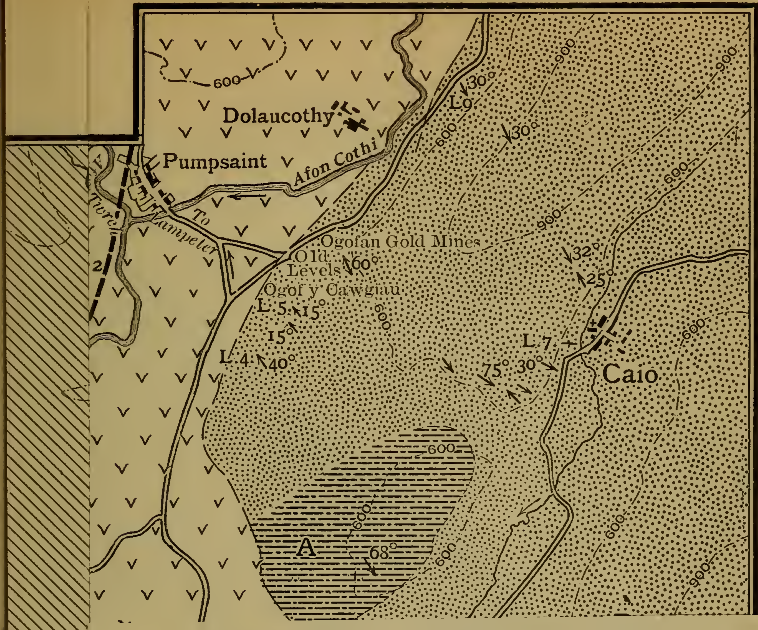
EXPLANATION OF PLATE XXIX.

Geological map of the district around Llansawel (Carmarthenshire), on the scale of 2 inches to the mile.

Discussion.

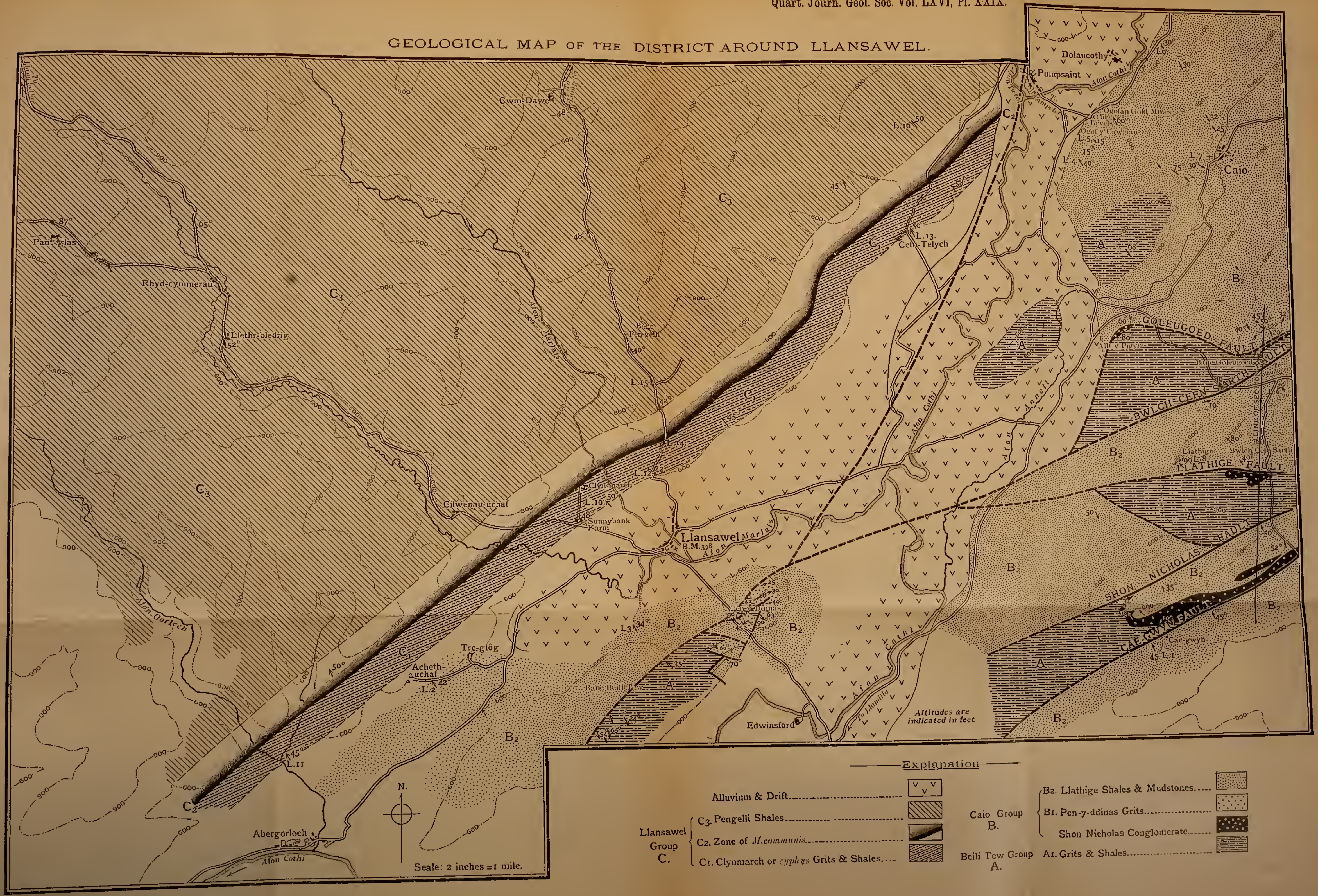
Prof. O. T. Jones congratulated the Authors on the patience and persistence with which they had carried out the investigation of a particularly difficult piece of country. The paper brought out for the first time the extraordinary difference between the facies of the Valentian rocks on opposite sides of the anticline which ranges down the Vale of Towy. On the south-east side is situated the type-area of Llandovery, characterized by 'shelly' fossils almost exclusively. Very few graptolites have ever been found in that area, but other fossils are abundant at certain horizons. On the north-west side of the anticlinal axis the Valentian fauna is almost entirely graptolitic, and no 'shelly' fossils have been recorded, except from the basal conglomerates. The distance which separates the two facies at the present day is only 8 to 10 miles, but must have been greater originally, as the rocks in the intervening space are considerably folded and repeated by strike-faults. Even making allowance for this, however, it is evident that the transition from one facies to the other must have taken place with comparative abruptness. The transitional belt can be traced from this region, both in a north-easterly direction into North Wales and in a south-westerly direction towards Pembrokeshire.

Dr. Herbert Lapworth congratulated the Authors on their completion of a very difficult piece of work. He referred to the remarkable fact that, although graptolitic zonal work had been carried on for over thirty years in the Llandovery rocks of Britain,



Dolaucothy
Pumpsaint
Afon Cothi
To Lampeter
Twrch
Ogofan Gold Mines
Old Levels
Ogof y Gawgiau
L. 9
L. 5
L. 4
L. 7
Caio
A
600
900

GEOLOGICAL MAP OF THE DISTRICT AROUND LLANSAWEL.



the original type-area of Llandovery itself was still untouched in this respect. He would be glad if the Authors would state whether in the Llansawel area they had observed a great lithological change from the lower dark beds to the upper pale shales and mudstones of the Gala type, occurring at the horizon where the genus *Rastrites* made its first appearance. This phenomenon, apparently, was to be seen in all other Valentian areas in Britain.

Mr. H. H. Thomas stated that he wished to add his congratulations to those of previous speakers. He knew enough of the country described by the Authors to understand the great difficulties that they had to surmount during the four years over which this work extended. The district was one in which cleavage, folding, faulting and poorness of exposures, combined with the high relief of the country, all conspired to make the work arduous. It was most gratifying, therefore, to find that despite all these discouraging factors, the Authors had brought their work to so successful a conclusion. He felt pleased that he had in a measure influenced the Authors in their choice of a district.

The President (Prof. W. W. Watts) regretted the absence of Prof. Charles Lapworth and of Dr. Marr. He complimented the Authors on their pluck and persistence in completing so difficult and unpromising a piece of work, and was glad that they had both received the award of the Daniel Pidgeon Fund. The establishment of graptolitic horizons in this area marked another advance in the subdivision of the monotonous country of Central Wales. The multiplication of local terms appeared to be a necessary evil, but one which was to be preferred to premature attempts to correlate the subdivisions with those of such an area as Llandovery, where the succession had not been studied in the light of modern methods.

Miss Drew, replying for the Authors, in answer to Dr. Herbert Lapworth, said that in the Llansawel district it was the *cyphus* grits which made by far the most prominent feature in the country occupied by the upper beds; as far as had been ascertained, there was nothing comparable to the *convolutus* grits of the Rhayader district. *Rastrites peregrinus* had not yet been found in the area under consideration, but at the horizon where it should occur there was a distinct change in the lithology, shales with black partings giving way to a series of tough pale-grey mudstones. The grits of Bala age had not been studied in much detail, but they seemed to be of a slightly nodular and impersistent occurrence. In conclusion, the Authors wished to thank the Fellows most heartily for their very kind reception of the paper.

17. *The* Rocks *of* Pulau Ubin *and* Pulau Nanas (Singapore).

By John Brooke Scrivenor, M.A., F.G.S., Geologist to the Federated Malay States Government, and formerly of H.M. Geological Survey of the United Kingdom. (Read December 1st, 1909.)

Contents.

I. Introduction.

In the January number of the 'Geological Magazine' for 1909 [1] a short note of mine appeared on the igneous rocks of Singapore, giving the results of observations made on occasional visits to Singapore from the Malay States during the years 1904 to 1908. Not many weeks after the paper had been despatched, a further opportunity presented itself of visiting some of the localities mentioned; and, as perhaps has happened to others, I found that the fresh information available in the quarries was so extensive and so significant that my remarks in the note mentioned appeared very meagre. It proved too late, however, to withdraw the paper, and therefore the following remarks must be considered in some sense supplementary to those in the earlier paper; but, at the same time, they embody other new information that will, I think, be found to be of considerable interest to those who have studied the geology of the East Indies.

My object in the present paper is to describe the granite of Pulau Ubin, veins of rhombic pyroxene-bearing rocks traversing this granite, as well as 'basic masses' in the granite of the same island; also to describe fragments of granite in tuffs on Pulau Nanas, and to show that these are derived from a granite mass distinct from and much older than that forming Pulau Ubin, and therefore also older than the tin-bearing granite that now forms the backbone of the Peninsula. Further, the mutual relations of the granite, the veins, and the basic masses on Pulau Ubin, and their relation to rocks in the Archipelago, will be discussed.

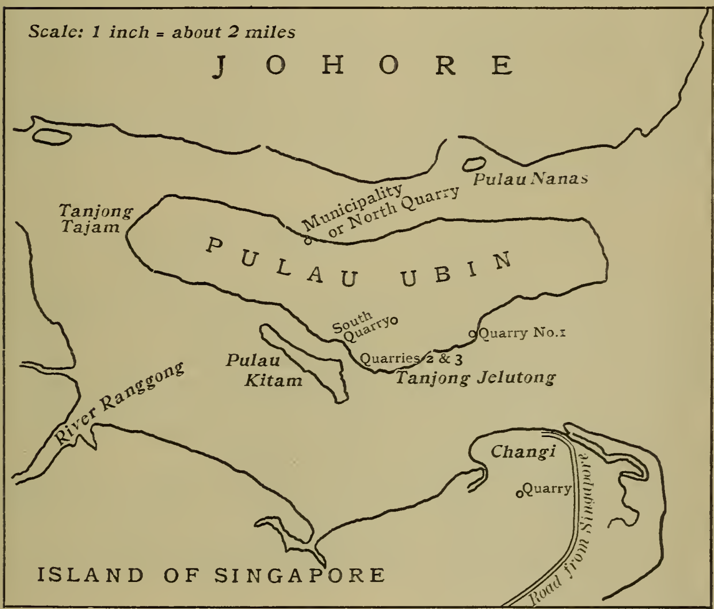
So far as previous literature is concerned, it is unnecessary to do more than note J. R. Logan's paper mentioned in my earlier

[1] 'Note on the Igneous Rocks of Singapore, with Special Reference to the Granite & Associated Rocks carrying Rhombic Pyroxene' Geol. Mag. dec. v, vol. vi (1909) pp. 17–22.

publication.[1] I would take this opportunity of mentioning, however, with regard to my record of tin-ore at Bukit Panjang,[2] the discovery this year by Mr. Loveridge of tin-ore, in quantities sufficient for working, at Bukit Mandai, near Bukit Timah.

Pulau Ubin[3] is a small, jungle-clad island set in the eastern entrance to the narrow Straits of Johore, which separate Singapore Island from the mainland of the Peninsula. Pulau Nanas is a still smaller island north of Pulau Ubin, lying close to the Johore coast. On both islands there are quarries, the stone worked being used in Singapore town; and of late a large quarry has been

Fig. 1.—*Sketch-map of Pulau Ubin and Changi (Singapore).*



opened up on Pulau Ubin, near Pulau Kitam, for harbour works. For convenience this will be referred to as the South Quarry, while the Municipality Quarry on the northern coast of Pulau Ubin will be referred to as the North Quarry. Quarries 1, 2, & 3 will be mentioned by their numbers.

[1] 'Notices of the Geology of the Straits of Singapore' (with geological map) Quart. Journ. Geol. Soc. vol. vii (1851) p. 310.

[2] Geol. Mag. dec. v, vol. vi (1909) p. 19.

[3] Pulau Ubin = the island (Pulau) of hard stone; Pulau Nanas = the pineapple island.

II. Pulau Ubin.

The Normal Granite.

The normal granite of Pulau Ubin is a medium-grained hornblende-granite. The proportion of ferromagnesian minerals (green hornblende and biotite) varies. Apatite, zircon, and magnetite are common. The felspars are orthoclase and a soda-plagioclase. In some slides the latter is abundant, in others scarce. There is nothing remarkable about the quartz.

Large quantities of the heavier minerals in this granite have been concentrated with a view to searching for pyroxene, good material for this purpose being found at Tanjong Jelutong, near Quarries 2 & 3. Monoclinic pyroxene was found in small quantities, but no rhombic pyroxene, except in one case (in the North Quarry) where the rock was so near rocks bearing rhombic pyroxene that the evidence was not conclusive. In the North Quarry two very small veins were found traversing the normal granite, one consisting of dark-green monoclinic pyroxene, hornblende, and garnet, the other containing wollastonite and garnet.

Microgranite with Monoclinic Pyroxene.

This occurs in the South Quarry: it is fine-grained and very pale. In section the dark minerals are seen to be granules of green monoclinic pyroxene, hornblende, biotite, sphene, and abundant magnetite. For the rest, the rock is composed of a rough mosaic of quartz, orthoclase, and soda-plagioclase, the last being common.

A small vein in this rock was found to consist of quartz, orthoclase, soda-plagioclase, sphene, and abundant monoclinic pyroxene. This vein was probably formed by segregation.

The microgranite occupies most of the South Quarry, but at one end (the far end from the landing-place) normal hornblende-granite was found. Its relation to the microgranite was not clear.

There are a few dark patches in the microgranite that will be described later.

Rocks bearing Rhombic Pyroxene in the North Quarry.

In my previous paper I mentioned three rocks from the Municipality, or North Quarry, which were designated by the letters *a*, *b*, & *c*.[1] On revisiting this quarry I found that work on the face had progressed greatly and that a very interesting section had been exposed: this is reproduced diagrammatically in fig. 2 (p. 423). No doubt exists now as to the relation of the rock *a* to the granite, as may be gathered from the following description of the section, based on a large number of slides cut from specimens collected from different parts of the face.

[1] Geol. Mag. dec. v, vol. vi (1909) pp. 19–21.

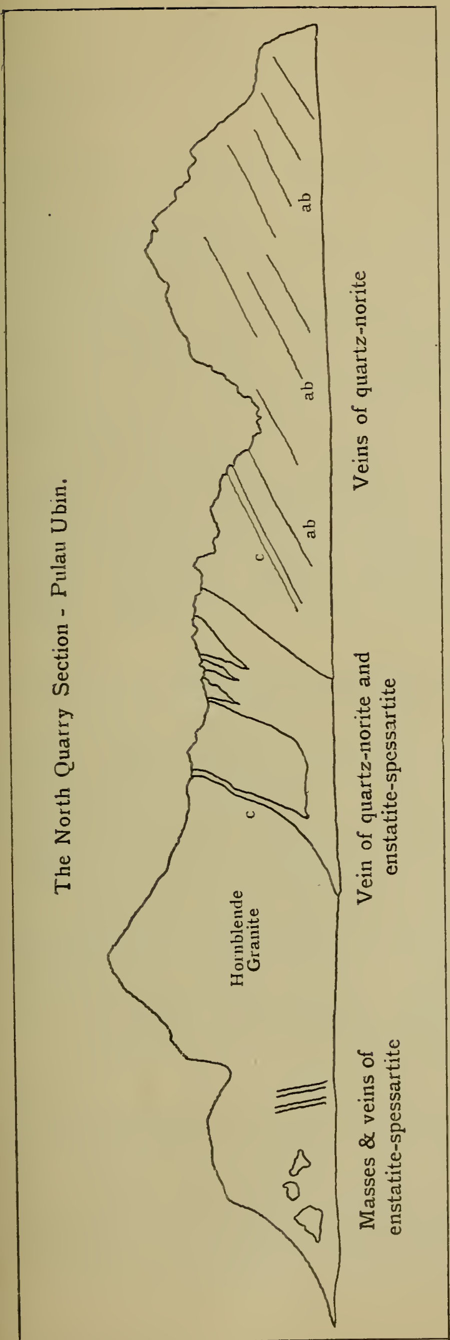


Fig. 2—(*Not drawn to scale*).

On the right of the section are nine roughly parallel veins (*ab*) of a crystalline rock (*a* & *b* in the previous paper) cutting the normal hornblende-granite. The veins are only a few inches thick, generally about 3 inches. They are composed of quartz-norite with subordinate biotite, hornblende, and monoclinic pyroxene. The felspar is mainly plagioclase, but enclosed in the crystals of plagioclase are small prisms which may be orthoclase. A separation, however, of the rock-constituents in iodides of mercury and potassium did not yield any orthoclase.[1] The rhombic pyroxene in good sections is almost colourless, and rarely can any pleochroism be observed. But, in thick sections and in grains separated from the crushed rock, it is seen to be coloured, and to give the characteristic pleochroism of rhombic pyroxenes. The position of the acute bisectrix could not be determined with certainty, nor could sufficiently clean material be separated for an estimation of the iron contents.

[1] A little felspar of the same specific gravity as quartz was obtained (2·66): the rest was slightly heavier. The maximum extinction-angle on sections perpendicular to the twin lamellæ was 23°. This points to the greater part of the felspar being between andesine and labradorite. The maximum extinction-angle observed in the plagioclase of the normal granite was 14°. In the pyroxene-microgranite the extinction-angle shows that some of the felspar approaches that in the quartz-norite.

Following Prof. Judd's description of the Krakatoa pyroxene,[1] therefore, I will refer to the mineral as enstatite.

The enstatite sometimes gives fairly good prism-sections, with straight extinction and low interference-colours. Basal sections show the cleavages and a bisectrix (which bisectrix is doubtful). The quartz is abundant, and occurs as interstitial grains between the crystals of plagioclase. Magnetite is abundant, while zircon and apatite are also associated with the ferromagnesian minerals. The hornblende, in part at any rate, is a secondary product derived from the enstatite. The specific gravity of the rock is about 2·81.

In the centre of the section is a large and complex vein, a branch of which (*c*) is the continuation into the face of the quarry of the 'dyke-like mass' figured on p. 20 of my previous paper, in the 'Geological Magazine' for 1909. This consists of a very fine-grained, dark, reddish-brown rock, and can be followed down into the mass of the vein in the base of the quarry-face. A separate vein (*c*) of the same rock occurs to the right of this big vein. The big vein itself consists of a mixture of the fine-grained rock and a rock of varying coarseness, which, in the hand-specimens, seems identical with that forming the veins on the right of the section. Under the microscope, sections show that it is of much the same composition, the points of difference being the greater proportion of green monoclinic pyroxene, and the predominance of hornblende and biotite over the enstatite. Quartz is abundant.

Specimens from the fine-grained rock (*c*) differ, in that one ferromagnesian mineral may be present in one specimen but absent in another. The rock, considered as a whole, may be described as follows:—The base consists of plagioclase and what appear to be minute prisms of orthoclase with some interstitial quartz. In this are ragged greenish-brown flakes of hornblende, small plates of biotite without crystal outline, and granules and ragged masses (which are, however, in optical continuity) of monoclinic pyroxene and rhombic pyroxene of the same nature as that in the coarser rocks. The last mineral is recognizable by its low interference-colours, straight extinction, and sometimes by the pleochroism.

On the left of the section are two parallel veins of the fine-grained rock (*c*) and several masses of the same rock, that can only be interpreted as included fragments caught up by the granite. With the exception of these masses, all the enstatite-bearing rocks in this quarry are certainly in the form of veins. Their mode of origin will be discussed later.

A curious point about the North Quarry is that on the whole of the large granite-face no 'basic patches' were observable when I visited it, unless the masses of the rock *c* be considered as such.

[1] 'The Eruption of Krakatoa & Subsequent Phenomena' Report of the Krakatoa Committee of the Royal Society, 1888, pp. 31, 32, & 34. The mineral in the Pulau Ubin rocks is probably bronzite; but, in the absence of definite information as to the position of the acute bisectrix and the percentage of iron, it is better to refer to it as enstatite.

In my previous paper I mentioned a small vein of pink garnet, pale-green monoclinic pyroxene, wollastonite (largely altered to calcite), and quartz in the rock *c*. The specific gravity of the fine-grained rock is 3·01.

Porphyry in the New Quarry behind the North Quarry.

A new quarry has been opened on the reverse slope of the hill in which the North Quarry is located. The rock exposed is fresh and dark, of fine grain, and showing phenocrysts. The microscope shows that orthoclase and quartz form the ground-mass, in which are set numerous badly-formed prisms of orthoclase and some plagioclase with secondary calcite. Ragged flakes of biotite occur, but more common are peculiar spongy masses of green hornblende, this structure being probably due to partial resorption of hornblende-crystals.

Here also must be noted a fine-grained rock (*d* in the previous paper, p. 21) found as large reddish-brown masses in the granite at Changi, on Singapore Island (see fig. 1, p. 421). This consists of orthoclase in short, well-formed prisms, a little plagioclase, abundant interstitial quartz in optical continuity over large areas of the field, biotite in small ragged flakes, green hornblende, and abundant apatite. No veins of this rock have been observed.

'Basic Masses' in Quarry No. 1.

I have already mentioned the occurrence of large, angular 'basic patches', which are better described as 'basic masses', in Quarry No. 1.[1] The number of those exposed now is very large, and all, with one exception, were at the time of my last visit of the same nature. This exception was a roughly spherical mass about 4 feet in diameter, of a dark reddish-brown colour and fine grain, resembling the fine-grained rock *c* in the North Quarry. Sections, however, showed a fine mosaic of quartz, orthoclase, and plagioclase, masses of large quartz-grains, biotite in minute flakes, a little ragged hornblende, and pale-green granules which show some of the properties of monoclinic pyroxene. A black dust is present also. This rock, which cannot strictly be called basic, strongly suggests an included mass of highly altered sediment or fine-grained ash. At one or two points in it granite was visible, probably forming small veins.

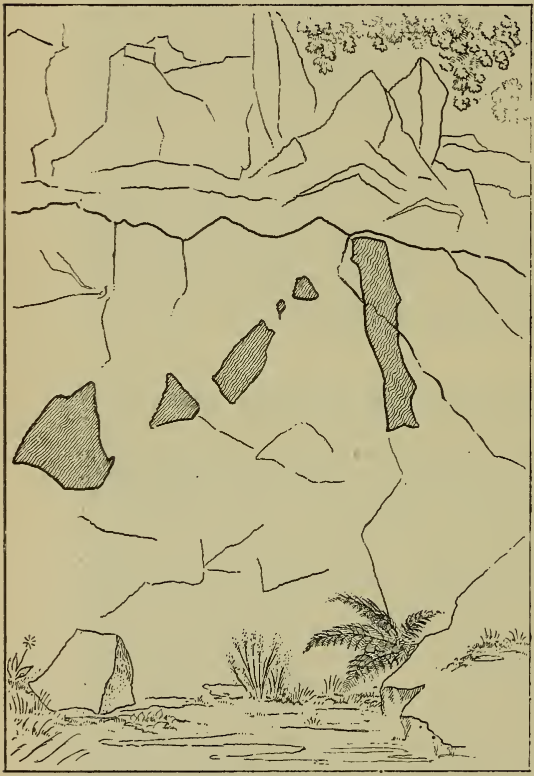
Fig. 3 (p. 426) shows some of the angular masses in the granite. The largest is remarkably like a portion of a dyke, but a close study of the quarry satisfied me that all these dark masses were

[1] Geol. Mag. dec. v, vol. vi (1909) p. 21.

enclosed in the granite and none of them intrusive. Specimens from several masses were collected, and the slides prepared from them reveal an unexpected resemblance to the veins *ab* and the coarse portion of the big vein in the North Quarry.

The following general description will illustrate this :—The rock composing the basic masses is crystalline and of medium grain, and the proportion of the dark minerals varies slightly. These dark minerals are biotite, green hornblende, pale-green monoclinic pyroxene, and sometimes rhombic pyroxene also (like the enstatite described above, but largely altered to green hornblende), accompanied by apatite, zircon, and magnetite. In some of the specimens it was noted that the hornblende occurs as spongy masses resembling those in the porphyry exposed behind the North Quarry. The apatite, in long prisms, is sometimes very abundant, and the crushed rock gives a heavy precipitate when a nitric-acid solution is treated with ammonium molybdate.

Fig. 3.—*Angular masses of quartz-biotite-gabbro in the hornblende-granite of No. 1 Quarry, Pulau Ubin.*



The clear minerals in these basic masses are plagioclase (like that in the quartz-norite of the North Quarry), perhaps a little orthoclase, and interstitial quartz, the amount of which varies considerably in different specimens. These masses are, then, of very similar composition to the coarse vein-stones in the North Quarry, and may be described as quartz-biotite-gabbro with subordinate enstatite.

Dark Masses in the Microgranite of the South Quarry.

In the microgranite of the South Quarry, a few ill-defined patches of dark rock occur, which are of interest in that they show a resemblance to the porphyry exposed behind the North Quarry. Slides prepared from these dark masses show that the clear minerals consist of quartz (sometimes interstitial between felspar crystals), orthoclase and plagioclase, which occasionally form phenocrysts, and micropegmatite. The dark minerals are green hornblende, in ragged flakes and sometimes in spongy masses (like those in the porphyry), monoclinic pyroxene, biotite, sphene, and magnetite.

This concludes the description of the Pulau Ubin rocks, a description that is far from complete, but emphasizes, I hope, the salient points. Before discussing their relations, I must pass to the Pulau Nanas tuffs and the included granite fragments.

III. Pulau Nanas.

One of the important features in the structural geology of Pahang, the largest and least known of the Federated Malay States, has proved to be a widespread series of volcanic rocks of considerable antiquity.[1] These vary in composition, and it is not yet known whether a number of 'greenstones' should be included in the group or not. For the most part, however, the series consists of dacites, with ashes of corresponding composition. These volcanic rocks, which I have named the Pahang Volcanic Series, are interbedded with calcareous rocks (the Raub Series) containing a few organisms referred to the Carboniferous and Permo-Carboniferous, and they are evidence of eruptions over a large area of the sea-floor in those times. A characteristic feature of the ashes is the inclusion of fragments of chert and carbonaceous shale; both ashes and lavas are sometimes found to be sheared, and to contain secondary minerals due to contact-metamorphism caused by the tin-bearing granite.

The general strike of the Raub Series and the Pahang Volcanic Series is such that they may be expected to extend into Johore, and therefore it is not surprising to find that Pulau Nanas consists entirely of ashes and lavas closely resembling some of those in the Pahang Volcanic Series. They are dacites and dacite-tuffs, and the influence of the neighbouring granite of Pulau Ubin is shown by their hardness, as also by the large development of secondary biotite and hornblende. In the tuffs I have found one or two small pebbles that appear to be altered chert, with very minute

[1] These were described in my 'Report of Progress: Sept. 1903–Jan. 1907' (Federated Malay States) Kuala Lumpur, pp. 9–11.

crystalline grains which are probably secondary hornblende, and a little calcite.

But the most remarkable feature of these tuffs is the presence of fragments of altered granite, and it is fortunate that, even though the large quarries on this island be abandoned, there will remain on the north side of the island an exposure washed by the water of the Straits, which, therefore, unlike most sections in the tropics, may be expected to endure, showing these granite fragments clearly, and showing, moreover, that the pieces of granite seen are not sections of veins.

Sections from the fragments of granite show that it is a biotite-granite, with orthoclase and small crystals of plagioclase often included in the orthoclase. The biotite is somewhat altered. In the felspar and biotite crystals there is a considerable development of secondary green hornblende; secondary brown mica is associated with the original biotite, and often occurs in the felspar also.

I have no doubt that the tuffs and lavas of Pulau Nanas form an extension of the Pahang Volcanic Series, and that the granite fragments have been as much affected by the contact-metamorphism of the younger granite as the volcanic rocks. The last must have been erupted on the earth's surface or on the sea-bottom, and it follows, therefore, that the granite mass from which these fragments were derived had consolidated much earlier. We are safe, then, in saying that these fragments are conclusive evidence of a pre-Carboniferous granite in the Peninsula; and I may mention here an interesting discovery of two small pebbles of schorl-rock in the Tembeling conglomerate, which is certainly older than the granite that now forms the backbone of the Peninsula. These pebbles may have come from the pre-Carboniferous granite; but as tourmaline in a granite mass always suggests the possibility of finding tin-ore also, I must add that hitherto I have found no detrital tin-ore in rocks older than the tin-bearing granite.

IV. The Relations of the Pulau Nanas Granite Fragments and the Pulau Ubin Normal Granite to the Granite Masses of the Archipelago.

The fragments of granite and the pebbles of schorl-rock are the only evidence available so far of pre-Carboniferous rocks in the Peninsula. This is a fitting place to discuss the relationship of the pre-Carboniferous granite and the younger granite[1] to granite masses described by the Dutch geologists in the Archipelago.

[1] I have elsewhere ('Geologist's Report of Progress: Sept. 1903–Jan. 1907' p. 13) discussed the possibility of the tin-bearing granite having been erupted at two distinct periods. The balance of evidence is against this view.

In dealing with areas so large as the Malay Peninsula and Archipelago it would be too much to assume, even were there no evidence to the contrary, that masses of granite far removed from one another are of the same age; but there is one factor in the geology of the East Indies that supports the correlation of certain granite masses. This is the presence of tin-fields; and we may suppose, therefore, that the granites of the Peninsula and the islands of Banka and Billiton,[1] which lie approximately on a prolongation of the axis of the Peninsula, are of the same age. With the exception of some radiolaria found on Billiton and described by Dr. G. J. Hinde as probably Palæozoic,[2] the two islands have afforded no palæontological evidence of the age of the granite; but on the Peninsula the case is different, and we have reason for supposing that the tin-bearing granite is post-Inferior Oolite, and certainly post-Triassic.[3] This gives us one limit of age: for the other we must turn to the Archipelago, where we have the significant fact that in Sumatra and Java are Tertiary deposits containing granite pebbles. Thus Dr. Verbeek & Dr. Fennema state that the oldest Tertiary conglomerates of Java contain granite fragments[4]; and, again, Dr. Verbeek in 1875 described Tertiary breccias in Central Sumatra[5] containing fragments of syenite, granite, quartz-porphyry, etc. We may say, then, that the other limit is not later than the oldest Tertiary; but if we go to Borneo, we find further though not such strong evidence. In his description of Central Borneo,[6] Prof. Molengraaff speaks of granite and pegmatite boulders found in great quantities in a conglomerate, probably of Cretaceous age, on the Seberoewang River, and on the slopes of Mount Oejan, adding, however, that nothing is known of the origin of those boulders. So it is possible that the granite of the Peninsula, and therefore the normal granite of Pulau Ubin, is post-Inferior Oolite and pre-Cretaceous, while it is almost certainly post-Triassic and pre-Eocene.

I am aware that Dr. Verbeek's opinion as to the age of the granite of Banka and Billiton was, at the time when he described

[1] See R. D. M. Verbeek, 'Geologische Beschrijving van Bangka & Billiton' Jaarboek van het Mijnwezen in Nederl. Oost-Indië, Wetensch. Gedeelte, vol. xxvi (1897).

[2] See Dr. G. J. Hinde's Appendix to Dr. Verbeek's memoir, 'Note on a Radiolarian Chert from the Island of Billiton' pp. 223–27 & pl. iii.

[3] R. B. Newton, 'On Marine Triassic Lamellibranchs discovered in the Malay Peninsula' Proc. Malacol. Soc. vol. iv, pt. iii (1900) pp. 130–35 & pl. xii; 'Fossils from Singapore, &c.' Geol. Mag. dec. v, vol. iii (1906) pp. 487–96 & pl. xxv; 'Age & Locality of the *Estheriella* Shales from the Malay Peninsula' *Ibid.* vol. ii (1905) p. 49; also T. Rupert Jones, 'A Triassic *Estheriella* from the Malay Peninsula' *Ibid.* pp. 50–52 & pl. ii.

[4] R. D. M. Verbeek & R. Fennema, 'Description Géologique de Java & Madoura' vol. i (1896) pp. 38 & 39.

[5] 'On the Geology of Central Sumatra' Geol. Mag. dec. ii, vol. ii (1875) p. 479.

[6] 'Geological Explorations in Central Borneo (1893–94)' pp. 251–54 & 433. London, 1902.

those islands, at variance with mine as expressed now. Dr. Verbeek said that this granite is probably later Palæozoic,[1] but his statement does not appear to have been based on any palæontological evidence derived from those islands. The radiolarian chert on Billiton only shows the granite to be probably younger than some part of the Palæozoic.

Again, in order to emphasize the possibility of the granite-masses of Borneo and the Peninsula being of different ages, it is necessary to quote Mr. Wing Easton's opinion that the granite of a part of Western Borneo either dates from before the deposition of the Triassic beds, or was contemporaneous therewith.[2]

The question remains—is there any known granite-mass in the Archipelago with which we can correlate the granite fragments in the tuff of Pulau Nanas? Thanks to the invaluable work of Dr. Verbeek, this can be answered in the affirmative. In 1899 and again in 1905, Dr. Verbeek described the geology of the Island of Amboyna, in the Banda Sea.[3] In the later publication the author described a series of sandstones and argillaceous schists with interbedded limestones. Fossils were found in the limestones which led to their being referred to the later Palæozoic, but Dr. Verbeek says that new fossils may show the beds to be Triassic. The important point, however, is that the granite of Amboyna is known to be older than the sandstones: because the latter contain granite-gravel, and there is no trace of action at the granite-contact with the sandstone that can be attributed to the granite, therefore 'the age of the granite cannot then be younger than the Permian.'[4] It is noteworthy, too, that on Amboyna hornblende-granites do not exist as rocks of any extent, and that the granites often contain cordierite.[5] No cordierite has been detected in the granite fragments on Pulau Nanas, but the hornblende appears to be all of secondary origin, while the younger normal granite of Pulau Ubin is a hornblende-granite. There is, then, at least a strong probability that the granite of Amboyna and the fragments in the tuff of Pulau Nanas belong to the same period of irruption.

[1] 'Geologische Beschrijving van Bangka & Billiton' Jaarb. v. h. Mijnwezen in Nederl. Oost-Indië, Wetensch. Gedeelte, vol. xxvi (1897) p. 23.

[2] 'Geologie eines Teiles von West-Borneo' *Ibid.* vol. xxxiii (1904) p. 369.

[3] 'Over de Geologie van Ambon' Verhandl. K. Akad. v. Wetensch. Amsterdam, sect. 2, pt. iv, No. 7, 1899; & 'Description Géologique de l'Ile d'Ambon' Édition française du Jaarboek v. h. Mijnwezen in Nederl. Oost-Indië, vol. xxxiv (1905) partie scientifique.

[4] *Op. cit.* 1905, p. 74.

[5] *Op. cit.* 1905, pp. 73–74.

V. The Relations of the Pulau Ubin Rocks.

We have now to consider the relations of the various rocks on Pulau Ubin. These (including the Changi rock on the Island of Singapore) may be divided as follows:—

I.

The normal hornblende-granite with a little monoclinic pyroxene.

II.

The pyroxene-micrchoogranite in the South Quarry with dark masses that resemble III (1).

III.

(1) The porphyry behind the North Quarry.
(2) The Changi rock, which has the mineral constitution of an amphibole-vogesite.

IV.

(1) The quartz-norite veins in the North Quarry.
(2) The fine-grained veins and masses in the North Quarry which have the mineral composition of an enstatite-spessartite,[1] but not the structure of a typical lamprophyre.[2]
(3) The masses of quartz-biotite-gabbro in Quarry No. 1.

I have already said that Pulau Ubin is a jungle-clad island. It is impossible, except at enormous expense, to hope to run traverses from one quarry to another in such a way that the relations of the different rocks may be made clear; and it is useless to wait for further information consequent on the growth of existing quarries or the opening-up of new faces, which might involve waiting indefinitely. It is to be regretted, but unavoidable, that the relations of Divisions II & III to the other rocks must for the present remain a closed book, the data available being insufficient for profitable discussion.

The most important is Division IV, not only on account of the mutual relations of the rocks on Pulau Ubin, but also because a comparison is possible with rocks in the Archipelago.

The first point that strikes one is that in the North Quarry we have two distinct types of veinstones, one type also occurring as masses included in the granite. The rock of coarser grain forms the thinnest veins in the quarry. It might be argued that this is due to these being formed by segregation of certain constituents of the granite along planes in the molten magma. Did the granite show any sign of foliation, or had it been proved to contain enstatite, this argument might hold good; but, in the absence of any such support, the veins can only be regarded as intrusive, and we must turn to some other explanation for the variation in grain. This

[1] In Geol. Mag. dec. v, vol. vi (1909) p. 22, I said that this rock might be described as enstatite-vogesite: enstatite-spessartite is a more correct definition.

[2] I refer to the 'panidiomorphic' structure.

seems to me to be clearly due to difference in time of intrusion. The coarse quartz-norite veins and the fine-grained enstatite-spessartite are of much the same mineral composition; and, if we assume that the veins of quartz-norite were intruded when the granite was very hot, and the enstatite-spessartite later when it was cooler, there is no difficulty so far as the veins are concerned, since the big complex vein in the centre of the quarry lends itself to the explanation that it was formed by a later eruption of enstatite-spessartite along the same path as that which the quartz-norite had taken. The masses of enstatite-spessartite must be left for the moment.

Passing to Quarry No. 1, where we have the same normal hornblende-granite, with basic masses (I have been careful to assure myself, by visiting small Chinese quarries, that this is the predominant rock on Pulau Ubin, and that it may reasonably be assumed to be all of the same period of irruption), these latter resemble the quartz-norite veins in the North Quarry; and, although the enstatite is not abundant, one is impelled towards seeking a common origin for both veins and masses. The problem then is this: in one quarry we have veins of enstatite-spessartite intruded when the granite was cool, and masses of the same rock included in the granite; while in the same quarry we have thin veins of quartz-norite, and in another, masses of a rock resembling this vein-rock. Spessartite and gabbro are both anterior to, and later than, the granite.

There is only one way of accounting for this, which is to assume that prior to the irruption of the granite there were two distinct magmas, one granitic, the other gabbroid, and that the granite in its ascent caught up portions of previously-irrupted gabbroid magma, while later irruptions of the same gabbroid magma invaded the consolidated granite. It is possible that in Divisions II & III we have a repetition of these relations; but, in the absence of clearly-defined vein-rocks, I cannot say more. If it should prove later that these divisions afford a parallel case, the problem will be greatly complicated. It will be remembered that some of the basic masses in Quarry No. 1 contain spongy masses of hornblende like those in the dark masses of the South Quarry, and in the porphyry behind the North Quarry.

It appears certain that a gabbroid magma[1] had been differentiated before the normal hornblende-granite of Pulau Ubin consolidated, and there is reason for supposing this granite to be pre-Eocene, if not pre-Cretaceous. It is remarkable that Dr. Verbeek's description of Amboyna enables us to find a place for

[1] The amount of quartz in some of the rocks derived from this magma is extraordinarily high for gabbro. The mean of the specific-gravity determinations (see Geol. Mag. dec. v, vol. vi, 1909, p. 21 & this paper) is not too low, however, for a gabbroid magma, and the felspar is mostly andesine-labradorite. In view of the variable amount of free silica in the rocks, silica-percentages would be sure to vary as much as the specific gravity.

these gabbroid rocks in the geology of the East Indies. Dr. Verbeek has described a series of lavas in Amboyna which he terms ambonites: they vary from acid to basic, and are characterized by the presence of bronzite, cordierite, and garnet. In his publication of 1905,[1] Dr. Verbeek argued at length in favour of the basic rocks being Cretaceous, but in this opinion he differed from Prof. Martin. In a later publication, however, Dr. Verbeek admits that the ambonites may belong in part to the older Tertiary.[2] Nevertheless, his opinion would appear to be that, about Cretaceous times, certain lavas bearing rhombic pyroxene were erupted on what is now Amboyna.

Prof. Molengraaff, again,[3] describes gabbro and norite from Borneo, and says that the gabbro is almost certainly younger than the 'Danau' formation, a series of rocks probably Jurassic in age.[4] In Sarawak I have found norites and hypersthene-andesites whose age I was unable to determine with certainty, but which are younger than the Middle Jurassic.

In themselves the rocks of Pulau Ubin afford a very interesting problem in petrography. To one whose aim in scientific work is to effect a junction with the Dutch geologists on the one hand, and the Indian geologists on the other, it is a great advance to find such evidence as the foregoing pointing to a correlation with rocks bearing rhombic pyroxene in Borneo and Amboyna; but it is most interesting to note that in Cretaceous times, and perhaps earlier, before the great tin-bearing granite masses of the Peninsula had consolidated, a basic magma had already been differentiated, capable of providing the vast outpourings of volcanic rocks that have continued so late as the terrific eruption of Krakatoa in 1883.

VI. Conclusions.

The foregoing remarks may be summarized as follows:—

(1) The normal granite of Pulau Ubin is hornblende-granite, the age of which is certainly post-Triassic and pre-Eocene, perhaps post-Inferior-Oolite and pre-Cretaceous.

(2) Veins of quartz-norite and masses of quartz-biotite-gabbro, and veins and masses of a fine-grained rock which may be described as enstatite-spessartite, are found in the normal granite of Pulau Ubin. These point to an early differentiation of a granitic and a gabbroid magma, perhaps in pre-Cretaceous times, and they are referable to rocks in Borneo and Amboyna.

[1] 'Description Géologique de l'Ile d'Ambon' pp. 101–105.

[2] 'Rapport sur les Moluques—Reconnaissances Géologiques dans la Partie Orientale de l'Archipel des Indes Orientales Néerlandaises' Édition française du Jaarb. v. h. Mijnwezen in Nederl. Oost-Indië, vol. xxxvii (1908) partie scientifique, p. 769.

[3] 'Geological Explorations in Central Borneo (1893–94)' 1902, pp. 433–34.

[4] *Id. ibid.* p. 414.

(3) A pyroxene-micrograpite and porphyry on Pulau Ubin, and a rock at Changi, having the mineral constitution of an amphibole-vogesite, are described. Their relations to the other rocks are not clear.

(4) The dacite-tuffs of Pulau Nanas contain fragments of granite which must be pre-Carboniferous, and are referable in point of age to the granite of Amboyna.

(5) The fragments of granite, and perhaps pebbles of schorl-rock, are the only evidence found in the Malay Peninsula as yet of pre-Carboniferous rocks.

18. *The* Tourmaline-Corundum Rocks *of* Kinta (Federated Malay States).

By John Brooke Scrivenor, M.A., F.G.S., Geologist to the Federated Malay States Government, and formerly of H.M. Geological Survey of the United Kingdom.

(Read December 1st, 1909.)

[Plates XXX & XXXI—Microscope-Sections.]

Contents.

I. Introduction: Previous Literature.

I propose in the following paper to describe and discuss the origin of certain rocks, remarkable alike in mineral composition and in structure, found in the Kinta Valley of Perak, the premier tin-field of the Federated Malay States. The two chief ingredients of these rocks are tourmaline and corundum; and it is evident, from the geological structure of the district, that they are the result of extreme metamorphism in beds associated with schistose rocks found chiefly on the west side of the valley, and perhaps also in thin beds intercalated with the crystalline limestone that generally forms the bed-rock of the tin-mines.

The previous literature dealing with the Kinta Valley, or, indeed, with Perak as a whole, is very scanty, and does not take long to review.

In 1882 M. J. Errington de la Croix [1] described the geology of the Malay Peninsula (pp. 9–20), noticing the Kinta limestones as being widely developed.

In 1884 the Rev. J. E. Tenison-Woods [2] said that the granite ranges of Perak are flanked by 'Lower Limestone ridges' forming detached hills about 1500 feet high.

> 'The limestone is crystalline, without a trace of organism[s], though lines of stratification can still be traced. . . . There is a Palæozoic sandstone, clayslate, or gneissose formation lying between the limestone and [the] granite. It is much decomposed, and gives rise to a red clay which generally goes by the name of laterite.'

In the same year the same author [3] mentioned an instance of a recent volcanic rock in Kinta, which appeared to be a basaltic dyke.

[1] 'Les Mines d'Étain de Perak (Presqu'île de Malacca)' Paris, 1882.
[2] 'Geology of the Malayan Peninsula' Nature, vol. xxx, p. 76.
[3] 'Physical Geography of the Malayan Peninsula' *Ibid.* vol. xxxi, p. 153.

In 1893[1] Mr. Leonard Wray, in a note on black limestone at Kamuning, said:—

'In the schistose beds beneath the limestone, graphite has been found at Batu Gajah.'

A year later Mr. Wray gave a sketch of the geology of Perak,[2] saying:—

'In some places, on the top of the limestone are small patches of heavy black trap, often vesicular in texture. It is evidently now only a fragment of what it once was, and is represented in many places by only a few scattered fragments. . . .'

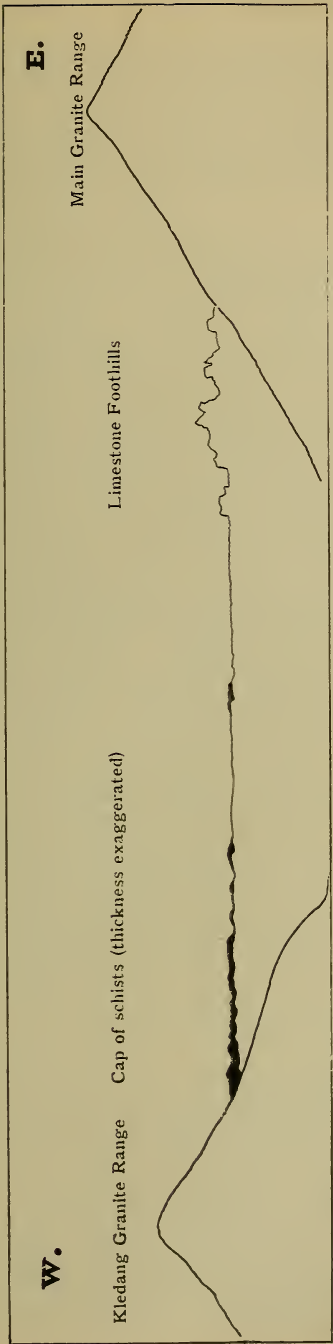
M. Octave J. A. Collet,[3] in a publication the date of which is unknown to me, mentioned (p. 79) schists and quartzites belonging apparently to the Silurian and Devonian Systems, and (p. 80) remarked on the possibility of the limestones being Carboniferous. M. Collet also mentioned traps, trachytes, and basalts, but gave no localities (p. 79).

I do not propose to dwell on the statements of the above-mentioned authors, except in so far as they affect the Kinta Valley; and that only for so long as is necessary to clear the ground of any misunderstanding. The schists in the Kinta Valley are above, and not beneath the limestone, as may be seen now in many a section; and there is no doubt, judging from my own observations, and from a collection of 'trap-rocks' in the Perak Museum at Taiping, that the tourmaline-corundum rocks which are the subject of this paper were mistaken for basalt. All these rocks are fine-grained, and as the collector was not in the habit of using a petrological microscope, he was, as perhaps many another might have been under similar circumstances, led astray by a superficial resemblance that would have been seen to be totally misleading if only a slice had been cut.

II. Main Features of the Geology of the Kinta Valley.

The structure of the Kinta Valley, which is now being mapped in detail, is roughly illustrated by the accompanying section (p. 437). On the east is the main granite range of the Malay Peninsula, rising to over 7000 feet. On the west is the Kledang Range, also of granite and also stanniferous, but rising to a much lower altitude. The floor of the valley is of crystalline limestone squeezed into sharp folds, and forming on the east a range of magnificent limestone foothills below the granite range. On the west the limestone is capped by small hills of schists and associated rocks, which also form rolling ground in some places above the limestone

[1] 'Perak Museum Notes' No. 1, p. 29.
[2] *Ibid.* No. 4, pp. 19-22.
[3] 'L'Étain: Étude Minière & Politique sur les États Fédérés Malais.' Brussels.



Diagrammatic section of the Kinta Valley, looking north: the folds in the limestone are not shown.

where it abuts on the Kledang granite. Schists occur on the east side of the valley at Gopeng, but none of the tourmaline-corundum rocks have been found on that side; and it is obvious, from the height of the limestone hills on the east (they reach 2000 feet) and the presence of the cap of schists on the west, that the general dip of the limestone, as a whole, is gentle and to the westward.

The limestone is, as M. Collet says, probably Carboniferous, and is almost entirely crystalline. It is sometimes pure white, sometimes grey, sometimes streaked with black and white bands, the black variety being carbonaceous. It is occasionally traversed by pipes and veins containing tin ore, and its rough pinnacled surface has caused in a large measure the concentration of the enormous wealth of tin dioxide which has made Kinta so famous. In the north of Kinta I have seen argillaceous partings between thin beds of grey limestone, but nowhere have I seen any schists, or indeed any rock, distinctly below and older than the limestone.

The thickness of the limestone, then, is unknown. A drill was put down at Lahat for 600 feet, but was still in limestone when the work ceased, although it might be reasonably expected that granite would have been encountered at a greater depth, since the drill was running parallel to a stanniferous deposit.

Nowhere have I traced any tourmaline-corundum rock interbedded with the Kinta limestone; but, on the east side of the valley, at Pulai and elsewhere, pebbles and boulders of pure corundum are found in the alluvium. This corundum, however, shows none of the extraordinary structures observed in the tourmaline-corundum rocks on the west, and must be considered as distinct.

III. Description of the Tourmaline-Corundum Rocks and the Associated Schists.

When I first visited Batu Gajah in 1903, my attention was attracted by a peculiar vesicular rock that was used largely for mending roads and paths and for making concrete foundations. I crushed some of the rock, and found tourmaline to be one constituent and probably corundum another. At that time I had no one to prepare sections for me, so sent a specimen of the rock home with others to be cut in England. On their return I found my diagnosis confirmed: if only by a pathetic note on the label 'Hardness 9,' and an extra charge for diamond dust. The mineral was separated, and proved to be corundum in shapeless grains.

Since 1903 every opportunity has been taken of collecting information about these rocks, but until 1907 their place in the structure of the country remained a mystery. In January 1907 my headquarters were moved to Batu Gajah; and I have been able to obtain sufficient data, while going over the western part of the Kinta Valley, to form as definite an opinion as is likely to be possible under the circumstances regarding the origin of these rocks.

The schists which cap the limestone on the west side of the Kinta Valley are never well preserved, while sometimes the cap is so thin that surface-water has attacked the limestone underneath, and reduced the schists to a soft mass in which little or no trace of bedding remains. In some sections, however, the bedding is seen distinctly, and it is evident that the schists, like the limestone, have been subjected to great lateral compression.

The schists are generally argillaceous, varying in colour owing to the strong weathering, but in some cases they are black and carbonaceous. Frequently, too, the clayey mass lying upon the limestone is very deeply coloured with carbon, derived no doubt from carbonaceous schists.

Fine-grained sandstone occurs, sometimes associated with the schists; and at Siak, near Siputeh, there is a long ridge over the limestone which was probably composed largely of fine sandstone before weathering destroyed the continuity of the beds forming the cap. Boulders of sandy schists are common, too, in the detritus from the Gopeng beds, on the east side of the valley; it is important also to note that on the sandstone ridge at Siak the tourmaline-corundum rocks are only found in small quantity and where they may have been deposited by river-action, while none have been observed as yet at Gopeng. In both localities, however, the sandy rocks contain tourmaline.

Angular masses of tourmaline-corundum rock are often to be seen embedded in the decomposed schists above the limestone; but I have never seen a continuous band of such masses, nor is this surprising when one considers how great is the effect of weathering in this country. In the month of August 1909 huge masses of the rock could be seen in softened schists, in an excellent section in the Pusing Bharu mine.

On rising ground boulders of the tourmaline-corundum rocks are sometimes very numerous and practically *in situ*. On one ridge, the left bank of the River Mendrus, I found that the soil even is formed from these rocks, containing large quantities of colourless and blue corundum and tourmaline.

The two best occurrences, however, of the tourmaline-corundum rock *in situ* are on the Redhills Mining Company's property, and about half a mile out of Siputeh on the bridle-path going towards Batu Gajah. On the Redhills property the rock is associated with iron-stained schists, and strikes about due north and south. At the southern end of the outcrop, near the Pusing Lama Company's boundary, it stands out much like a dyke from the surrounding country, owing no doubt to its superior hardness and resistance to weathering.

On the bridle-path near Siputeh an enormous mass of the rock occurs. The surface is much iron-stained, and it was necessary to have recourse to blasting before good specimens could be collected. It was possible then to see traces of the original bedding, and it was found that in parts the rock was rich in carbon and heavily mineralized with metallic sulphides, chiefly arsenopyrite. No gold or silver was found on assay, however, nor was any tin-ore found.

Tin-ore frequently occurs in schists with which the tourmaline-corundum rocks are associated, but I have never yet found any cassiterite in the tourmaline-corundum rocks themselves.

Apart from the occurrences of these rocks *in situ*, the alluvium overlying the limestone is rich in pebbles and boulders that afford excellent material for study, and in some places the surface of the limestone is so strewn with them that one cannot escape the conclusion that they are all that remain of a former cap of younger rocks. The description below is largely based on such material.

So far, I have spoken generally of ‘tourmaline-corundum rocks.’ In composition, however, they vary considerably, but I have found that it is possible to explain this difference as being due to greater or less alteration; indeed, it is possible to trace a gradation from light-coloured specimens with little or no tourmaline or corundum to a rock composed of tourmaline, corundum, and black carbonaceous dust, or to a rock composed of corundum and white mica. The clearest method of describing in detail the various rocks (including the schists) will be to arrange representative specimens under headings, beginning with the least altered. The most abundant rock, apart from the schists, and therefore the rock that should be considered as the type of the group, is the Redhills rock, which will be described in its place.

Petrological Details.

(i)

Argillaceous schists, frequently mineralized.

Localities numerous.

(ii)

Fine-grained sandstone and sandy schists, sometimes mineralized, and generally containing tourmaline.

Localities: near Batu Gajah; Siak; Lahat; open cut behind Redhills; Gopeng (but no tourmaline-corundum rock).

(iii)

Black carbonaceous schist.

Localities numerous.

(iv)

Black, carbonaceous, fine-grained, siliceous rock, with a trace of radiolarian structure.

Locality: open cut behind Redhills. (Pl. XXXI, fig. 5.)

(v)

Light-coloured rocks: no tourmaline or corundum.

Localities various.

(*a*) Under the microscope, this is seen to be made up entirely of bodies that strongly suggest oolitic grains. They sometimes show concentric structure. The rock, however, is siliceous, very fine-grained, and contains abundant white mica in minute flakes. There is some pale yellow dust present. (Pl. XXX, fig. 1.)

(*b*) The base of this rock is siliceous and contains mica like (*a*). It is full of similar round and oval bodies, and also contains round bodies arranged in lines.

(*c*) A fine-grained siliceous rock, with flakes of mica. It is much veined, and suggests some of the altered cherts of Pahang (see pp. 445, 446).

(*d*) Numerous round and oval bodies, many showing a dark centre and lighter border, the former being caused by black dust in greater quantity than in the border. The rock contains carbon: the base is very fine, and apparently siliceous. A few veins of tourmaline occur in this rock. (Pl. XXX, fig. 2.)

(*e*) A carbonaceous rock strongly suggesting an altered chert. Numerous obscure markings.

(*f*) The base is very fine-grained and crystalline, composed apparently of silica and mica. It is schistose, the schistosity being shown by bands of white opaque material. Pyrite crystals, surrounded by a clear border, are abundant, and there are numerous small, clear, round bodies with a core of pyrite.

(vi)

Rocks with tourmaline only.

Localities various.

(*a*) A very fine-grained siliceous rock, with minute prisms of tourmaline and veins of micaceous material. Coarse black dust and perhaps carbon are present.

(*b*) Like (*a*), but with round bodies enclosing black dust.

(*c*) The base is very fine-grained, and contains round bodies faintly marked by tourmaline grains.

(*d*) This is very fine-grained, and contains white dust. It is veined with pale yellow tourmaline.

(*e*) The base is fine and siliceous, and contains minute prisms and veins of a mineral that is probably colourless tourmaline (achroite). There are numerous round and four-cornered clear spots, composed probably of achroite also, and containing sometimes a yellow mineral that could not be determined.

(*f*) This is composed entirely of brown and bluish tourmaline.

(vii)

Light-coloured rock with corundum only.
Localities various.

(*a*) A very light-coloured rock. The base is fine-grained, and composed apparently of silica and white mica. There is a little corundum showing no definite structure.

(*b*) The base of this rock is fine-grained and apparently siliceous. Blue corundum occurs as veins (Pl. XXX, fig. 3) and masses. There are numerous round bodies like those already mentioned, but in some cases the material composing them has been replaced by corundum. Fig. 4 (Pl. XXX) shows a good example of these bodies. The centre is of corundum darkened by black dust; the clear rim is of a finely crystalline material that may be micaceous but cannot be determined. The unaltered bodies contain much pale-yellow opaque matter, which is present throughout the rock. An accumulation of this in the centre forms a nucleus for the bodies in some cases.

(*c*) This rock resembles (v) *a*, and (v) *b*, but there is much carbon present and a little corundum; the latter, however, does not occur in the numerous bodies, which are nearly all elongated, owing to a marked schistosity in the rock. The bodies show concentric structure. There is a little pyrite.

(*d*) This rock is coarser in grain than usual, and is distinctly rough to the touch. It is weathered, and resembles sandstone. The section shows nothing but discs of corundum, some of which are hollow in the centre, and yellow opaque matter. A part of the specimen was fused with carbonate of soda, and yielded 42·3 per cent. of corundum. It seems that something, probably mica, was lost in making the slide. The corundum discs suggest in some cases round bodies completely replaced by corundum.

(*e*) A light-coloured rock with small, dark, blue-black nodules of varying size. The base is siliceous, and full of minute micaceous flakes. Round bodies are numerous, and show a faint concentric structure. In some cases they are partly formed of corundum; while one consists of a broad ring (in section) of corundum, enclosing a fine mosaic of white mica. There are numerous opaque rods and irregular bodies of iron oxide. This rock was found to contain 1 per cent. of corundum. The nodules contain more corundum than the rest of the rock, and enclose small round bodies like those observed elsewhere in the rock.

(*f*) This rock also resembles sandstone in the hand-specimen. It is much weathered, but consists mainly of deep-blue corundum in irregular grains.

(*g*) (Pl. XXX, fig. 5.) A sandy-looking rock, the base of which is greenish in section and probably siliceous. In this are some dark bodies showing marked concentric structure, and many round bodies of corundum which are replacements of the former, and also exhibit in some cases concentric structure.

(viii)

Schists with corundum.

Localities various.

It has been found that corundum is present in some of the schists. Unfortunately, none of the specimens are well preserved; but tourmaline-corundum rocks always occur associated with them.

The sections frequently contain tourmaline.

(ix)

Corundum-mica rocks.

These are not common. Near Batu Gajah a large boulder was found lying upon limestone. It had a rough and iron-stained surface, and was intensely hard. A fresh fracture showed a dark greyish-blue rock, with veins of a bluish material; and a magnifying glass showed that a platy mineral was present also.

Some pyrite was visible. Under the microscope, by reflected light, it was seen that the rock is largely composed of pyrite and an opaque white substance. Blue corundum occurs in veins, and there is a little brown mica in small flakes. The platy mineral, which is abundant, was separated and proved to be white mica with a wide axial angle. A few grains of tourmaline were seen. The percentage of corundum in this rock was determined as 16·6.

A still more remarkable rock was found in the head-waters of the River Johann (Pl. XXX, fig. 6). A section shows discs and rings of corundum, set in a base that consists entirely of white mica. They are sometimes white, sometimes black with an included dust, and sometimes showing concentric structure by means of this dust, which also imparts to some of the discs a spotted appearance. It was found, by separating the corundum, that the discs and rings are composed of small shapeless grains.

(x)

Dark rocks with corundum and tourmaline.

The colour of worn specimens is generally deep blue-black. The majority of specimens show cavities or bodies, measuring about 6 millimetres, which suggest vesicles or amygdaloids in lava. In some cases the rock is compact. The specific gravity of a compact specimen proved to be 3·01. All these rocks are very hard and fine-grained. In nearly all of them a dense black dust is observable, which sometimes is so thick as to make the slide opaque. This was proved, by treating the crushed rock, to be, for the most part at any rate, some form of carbon.

(*a*) The Redhills type-rock, *in situ*.—In a hand-specimen this rock is dull black. The grain is fine, but the rock is very rough to the touch. Throughout it are cavities about 6 millimetres across, some round, some elongated, some irregular. These are sometimes empty, sometimes partly filled or lined with minute lustrous tourmaline crystals, and they sometimes show a faint pale border outside these crystals. The rock is very hard and heavy, and might easily be mistaken at first sight for a vesicular lava.

In section the rock is seen to consist of tourmaline, corundum, and black carbonaceous dust. The grain varies slightly, and when coarsest there is little or no structure to be seen. In the fine-grained rock, however, the structure is remarkable. With powerful illumination it is seen that there are present numerous round and oval bodies, and also large cavities, which are the cavities seen in the hand-specimen. The smaller bodies are composed of corundum alone, while the larger have a shell of corundum and a core of tourmaline grains. In one case the core consists of a single grain of tourmaline.

The corundum shells are made up of small shapeless grains (Pl. XXXI, fig. 3). The large cavities are of a similar structure. Generally there is an outer border of corundum grains, and an inner border of tourmaline. Pl. XXXI, fig. 4 shows an exceptional case, where the border is composed of a double band of corundum grains with tourmaline and corundum between these two bands, and tourmaline on the inside of the inner band.

Apart from these structures, the corundum occurs as irregular and vein-like masses.

The tourmaline rarely forms well-defined crystals, and in this case is brown. The corundum is sometimes pale blue.

It may be mentioned here that the largest tourmaline grains measured in any of these tourmaline-corundum rocks were only 0·37 mm. in greatest width.

In some detrital specimens large bodies are found of the same size and shape as the cavities in the Redhills type-rock. They are solid, and consist of tourmaline and corundum, which, generally speaking, are arranged in such a way as to suggest a rough concentric structure, with the corundum more abundant near the outside of the bodies than in the centre. In the Redhills type-rock there is no reason to suppose that the cavities ever contained a solid core of tourmaline, or of corundum and tourmaline, although it is probable that the original structures replaced by these minerals were solid.

(*b*) The Siputeh rock, *in situ*.—Specimens from this mass of rock vary considerably. Some when collected were dead black and soiled the fingers, and contained so large a quantity of metallic sulphides, precipitated no doubt by the carbonaceous powder which gives the black colour, that oxidation of these sulphides caused the specimens to crumble quickly away.

In some slides the same bodies of tourmaline with corundum shells are seen as in the Redhills rock. The larger cavities, however, are not common, although numbers of them occur in boulders and pebbles hard by.

In one case a round body was found to have a core of pyrite enclosing grains of tourmaline. In another specimen a round body occurs, larger than usual. The core consists of indigo-blue tourmaline; the shell is of colourless corundum, with a few grains of tourmaline and minute flakes of pale-brown mica.

Arsenopyrite occurs, and in one slide it is shown to have been partly replaced by micaceous material, leaving the original crystal outline sharply defined. The arsenopyrite also encloses small flakes of the pale-brown mica, which occurs too in the tourmaline base.

Some specimens from this mass show yet another mineral that has not been mentioned before. This is pleonaste, deep green in section, and occurring in masses of small grains. The first slide cut containing this mineral did not show any corundum, but a portion of the powdered rock afforded a considerable quantity, some being blue. The tourmaline sometimes exhibits good basal sections with crystal outline; and a large part of the rock is composed of a clear flaky mineral, which on separation proved to be white mica with a wide axial angle, so wide indeed that some of the sections show an axis emerging on a prism face. Another curious feature is that the lath-like sections sometimes show a cross-fracture (secondary cleavage parallel to 010?).

Another specimen shows tourmaline, spinel, white mica, brown mica, and sulphides.

Yet another variation is a tourmaline-hæmatite rock, with a little white mica.

The tourmaline in the Siputeh rock is indigo blue.

The following specimens were found as boulders or pebbles:—

(*c*) A schistose and very dark rock, with small light bodies elongated along the planes of schistosity and large solid bodies mainly composed of corundum. The dark appearance of the rock was proved to be due to carbon. A little corundum and tourmaline occur, also some pyrite.

(*d*) In this there are traces of a fine base, which may be siliceous or micaceous. Tourmaline and corundum occur.

(*e*) Tourmaline is abundant, and sometimes forms round bodies. Corundum and minute flakes of white mica are subordinate.

(*f*) The base of the rock is siliceous. Indigo-blue tourmaline and corundum are abundant. There are some round bodies composed of tourmaline only. One slide, containing some isotropic material, shows a pear-shaped body composed of tourmaline, white mica, and granules that may be corundum (Pl. XXXI, fig. 1). Another slide shows a large cavity lined with corundum.

(*g*) In this rock the tourmaline grains are larger than usual. There is a little corundum and abundant pleonaste, with a quantity of white mica forming a fine mosaic.

(*h*) This is a compact rock consisting entirely of corundum, greenish-brown tourmaline, and black dust. A separation of rock-powder was made and 9 per cent. of corundum obtained. In the slide the percentage of corundum appears to be higher. (Pl. XXXI, fig. 2.)

(*i*) This rock occurs as angular blocks in stiff clay at Rotan Dahan. It consists of corundum, tourmaline, and rutile. A similar rock has been obtained from Pusing Lama. The rutile occurs in well-formed, deep-brown crystals, and is present in some quantity.

IV. Origin of the Tourmaline-Corundum Rocks.

It is hoped that the foregoing descriptions will give some idea of the many varieties of the tourmaline-corundum rocks. That they are not igneous is unquestionable. The prominence of the two minerals tourmaline and corundum and the evidence of their gradual development leave no room for doubt that they are extraordinary examples of metamorphism effected by the tin-bearing granite in beds the original characteristics of which cannot be observed now in any sections showing a passage from the unaltered to the altered state. That the granite and its modifications were the cause of the metamorphism is evident from the geology of the Kinta Valley, there being no other igneous rocks known in the district; and it is unnecessary to quote literature to show that both tourmaline and corundum are already known as results of contact-metamorphism by granitic rocks.[1]

Without sections such as those that I have just mentioned, namely sections showing a passage from the unaltered to the altered rocks, I doubt whether it is possible to prove anything regarding the origin of these tourmaline-corundum rocks. The most that can be done is to state the facts, and indicate the possible hypothesis to which they tend. It may be that in future mining operations some section will be laid bare, such as will confirm or refute the hypothesis which I am about to put forward; but, unfortunately, a knowledge of the country and the mines of the present day makes me think it unlikely that such a proof, or the reverse, will be obtained.

Let it be admitted, then, that in the abundance of the minerals tourmaline, corundum, white and brown mica, and spinel, we have an example of metamorphism by a granitic mass that is remarkable only in the degree to which these minerals have been produced. There remains the problem of the origin of the extraordinary bodies and cavities observable in the tourmaline-corundum rocks. That structures of the same shape but different material existed before the granite effected this striking transformation, and that the spherical and other bodies and cavities were not created *de novo* at the time of granitic intrusion, would be hard to question under any circumstances, while the evidence of the bodies in the light-coloured specimens under group (v) of the foregoing descriptions (p. 440) places the matter beyond doubt.

The points which seem to be most important in discussing the origin of these structures are as follows :—

(1) The rocks are all fine-grained.

(2) When any ground-mass is visible apart from tourmaline and corundum, it is very finely crystalline, and either siliceous or micaceous.

(3) Carbonaceous schist is commonly found associated with the tourmaline-corundum rocks.

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[1] At Lenggong, in Upper Perak, pale-yellow tourmaline, corundum, and spinel were found together in crystalline limestone. All three occur in small grains, the spinel appearing colourless under the microscope.

(4) Carbon is a frequent constituent.

(5) Where sandstone or sandy schist is present in any quantity among the beds overlying the limestone, the tourmaline-corundum rocks are rare or absent.

(6) In the open cut behind Redhills, a black, carbonaceous, fine-grained siliceous rock was found, which, if mixed with a number of specimens of radiolarian chert from Pahang could hardly be distinguished from them, although it must be admitted that the radiolarian structure observable in this rock is not so clear as in the Pahang rocks.

(7) Some of the light-coloured pebbles and boulders found with the tourmaline-corundum rocks strongly resemble bands of fine silty rocks associated with the Pahang cherts.

(8) The tourmaline-corundum rocks are evidently derived from certain beds forming part of a series overlying massive beds of limestone.

I will not say that these facts show that the original rocks from which the tourmaline-corundum rocks have been derived were of deep-sea origin, since such a statement would open up a question that cannot be discussed here, although it is of especial interest to those who have studied the geology of the East Indies; but I may point out that there is good reason to suppose that the tourmaline-corundum rocks were derived from rocks which were laid down under conditions similar to those that obtained when radiolarian cherts and associated carbonaceous rocks were deposited elsewhere. Such rocks occur in Pahang,[1] the cherts generally containing carbon, and there the evidence in the field points to the chert and carbonaceous shale being closely connected with Carboniferous or Permo-Carboniferous limestone and calcareous shales, together with contemporaneous volcanic rocks.

But, while it is more than probable that the bulk of the tourmaline-corundum rocks were derived from beds younger than the crystalline limestone of Kinta, there is evidence to show that some may have been formed by the extreme metamorphism of beds that are still to be seen intercalated with the limestone on the west of Changkat Pari, near Ipoh. These beds occur as thin partings in massive limestone pinnacles, that were originally covered by sandy alluvium. They are soft, and are slightly greasy to the touch. Some of them are very light in colour, with dark spots, caused by an accumulation of black dust. One bed is very dark and resembles serpentine, its darkening being due to abundant black dust. The ground-mass of these rocks appears to be composed of a fine micaceous mineral and isotropic matter. In some of the lighter-coloured partings minute white spots are seen, which, under the microscope, bear a remarkable resemblance to the smaller bodies found in the light-coloured rocks accompanying the tourmaline-corundum rocks. Nearly every body is surrounded by a clear ring that is found, under a high power, to consist chiefly of isotropic material like that in the ground-mass, while the body itself is composed of white, opaque, hair-like bodies and dust. Sometimes the

[1] These rocks were described in my 'Report of Progress: Sept. 1903–Jan. 1907' (F.M.S.) Kuala Lumpur, pp. 2 & 3.

arrangement is as follows:—On the outside is the clear ring, then a ring in which the white opaque substance is abundant, and a nucleus in which a micaceous mineral predominates, appearing clearer than the inner ring, but not so clear as the outer ring. These rocks instantly suggest spotted schist, but it is impossible to determine how the spots originated, whether they mark the remains of some pre-existing structure, or the incipient growth of a secondary mineral, as some spots mark the first appearance of andalusite. Another noteworthy point in these partings in the crystalline limestone is that nearly all the sections cut from them contain abundant, and very minute prisms of tourmaline, while no tourmaline has been found in the limestone. The tourmaline prisms also occur in the nuclei of the spots.

The structures in the tourmaline-corundum rocks fall into two classes—the larger solid bodies and cavities, measuring about 6 millimetres in greatest width, and the smaller solid bodies. We have also to consider the dark nodular masses seen in (vii) *e*, p. 441.

To take the larger solid bodies and cavities first: the first point that strikes one is that they are a development of the structures described under (v), p. 440, and an examination of the slides submitted with this paper will show that the rocks containing these structures are probably silicified oolitic limestones, with a secondary development of mica. It is impossible to assert that the large solid bodies of tourmaline, corundum, and other minerals are replacements of oolitic grains, beecause as yet no calcareous oolitic grains have been observed in the Kinta limestone at all. But oolitic limestone, supposedly of the same age as the Kinta limestone, occurs in Pahang, and there is no *à priori* reason why such limestone should not have been part of the Kinta series. The marked concentric structure so often observable in the tourmaline-corundum bodies is strongly in favour of the hypothesis of the original structures having been oolitic grains, and more than that, I think, cannot be said. A better suggestion would be welcome.

I have only a tentative suggestion to offer for the origin of the dark nodules in (vii) *e*. A specimen sent with the exhibit to illustrate this paper shows dark structures that recall organic remains. In (vii) *e* it was found that the dark nodules contain more corundum than the rest of the rock, and it is conceivable that organic remains in a pre-existing limestone absorbed more alumina during the process of metasomatism than the rest of the rock. Against this we have to remember that the nodules in (vii) *e* enclose small round bodies resembling those in the lighter portion of the rock.

I have indicated above that the beds from which the tourmaline-corundum rocks were derived were laid down under conditions similar to those under which the Pahang Chert Series was deposited. Distinct remains of radiolaria are not common in the Pahang cherts; but of commoner occurrence are circular clear spots and bodies such as those illustrated in Pl. XXXI, fig. 6. This microphotograph is taken from a section of a dark carbonaceous chert exposed at the Bentong Reservoir. Carbon is so abundant as to make the section nearly opaque. At one point in the slide there is a spine that may be a sponge-spicule or a detached spine from a radiolarian test (this is not included in the microphotograph); but throughout the slide are numerous opaque round bodies with a clear rim. That these are the remains of organic structures, probably radiolaria, is likely, but no recognizable organic structure can be seen in them now. Their significance lies in their resemblance to some of the smaller bodies in the tourmaline-corundum rocks; and it is a reasonable assumption that these smaller bodies in the Kinta rocks may be the result of replacement of the materials composing such structures in chert or silicified limestone by tourmaline and corundum, the carbon alone of the original structure remaining. This assumption is strengthened by the trace of radiolarian structure in the rock found in the open cut behind Redhills; on the other hand, it is necessary to emphasize the fact that in the tourmaline-corundum rocks themselves no trace whatever of radiolarian structure has been seen. Another point against the radiolarian origin of any of the smaller bodies is that in the Pahang chert the remains of sponge-spicules are occasionally found, whereas nothing has been seen in the tourmaline-corundum rocks that can, with anything approaching certainty, be referred to such spicules. The concentric structure seen in some of the smaller bodies composed of corundum may point to an origin from small oolitic grains.

Never having been able to take the opinion of another petrologist on these rocks as they occur in the field, and describing them now for the first time to an audience, many members of which are probably unable to visit the district, I feel that it is a very difficult task to convey an adequate idea of the peculiarities of the tourmaline-corundum rocks of the Kinta Valley, and more especially to put forward any convincing argument in favour of the hypothesis that seems most acceptable with regard to their mode of origin.

V. Conclusions.

In conclusion I will briefly summarize the main points in the composition of the tourmaline-corundum and associated rocks, and the hypothesis adopted to explain their origin.[1]

(1) The tourmaline-corundum rocks of Kinta consist of varying amounts of tourmaline, corundum, carbon, white mica, spinel, and other minerals.

(2) They contain cavities measuring about 6 millimetres in greatest width, generally bordered by a layer of corundum grains, with tourmaline grains on the inside of this border. Sometimes solid bodies similar in size and shape to the cavities occur. They are composed of tourmaline and corundum, the former mineral,

[1] Much that is of interest concerning the association of corundum with tourmaline, spinel, and rutile will be found in 'A Manual of the Geology of India—Economic Geology: Pt. i. Corundum' Calcutta, 1898.

generally speaking, being more abundant towards the centre. Such bodies also show concentric structure.

(3) Smaller bodies occur, sometimes, but not always, accompanied by the larger cavities and bodies. They consist of tourmaline, of corundum, and of both tourmaline and corundum. When both minerals are present, the corundum forms a shell to a nucleus of tourmaline. The corundum bodies frequently show concentric structure.

(4) The tourmaline-corundum rocks are associated with other rocks which lead to the conclusion that the structures described in the two immediately preceding paragraphs are the result of replacement of the materials of pre-existing bodies at the time of extensive granitic intrusions.

(5) They are also associated with rocks which point to the original beds having been laid down under conditions similar to those that obtained when the Pahang Chert Series was deposited.

(6) As the tourmaline-bearing partings in the limestone at Changkat Pari constitute a case of selective metamorphism, so it is thought that the tourmaline-corundum rocks, as a whole, mark a process of selective and intense metamorphism in beds associated with schists overlying the Kinta limestone.

(7) These beds were probably chert and silicified limestone, both being in many cases carbonaceous.

(8) The large cavities and bodies mentioned in (2) are believed to be the result of replacement or partial replacement of oolitic grains.

(9) The smaller bodies may be, in part, the result of replacement of the materials forming casts of radiolarian structures; in part, the further development or replacement of spots, such as those seen in the soft partings found in the limestone at Changkat Pari; and in part, the result of the replacement of small oolitic grains.

EXPLANATION OF PLATES XXX & XXXI.

[The magnification in both plates is about 12 diameters.]

PLATE XXX.

Fig. 1. Slice cut from a pebble of silicified oolitic limestone (?).

2. Round and oval bodies in fine-grained carbonaceous rock containing no corundum, and only a little tourmaline as veins. Some of the bodies show a light shell and dark centre, others a concentric light and dark structure.

3. Fine-grained siliceous rock veined with blue corundum. Some round bodies are visible, but the corundum veins run independently of them.

4. Slice cut from the same rock as fig. 3: the dark centre of the bodies consists of corundum with black dust. The material in the clear rim is too fine for determination.

5. Round bodies of corundum, partly darkened by black dust and showing concentric structure, in a greenish base.

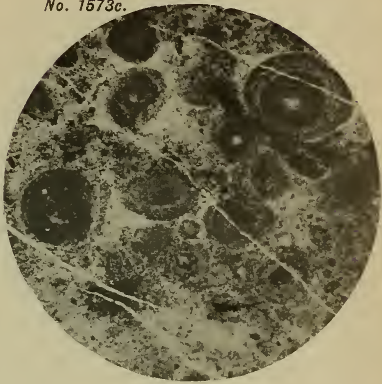
6. Slice cut from a pebble found in the Ulu Johann, Kinta. Discs and rings of corundum with black dust, in a base of white mica.

1

No. 433.

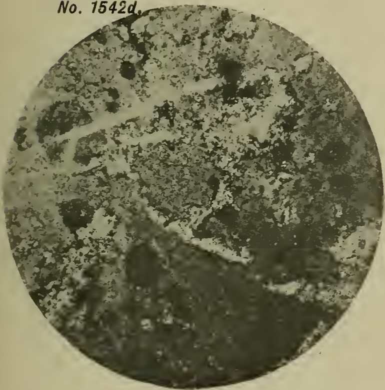
2

No. 1573c.



3

No. 1542d.



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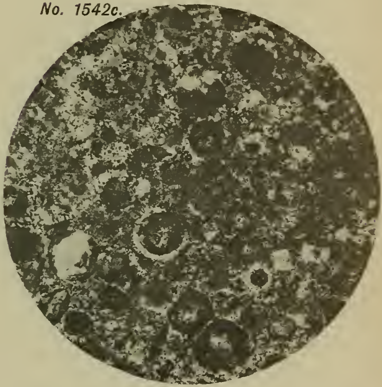

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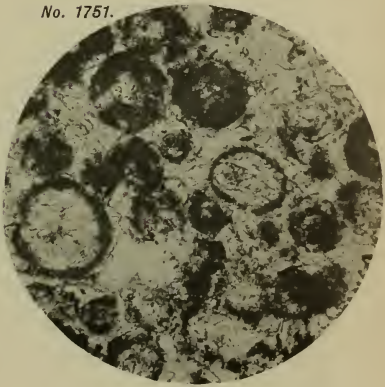


Bemrose Ltd., Collo., Derby.

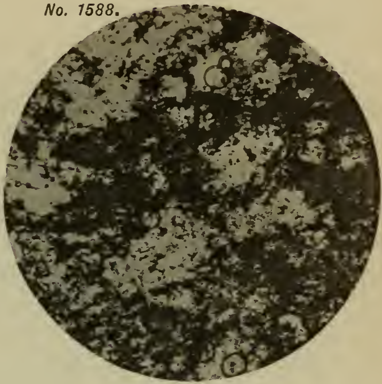
TOURMALINE-CORUNDUM ROCKS OF THE KINTA VALLEY.

1

No. 1570e.

2

No. 1588.



3

No. 1696n.

4

No. 1696n.

5

No. 1733.

6

No. 1764b.

Bemrose Ltd, Collo., Derby.

TOURMALINE-CORUNDUM ROCKS OF THE KINTA VALLEY.

Plate XXXI.

Fig. 1. A large pear-shaped body, composed of tourmaline, white mica, and granules that may be corundum.

2. Tourmaline-corundum rock showing no definite structure.
3. The Redhills type-rock. The microphotograph shows a body consisting of a shell of granular corundum and a nucleus of brown tourmaline grains.
4. Showing the structure of a large cavity in the Redhills type-rock. There is a double lining of corundum grains, and tourmaline and corundum grains between the two, and tourmaline again on the inside of the inner lining.
5. Black carbonaceous and siliceous rock, showing a trace of radiolarian structure, from the open cut behind Redhills. Below the centre of the photograph a fine reticulated structure can just be seen. In the same slide clear circular spaces are numerous, as in the radiolarian cherts of Pahang.
6. Structures in a dark carbonaceous chert from the Pahang Chert Series (Bentong Reservoir), resembling the smaller bodies in some of the tourmaline-corundum rocks.

[The Author is greatly indebted to Mr. H. H. Thomas, M.A., F.G.S., for assistance in preparing these plates.]

19. *The* Gneisses *and* Altered Dacites *of the* Dandenong District (Victoria), *and their* Relations *to the* Dacites *and to the* Granodiorites *of the* Area. By Prof. Ernest Willington Skeats, D.Sc., A.R.C.S., F.G.S. (Read January 12th, 1910.)

[Plates XXXII–XXXIV—Microscope-Sections.]

Contents.

I. Introduction.

The rocks with which this paper deals occur about 25 miles distant from Melbourne, in a direction a little south of east. The area is all included within the parish of Narree Worran, in the counties of Evelyn and Mornington. The oldest rocks in the district are sediments of Lower Palæozoic age, either Silurian or Ordovician; but with these the paper is not directly concerned.

Intruded into these sediments is a mass of granodiorite, which is now exposed at the surface in the southern part of the area. To the north of the granodiorite lies an extensive area of hypersthene-biotite-dacite and quartz-porphyrite, which forms the Dandenong Hills. This rock series is also younger than the Older Palæozoic sediments, for in some places it appears to rest upon them, and in others to be intrusive into them. The boundary between the granodiorite and the dacite runs in an easterly direction, and while examining this junction in 1905 I discovered a belt of gneissic and altered rocks which for several miles come between the normal development of the granodiorite and of the dacite. It is with these rocks and their relations to the plutonic and volcanic series adjoining them that this paper deals.

Hitherto gneissic rocks have been recognized in Victoria only in certain parts of the Western District and in North-Eastern Gippsland. These, however, are probably of Archæan age, and certainly have nothing in common with the foliated rocks described below.

II. Previous Literature.

The origin, age, and field-relations of the big volcanic dacite masses of Victoria constitute one of the important problems in

Victorian geology. The following are the principal papers in which the dacite series is more or less directly discussed:—

(1) A. R. C. Selwyn. Rep. Geol. Surv. Vict., Nov. 1854, pp. 3–10.
(2) A. W. Howitt. 'Notes on the Geological Structure of North Gippsland' Geol. Surv. Vict. Progr. Rep. iv (1877) pp. 75–117.
(3) R. A. F. Murray. 'Geology & Physical Geography of Victoria' 1895.
(4) J. Stirling. Geol. Surv. Vict. Progr. Rep. Nos. 8 & 9 (1899) pp. 28–29.
(5) A. E. Kitson. Geol. Surv. Vict. Month. Progr. Rep. No. 11, 1899, pp. 9–18.
(6) V. R. Stirling. Geol. Surv. Vict. Month. Progr. Rep. No. 1 (n. s.) 1899, pp. 10–11.
(7) J. W. Gregory. 'The Geology of Mount Macedon (Victoria)' Proc. Roy. Soc. Vict. n. s. vol. xiv, pt. ii (1902) pp. 185–217.
(8) Ian M. Sutherland. 'The Relations of the Granitic & Lower Palæozoic Rocks near Dandenong' *Ibid.* vol. xvii, pt. i (1904) pp. 112–17.
(9) F. Chapman. 'Victorian Naturalist' vol. xx (1904) p. 127.
(10) A. E. Kitson. *Ibid.* vol. xxii (1905) p. 128.
(11) H. S. Summers. 'The Cherts & Diabase Rocks of Tatong' Proc. Roy. Soc. Vict. n. s. vol. xxi, pt. i (1908) pp. 240–46.
(12) *Id.* 'Geology of the proposed Nillahcootie Water-Conservation Area' *Ibid.* pp. 285–301.
(13) H. C. Richards. 'On the Separation & Analysis of Minerals in the Dacite of Mount Dandenong (Victoria)' *Ibid.* pt. iii (1909) pp. 528–39.
(14) E. W. Skeats. Pres. Addr. Sect. C. Aust. Assoc. Adv. Sc. (Brisbane) 1909.

Selwyn (1) and Murray (3) described the series as 'traps,' regarded them as intrusive rocks of Palæozoic age, and expressed the view that in some places a gradual passage could be traced between them and the granitic rocks. Prof. Gregory (7) was the first to describe them as dacites, and maintained that at Macedon they are quite distinct in composition and origin from the granodiorites and are entirely unaltered near the contact with these. He regards the dacites as volcanic rocks poured out over a denuded Palæozoic platform of sedimentary rocks and granodiorite, and maintains that they are far younger than the granitic rocks and may be of Lower Kainozoic age.

Since 1905 I have been investigating the relations between the dacites and the granodiorites in Victoria, and the evidence that I have obtained south of the Dandenong Hills, at Warburton, and at Marysville, has led me to draw different conclusions from those of previous observers. Mr. Summers (11 & 12) has come to conclusions similar to mine, as the result of evidence obtained in the Strathbogie ranges; while detailed examination of the Macedon district by Mr. Summers and myself has afforded similar results. In a Presidential address on the volcanic rocks of Victoria (14), given by me to the Geological Section of the Australasian Association for the Advancement of Science at the Brisbane meeting in January 1909, I summarized the evidence and conclusions arrived at in the above areas. The detailed evidence from the Macedon area will appear shortly in a 'Bulletin' of the Geological Survey of Victoria.

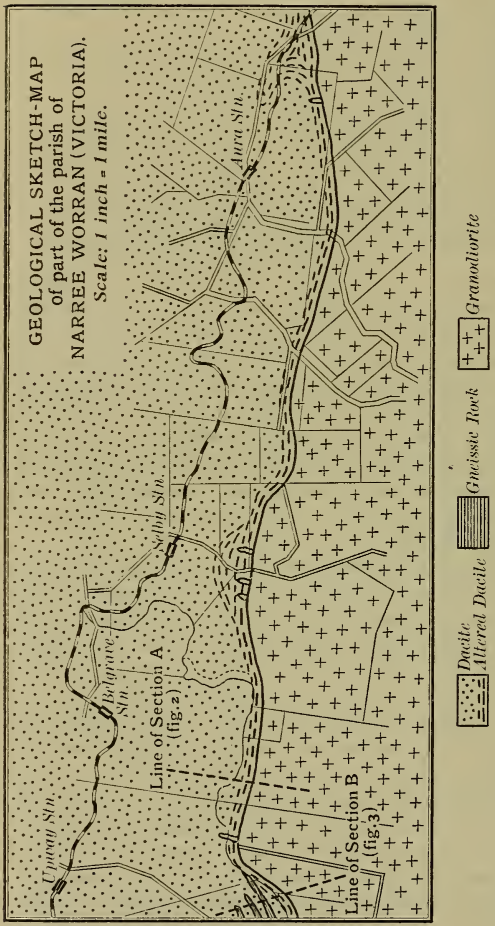
Mr. Richards's work (13), undertaken at my suggestion, deals with the chemical composition of the normal dacite and with the separation and analysis of the ferromagnesian minerals of variable composition which occur in it. It provides valuable material for the discussion of the interesting mineralogical changes which the dacite has undergone at its contact with the granodiorite.

III. Geological Relations in the Field.

(*a*) Description of Geological Boundaries.

The accompanying sketch-map (fig. 1) shows the geological boundaries in the area described. The Dandenong Hills, composed of dacite, lie for the most part to the north of the area, while on the south the granodiorite extends for some miles beyond the limits of the map. The line of separation between the dacite and the granodiorite runs approximately from west to east, generally occupies relatively low-lying ground, and for a considerable distance closely follows the course of Monbulk Creek. The narrow-gauge railway from Ferntree Gully to Gembrook runs for some distance almost parallel to this boundary, and some little distance to the north of it. Between Aura and Emerald, however, the railway-line crosses the boundary between the two rock series, and the stations along this line give the most convenient access to the area. The length of junction examined is about 6 or 7 miles. At the western end of the line, the junction of the two series is obscured beneath the alluvium of the lower part of Monbulk Creek. At the eastern end, near Emerald, the junction is hidden beneath a later basaltic flow.

Fig. 1.



(*b*) The Altered Dacites.

In most places in Victoria where the junction of dacite and granodiorite has been observed, the dacite, for a few feet from the junction, commonly shows a slight tendency to a schistose character, and, as will be seen subsequently, this is accompanied by interesting mineralogical changes revealed under the microscope. At Macedon the junction is of this character, and also at Nyora and probably near Marysville.

For a considerable distance along the contact in the Dandenong area the contact-rocks of the dacite series are of the above character. This is the case to the south-west of Upway, and also in the district between Selby and Aura and for a little distance east of Aura, where the dacite, besides being slightly schistose, is much coarser in grain and approaches somewhat closely to a plutonic rock in habit and texture.

(*c*) The Gneissic Rocks.

South of Upway, Belgrave, and Selby, at and near the junction with the granodiorite, a remarkable series of gneissic rocks is developed. This can be traced eastwards to a point south-west of Aura Station, where its place is taken by the coarse-grained and but slightly schistose dacite already mentioned. Farther east, between Aura and Emerald, the gneissic rocks are seen once more. In places the rocks are typical gneisses, being very well foliated. The planes of foliation are approximately parallel with the junction of the granodiorite. Biotite, quartz, and felspar appear to be the constituent minerals, and a considerable variation in texture, from fairly coarse-grained gneisses to fairly fine-grained schists, is noticeable in the field.

(*d*) Relations of the Granodiorite to the Altered Dacite and to the Gneissic Rocks.

The exact junction between the granodiorite and the gneissic rocks, owing to limited exposures, cannot everywhere be seen. The area is well wooded, and at the point where the gneisses were first seen the junction with the plutonic rock could not be found. I at first thought that the foliated gneiss might be a modification of the granodiorite produced by differential movement at its margin during the later stages of consolidation. Further examination of that part of the contact which lies between and south of Belgrave and Selby provided definite evidence that this view of the origin of the gneisses must be abandoned. In many places between these limits the actual junction could be seen to be perfectly sharp and well defined, and several junction-specimens have been collected. The granodiorite examined in the heart of the mass is a quartz-biotite-felspar rock, with hornblende and basic patches occasionally developed. It shows no trace of foliation, and retains these characters up to the junction. It is clear that the gneiss cannot be regarded as a marginal modification of the granodiorite, but is a rock having a distinct mode of origin. Close examination of the junction provided definite evidence, not only that the gneiss is older than the granodiorite, but also that it received its foliation before the final consolidation of the granodiorite took place. This is demonstrated by the occurrence of acid veins allied to aplite and pegmatite which traverse the gneiss at and near the junction with the granodiorite, and often cut right across the foliation of the gneiss. These acid veins show no signs of having undergone disturbance since their intrusion into the gneiss. Several of them, ranging in size from a quarter of an inch up to several feet in diameter, occur at and near the junction of the granodiorite on a ridge about a third of a mile south of Selby Station. In addition, a large acid intrusion, about 100 yards long and 20 feet in minimum breadth, is intercalated among the gneissic rocks of the ridge and parallel to their planes of foliation. There can be no doubt, therefore, that the rock which is now a gneiss became foliated before the intrusion of the acid veins.

In those parts of the contact where the gneisses are absent and the dacite is but partly schistose, evidence is also obtainable that the granodiorite is a later rock intrusive into the dacite series. South of Upway and in one or two other localities acid veins at the contact can be seen penetrating the slightly altered dacite. It is also to be noted that a tourmaline-bearing pegmatite vein, a few inches thick, traverses the fairly normal dacite in a railway-cutting immediately east of the bridge near Belgrave Station.

The relations of the granodiorite to the altered dacites and to the gneisses are thus seen to be similar. In each case the plutonic is the younger rock intrusive into the older series.

Apart from the acid veins mentioned above, a few dykes of hornblende-porphyrite have been seen near Aura, both in the granodiorite and in the gneissic and dacite series. These, of course, afford no certain evidence as to the relative ages of the rocks which they traverse; but it is believed that they are genetically connected with the granodiorite and form one of the later incidents connected with the intrusion and consolidation of the plutonic rock.

(*e*) Relations of the Gneisses to the Dacites.

While the junction of the gneisses with the plutonic rocks is, wherever seen, sharp and definite, no such clear demarcation has been made out between the gneisses and the dacites. Rock-exposures are not numerous, as the country is densely timbered and there is generally a somewhat luxuriant undergrowth. In places, however, clearings have been made; while sometimes a forest fire serves the same purpose, and then fairly continuous rock-exposures can be seen.

Three localities will serve to illustrate the relations of the two rocks, which are also illustrated in figs. 2 & 3, p. 456:—

(α) A traverse from south to north from the granodiorite between Belgrave and Selby shows first the sharp junction with the gneiss, then a thin belt of gneisses, and farther north a less foliated rock occurs, which appears to pass through schistose dacite into the normal rock.

(β) Walking northwards from south of Selby, after passing over a fairly broad belt of gneissic rocks exposed on rising ground, a narrow ridge is reached consisting mostly of foliated gneiss. On this ridge, however, there occurs a small elliptical area, about 20 yards in longest diameter, which consists of normal dacite in the centre and slightly schistose dacite at its margin. Unfortunately, the section is not quite clear; but within a yard or two there is a change to the foliated gneiss, which is farther north replaced by schistose and then normal dacite.

(γ) A third traverse, in a northerly direction from south of Upway, also shows interesting and puzzling features. The junction of the granodiorite with a schistose dacite occurs immediately south of Monbulk Creek, and is quite sharp. Acid veins traverse the schistose rock near the contact. North of Monbulk Creek a pathway rises for about 200 yards towards a cottage. Occasional exposures along this path consist alternately of fairly normal dacite and of a highly schistose rock. Several schistose zones appear to be developed in belts trending east and west and roughly parallel to the boundary of the granodiorite and dacite. To the north of these exposures normal dacite alone is seen, except that a quartz-vein about 2 feet wide occurs in the dacite in a cottage garden immediately south of the road from Upway.

IV. Petrography.

(a) The Granodiorite and the Acid Veins.

The granodiorite.—No special study has been made of this rock. It belongs to the granodiorite group, as defined by Lindgren. This is clear from its chemical composition, and from the fact that the ratio of soda-lime to alkali felspars is more than 2:1. The soda-lime felspars are generally zoned, and range from oligoclase to labradorite in composition. They are usually idiomorphic, especially with respect to the alkali felspar and the quartz, both of which are fairly abundant. The alkali felspar sometimes shows a perthitic intergrowth with albite. The ferromagnesian minerals are biotite (very abundant), and hornblende, which is fairly common near the boundary with the dacite, but appears to be less common away from the junction. It is especially to be noted that

Fig. 2.—*Diagrammatic section* (A *on the map, fig. 1, p. 452*) *from south-east of Upway, showing the relations of the dacite and altered dacite to the granodiorite.*

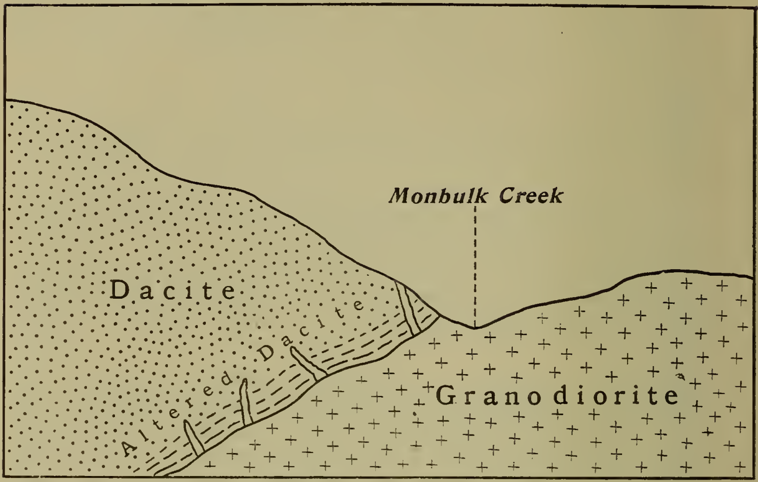
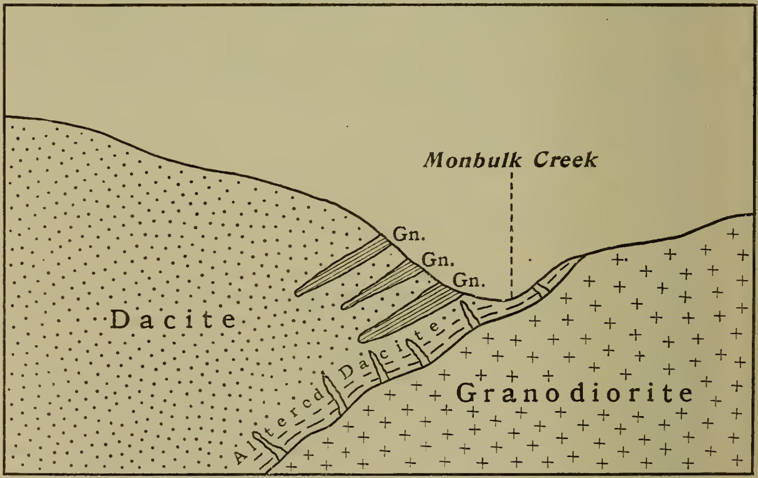


Fig. 3.—*Diagrammatic section* (B *on the map, fig. 1, p. 452*) *from south of Upway, showing the relations of the dacite, altered dacite, gneissic rocks* (Gn.), *and granodiorite.*



there is no tendency towards a schistose structure in this rock; and, apart from a slight undulose extinction in some of the quartz, no evidence of strain is observed under the microscope.

The acid veins.—Several of the acid veins are almost free from coloured minerals, and look like aplite. They have, however, a hypidiomorphic to graphic and not a panidiomorphic structure. They consist chiefly of alkali felspar, with a perthitic intergrowth of albite and of quartz. A little acid oligoclase, biotite, and tourmaline are also present. One true pegmatite vein occurs in the railway-cutting near Belgrave Station, and consists of alkali and lime-soda felspars, quartz, and tourmaline. The section shows a fairly good intergrowth of quartz and felspar. In no case do any of these acid veins exhibit any signs of strain or foliation, either in the field or under the microscope.

(*b*) The Dacite.

As an example of a fairly normal dacite, the rock described by one of my assistants, Mr. H. C. Richards (13), from a quarry just west of Upway Station, may be noted. The following account is taken chiefly from Mr. Richards's description. The dacite is a dark-grey and very hard, compact, porphyritic rock. In the hand-specimen phenocrysts of felspar and of a dark-brown biotite, in well-formed hexagonal flakes, can be seen. Under the microscope in thin section are seen abundant regular zoned phenocrysts of plagioclase, which are mainly Ab_1An_1 in composition, as determined by the Michel-Lévy method. Dark-brown biotite, pale-green hypersthene, occasionally quartz, and opaque grains of ilmenite are also porphyritic constituents. Some ilmenite occurs as inclusions both in the hypersthene and in the biotite. In places ilmenite grains are surrounded by narrow fringes of biotite, in such a way as to suggest that before the ground-mass crystallized under superficial conditions reaction occurred between the ilmenite and the acid ground-mass, giving rise to a fringe of secondary biotite. The phenocrysts are set in a fine-grained microcrystalline ground-mass of quartz, felspar, and biotite. The felspar of the ground-mass appears to be a mixture of orthoclase and of plagioclase of the composition Ab_9An_8. Phenocrysts and ground-mass are about equally represented. The average diameter of the phenocrysts is about 0·1 millimetre, and of the minerals of the ground-mass only about 0·01 mm. Mr. Richards's calculation of the mode of the rock by Rosiwal's method yielded the following result:—

		Mineral percentage.
Phenocrysts	Plagioclase (Ab_1An_1)	24·13
	Hypersthene	12·17
	Biotite	10·96
	Quartz	1·22
	Ilmenite	1·08
Ground-mass	Felspar { Orthoclase and Plagioclase (Ab_9An_8). }	22·95
	Quartz	20·34
	Biotite	7·15
	Total	100·00

Some sections of the dacite exhibit flow-structure, but no signs of strain or of the effects of subsequent movement in the rock are to be seen. Pl. XXXII, fig. 1 illustrates the appearance of a normal dacite in thin section.

(c) The Altered Dacites.

In these rocks, which are found only near the contact with the granodiorite, a more or less definite parallelism in the arrangement of the minerals is noticeable, and in the field they appear slightly schistose. Under the microscope this is only sometimes noticed, but important mineralogical changes, described below, are recognizable.

Biotite after ilmenite (No. 418).—This may be taken as a type of dacite in which the schistose structure is but feebly developed. The same minerals occur as in the normal dacite; but secondary changes are common, and produce characteristic mineral aggregates. Pl. XXXII, fig. 2 shows the most noticeable feature, which is the pronounced development of more or less circular clusters or aggregates of secondary biotite, arranged in criss-cross fashion. In examining a number of sections of the altered dacites all stages can be traced, from that in which the biotite aggregates occur only as a thin fringe to the ilmenite, through stages in which the biotite is more developed, to the extreme case in which no ilmenite remains and the cluster is composed entirely of biotite. In the case of this rock, which occurs close to the granodiorite boundary, it is clear that reaction between the ground-mass and the ilmenite has resulted in the formation of clusters of secondary biotite. This differs somewhat in appearance, habit, and optical behaviour from the primary biotite phenocrysts, and suggests that the secondary is probably different from the primary biotite in composition as well as in mode of origin.

Corrosion of biotite phenocrysts by the ground-mass (No. 374).—This rock was taken from a quarry near Upway Station, almost a mile from the granodiorite junction, but it shows certain features more commonly seen in the rocks close to the contact. Examination under a high power shows a large phenocryst of biotite, which has been attacked at its margin by the ground-mass. Small particles of biotite, which probably once formed part of the original crystal, are now seen a short distance from its margin; while their place is now taken by minute quartz and felspar granules, which appear to indent the edge of the phenocryst. This effect is only seen occasionally in the normal dacite, in which case it probably results from the corrosive action of the still molten ground-mass on the biotite phenocryst, which was only stable under deeper-seated conditions. It is, however, a feature which is practically always present in the altered and slightly banded dacites adjoining the granodiorite.

Biotite after hypersthene.—Among the altered dacites near the granodiorite contact, secondary biotite is sometimes formed at the expense of the original hypersthene.

Slide No. 458 (Pl. XXXIII, fig. 1) shows a large phenocryst of hypersthene, the margin of which is now frayed and ragged. Immediately surrounding the hypersthene are numerous minute flakes of secondary biotite derived from the hypersthene.

Secondary quartz from hypersthene.—In the same slide some clear grains of quartz associated with the biotite appear also to be secondary and to be derived from the hypersthene.

Enstatite and bastite after hypersthene.—In some cases near the contact the alteration of the hypersthene has proceeded differently. Iron has been transferred from the central to the marginal parts of the crystal. The result has been the formation of enstatite, often altered to fibrous biotite, and the deposition of hæmatite or of secondary biotite round the margin of the crystal. The conversion of hypersthene into enstatite and bastite is a change commonly attributed to weathering, and it is quite possibly due to that cause in this case.

Secondary tourmaline.—In many of the altered dacites near the granodiorite contact tourmaline has been recognized.

No. 812 shows in the centre of the field a minute elongated brown crystal which has a high refractive index, no cleavage visible, and intense pleochroism, the maximum absorption occurring in a position at right angles to that characteristic of the biotite. The mineral shows straight extinction, is uniaxial and negative, and there can be no doubt that it is tourmaline. This is the only section in which normal brown tourmaline has been noticed in an altered dacite. Quite a considerable number of slides of the altered dacites contain aggregates of very minute and generally irregular granules of a bluish-grey pleochroic mineral. This I at first regarded as a soda-hornblende, and have referred to it as such (14). Later and more detailed examination shows that a number of the granules are hexagonal in outline, and one or two elongated sections were seen. These latter show straight extinction, strong pleochroism, absorption in a position at right angles to that shown by biotite, and are optically negative. These characters, together with the hexagonal shape of some of the sections, indicate that the mineral is a peculiar variety of blue tourmaline. It is to be noted—and this is well seen in such sections as No. 465 (Pl. XXXIII, fig. 2)—that this blue tourmaline is nearly always closely associated with hypersthene and less commonly with biotite. In No. 465 clusters of tourmaline occur at both ends of a corroded hypersthene phenocryst. This I regard as indicating that the mineral is secondary in origin, and formed by the reaction of boracic vapours or solutions with the ferromagnesian minerals of the dacite. It is a curious circumstance that, up to the present, tourmaline has not been noticed in the highly schistose or gneissic rocks.

In the altered dacites just described the banded or slightly schistose structure is more noticeable in the field than under the microscope, although in some cases a parallel arrangement of the minerals can be seen in thin sections.

Highly altered dacites.—No. 426 (Pl. XXXIV, fig. 1) may be taken as an example of a rather more banded or schistose dacite, in which, however, none of the effects—such as strain-polarization, or granulitization of the phenocrysts—attributable to dynamic metamorphism can be seen. There is, nevertheless, a noticeable parallelism in the disposition of the minerals in the rock. This may be in part due to an original flow-structure in the rock, or may be of later origin. Certain structural and mineralogical changes, such as the criss-cross aggregations of biotite and the marginal corrosion of both biotite and hypersthene, are almost certainly of secondary origin. Some of the felspar phenocrysts also show minute granules of secondary felspars developed within them. All these characters closely ally the rock with the less banded or schistose dacites.

(*d*) The Gneissic Rocks.

In these rocks very extensive structural and mineralogical changes have taken place. The field-evidence already adduced shows clearly that the gneisses are not marginal modifications of the granodiorite, but suggests strongly that they represent an extreme stage of alteration of the dacites. In thin section these rocks have a granular ground-mass of quartz and felspar similar to that of the altered dacites described above. In both series the size of the granules in the ground-mass shows variations in different rocks, but the granules are larger in the gneisses than in the banded dacites.

No. 371 (Pl. XXXIV, fig. 2) is a representative of the extreme gneissic stage, from a locality south of Selby. Both structurally and mineralogically this rock shows certain differences from the less altered rocks. In some of the more altered dacites near the contact the progressive replacement of ilmenite by biotite, and of hypersthene by biotite and quartz, has been described. In the gneisses hypersthene is entirely absent, and ilmenite is very rarely present. In their place one notices an abnormal development of biotite. The proportion of phenocrysts to ground-mass in the two types appears to be about the same, and the total area occupied by biotite, hypersthene, and ilmenite in the dacite is about the same as that of the biotite in the gneiss. The plagioclase phenocrysts are still recognizable in the gneiss, while clusters of biotite and quartz are occasionally so arranged as to suggest by their shape the outlines of hypersthene phenocrysts. It appears, therefore, to be the case that in these gneisses we are dealing with the limiting stages of mineralogical change, the interesting earlier stages of which are represented by the altered dacites already described. The rock shows a marked parallel orientation of the minerals, and this is accompanied by certain strain-polarization effects. Some of the felspar phenocrysts show granulitization at their extremities, and a few now consist of aggregates of secondary felspar which fairly preserve the original shapes of the phenocrysts. Combined with these changes I often noticed the development of secondary granules within the felspar phenocrysts and a criss-cross aggregation of the biotite, which allies these rocks with the altered dacites.

V. Chemical Composition of the Minerals and Rocks.

Investigation of the chemical composition of the minerals of the dacite and bulk analyses of the dacite, the gneiss, and the granodiorite were undertaken, in the hope that they would throw light on two problems:

(1) The relations existing between the dacite, the gneiss, and the granodiorite; and

(2) The evidence as to the conversion of original minerals in the dacite into the secondary minerals of the altered dacites.

In 1906 two of my students, Mr. Plante and Mr. Richards, at my suggestion made chemical analyses of the normal dacite, the gneiss, and the granodiorite. Their results showed that a very close similarity in composition exists between the three rock types. The analyses were, however, not entirely satisfactory, since no determination was made of the alkalies present in the reagents used, and in consequence too high a percentage of soda was indicated in the rocks. As, however, all three analyses were made under similar conditions, they are useful for purposes of comparison. They show in each case that the percentages of alkalies and alkaline earths are practically identical, and that the granodiorite has rather more silica and less total iron-oxides than either the dacite or the gneiss. The differences are, however, so slight, and the resemblances so close, that all the rocks may confidently be referred to a common magma-reservoir and to the same geological period.

Mr. Richards's later chemical work (13) is of considerable importance, and includes analyses of the normal dacite and of each of its ferromagnesian minerals. His results are as follows:—

	A.	B.	C.	D.	E.
SiO_2	63·27	63·31	39·86	50·42	...
Al_2O_3	16·50	14·44	11·13	4·06	...
Fe_2O_3	0·68	1·48	1·39	2·10	...
FeO	5·10	4·66	18·10	23·54	31·92
MgO	2·48	2·35	9·88	13·04	0·80
CaO	4·18	3·67	sl. tr.	1·30	...
Na_2O	2·36	4·56?	0·35	trace	...
K_2O	2·68	2·67	6·73	0·69	...
H_2O+	0·52	...	3·20	0·06	...
H_2O-	0·09	0·79	0·43	0·10	...
CO_2	...	...	...	...	...
TiO_2	1·30	1·82	7·95	3·51	67·28
P_2O_5	0·15	0·39	trace	0·92	...
$S(FeS_2)$	0·16	..	...	...	...
MnO	0·03	0·88?	0·58	0·24	trace
Li_2O	trace	...	sl. tr.	...	...
Totals	99·50	101·02	99·60	99·98	100·00
Specific gravities	2·76	...	3·16	3·36	4·86

A = Dacite near Upway; B = Gneiss, Monbulk Creek; C = Biotite in dacite from Upway; D = Hypersthene in dacite from Upway; E = Ilmenite in dacite.

The formulæ of the minerals are as follows:—

Biotite:

$$2R_2O . 4RO . R_2O_3 . 6SiO_2 = 2(KH)_2O . 4(FeMg)O . Al_2O_3 . 6(SiTi)O_2.$$

Hypersthene:

$$12RO . R_2O_3 . 16RO_2 = 12(FeMg)O . (AlFe)_2O_3 . 16SiO_2.$$

Ilmenite:

$$RO . 2RO_2 = (FeMg)O . 2TiO_2.$$

The felspars in the rock determined optically were

Phenocrysts—Plagioclase (Ab_1An_1).
Ground-mass—Orthoclase and plagioclase (Ab_9An_8).

With the foregoing evidence it is possible to see how far the mineralogical changes observed under the microscope in the schistose series can be confirmed by reference to the known composition of the primary minerals in the rock.

The most important mineralogical changes noted were

(i) The alteration of hypersthene to secondary biotite and secondary quartz; and
(ii) the reaction between ilmenite and the ground-mass, giving rise to secondary biotite.

(i) On reference to the mineral analyses, it is seen that the hypersthene, compared with the biotite, shows a marked excess of silica, a deficiency in alumina, an excess of ferrous oxide and magnesia, and a marked deficiency of potash. If an excess of orthoclase, present in the ground-mass, be added to a molecule of hypersthene, a mixture can be obtained bearing a close general resemblance in composition to the biotite, with the exception that a considerable excess of silica remains. It follows, then, that the observed passage of hypersthene into secondary biotite and secondary quartz is in harmony with the known chemical composition of the minerals present in the parent rock.

(ii) The addition of orthoclase to the ilmenite will give a mixture resembling in composition a biotite very low in magnesia and very rich in ferrous oxide. The observed optical characters of the secondary biotite fringing the ilmenite are somewhat different from those of the primary biotite phenocrysts, and suggest that the change has taken place on the lines stated above.

The general results obtained from an examination of the chemical composition of the three rock-types and of the minerals of the dacite are therefore :—

(1) The granodiorites, gneiss, and normal dacite are all the products, very slightly differentiated, of a common magma-reservoir, and they all belong approximately to the same geological period (probably the Lower Devonian).

(2) The secondary minerals mentioned above have been derived from the alteration of, and reaction between, the primary minerals of the dacite.

VI. Effects produced by Contact-Metamorphism.

The field-evidence for the intrusion of the granodiorite into the dacite series has already been summarized. The sharp junction, the acid veins penetrating the dacites, and the alteration in appearance of the dacites near the contact serve to establish this point. The evidence of thin sections adduced in the foregoing pages shows that the dacites near the contact exhibit definite mineralogica changes, while the chemical evidence also supports these conclusions. The question of the origin of the gneiss will be discussed later; but the other alterations in the dacite near the contact may be confidently regarded as the results of thermal or contact-metamorphism.

These changes may be summarized as follows :—

(1) The constant corrosion of primary biotite by the ground-mass with marginal flaking-off of small biotite crystals.
(2) The production of marginal fringes of secondary biotite surrounding the original ilmenite.
(3) The partial alteration of hypersthene to secondary biotite and secondary quartz.
(4) The reaction between ilmenite and the felspar of the ground-mass, leading to the formation of secondary biotite.
(5) The formation of minute grains of blue tourmaline, noticed only in the dacite near the granodiorite contact.
(6) The production of a subparallel orientation of the minerals in the dacite, giving rise to a slight banded or schistose tendency in the rock.

The literature dealing with the effects of the intrusion of plutonic into volcanic rocks is not copious. To some of this I have but recently had access, so that my observations were completed before I could read some of the papers dealing with this subject. Prof. Judd,[1] in dealing with the intrusion of igneous masses into the andesites of Mull, describes the alteration of pyroxenes, hornblendes, and micas into finely granular aggregates of an almost colourless pyroxene and magnetite grains. Secondary biotite also occurs, and the crystals increase in size as the intrusive mass is approached.

The description by Dr. Marr & Mr. Harker[2] of the intrusion of the Shap Granite into the Borrowdale andesites indicates that some of the effects produced are also noticed in the rocks which I have examined.

A later memoir by Mr. Harker[3] deals with rocks of more basic composition, and describes the alteration of basic lavas by the intrusion of gabbros and granites.

Mr. A. L. Hall[4] describes the intrusion of granite into felsite north-east of Pretoria; he shows that the contact is sharp, that granite-veins penetrate the felsite for a few feet, and that no very obvious change in the felsite is observed in the field.

Two papers by Mr. Kynaston appear to provide the closest parallel to the evidence which I have obtained. In a Survey memoir by several authors, Mr. Kynaston[5] describes the intrusion of the Ben Cruachan granite into masses of porphyrite. This description will be referred to again, in connexion with the origin of the gneissic rocks described above. The effects due to contact-metamorphism include the alteration of the augite and hornblende of the andesites. The augite passes into uralitic hornblende or flakes of pale-green hornblende, but little secondary biotite is formed. In the more altered rocks the ground-mass is completely reconstructed, and consists of a granular mosaic of felspar and quartz with secondary biotite and green hornblende. The felspar phenocrysts are also frequently honeycombed with inclusions of the ground-mass.

Another and earlier paper of Mr. Kynaston's[6] describes the alteration of the andesites by the intrusion of granite in the Cheviot Hills. The effects described are in many respects similar to those that I have noted above, but certain interesting points of difference arise. Mr. Kynaston shows that silica and potash are more abundant in the granite, and soda in the andesites. Intermediate dykes (lamprophyres) and acid dykes penetrate the andesites and represent 'complementary' dykes. Contact-metamorphism in the andesites extends for half a mile from the contact. The normal rock is an enstatite-andesite. In the less altered rocks are produced minute granules of secondary pyroxene, ragged minute secondary

[1] Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 370.
[2] *Ibid.* vol. xlvii (1891) p. 266.
[3] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 50.
[4] Rep. Transvaal Geol. Surv. for 1904 (1905) p. 40.
[5] 'Geology of the Country near Oban & Dalmally' (Expl. of Sheet 45) Mem. Geol. Surv. Scot. 1908, p. 96.
[6] Trans. Edin. Geol. Soc. vol. vii (1899) pp. 390–415.

biotite, and magnetite dust. The mica clusters round phenocrysts, which are corroded. The enstatite is surrounded by pyroxene granules, biotite flakes, and magnetite dust, which also occur in cracks in the crystals. In the rocks near the granite the flakes of biotite are larger, and cluster round the margins of the porphyritic pyroxenes. The enstatite, where changed to fibrous pseudomorphs, shows secondary biotite and pyroxene in cracks.

At the contact with the granite there is a great increase in the development of secondary biotite. The enstatite sometimes is altered to secondary biotite and magnetite with granular pyroxene, sometimes to a green, fibrous, secondary amphibole. The former type of alteration is from fresh enstatite, the latter when the enstatite had first been changed to bastite. Banded rocks with a streaky appearance occur in the altered zone, and Mr. Kynaston thinks that they may be altered tuffs.

It will be noted that the production of secondary biotite and its aggregation into clusters or as fringes to primary minerals are features which both Mr. Kynaston and myself have noticed as characteristic of the contact-zone in volcanic rocks of intermediate composition. I have not seen the production of secondary granular pyroxene nor of secondary hornblende, described by Mr. Kynaston. Alterations noted by me, and not occurring in the rocks described by Mr. Kynaston, are the corrosion of primary biotite, the production of secondary quartz as one of the alteration-products of a rhombic pyroxene, the production of secondary biotite from ilmenite, and the presence of tourmaline in the altered rocks.

VII. Origin of the Gneisses.

Examination of these rocks in the field and in thin sections has led me to describe them as being produced by extreme thermal metamorphism of the dacite by the granodiorite (14). Further work on this series has shown me that the evidence is not sufficiently conclusive for a very definite statement as to their mode of origin. The occurrence of the rocks is peculiar. The acid granitic veins traversing the gneiss generally cut across the foliation of the rock. The acid veins are quite unfoliated, and show clearly that the production of the foliation was antecedent to the intrusion of the acid veins. This fact led me to attribute the foliation to contact-metamorphism. Difficulties occur, however, in the distribution of the gneissic rocks. They occur in the Dandenong and in the Warburton areas, but have not been noticed at Macedon, Nyora, and other places where granodiorite is intruded into the dacite series. Furthermore, as seen above, they only occur along part of the line of contact in the Dandenong area. In other parts only slightly schistose dacite, or (as south of Aura) a coarse-grained slightly schistose dacite forms the contact-rock. South of Upway, as seen in the sketch (fig. 3, p. 456), schistose dacite occurs at the contact; and, on going northwards from this, alternations of normal and highly schistose or gneissic dacites are observed for a few hundred yards.

These occurrences are difficult to explain simply on the hypothesis of contact-metamorphism, unless we are to attribute them to the alteration of a special flow or band of tuff of peculiar composition and more susceptible of structural change than the normal dacite.

An alternative view is that they are the results of dynamic metamorphism. Close examination of thin sections of these rocks shows that some of them exhibit signs of granulitization in the porphyritic felspars and quartz, and the production of strain-polarization effects in these two minerals. Further, there is a very noticeable parallel orientation of the minerals and a more extreme mineralogical change than occurs in the slightly schistose rocks. In the gneiss the hypersthene has completely disappeared, its place being taken by secondary biotite and secondary quartz. Ilmenite is rarely seen, as secondary biotite has been formed from it. On this view, too, the partial distribution of the gneiss can be more readily accounted for, as due to differential movements within the dacite mass. These must, however, have taken place before the intrusion of the acid veins, since the latter commonly cut the foliation planes. They may have formed before the complete consolidation of the whole mass of the dacite.

A third view is that the structures and mineral characters of the gneisses may be due to a combination of dynamic and contact-metamorphism. According to this view the foliation and granulitization were first impressed on the dacite after extrusion, and possibly before its complete consolidation. Following this was the intrusion of the granodiorite, and at a later stage the intrusion of the acid veins into the already foliated rock. To contact-metamorphism may be ascribed certain mineralogical and structural peculiarities, such as the criss-cross arrangement of some of the clusters of secondary biotite; while the absence of marked granulitization and other strain-phenomena in some of the gneissic rocks does not necessarily imply that these structures were never present, but may be explained on the assumption that these phenomena have been obliterated by later recrystallization due to heat and the passage through the rock of heated vapours or solutions from the margin of the granodiorite.

I am not able as yet to discuss this problem with much confidence, but, on the present evidence, I am inclined to favour the last hypothesis. It is recognized as a difficulty in the way of accepting the first explanation, that practically no clear case has yet been described of a gneiss having originated solely by the contact-metamorphism of a volcanic rock. In the memoir by Mr. Kynaston quoted above (p. 464) on the alteration of a mass of porphyrite by the Ben Cruachan granite, is a description of a band of foliated and gneissic rocks which fringe the contact for several miles. In some of the microscope-slides a marked schistose or gneissic structure is described as an effect produced by differential movement in the rock, combined with features due to contact-metamorphism. Through the courtesy of Dr. J. S. Flett, to whom I am also indebted for several helpful suggestions, I have had an opportunity of examining these slides, and in a general way the structures shown resemble those in the gneissic rocks which I have described above.

Until further evidence is available, it would be unwise to say more than that the weight of evidence at present seems to be in favour of regarding the true gneisses as rocks which were originally dacites, and owe their special structural and mineralogical characters mainly to differential movement and in a subsidiary way to later thermal metamorphism.

VIII. Summary and Conclusions.

The area described lies about 20 or 25 miles south-south-east of Melbourne. By the earlier surveyors the dacites were described as traps of Palæozoic age passing gradually into the granites. Prof. Gregory has described them as dacites, and as probably of Lower Tertiary age and resting upon the denuded surface of the granodiorite. I believe that large masses of hypersthene-biotite-dacites were poured over and also intruded into Silurian or Ordovician sediments, probably in the Devonian Period. At a slightly later date, and from the same magmatic reservoir, granodiorite was intruded into the sediments and the dacites. Along the contact with the dacites acid veins are developed, and altered and gneissic modifications of the dacite occur. The characters of the dacite, granodiorite, and schistose and gneissic rocks under the microscope are described.

In the contact-rocks, hypersthene and ilmenite in particular pass over into secondary biotite and quartz and secondary biotite respectively, while blue tourmaline is also found. The chemical compositions of these rocks and of the ferromagnesian minerals are given, and it is shown that their chemical compositions are in accord with the observed mineralogical changes. These effects, together with the production of a slight banding or schistosity, are referred to the contact-metamorphism produced by the intrusion of the granodiorite, while the origin and distribution of the true gneissic dacites is a more difficult problem. This production was formerly referred to contact-metamorphism alone, but now, partly owing to peculiarities of distribution and partly to evidence of crushing, these rocks are tentatively thought to be due mainly to differential movements in the dacite before the intrusion of the granodiorite, complicated by mineralogical and structural changes due to its intrusion.

EXPLANATION OF PLATES XXXII–XXXIV.

[The numbers refer to the slides in the Geological Collection of the University of Melbourne.]

Plate XXXII.

Fig. 1. No. 71. Magnified 25 diameters (ordinary light).—Biotite-hypersthene-dacite from Mount Dandenong, showing phenocrysts of plagioclase, hypersthene, biotite, and ilmenite in a microcrystalline ground-mass of quartz, felspar, and biotite. (See pp. 457–58.)

2. No. 418. Magnified 25 diameters (ordinary light).—Altered dacite (slightly schistose), 100 yards from the contact with the granodiorite, south of Selby. The section shows criss-cross aggregates of secondary biotite, formed by the reaction of ilmenite with the ground-mass. (See p. 458.)

Plate XXXIII.

Fig. 1. No. 458. Magnified 106 diameters (ordinary light).—Banded dacite, Monbulk Creek. The section shows the corrosion of a phenocryst of hypersthene, with marginal formation of secondary biotite, quartz, and blue tourmaline. (See p. 459.)

2. No. 465. Magnified 106 diameters (ordinary light).—Altered dacite, south of Upway, near the contact with the granodiorite. Note the corrosion of the phenocryst of hypersthene and the formation at its extremities of secondary biotite, quartz, and a considerable amount of blue tourmaline. (See p. 459.)

Plate XXXIV.

Fig. 1. No. 426. Magnified 25 diameters (ordinary light).—Altered and schistose dacite, near the contact with the granodiorite south of Selby. Note the parallel orientation of the minerals and the fact that the big phenocryst of hypersthene is largely altered to secondary biotite and quartz. (See p. 460.)

2. No. 371. Magnified 25 diameters (ordinary light).—Gneiss from the upper part of Monbulk Creek. Note the absence of hypersthene and ilmenite from the rock, as also the well-developed foliation which it exhibits. (See p. 460.)

Discussion.

Dr. A. P. Young noted the marked contrast in structure between the effusive and the intrusive rocks, leading to the conclusion that the former had accumulated to a great depth before the intrusion took place. In the scanty proportion of dark constituents, the vein-like occurrences in the dacites resembled aplites. It would be interesting to know the composition of the felspars and to learn how far the relative proportions of lime-, soda-, and potash-felspars obtaining in the granodiorite had been maintained.

The parallel structure of the dacite recalled the fine banding often seen in andesitic rocks elsewhere, notably in those of Ecuador so well shown in the collections of Dr. W. Reiss & Dr. A. Stübel. In this case, however, the characters in question had been acquired at first hand in the course of consolidation, and it seemed impossible to interpret them as contact-effects due to later intrusions.

In the Klausen district of Tyrol rocks of a dioritic series broke through the 'Feldstein,' which was much older than the diorite

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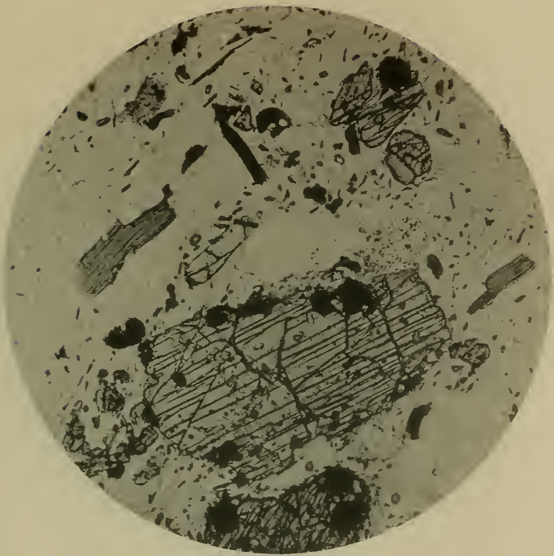

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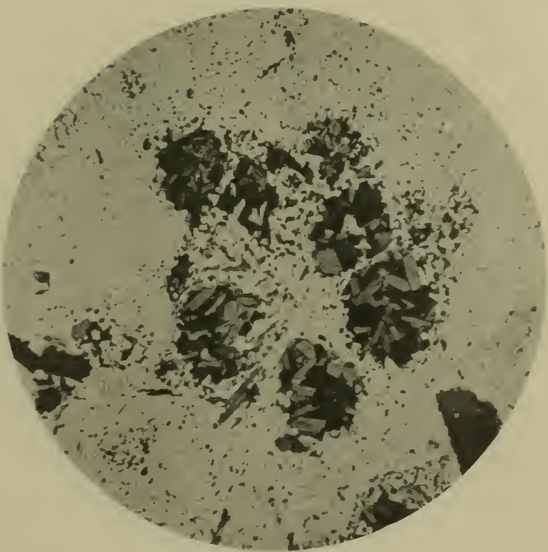

H. J. Grayson, Photo.

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DACITES FROM VICTORIA.

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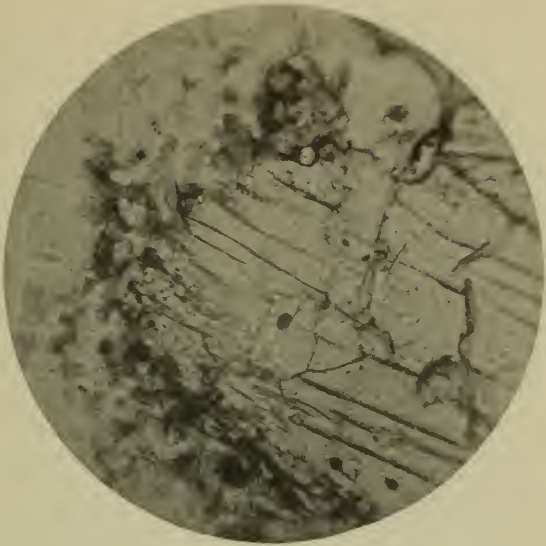

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H. J. Grayson, Photo. *Bemrose Ltd., Collo., Derby.*

DACITES FROM VICTORIA.

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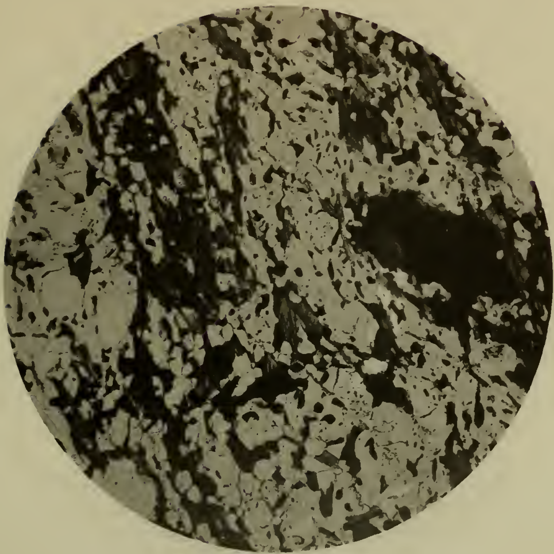

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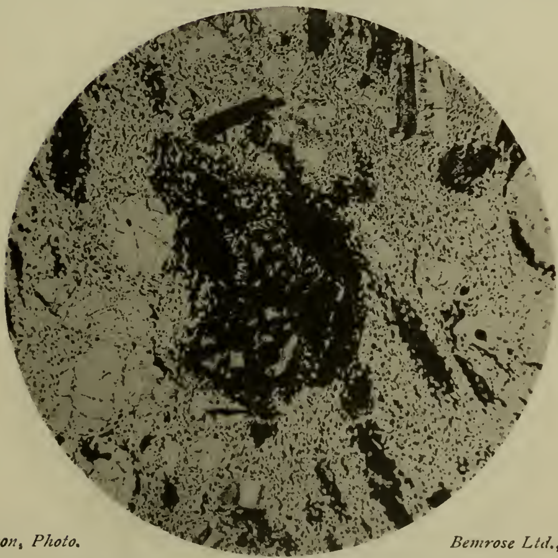

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DACITE AND GNEISS FROM VICTORIA.

and conspicuously foliated, but doubtless of igneous origin. At the junctions tourmaline was found, not only in the Feldstein, but frequently also in the diorite. On the strength of this fact, it seemed desirable to institute a search for tourmaline along the border of the Victoria intrusive.

Mr. A. Wade said that he was much interested in the paper, having just had an opportunity of observing an apparently similar intrusion of a granitic mass into more basic rocks, with resulting foliation of both, upon the island of Shadwan in the Red Sea. He asked the Author whether he could assign an age to the intrusion of the granodiorite.

The Author thanked the Fellows for their reception of his paper. In answer to Dr. Young, he stated that a great thickness of dacite was intruded and extruded before the granodiorite was intruded into it. Tourmaline had not been recognized in the granodiorite, but occurred in some of the acid veins proceeding from it and traversing the gneiss and dacite. The veins appeared to be aplitic in the field, but their texture was hypidiomorphic to graphic.

In answer to Mr. Wade, the Author agreed that the comparison with intrusions in the Red Sea area was interesting; but a difference arose, inasmuch as in the Dandenong area the granodiorite was quite unfoliated, whereas the granite mentioned by Mr. Wade was foliated near its boundary.

The age of the granodiorite of the Dandenong area could not be fixed with certainty. It was intrusive into Lower Palæozoic sediments, and probably belonged to the lower part of the Devonian Period.

20. *The* Natural Classification *of* Igneous Rocks.

By Dr. Whitman Cross, F.G.S. (Read June 15th, 1910.)

Contents.

I. Introduction.

In how far may the systematic classification of igneous rocks, the basis of their petrographic description and nomenclature, be constructed by the application of truly 'natural factors'? This question has long been debated, but petrographers have not reached agreement as to the answer. Meanwhile petrographic system has become greatly confused through varying views as to what are 'natural relations,' and by the illogical or inconsequent use of arbitrary factors. It seems useless to hope for agreement in this matter until the petrographers of different schools have come to understand thoroughly each other's points of view, which are based largely on experience in widely separated fields of work. It is with the idea of promoting in some measure this mutual understanding, that I offer this discussion to the Geological Society of London.

The rocks of the earth exhibit a great variety of relationships of geological importance, as to their origin, their mode, form, and place of occurrence, and possess, in many groups, a complex and often obscure character. The rock is usually defined with emphasis on its geological importance, and it is considered as a geological unit. But there has not always been the desirable clear distinction between the rock-mass, of certain relations of form or position with regard to the earth, and the substance of the mass, the rock proper.

From various standpoints of geology classifications of rocks have been set up, more or less refined, for special or general purposes. All of these classifications are of use so long as their generalizations agree with experience, but manifestly they cannot be all combined in the one scientific systematic classification of petrography, from which the rocks derive their specific names. There must be various classifications of rocks or of rock-masses, from the purely geological side,[1] but there should ultimately be but one petrographic system, based on thorough knowledge, comparable with that of zoology or botany.[2]

In recent years there has been much discussion as to the proper basis for the systematic classification of igneous rocks. In this discussion the adjectives natural, arbitrary, and artificial are often applied to current or proposed bases of classification. In common, I presume, with all other petrographers, I should be glad if a petrographic scheme of classification were possible to which the term natural might be appropriately applied. But I do not believe that such a system is possible, and, further, it seems to me that the systems devised for igneous rocks during the last century are unnatural, and without good reasons for most of their artificial or arbitrary features. Certain American colleagues, who entertain similar beliefs, have united with me in the formulation of the 'Quantitative System for the Classification of Igneous Rocks,'[3] in the construction of which several factors prominent in earlier systems have been ignored. Some of these discarded factors are corner-stones in the systems advocated by believers in a possible natural system. In current criticism of the Quantitative System it is commonly called arbitrary or artificial, with the implication or direct assertion that a much more nearly natural system is in existence or may reasonably be hoped for. With a desire to contribute to the general discussion of this important question, as well as to explain once more my personal point of view, which led me to join in proposing the Quantitative System, I wish to present some considerations as to the availability of the natural relations of igneous rocks as factors in their systematic classification.

It may be well, however, before taking up this subject, to call attention to some general considerations which are no doubt in the minds of many petrographers but should be regarded by all, in discussions of classification. First may be mentioned the importance of definite names for rocks. Our use of a name should imply a certain meaning in our own consciousness, and the use is certainly without desired effect if the same significance is not conveyed to others. This necessitates a definition, which, in the case of a rock

[1] W. Cross, 'The Geological *versus* the Petrographical Classification of Igneous Rocks' Journ. Geol. Chicago, vol. vi (1898) p. 79.

[2] The obscure character of many igneous rocks on the one hand, and the need for a nomenclature based on external characters, where chemical and microscopical study is impossible, on the other hand, seems to render a field-nomenclature advisable. Such a scheme has been proposed by Cross, Iddings, Pirsson, & Washington, and elaborated by L. V. Pirsson in a textbook intended for the field geologist and mining engineer; but such a classification is clearly not for the petrographer as a specialist. 'Rocks & Rock Minerals' 1908, pp. 414.

[3] W. Cross, J. P. Iddings, L. V. Pirsson, & H. S. Washington, 'Quantitative Classification of Igneous Rocks' Journ. Geol. Chicago, vol. x (1902) pp. 555–690, and in book form, Univ. of Chicago Press, 1903.

or other systematic unit, means a precise statement of the qualities characterizing it. Petrographic nomenclature must be based on a universal scientific system of classification in order that general discussions concerning rocks may be fruitful, as well as for the sake of convenience and clearness in description. There are reasonable grounds for the suspicion that many petrographers of to-day have a very hazy idea of what they mean in using most rock-names. The reader of petrographic literature is often quite uncertain as to the real character of rocks named, but not fully described.

All petrographers should realize that when they advocate 'a natural classification' of igneous rocks, or refer to existing usage as 'natural,' in any particular, they must mean *according to the nature of those objects*. Yet the relations assumed to be natural are actually, in most cases, merely empirical formulæ long since shown to have limited application. Only generalizations without known exceptions in experience can be applied to the construction of a system that may be called *natural*. Let us have regard for things as they are, not assume them to be as we wish they were, or as it would be convenient to have them.

A classification of natural objects worthy of acceptance as the systematic scheme for a branch of natural science must be logical and consistent in construction. As numerous logicians and philosophers have pointed out, a systematic classification must be constructed by the use of factors vitally related to the differing properties of the objects to be classified, and their application should follow the order of their importance. A scientific specialist should not be satisfied with a system which is such only in the mechanical plan of its construction, or with one which does not apply to all objects of the class in question.

With these principles in mind it appears to me that most classifications of igneous rocks must be called *unnatural and illogical or unscientific* in construction. These defects arise from two principal causes. In the first place, *what has been found or believed to be true of the rocks of a petrographic province, or of a certain group, has often been too quickly assumed to be true of all igneous rocks, and an erroneous factor has been thereby introduced into the system*. The age distinction, for example, seemed natural to Continental petrographers, while British geologists knew it to be unnatural, in the light of their observations. Such assumptions are perhaps unavoidable in the early history of a science, but the time must come when they should be rigorously tested in their application to the rocks of the whole earth. In the second place, *it has been the practice of many of the most eminent petrographers to assume as true certain relations of rocks which were known to be but approximately in accordance with observed facts*. The assumptions that texture is a function of depth, or of pressure, or of a eutectic mixture, illustrate this point. It is usually, in such cases, the convenience of the would-be systematist which is regarded, and the resulting scheme cannot be permanent.

The first step in all current petrographic systems may be called a natural one. Igneous, sedimentary, and metamorphic rocks are grand divisions made in recognition of the intimate relation between the most important characters of rocks and certain great earth-building or modifying processes. The further use of geological factors in the classification of each grand division must depend upon their suitability for this purpose.

Chemical composition, mineral constitution, and texture are, in this order, the generally recognized natural properties of igneous rocks available for their classification. The chemical characters are certainly fundamental, and most closely connected with the molten condition. Are the chemical differences of igneous rocks clearly determined by a geological factor which may be used in the next step in classification? It does not seem to me that such is the case, but that is the *crux* of this discussion, and I desire to consider the actual, that is, the natural, relations of rock-characters to mode of origin or geological occurrence, and compare these with the assumptions current in petrographic system.

II. Factors of Chemical Composition.

The chemical composition of igneous rocks as a class is now fairly well known. No one can safely question the fact that the great majority of rocks belong to a category in which there is gradation in composition from one type to another. Even the extreme chemical types are no doubt connected with the average rock by a continuous series, although some units may be, as yet, undescribed. Classification on a strictly chemical basis is, then, necessarily arbitrary or artificial, and a natural classification that is to express the fundamental chemical characters of igneous rocks must rest on facts of genesis, or of occurrence vitally related to the known features of composition.

Origin of differences of composition.—The observed differences in chemical composition of magmas may be due to several causes:

(*a*) Primeval differences in the composition of the earth's crust at different places. These variations are necessarily difficult to define, and are hypothetical as to origin. They must be expressed as facts of distribution.

(*b*) Magmatic differentiation,—by which a homogeneous magma has split up into component parts of differing composition.

(*c*) Assimilation,—by which a given magma has been changed in composition through the fusion and absorption of unlike material.

The first of these possible causes is quite hypothetical, and not certainly distinguishable from the others in its effects. Probably it would be most prominently visible in the geographical distribution of chemically different rocks. It is not intended to imply that the observed variation in composition of the rocks of different parts of the earth is of this origin.

Differentiation and assimilation are in a measure antithetical processes. The former must proceed by laws; the latter is not related to the former in any definite way, and its effect may be regarded as determined by chance. Assimilation is not uncommonly assumed to have occurred in masses open to our examination and at the place where the rock is now seen. My own experience leads me to question the correctness of this assumption except in rare instances, but it is difficult for me to conceive that fusion does not take place at lower levels. If assimilation occurs within a magma-basin where differentiation has been in progress, it may affect only products of that basin, and thus merely disturb the ordinary sequence of descendant magmas. But if other materials, such as sediments, deeply infolded or faulted, should be dissolved by a magma and assimilated, it is plain that the composition of the new solution may be radically changed. Quartzite, limestone, shale, or old volcanic rocks of different composition would modify the character of an assimilating magma in very different ways, and quite independently of the earlier history of that magma.

If the ideas of isostatic adjustment within the earth's crust, by lateral flow of magma, now receiving much support from geophysicists, are correct, it appears quite possible that magmas of a given character may be moved to places where they may attack and assimilate materials of different character. When this new molten solution resolves by differentiation into parts, the products may be notably different from those which would have formed under the earlier conditions.

If the deep-seated magmas of large volume have acquired their various chemical characters in different ways, it appears at once evident that this primary genetic factor cannot be used in classification, unless the characters of different origin can be distinguished in the rocks. It seems to me clear that the antithetical and wholly independent processes of differentiation and assimilation cannot be recognized in their resultant rocks, except in the relatively rare cases where they occurred at places subsequently revealed to our examination.

If certain rocks can be recognized as deriving their chemical characters from magmatic differentiation (or from assimilation), it is logically possible to introduce this factor into classification by a primary division into: (*a*) rocks due to magmatic differentiation (or to assimilation); and (*b*) rocks not demonstrably of such origin. But such a proposition would hardly be seriously considered as suitable for general petrographic system.

Despite the inherent difficulties of genetic classification, many attempts have been made to render systematic classification natural by using factors of origin and occurrence, and it is now desired to review the various propositions of this kind.

Classification by geographical distribution of chemically different rocks.

If the igneous rocks of the northern and southern hemispheres, or of the several continental masses, differed radically in chemical composition, with no or but few common types, we might use this fact as a primary means of classification, even if the reason for such differences were not understood. But the rocks exhibit no such sharp limitations in occurrence, although certain notable features of distribution have been pointed out. Some attempts have been made to introduce these factors into petrographic system.

The Atlantic and Pacific kindred.—In 1892 Iddings pointed out that rocks rich in alkali seemed to be abundant in certain parts of the world and rare in others,[1] outlining to some extent their distribution. Later, Harker commented on the correspondence of the areas characterized by the alkali and subalkali groups with the broad Atlantic and Pacific basins, and suggested a kind of correlation between these magmatic facies and crustal movements.[2] But this vague distinction of chemical groups first assumed systematic importance through the proposition of Becke[3] to distinguish the Atlantic and Pacific 'Sippen' or kindred, which is, in fact, as he states, an attempt to provide brief and convenient terms for cumbersome expressions used by Rosenbusch and his followers to designate the 'foyaitic-theralitic' and 'granito-dioritic and gabbro-peridotitic' magma series. These series are really based upon chemical differences, and will be referred to again. Aside from the question as to whether such a primary chemical division is justifiable, the use of the terms Atlantic and Pacific, in the manner suggested by Becke, implies a generalization as to facts of distribution to which there is such a multitude of exceptions that its expression in system is unwarranted.

It may be true that the lands adjacent to the Atlantic Ocean are richer in the so-called alkali-magmas than those bordering the Pacific, but existing data concerning large areas involved in this generalization are very meagre, and the question has never been discussed in print with the thoroughness which it deserves. This is manifestly not the place for extended comment on this matter, but I wish to point out certain facts among many which might be cited as bearing on the problem.

Bohemia, the younger rocks of which country Becke strangely selects as representing the Atlantic kindred, lies between Hungary and Germany. The great series of volcanic rocks of the former country are admittedly typical of the Pacific kindred; and Germany, though exhibiting many rocks of both series, is particularly the land of the Pacific lamprophyres—minette, kersantite, vogesite,

[1] 'The Origin of Igneous Rocks' Bull. Phil. Soc. Wash. vol. xii (1892–95) pp. 89–213 (pp. 183, 184).

[2] 'The Natural History of Igneous Rocks' Science Progress, vol. vi (1897) pp. 12–33.

[3] 'Die Eruptivgebiete des Böhmischen Mittelgebirges & der Amerikanischen Andes' Tscherm. Min. Petr. Mitth. vol. xxii (1903) pp. 209–65.

spessartite, odinite, etc., which, according to Rosenbusch, indicate the presence of deep-seated parent magmas of the Pacific kindred.

As to the North American continent, Iddings[1] once remarked that alkali-rocks occur more abundantly along the eastern base of the Rocky Mountains than in the Great Basin and along the Pacific Coast. I do not know that this is the basis for Prior's[2] statement that it 'has been noted that the eruptive rocks in the United States become more and more rich in soda as one proceeds from west to east,' but an examination of Washington's tables of analyses shows some peculiar facts of distribution which hardly support the latter generalization.

It seems that the analysed rocks of the Pacific coast are dominantly alkali-calcic and those of the eastern Rocky Mountain zone more strongly alkalic. But this difference appears less striking than the predominance of soda-rocks on the Pacific coast. In fact there are at least a dozen rocks of the Pacific coast, from Alaska to Southern California, which show a greater excess of soda over potash than appears in any rock of Montana, Wyoming, Colorado, or New Mexico. Conversely there are no rocks on the Pacific coast so rich in potash as the leucite-rocks of Wyoming. Some of these soda-rich rocks are also high in lime, but others are so clearly alkalic rocks that they must be referred to the 'Atlantic kindred' of Becke. Some of the more striking occurrences are indicated in the following table, with a few other rocks on which comment will be made :—

Rock.	*Locality.*	Analysis shows				Norm has			
		SiO_2.	CaO.	Na_2O.	K_2O.	An.	Ab.	Or.	Ne.
Quartz-porphyry (Turner).	Plumas Co., Cal.	72·77	2·47	4·95	0·34	12·5	41·9	1·7	0·0
Soda-rhyolite (Palache).	Berkeley, Cal.	75·46	0·95	6·88	1·09	1·7	58·2	6·7	0·0
Aplite (Turner).	Mariposa Co., Cal.	74·21	1·71	7·62	0·10	5·3	63·9	0·6	0·0
Soda-syenite porphyry (Turner).	Tuolumne Co., Cal.	67·53	0·55	11·50	0·10	0·0	95·4	0·6	0·0
Soda-syenite (Becker).	Treadwell Mine, Alaska.	63·01	2·66	10·01	0·39	4·4	83·3	2·2	0·6
Carmeloite (Lawson).	Carmelo Bay, Cal.	52·83	7·35	6·61	2·52	10·8	35·6	15·0	11·1
Essexitic andesite or trachydolerite.	Crater of Haleakala, Hawaii.	49·55	7·01	6·12	2·29	14·5	34·1	13·3	9·4
Essexite (Rosenbusch).	Salem Neck, Mass.	47·94	7·47	5·63	2·79	13·9	25·7	16·7	11·9
Augite-teschenite (Fairbanks).	Point Sal., Cal.	49·61	10·05	5·62	1·04	23·9	23·1	6·1	13·3
Teschenite (Fairbanks).	Cuyamas, Cal.	50·55	7·30	8·37	2·27	11·7	17·8	13·3	28·7

[1] 'The Origin of Igneous Rocks' Bull. Phil. Soc. Wash. vol. xii (1892–95) p. 184.

[2] 'Contributions to the Petrology of British East Africa' Min. Mag. vol. xiii (1901–03) p. 261.

A large proportion of the dominant alkalicalcic rocks of California are very rich in soda as compared with potash—a much larger proportion than among the rocks of the Rocky Mountains. The Pacific coastal zone appears to be a soda-rich province, as compared with the Rocky Mountain portion of the United States.

Another distinction which seems notable from a study of Washington's tables is that on the Pacific coast high silica goes with high soda, so that foyaitic magmas, nepheline-rocks, are rare, especially among persalanes and dosalanes. In the salfemane class there are some nepheline-bearing rocks, as illustrated by three cases of the foregoing table. These belong, of course, to the Atlantic kindred, with the essexite of Salem Neck, which is included in the table for purposes of comparison.

These facts regarding the rocks of the Pacific zone of North America indicate, I think, that they possess provincial peculiarities of interest; but these are not by any means identical with the features emphasized by Becke and others as characterizing the Pacific kindred.

The dominance of soda over potash is also very strong in all rocks from the Hawaiian Islands thus far analysed; and several of these belong to the 'Atlantic kindred' of Becke, including trachyte,[1] melilite-nephelite basalt, and others usually but not well called basalt, such as the one from the crater of Haleakala, collected by myself, which has in part the composition given in the foregoing table. This rock contains but 2·49 per cent. of magnesia. It is evidently very near the typical essexite in chemical character, for which reason I apply to it the name 'essexitic andesite' in the table (=trachydolerite).

The broad underlying significance of these facts of geographical distribution postulated by Harker, Becke, and independently by Prior,[2] has been touched upon by these authors. Becke points out that the Pacific kindred of young volcanic rocks seem to be connected with mountain-chains representing folding under tangential stress, according to Suess, while the Atlantic kindred occur on lines of fracture through radial contraction. Whether this is true or not (and it certainly needs confirmation and elucidation) the relationship involved is not that responsible for the chemical differences of the magmatic series; nor does it appear that the generalization of distribution applies to the older rocks. Thus in the Great Rift Valley of East Africa, the rocks of which have been so well described by Prior, the younger foyaitic-theralitic series of magmas of the Atlantic kindred are underlain by old crystalline granites, gabbros, paragneisses and other rocks, which from Prior's descriptions seem to belong to the Pacific kindred. The same relations probably exist in the Bohemian Mittelgebirge, the volcanic rocks of which are

[1] W. Cross, 'An Occurrence of Trachyte on the Island of Hawaii' Journ. Geol. Chicago, vol. xii (1904) pp. 510–23.

[2] 'Contributions to the Petrology of British East Africa' Min. Mag. vol. xiii (1901–03) pp. 228–63.

made by Becke the type of the 'Atlantische Sippe,' for granites, gneisses, gabbros, minettes, kersantites, and other igneous rocks of the adjacent Erzgebirge are certainly of the contrasting kindred. Systematic classification is, however, not for Tertiary rocks alone.

Petrographic provinces.—The interesting and significant 'blood-relationship' shown by the rocks of certain cycles of eruption in many petrographic provinces, or comagmatic regions, is clearly not adapted to systematic purposes. Many types are common to various provinces, and the peculiar characters of a province are seldom, if ever, so fundamental as the properties uniting the rocks of different provinces. The type of consanguinity may be marked only for the products of an epoch of eruption, rather than for all rocks of a province, as seems to be the case of the East African region above mentioned.

III. Factors of Magmatic Differentiation.

General considerations.—I suppose that all present-day petrographers recognize magmatic differentiation as a general process by which many of the observed chemical differences in igneous rocks must be explained. In numberless volcanic centres there is evidence of a sequence of lavas, by no means uniform, but resulting in final complementary products of rhyolite and basalt. In certain masses, like the Shonkin Sag laccolith, made classic by Pirsson, the differentiation has occurred after intrusion, and we may see the results; in many localities a large central mass is attended by numerous smaller bodies, the clanship of which and their derivation from the main magma are demonstrable.

The recognition of magmatic differentiation as a natural phenomenon involves no acceptance of theories of explanation. It is already clear that effects comparable in kind are produced by the operation of various processes. When the complexity of the magmatic solution and the multiplicity of conditions to which it may be subjected in the eruptive history of a single centre are borne in mind, it appears certain that we can as yet have but a faint conception of the true character of what we include under the term magmatic differentiation.

The recognition of this vague but undeniable natural phenomenon has furnished to some petrographers an all too alluring opportunity for speculation and assumption, and on the other hand it has suggested a most difficult and extensive field of physico-chemical research. The genesis of igneous rocks is manifestly destined to be an important department of petrology and a fundamental element of the general science of geology. We are here concerned, however, with the special question whether the systematic classification of igneous rocks can be made natural, in one of the primary steps, by the use of a genetic factor connected with differentiation.

The now general beliefs that magmas are essentially mixed solutions, and that most igneous rocks represent differentiation-products, render the conception logical that all igneous rocks may be derived from one homogeneous earth-magma. The only escape from this lies in the assumption of hypothetical primary differences in the earth-mass. Rosenbusch [1] and many others doubtless assume the original homogeneity of the earth-magma. Differentiation in the abstract might be used as a systematic factor, if we knew the composition of the supposed primordial magma, and if we were sure that the composition of that magma could never be repeated by the mixture of differentiates. But such division of rocks is not likely to be proposed, for divers evident reasons.

Aschistic and diaschistic magmas.—Differentiations may lead to a general distinction between parent magmas and their derivatives, passing over the supposition that the great differences in composition of parent magmas themselves are due to differentiation. This would be making a general division corresponding to that which Brögger has found useful between the parent magma of a given centre and the partial magmas derived from it, and expressed by the respective terms aschistic and diaschistic.[2]

The introduction of this distinction into general system would be difficult and of doubtful utility. Thus the parent magmas of various regions, or centres of eruption, differ so much that the early differentiates of one would certainly be practically identical with the parent magma of another centre; many rocks do not visibly belong to a series, and the personal equation would necessarily enter into many cases where judgment is necessary. For these and other reasons no proposition of this kind is likely to be made.

The 'dyke rocks' of Rosenbusch.—Leaving general considerations, we now come to the definite proposition of Rosenbusch to distinguish the class of 'dyke rocks,' really on a genetic chemical basis, though this is obscured by the name. Here is opportunity for a discussion touching practically all phases of the problem as to the application of chemico-genetic factors in petrographic system.

For the analysis of this important proposition it will be well to have before us the most recent definition of the 'dyke rocks' as a systematic division. In the 4th edition of the 'Mikroskopische Physiographie: Massige Gesteine' vol. ii, pt. i (1908) pp. 487, 488, is the following:—

'Als Ganggesteine bezeichne ich nur solche Eruptivmassen welche als selbständige geologische Körper nach dem augenblicklichen Stande unserer Erfahrungen nur in typischer Gangform und im Vergleich zu den Tiefengesteinen geringer Masse des einzelnen Gesteinskörpers auftreten. . . . . Die stoffliche Natur der wichtigsten Ganggesteine ist [dagegen] bedingt, nicht durch diese selbst, sondern durch gewisse Tiefengesteine, an die sie gebunden sind und ohne die sie nicht sein würden.'

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[1] 'Ueber die Chemischen Beziehungen der Eruptivgesteine' Tscherm. Min. Petr. Mitth. vol. xi (1889) p. 144.

[2] 'Die Eruptivgesteine des Kristianiagebietes, I: Die Gesteine der Grorudit-Tinguait Serie' 1894 (Vidensk. Selsk. Skrifter, I. Mathemat.-Naturv. Klasse No. 4) p. 125.

The positive assertion of limited association enters also into the definition of many of the kinds of 'dyke rocks.' As an example may be cited the statement concerning camptonite:—

'Alle Gesteine vom Camptonittypus gehören als Ganggefolge zu den foyaitischen und theralithischen Tiefengesteinen und verhalten sich zu Bostoniten, Tinguaiten u.s.w. wie die Minetten, Kersantite, Vogesite, u.s.w. zu den Apliten.'[1]

It is well also to remember that Rosenbusch considers magmas as made up of one or more stoichiometric compounds, called by him Kerne, some of which are mineral molecules, while others are not. Further, it is essential to consider that Rosenbusch refers the principal magmas which have developed by differentiation from a homogeneous earth-magma, through the separation of the Kerne, to two contrasting series, the 'granito-dioritic and gabbro-peridotitic' and the 'foyaitic-theralitic.'

Before entering upon the critical discussion of this matter, I wish to repeat a former statement that

'I must not be understood as failing to appreciate the great advance in our knowledge of the origin of igneous rock varieties and of their structures, and of the genetic relationships of types which has come within the past few years largely as a result of . . . . the theoretical ideas [of magmatic differentiation] lying back of the systematic scheme advocated by Rosenbusch. One may well deny the desirability of the Dike rock group of Rosenbusch and be at the same time an ardent advocate of the [genetic] theories upon which the group was established, and which have little connection with the fact of geological occurrence expressed in the name.'[2]

The inappropriateness of the term 'dyke rocks,' as used by Rosenbusch, may be passed over here; nor is the weakness of the 'Kerntheorie' proper of great significance in itself. The elaborate review of the latter by Brögger reaches an important conclusion, however: namely, that in the theoretical discussion of magmatic differentiation the 'Kerne' of Rosenbusch must be replaced by molecules common in the minerals of igneous rocks, and that the number of these is somewhat greater than that assumed by Rosenbusch for the 'Kerne.'[3] Brögger's discussion seems to me quite convincing, and the conclusion is certainly in harmony with the facts of the rocks and of modern researches on molten solutions. Iddings advocates the same view in the discussion of differentiation, in his recent work on igneous rocks.

A peculiar feature of the 'dyke rock' group of Rosenbusch deserving examination here is the asserted exclusive association of certain kinds with particular deep-seated parent magmas, from which alone they could have been derived by magmatic differentiation.

[1] 'Mikroskopische Physiographie: Massige Gesteine' 4th ed. vol. ii, pt. i (1908) p. 685.

[2] 'The Geological *versus* the Petrographical Classification of Igneous Rocks' Journ. Geol. Chicago, vol. vi (1898) pp. 89–90.

[3] 'Die Eruptivgesteine des Kristianiagebietes, III: Das Ganggefolge des Laurdalits' 1898 (Vidensk. Selsk. Skrifter, I. Mathemat.-Naturv. Klasse, 1897, No. 6) p. 332.

Vitally connected with this is the asserted existence of two great magma series. Let us examine the latter point first.

The magmatic series of Rosenbusch are unnatural.—At the outset I must deny that the 'granito-dioritic and gabbro-peridotitic' and the 'foyaitic-theralitic' series are natural. They are both arbitrary and ill-defined. Magmas of corresponding silica-contents in the two series are connected by intermediate ones, just as are the parts of each series. An examination of Washington's tables of rock-analyses, particularly if they are studied and compared by use of the norms there given, will show this gradation. From the theoretical side, viewing magmas as mixed solutions of rock-mineral molecules, it is difficult to see any reason why the two series of Rosenbusch should not be connected at all points. The fact that the distinction is both arbitrary and indefinite makes it easy for those who wish to do so to assign magmas one way or the other, just as syenite and diorite were easily and conveniently separable until the uncomfortably logical Brögger demanded recognition of the equally important intermediate monzonite.

Rosenbusch is forced to recognize that monzonite occupies in some respects what he regards as a rare or peculiar (eigenartige) position between his two great magmatic series. But he claims that those who (with Brögger) put monzonite in a series monzonite-banatite-adamellite miss the natural relationships.[1] It is difficult for me to understand why the position of monzonite and essexite as intermediate in more than one direction should not be recognized. The existing chemical data clearly show this broader relationship.

As we are discussing natural classification as necessarily based on the facts of nature, it is here an appropriate place to point out that the 'dyke rock' division of Rosenbusch loses one of its most strongly emphasized peculiarities if the dual series just discussed are arbitrary.

The restricted association of 'dyke rocks.'—As to the sharply restricted association of 'dyke rock' types, asserted by Rosenbusch and made a part of their definition in many cases, no one of wide experience can fail to recognize the kernel of significant truth in this generalization. Some rock-types are much more abundant in certain associations than in others. The more rare and peculiar it is in composition, the more likely is a rock to be restricted as a magmatic differentiate; and, conversely, certain parent magmas must inevitably transmit certain prevalent characters to their descendant parts. But with differences in parent magmas must come variations in the prevalence of derived characters and in associations of descendant forms.

It is difficult to present the evidence that many 'dyke rocks' have not the restricted genesis assigned to them by Rosenbusch

[1] 'Mikroskopische Physiographie: Massige Gesteine' 4th ed. vol. ii, pt. i (1908) p. 166.

in a form which will convince the partisans of that belief. To quote from an experienced correspondent on this matter:—

'If you show that there is no large mass to connect the dykes with, they say it is underground and not exposed by erosion; if you present evidence that this is improbable, then the province is an alkalic one anyhow and such rocks are to be expected. If you show that the dykes are associated with a kind of rock different from what was to be expected, you are informed that you are mistaken; that you have not understood the real nature of the rock-mass, that it is, for example, not a diabase or gabbro, as hitherto regarded, but really an essexite. Or, if the parent mass is too plainly fixed to shift its base, then you are mistaken in your idea of the dykes—they are not actually camptonite, but a variety of spessartite with brown hornblende!'

This situation arises from the indefinite, arbitrary distinction between the two magmatic series above discussed.

Certain 'dyke rocks' of Colorado.—We may pass now to a specific case of notable exception to the rule, postulated by Rosenbusch, that bostonite, camptonite, and monchiquite magmas belong exclusively to the 'Gefolgschaft' of foyaitic-theralitic parent magmas. In the Engineer Mountain quadrangle of South-Western Colorado there occur several thin laccoliths and sills of a rock which I call 'quartz-trachyte.' In the immediate vicinity are numerous small dykes of typical monchiquite and some of the camptonitic rocks, and others. While the region is rich in all manner of Tertiary igneous rocks of the 'granito-dioritic series' there are none of the 'foyaitic-theralitic series'. No analysis has been made of the monchiquite, but the quartz-trachyte has the composition stated in column I of the following table, while in column II is tabulated the analysis of the typical bostonite of Marblehead Neck (Mass.). In adjacent columns are tabulated the calculated norms of the two analyses.

TABLE OF ANALYSES AND NORMS.

Analyses.

	I.	II.
SiO_2	70·73	70·23
TiO_2	0·34	0·03
Al_2O_3	14·22	15·00
Fe_2O_3	1·59	1·99
FeO	0·59	undet.
MnO	0·11	0·24
MgO	none	0·38
CaO	0·72	0·33
Na_2O	4·96	4·98
K_2O	5·57	4·99
H_2O-	1·16	0·91
H_2O+	0·32	1·28
P_2O_5	0·03	0·06

Norms.

	I.	II.
Quartz	19·6	19·6
Orthoclase	33·4	29·5
Albite	41·9	41·9
Anorthite	...	1·7
Corundum	...	0·8
Femic molecules	3·8	4·1

I. Quartz-trachyte, Grayrock Peak, Engineer Mountain quadrangle (Colorado). Analysis by George Steiger.
II. Bostonite, Marblehead Neck (Mass.). Analysis by T. M. Chatard.

The quartz-trachyte is nearly identical chemically with the type bostonite. The name chosen expresses the fact that it has a strong textural resemblance to trachyte, since it contains numerous tabular phenocrysts of sanidine and a few flakes of biotite, in a trachytic fluidal holocrystalline ground-mass. The quartz occurs only in interstitial particles.

The intrusive bodies of this trachyte occur in various sedimentary formations, the youngest being of late Cretaceous age, and side by side with quartz-monzonite porphyry bodies, typical of rocks widespread in the Rocky Mountain and Plateau provinces. The monchiquite dykes, some of which cut the quartz-trachyte, are all small, rarely exceeding a few feet in thickness.

In immediate association with the two rocks already mentioned are other lamprophyric types, some of which are camptonitic; others are nearer to kersantite and minette.

A few miles south of the quartz-trachyte area, in the La Plata Mountains, are camptonitic dykes associated with a large number of intrusive dioritic, monzonitic, and syenitic rocks in laccolithic or stock intrusions. The La Plata Mountains are in fact one of the laccolithic groups, like the Henry, Abajo, Carriso, El Late, and Rico Mountains, where the same types of alkalicalcic magmas occur in closely comparable manner. That these dyke rocks are chemically camptonitic seems evident from the following table of analyses and norms. Mineralogically they contain abundant brown hornblende, partly in large phenocrysts, with more in the ground-mass. The principal felspar is a plagioclase.

Analyses and Norms of Camptonites.

Analyses.	I.	II.	III.	IV.	*Norms.*	I.	II.	III.	IV.
SiO_2 ...	47·25	43·98	44·22	42·73	Orthoclase .	15·0	9·5	10·0	12·8
Al_2O_3 .	15·14	13·30	12·73	14·50	Albite	17·8	15·7	17·8	21·0
Fe_2O_3 .	5·05	3·67	5·68	4·03	Anorthite ...	22·8	21·7	20·3	19·2
FeO ...	4·95	6·92	5·18	7·28	Nepheline...	1·4	1·4	...	2·8
MgO ...	6·87	7·03	6·98	5·46	Diopside ...	21·4	25·5	24·0	16·9
CaO ...	9·98	10·66	11·57	8·46	Hypersthene	...	...	4·7	...
Na_2O...	2·39	2·15	2·12	3·11	Olivine	7·2	9·3	3·1	6·8
K_2O ...	2·60	1·64	1·71	2·28	Magnetite...	7·4	5·3	8·4	5·8
H_2O+ .	2·12	1·52 }	2·74	3·08	Ilmenite ...	2·3	2·3	4·8	8·3
H_2O- .	0·40	0·42 }		0·36	Apatite	...	...	2·5	2·5
CO_2 ...	1·87	6·46	3·66	3·76					
TiO_2 ...	1·22	1·18	2·50	4·30					
P_2O_5 ...	0·25	0·32	1·05	0·93					
MnO ...	0·17	0·22	0·45	0·19					

Complete analyses show small amounts of other constituents.

I. Camptonite, Snowstorm Peak, La Plata Mts. (Colo.). Analyst, W. F. Hillebrand. Bull. U.S. Geol. Surv. No. 168 (1900) p. 162, and La Plata Folio.

II. Camptonite, Indian Trail Ridge, La Plata Mts. (Colo.). Analyst, W. F. Hillebrand. Bull. U.S. Geol. Surv. No. 168 (1900) pp. 162–63, and La Plata Folio.

III. Camptonite, Kjose-Aklungen, Norway. Analyst, V. Schmelck. W. C. Brögger, 'Die Eruptivgesteine des Kristianiagebietes, III: Das Ganggefolge des Laurdalits' 1898, p. 51.

IV. Camptonite, Mount Gunstock (New Hampshire). Analyst, H. S. Washington. 'Chemical Analyses of Igneous Rocks' Prof. Paper No. 14, U.S. Geol. Surv. 1903, pp. 318–19.

To me the occurrence of the rocks described in Colorado seems incompatible with the idea of their exclusive association with foyaitic-theralitic magmas, although I grant that experience shows them to be elsewhere frequently connected genetically with such magmas.

The general relations of camptonite occurrences.—Examining the statements of Rosenbusch concerning the distribution of camptonite, in his 'Physiographie,' we find the frank avowal that the derivation of the original type camptonites of New England from foyaitic magmas was inferred by him from their frequent association with bostonite. But not all of these rocks occur in close connexion with foyaitic-theralitic magmas. Rocks of the granito-dioritic series also occur in the region. The original camptonites described by Hawes are many miles distant from the nearest occurrence of alkalic rocks at Red Hill, and no alkalic parent magmas are known in connexion with them. The numerous dykes of camptonite described by Kemp and Marsters are much nearer to the great anorthosite and gabbro masses of the Adirondacks than to any foyaitic bodies. Camptonite and bostonite or keratophyre also occur in the Adirondacks.

Rosenbusch asserts that the lamprophyric dyke-rocks of the one great series are never connected with those of the other by transitional forms, and in accordance with this belief assigns all rocks described to a definite place. It is manifestly impossible to determine in the field the genetic association of many camptonites, bostonites, kersantites, and aplites. From the vast amount of evidence that the two magmatic series are connected by equally abundant intermediate magmas, I can but believe that the sharp distinction between the two 'dyke rock' groups is a purely arbitrary one, resting on an unproved hypothesis.

Conclusion as to 'dyke rocks.'—Our present knowledge of the processes of magmatic differentiation is too slight to permit a definite assertion, that from a given parent magma certain differentiates must be formed. But it is reasonable, I think, to suppose that typical foyaitic, monzonitic, and dioritic magmas, subjected to the same conditions, must produce differing series of descendant partial magmas. It does not necessarily follow that those series must be markedly different in all their members. If different conditions attend the differentiation of the magmas, the resultant partial magmas may not fully correspond to those formed under uniform conditions.

Given an intermediate monzonitic magma, is it not natural to suppose that its descendant magmas must be intermediate in many respects between the series derived from foyaitic and dioritic parent magmas, and that a shifting of conditions may throw the dominance of characters either one way or the other?

IV. Classification by Eutectics.

Recognition of the fact that magmas are solutions implies the existence of eutectic mixtures in them. The low melting-point of the eutectic suggests that partial crystallization necessarily brings the residue of the magma nearer to the eutectic proportion in composition. The study of magmas in the light of physical chemistry has, then, naturally led certain investigators to hope that in this relatively new field of rock-properties there may be something available for fundamental genetic or natural classification. Becker, Vogt, and Harker have made the most important suggestions in this direction.

Becker's suggestion.—G. F. Becker was the first to express the idea of classification by eutectics.[1] He regards the eutectic as the solvent in the magmatic solution and hence of greater importance than the variable materials in excess, which, in porphyries, are developed as phenocrysts. This idea is not in accord with the conception now current that the magma is a mutual solution of its several components. The following quotations indicate the way in which Becker would use eutectics in classification, and the special purpose subserved by so doing :—

'...... If we knew all about magmas, it seems fairly certain that we could define a number of eutectic mixtures, each, when heated above its melting point, yielding an infinite variety of solutions corresponding to rocks of an infinite variety of compositions..............................

'From this point of view the groundmass of rocks would be more interesting and important than the phenocrysts, while it has usually been studied with less care, because of the greater difficulties in the way of mineralogical determination. The groundmass would either consist substantially of the eutectic mixture, or afford a closer approximation to it than does the whole rock.

'It is difficult to imagine that the comparatively small number of elements which enter largely into the composition of massive porphyritic rocks should form any very great number of independent eutectic mixtures; and it seems to me that it would be possible to elaborate a eutectic classification of those rocks which have consolidated from the liquid state—I mean the porphyries—each rock-group representing a series of solutions in one eutectic liquid. Such a classification would also have certain geological advantages over others, for the composition of the groundmass of rocks largely determines their orogenic significance..............................

'Even among the rocks which represent solidified fluids there is a class not subject to such a classification as is here proposed. It seems an inevitable conclusion from the laws of precipitation that there must be many rocks which have been formed by fractional crystallization..........................

'Now, such fractional precipitates are essentially impure. Either in nature or in the laboratory, they represent neither the substance dissolved nor the solvent or mother liquor, but only fortuitous mixtures of the two—crystals of precipitate, including and entangling variable quantities of mother liquor; crusts, which vary in composition from millimetre to millimetre. Rocks of such origin appear to me insusceptible of any strict classification and fit only to throw a dim light on the qualitative composition of the magma, which they represent, indeed, but only partially and irregularly. Were a eutectic classification worked out, it would probably be easy to recognize these impure partial precipitates, which would then receive the scant attention they deserve.'

[1] 'Report on the Geology of the Philippine Islands' 21st Ann. Rep. U.S. Geol. Surv. pt. iii (1901) pp. 487–614 (pp. 519–20).

Eutectic classification as outlined by Becker is plainly not adapted to general petrographic system. It ignores the fact that the rock is the result of the consolidation of the whole magmatic solution, except the escaped volatile constituents, and not of the eutectic alone. It is not applicable to all rocks, and would be primarily of use in purely physical discussions, such as the influence of varying fluidity of lavas upon the form of volcanic cones.[1]

Vogt's proposition.—A proposition by J. H. L. Vogt[2] to utilize eutectics in the genetic classification of igneous rocks is combined with an hypothesis of magmatic differentiation. It must be assumed that the reader is familiar with the notable series of experimental investigations, statistical studies, and theoretical discussions which led Vogt to his conclusions as to the existence and approximate character of the eutexia of magmas. By supposing that the parent magmas of various centres are not themselves very nearly of any eutectic composition, Vogt pictures the process of differentiation to consist in the concentration of components which are in excess of the eutectic. By long-continued migration of these substances and their concentration in certain places there may result partial magmas rich in plagioclase, pyroxene, olivine, titanium and iron ores, spinel, or some other mineral. These approach the simple composition of a single mineral in many cases. The complementary result of such a process is an approach on the part of the residue of the parent magma to the eutectic mixture.

Theoretically, the differentiation pictured by Vogt should end with the production of a eutectic magma. Practically it does not, owing to disturbance of equilibrium by some external influence, and several anchi-eutectic magmas may be formed from a single parent magma, as Vogt admits.

Vogt believes that most magmas may be practically classified either as anchi-monomineralic or anchi-eutectic, and that such groups may serve as the basis of a genetic system for igneous rocks.

Although the extremely suggestive studies which have led to this preliminary proposition are of the highest importance, there are many reasons for questioning whether the genetic factors concerned are applicable to petrographic system. It is universally recognized that many genetic factors are not of systematic value.

Objection to eutectic classification may be made on several grounds. In the first place, the genetic importance of eutexia in magmas remains to be established and defined. It is no disparagement of Vogt's work in this direction to say that he deals chiefly

[1] G. F. Becker, 'The Geometrical Form of Volcanic Cones & the Elastic Limit of Lava' Am. Journ. Sci. ser. 3, vol. xxx (1885) pp. 283–93.

[2] 'Ueber anchi-monomineralische & anchi-eutektische Eruptivgesteine' Vidensk.-Selsk. Skrifter, I. Math.-Naturv. Klasse, 1908, No. 10; also under a similar title in an earlier publication.

with unknown quantities and processes. The parallelism between differentiation and crystallization on which Vogt depends is not an established law, attractive as it appears as a working hypothesis. The cause of molecular migration in differentiation is unknown, and there may be several causes leading to dissimilar products. No eutexia of rock-minerals are known. Vogt may have reached approximately correct proportions for some of them, but in view of the unknown influence of water and other mineralizers, of impurities of various kinds, and of a long series of changing conditions, one may be pardoned for lack of confidence in his results.

If we assume that there are ten or more important eutexia of rock-making minerals, and that these are little affected by various conditions and impurities, it is of course plain that each eutectic mixture represents a centre-point about which many rocks cluster. This must be the case whether the nearly pure eutexia are more numerous than other mixtures or not. The statistical studies of Vogt fail, it appears to me, to demonstrate that degree of quantitative dominance of the eutexia which must exist to warrant the systematic proposition made by him. The range of variation covered by the term 'anchi' (meaning almost), as used by Vogt, is so great as to destroy its significance.

When one considers the probable influence of some of the variable factors ignored by Vogt—and especially that of water—it seems not impossible that the whole fabric of Vogt's speculations may fall, with the advance of knowledge on these points.

Magmatic classification by eutectics is fundamentally weak, because it rests on hypothesis, because it does not apply to all rocks, and because it does not consider the entire magma of most rocks. As developed by Vogt it does not adequately recognize the very important rocks representing parent magmas which are not anchi-eutectic, nor the numerous intermediate rocks ('Zwischenstufen').

Turning from the magma to the rock, what stamp has the eutectic placed on the consolidation-product, justifying its use in classification? Becker's conception that the ground-mass of porphyries is practically the eutectic must be extensively qualified; and, if it were true, the conclusion that the phenocrysts are of little systematic importance is not admissible from the petrographic standpoint.

The porphyritic texture is determined by conditions of consolidation, of which approach to the eutectic proportion in the still liquid part of the mass is but one. A vast number of porphyries, both extrusive and intrusive, possess ground-masses that are simply that part of the magma which was liquid at the time of eruption. The eruptive act takes place independently of the stage of crystallization reached in the magmatic reservoir. The change of physical conditions is, in many cases, sufficient to prevent further phenocrystic growth.

Doubtless the ground-mass of many porphyries is nearly of eutectic composition. But the most typical porphyrics of my experience, the monzonitic rocks of laccoliths, sills, and dykes in the Rocky Mountain and Plateau districts of the United States, possess a ground-mass consisting chiefly or exclusively of quartz and orthoclase, while abundant plagioclase occurs in phenocrysts. Surely plagioclase (Ab+An) entered into the eutectic of these magmas.

I believe it to be a fact of experience that the consolidation-products of any given magma exhibit, under the various conditions of different occurrences, all possible proportions of ground-mass to phenocrysts.

The view that certain textures, such as the graphic, the spherulitic, and the felsitic, are characteristically eutectic seems to me incorrect. Intergrowth, whether graphic or spherulitic, may mean simultaneous crystallization, but I question the necessity for eutectic proportions. In any case these textures are due to physical conditions, since it must be admitted that they are by no means always developed in the presence of the eutectic.

Conclusion.—In view of the care with which a host of observers have studied all details of rocks, the world over, it does not seem to me rash to assert that the eutectic has left no stamp on the consolidated magma, the rock, with possibly a few exceptions. If we consider the mineral and textural characters of the igneous rock it appears that, in the first place, the composition of the solution as a whole, and, in the second place, the conditions influencing crystallization, such as supersaturation, mass action, rate of cooling, escape of volatile constituents, and viscosity of the magma, have had far more influence upon the rock than the character of the eutectic. The latter has itself split up into minerals which are not different in their rock-making qualities from those molecules that were in excess in the magmatic solution, and they must be in part identical. In many cases escape of mineralizers, fractional crystallization, and other influences seem likely to have so changed the character of the assumed eutectic that the magma may have had several different eutectics in the course of crystallization.

The propositions of Vogt do not seem to me to have significance as bearing on systematic petrography. He has gone far from the base of real knowledge of rock eutectics, and while his brilliant original studies and theoretical discussions have done much to advance the application of physical chemistry to the study of magmas, they do not appear to have indicated a future practical factor for petrographic system. A classification by eutectics may in the future be realized, but it seems inevitable that it must be a classification for a special interest, not for the general science of petrography.

V. Factors of Mineral Composition.

The actual mineral constitution of an igneous rock (its mode) is the second of its features in importance, because it is very largely an expression of the fundamental chemical composition and also determines many of the most obvious characters of the rock. If a natural classification cannot be based on the chemical composition, we must turn next to the mineral characters in our search for appropriate factors of systematic arrangement.

At the outset it must be recognized that mineral composition is not a simple function of the chemical constitution of the magma. Magmas of complex character may form various mineral combinations under differing conditions of crystallization. Any attempt to express chemical character through mineralogical classification must, therefore, be only an approximation.

The minerals of igneous rocks are much more numerous than the chemical elements of corresponding importance in them, and many minerals have a known quantitative range in rocks, from a trace to strong predominance. Hence systematic divisions on mineral composition are necessarily arbitrary or artificial, and the difficulties of constructing a logical system by this means are even greater than on a chemical basis.

The relationship of mineral composition to factors of genesis or occurrence is complex. Some constituent minerals of igneous rocks are formed only under a limited, and others under a much wider, range of chemical or physical conditions. Moreover, many rocks contain minerals formed at different places under different conditions, as illustrated by intrusive and effusive masses. These facts are of great importance in the natural history of the rock, but are not practical bases of systematic classification.

It is so generally admitted that all mineralogical classification of igneous rocks is arbitrary, that this point might well be dismissed here, were it not for the desirability of referring to current usage. It was once supposed that certain approximately proportionate combinations of minerals constituted groups which were much more abundant than the rocks of intermediate composition, and were thus in a measure natural units, such as granite, syenite, diorite, etc. Although no one may now maintain this position, the fact is tacitly ignored by many petrographers that these and all other terms based on mineral composition cannot be precisely defined, as is necessary for accurate and universal concordant classification of rocks, without recourse to an arbitrary quantitative factor. The necessity for sharp definition is becoming more and more evident as petrographers study the rocks of certain series in detail; and here and there the arbitrary quantitative line is being introduced into definition, but without a consistent logical basis. The outcome can but be confusion worse confounded.

The distinction between felspathic and non-felspathic rocks which has been so prominent in current system is not only unnatural, but is in the highest degree arbitrary. There is no logical consistency displayed in characterizing and treating as felspathic a rock whose predominant characters of all sorts are due to the greater abundance of non-felspathic constituents. It is done purely for the convenience of the systematist.

VI. Factors of Rock-Texture.

The texture of igneous rocks is very commonly used in their classification. Let us consider whether this factor is or can be applied for that purpose, in accordance with the facts of nature.

Nature of rock-textures.—Rock-texture may be considered to embrace all the material features exhibited by the rock constituents, whether mineral particles or glass, and whether megascopic or microscopic. It thus includes a great variety of allied characters which may be conveniently brought into three categories[1] :—

(1) Crystallinity—the degree of crystallization.
(2) Granularity—the magnitude of the crystals.
(3) Fabric—the shape and arrangement of the crystalline and non-crystalline parts.

Texture is a physical feature, largely independent of chemical or mineral composition, produced during the consolidation of the magma into rock. The range of crystallinity is from holohyaline to holocrystalline; of granularity, from very coarse to submicroscopic; of fabric, an almost infinite variety of design with many pronounced forms and often a mingling of them in a single rock. The common grouping of textures under the heads granular, porphyritic, fluidal, or glassy, is a crude approximation to the truth, useful when applied in accordance with the facts, but often serving to obscure or conceal actual relations. A granular rock answering to the definition is rare, as compared with the aberrant forms called granular for convenience; and the porphyritic fabric is one of limitless transitions to the granular, the felsitic, the fluidal, and the hyaline.

Origin of rock-textures.—As already remarked, texture depends upon the conditions controlling consolidation. Each magma has an infinite range of possible textures representing

[1] This classification of textural features, and the general view of the subject here adopted, is presented more fully in a paper by the writer and his colleagues Iddings, Pirsson, & Washington, published a few years ago ('The Texture of Igneous Rocks' Journ. Geol. Chicago, vol. xiv, 1906, pp. 692–707). In this paper the great variety of textural features is emphasized, the paucity of adequate terms for descriptive purposes is pointed out, and a large number of new terms proposed.

varying conditions. If we perfectly understood the influence of conditions on texture we might sketch the history of each rock during its consolidation period. But chemical composition has also a general and very important bearing upon texture, in that the influence of given conditions varies with the chemical character of the magma. No set of conditions produces the same result on all magmas.

A discussion of the origin of various textures is not necessary for our present purpose. It will suffice to recall that we now know rate of cooling to be the principal factor in the production of texture, with varying results according to the composition of the magma. Rate of cooling depends on initial temperature of magma, mass, pressure, temperature, and conductivity of wall-rock, escape of gases from solution, and on other factors. Another factor of great influence in producing texture is movement of the partly solidified magma. Wherever this occurs orientation of mineral particles is a natural result.

Applying these considerations to the granular fabric, it is plain that slow cooling and uninterrupted crystallization may most commonly be expected for deep-seated masses; but, wherever the necessary conditions are realized, the granular fabric must result. Granite, once believed to be possible only as a result of crystallization at great depth, is now known to have formed also very near the surface. Dykes which penetrate a volcanic centre where long eruptions have been in progress have often the same texture as that exhibited by plutonic masses of the same rock. Basic magmas find conditions favourable to granular fabric provided in the interior of surface-flows, as well as in intrusive plutonic bodies.[1]

Use of texture in classification.—Texture has always been very prominent in the classification of igneous rocks. Although its systematic application has seldom been consistent, we have, in fact, one set of names for what are stated or assumed to be granular rocks, and another set for porphyritic, fluidal, and more or less glassy rocks, which are their chemical equivalents. A general dependence of texture on conditions of consolidation was long ago recognized, and the convenient assumption was made that pressure is the principal element of the conditions favourable to the production of the granular texture. Further, pressure was considered a function of depth. The latter is true only if tangential stress and eruptive force bearing on an intrusive magma are ignored; and, as above mentioned, pressure is now known to be less potent in determining texture than a variety of other conditions.

The old idea of the relation of pressure to production of the

[1] This was recognized by B. von Cotta, who pointed out that, if the chlorite of diabase should prove to be of secondary origin, 'the whole original difference would perhaps lie in the level at which solidification took place' 'Gesteinslehre' 2nd ed. (1862) p. 84.

granular texture made it appear possible to express two important genetic relationships at once, in the distinction between Plutonic and Volcanic rocks. The former might, with a few known exceptions, be called granular, and they thus stood in marked contrast to surface volcanics, which are glassy or highly fluidal in their typical occurrences about volcanoes.

Plutonic and volcanic rocks are certainly different in texture, to a degree rendering their separation and the distinct names which they bear eminently desirable—if that were the whole story. But this procedure ignores the fact that the earth's crust for a few thousand feet downwards is, in many great mountain-tracts and in other places, characterized by a complex of igneous masses of all shapes and sizes, and representing the entire range of chemical variation. And with our present understanding of rock-texture it is easy to see that here must occur both the textures of the depths and of the surface, with others less commonly produced above or below. With this recognition of the zone of intrusion, as it is sometimes called, came as the first proposition, to make three classes: I, Abyssal (Plutonic); II, Hypabyssal (Intrusive); III, Volcanic (Effusive) rocks. This is nominally on a basis of geological occurrence. It is, however, not a natural division, as such, because there must be arbitrary lines between the Hypabyssal zone and both the Abyssal and Volcanic. If these divisions are equivalent to Granular, Porphyritic, and Fluidal or Glassy, the scheme is arbitrary, since those textures grade most insensibly into each other. It is unnatural, because the textures have no such restriction in occurrence. It is certainly illogical to make in fact a textural division while expressing one of occurrence, and *vice versa.*

Brögger frankly states that his principal object in distinguishing the Hypabyssal rocks is to make it possible to give special names to the porphyritic rocks. This he illustrates by asserting that laurvikite, rhomb-porphyry, and trachyte are three essential names for textural phases from the same magma.[1]

Conclusion as to textural classification.—The plain fact is that classification by occurrence, as determining texture, or by texture, as expressing the broad phases of occurrence, is based on long disproved generalizations made from limited observation. But, like the age distinction, the unnatural connexion of texture with occurrence has so many expressions in system or nomenclature that recognition of the truth is embarrassing. Witness the treatment of many diabasic and allied rocks by Rosenbusch, classifying them at first with the plutonics, now with the effusives, yet a host of them are neither, being hypabyssal in actual occurrence. The known

[1] 'Die Eruptivgesteine des Kristianiagebietes, I: Die Gesteine der Grorudit-Tinguait Serie' 1894, p. 124.

occurrence of hundreds, if not thousands, of rocks of all kinds is disregarded by their classification in Rosenbusch's work into deep-seated or effusive rocks, to say nothing of the dyke rocks.

The connexion of texture with geological occurrence in a systematic way dates from days of ignorance concerning the origin of texture, and of very limited knowledge of the rocks of the hypabyssal zone of the earth, with their multiplicity of textural forms. Once this systematic proposition seemed a close approximation to a statement of natural relations. Now we know that it is not in accord with the nature of things; its use to-day is purely arbitrary (often a matter of personal convenience), and yet it is commonly referred to as 'natural'! This course simply serves to befog the discussion of truly natural classification.[1]

To classify igneous rocks as plutonic, intrusive and extrusive, or by other equivalent terms, with the idea that because such a scheme expresses certain geological relationships it must perforce be accepted as 'a natural system,' may be compared with dividing vertebrate animals into aquatic, terrestrial, and aërial, or those that swim, walk, and fly, respectively. This division is natural in its way, and agrees with zoological system in its general results. The zoologist, however, does not call the whale a fish because it lives in the water and swims, nor the bat a bird because it flies, although it is more confined to this form of locomotion than is any bird.

VII. Quantitative Classification.

Introductory.—If the considerations thus far presented are well founded and sufficiently comprehensive, it appears that a natural classification of igneous rocks, expressing a relation between their most notable chemical or physical properties and the origin of those properties in geological occurrence, is impossible. The natural

[1] As an instance of recent advocacy of this systematic proposition, I would cite a paper by Dr. F. H. Hatch, 'The Classification of the Plutonic Rocks' (Science Progress, Oct. 1908), where the appropriateness of recognizing the two great divisions of plutonic and volcanic rocks is stated without further discussion in these terms:—'Apart from mode of occurrence, the difference in internal structure or texture between a eugranitic plutonic rock, that has cooled slowly as a deep-seated mass under pressure and in the presence of occluded water, and a porphyritic or semi-vitreous volcanic rock, that has been erupted at the surface and has cooled quickly, is so great that a system can scarcely be termed natural that places two such different rocks in the same category. In a natural classification, therefore, the plutonic and the volcanic rocks must be recognized as distinct classes.' (Sep. cop. p. 1.)

The necessity for a distinction on this ground is less obvious when we consider that coarsely crystalline or even granular basic rocks are known, which have cooled slowly in a surface-flow, while there are equivalent porphyritic or semivitreous rocks, which have evidently formed as a result of rapid cooling in the hypabyssal zone or below. Classification is not for granitic rocks alone, nor for plutonics, though many suggestions in classification have seemingly been made without consideration of the needs of other rocks.

history of the objects is too complex. The only remaining basis for systematic classification is in the characters of the objects themselves.

The chemical, mineral, and textural characters of igneous rocks are each gradational as regards several elements. No systematic division can be made except along arbitrary or artificial lines, and in this sense petrographic classification must be unnatural, as the units are not obvious, though no reproach necessarily attaches to the artificial scheme, since it is unavoidable in the nature of things.

Any systematic classification of rocks worthy of the terms logical and scientific must be constructed with due regard for the facts of the rocks and the relative importance of their characters. Chemical composition is the fundamental character of igneous rocks, and it seems inevitable that it must be the basis of their scientific classification. In magmas, a few chemical elements are sufficiently abundant to influence materially the character of the minerals developed. The number of minerals is somewhat greater. Whether ultimate chemical or actual mineral components are considered, the differences exhibited by rocks are mainly due to the relative proportions of the components. Any system expressing these relative proportions may be called a quantitative system, and such would appear to be the logical one for petrography under the circumstances.

This is the age of quantitative investigation, statement, and definition. Everywhere the effort of scientific men is to determine constants and make definition precise, to discard estimate, approximation, assumption, where greater exactness may be attained. Petrographic system should not lag behind.

The use of chemical composition in quantitative classification.—There are several ways of expressing the chemical differences of rocks in classification. The elements themselves, the molecules in which an analysis is commonly stated, and combinations of the latter, may be used. Since the rock, generally crystalline in some degree, is the object of classification, a scheme based on elements or simple molecules as such, is less satisfactory, less logical, than one expressing the connexion between chemical and mineral composition.

The use of the 'Atomzahl' by Rosenbusch, in certain discussions, has not appealed to many petrographers. Ratios of certain oxides or groups of molecules stated in the analysis are all more or less inadequate for the purpose, because their bearing on mineral composition is more or less indirect.

The various efforts of recent years to determine certain molecular ratios for rock-units, primarily established on a mineral basis, serve to characterize the special rocks considered; but no true system can be reached in this way, without the ultimate necessity of constructing a rigid chemical framework on some logical basis.

This would be a quantitative system, and no such scheme has been presented.

The representation by diagrams of the average composition of rocks, to which certain names are given in the current system, is valuable as illustrating the influence of chemical on mineral character. Certain characteristics of selected centre-points are thus brought out. But the intermediate centre-points have also their characteristic diagrams, and no systematic solution is reached until a quantitative basis for the units has been formulated.

The connexion between mineral and chemical composition is definite for some rocks, and approximate for most others. Hence, if the varying chemical analyses can be interpreted in terms of minerals, we can appreciate the significance of their differences. An attempt to provide such a basis of comparison has been made by Iddings, Pirsson, Washington, and myself; and I wish to discuss that proposition the more fully, because it has not been understood by many petrographers, who have viewed it entirely as a part of the Quantitative System.

The 'norm' as a means of interpreting and comparing rock-analyses.—An analysis of a fresh igneous rock gives the composition of the magma which it represents as closely as possible, the lost volatile constituents being no longer determinable. A magma on crystallization yields certain minerals; and, while the micas, amphiboles, pyroxenes, and many felspars are complex mixed crystals, they can be regarded as composed of simpler mineral molecules, most of which may occur alone. It is possible to select a series of comparatively simple mineral molecules, into which all rock-analyses may be translated by calculation. If this is done by an invariable rule, the meaning of chemical differences in analyses is more clearly brought out than by comparing the oxides or any chosen ratios.

A definite set or series of mineral molecules was selected for this purpose by my colleagues and myself, and called by us the norm, meaning a standard of measurement or comparison. This series of molecules was not a haphazard selection from among those that might be used, nor was the procedure in calculation adopted without special reason. Chemical affinities and the laws which seem to control crystallization were regarded as far as possible, and the norm is a kind of statement of potential mineral composition of a magma. To an extent greater than we realized at first, it now seems probable that the molecules of the norm may actually be the molecules present in molten solution. Molecules with the composition of quartz, orthoclase, albite, nepheline, leucite, anorthite, corundum, diopside, hypersthene, olivine, magnetite, apatite, and others are not unlikely to exist as such in the magmas. The metasilicates of the alkalis may also be there, though entering into acmite or a similar mineral on crystallization.

The chemico-mineralogical expression of an analysis, obtained in the norm, is found to agree very closely with the actual mineral composition (mode) of many comparatively simple rocks. Neither the norm nor any other calculated set of molecules representing minerals can correspond with the mode of most intermediate and femic rocks, for mineral composition is not a function of chemical composition alone, but is controlled largely by the varying conditions under which a given magma consolidates in different places. The molecules of the magma may form a considerable number of complex compounds, and these undoubtedly vary as the equilibrium in the solution is disturbed by changing conditions, and magmatic reactions occur.

To repeat, the norm is primarily a means of comparison, and has in itself nothing to do with system. We seem to have made a mistake in assuming that, provided we were explicit in definition, this standard could be called a norm and its adjective normative without confusion with the old term normal. Norm and normative had not been used in petrographic discussion, as far as I am aware, before their introduction by us for a special purpose. When proposing the terms norm and normative, we stated that

'the standard minerals which make up the norm are to be called the normative minerals, not the normal ones, since the latter adjective has the meaning of usual or common.'[1]

But it has been one of the commonest criticisms of the Quantitative System that we assume as normal to a rock a composition which it does not exhibit.[2] Such is not the case. The norm is simply a standard form of expressing the chemical analysis of a rock in comprehensible terms, which also apply to its magma. The calculation of the norms for a set of rock analyses in no wise classifies the rocks. It does assist more than any other expedient, in my opinion, in understanding the complex relation between chemical analysis as usually stated and mineral composition. An example of its use independent of system is afforded by the discussion of the analyses of camptonite in this paper.

The 'norm' in quantitative classification.—A quantitative classification of rocks according to chemical factors may be based on the usual analytical statement of composition, or on some other expression calculated from the analysis. If a proper expression of chemical composition in mineral terms can be found, it seems desirable to use that expression in classification. The norm was of course planned for this ultimate purpose, as well as for

[1] 'Quantitative Classification of Igneous Rocks' 1903, p. 147.

[2] The recently published brief statement of the Quantitative System by Mr. L. Fletcher, which I know must have been intended for a fair *résumé* ('An Introduction to the Study of Rocks,' 4th ed., 1909, p. 146), refers to the molecules of the norm as 'imaginary' (!). I can but deprecate the use of a term serving rather to prejudice the reader than to explain the system.

immediate comparison. If a method can be found for analysing the differences of composition expressed by the norms, the latter may serve as the basis of classification.

The 'American' Quantitative System.—The foregoing discussion was written before I had an opportunity of reading the masterly treatise on the 'Natural History of Igneous Rocks' by Alfred Harker. For that work I have profound admiration, and feel that the science of petrology has been materially advanced by this mature and progressive treatment of the major problems of igneous rocks. I can cordially agree with the author in most of his conceptions as to the natural relations of igneous rocks. In general, I subscribe to his optimistic view (*op. cit.* p. 362) that

'we have almost within grasp a fundamental principle analogous with that of descent, which lies at the root of natural classification in the organic world,'

but unfortunately see no ground for the hope that we can apply that principle in petrographic system. The laws of magmatic descent operate on such complex solutions and under such a variety of conditions, that factors of necessary simplicity and of clear application in logical system seem to me impossible of realization. The future must decide which view is correct.

It was no part of the original plan of this paper to advocate or defend the quantitative system proposed by my colleagues and myself, often referred to as 'the American system.' But it has been so severely criticized by Harker in the work just quoted, in connexion with a general plea for the 'natural' classification of igneous rocks, that a brief reply to certain points seems not to be out of place.

I will pass over such comment on the system as comes from the general objection to a quantitative as opposed to a natural system. The preceding discussion shows why the desirable natural system seems to me unattainable. The fact that Mr. Harker is able to make no definite proposition of systematic value, after his exhaustive study of the natural relations of igneous rocks, seems confirmatory of this view. The hope that in eutectics there may be found a natural principle suitable to classification seems futile, in view of the probable complexity of that relation and of other considerations, as has already been pointed out.

The general criticism of the Quantitative System that it separates similar things is inherent in any system with precise definition of units. The current mineralogical system is everywhere approaching that situation with no definite, consequent basis for its precision.

As to the basis of the system, the norm, I find a strange reluctance on the part of Mr. Harker to acknowledge that it has any merit or significance, while certain features are repeatedly referred to in terms of condemnation, as wofully artificial. The basis is alluded to as chemical in 'a disguised form,' and as 'a circuitous manner of representing a chemical analysis.' The authors consider it 'chemico-mineralogical' and as, in fact, an indispensable interpretation or expression of the purely chemical. Mr. Harker says that the Quantitative System is based

'upon a hypothetical mineralogical composition which is not in general that of the actual rock.' (*Op. cit.* p. 363.)

The norm is otherwise called 'ideal,' and 'a certain artificially selected "standard" list' of minerals. He notes that the complex micas, garnets, aluminous hornblendes and augites, melilite, spinel, and others, are not in the norm,

'while in their place we find kaliophilite, sodium and potassium metasilicates, wollastonite, and åkermanite,—compounds which are foreign to igneous rocks, and some of which are not known in Nature.' (*Op. cit.* p. 365.)

Nowhere do I find recognition of the plain fact that the norm is almost wholly made up of substances which Mr. Harker and many others believe to be the principal simple molecules of the magmatic solution. Nor is the repeated statement of the authors of the Quantitative System that it is essentially a magmatic classification, so far as the new divisions go, emphasized as it should be.

I wish to return to the discussion of the norm in connexion with the third desideratum of an 'ideal system' presented by Mr. Harker, which it seems well to quote in full:—

'III. Since rock-magmas are mixtures of minerals, and the variation met with in igneous rocks is a variation in the associations and relative proportions of minerals, it follows that a natural classification must be in its expression a mineralogical one, not a chemical. It is true that the actual mineralogical constitution of a given magma may vary to some extent in accordance with temperature and other conditions, and this would seem to import some complication where successive differentiations have been effected at higher and lower temperatures. If it should be found necessary to represent complex low-temperature minerals by simpler compounds, these must at least be compounds which actually exist in the rock-magmas.' (*Op. cit.* pp. 376–77.)

The first sentence of this statement appears to recognize that one element in an ideal system is an expression of the relative proportions and associations of the mineral molecules in magmatic solution. The second sentence recognizes variation in molecular constitution in accordance with conditions, and the last one that complex molecules may be necessarily represented by simpler ones in any statement.

In his discussion of rock-magmas (*op. cit.* chap. vii, p. 169), Mr. Harker states that

'the constituents of a molten rock-magma exist there in the form of definite compounds, mostly silicates, and in general identical with those compounds which are familiar in the less complex rock-forming minerals.'

I find direct mention of orthoclase, albite, anorthite, leucite, nepheline, quartz (tridymite), and corundum, and must infer that he would include sodalite, noselite (nosean), and zircon. These mineral molecules are the only ones in the salic division of the norm, by which three classes of igneous rocks are classified as far as the subrang.

Of the femic normative silicates Mr. Harker recognizes the chief: acmite, diopside, hypersthene, and olivine, as magmatic molecules, and the general rule that meta- or orthosilicates of calcium, magnesium, and iron are present in the magma in relation to the silica contents. In short, if Mr. Harker should attempt to compare magmas, in a consistent manner, by study of rock-analyses, and to express their character in terms of the mineral molecules that he believes to be in solution (see quotation above), his list must apparently be very nearly that of the norm. If the metasilicates are combined in regular proportions in diopside, hypersthene, and acmite, he will occasionally have an excess of sodium and calcium metasilicates. The latter he might prefer to call pseudo-wollastonite, the enantiotropic form of $CaSiO_3$ existing above 1180°.[1] He would also encounter the necessity of recognizing some subsilicate molecule for high lime contents in the magmas of melilite rocks, for the latter would be a difficult complex molecule to insert into his standard scheme.

Mr. Harker might call his standard scheme of magmatic molecules 'the norm' or apply some other term; he might use it in his ideal classification or not; but its usefulness for comparison and interpretation would, I think, be considered greater than diagrams or arbitrary ratios of oxides could be.

Apparently, Mr. Harker's reluctance to recognize the significance of the norm comes from his inference that

> 'the underlying idea seems to be that the constituents exist in a rock-magma in the form of free oxides, a conception which necessarily obscures natural relationships.'

This inference is perhaps not unnatural, in view of the statement by Iddings in 1892,[2] that oxides and not definite silicate compounds were present in the magmatic solution, and because this idea was not specifically disclaimed in the presentation of the Quantitative System. It is true that in 1902, when the System was issued, the components of magmatic solution were by no means so clearly known or indicated as at the present time. But the idea that mineral molecules were the important ones, under the conditions immediately preceding crystallization, was by no means unknown to the authors of the Quantitative System, nor were they at that time advocates of the hypothesis that the magma contained oxides and silicate compounds.

[1] E. T. Allen & W. P. White, 'On Wollastonite & Pseudo-Wollastonite, Polymorphic Forms of Calcium Metasilicate; with Optical Study by Fred Eugene Wright' Amer. Journ. Sci. ser. 4, vol. xxi (1906) pp. 89-108.

[2] 'The Origin of Igneous Rocks' Bull. Phil. Soc. Wash. vol. xii (1892-95) p. 158.

I do not mean to claim that our ideas in this matter were as clear as they are to-day. We may have builded better than we knew. But there was every reason why we should not go into theoretical discussion of the molecular constitution of the magma in connexion with the norm, for we laid stress on the belief that systematic classification should not be based on theory. The constitution of the magma is still imperfectly known; it was much less so in 1902. Some degree of electrolytic dissociation in magmas is assumed by Iddings, Vogt, and Harker.

Whatever our views on the magmatic solution may have been, the important point, so far as the character of the norm is concerned, is that the normative molecules were chosen after a very careful consideration of the laws of chemical affinity, which have been evident in synthetic work and are expressed in crystallization, and would control the combinations of oxides and other primary constituents of rock-magmas, whenever combination was possible. These considerations are stated very concisely, but definitely, in explaining the norm and the order of procedure in its calculation. For all the purposes of this discussion it is immaterial whether these laws become effective at crystallization or before it. The significant fact is that the laws of chemical affinity, recognized in formulating the norm, appear to have been in the main correctly understood; that they have operated in the magmatic stage, and still hold good to a large degree under the average conditions of crystallization.

The remark of Mr. Harker that the 'rangs and subrangs are made to depend directly on chemical characters, viz., the molecular ratios of certain oxides,' while other divisions rest on proportions of mineral molecules, shows that he did not understand why this was done and deserves explanation, destroying the critical force of the comment. The molecular ratios of K_2O, Na_2O, and CaO, on which rangs and subrangs depend, in Classes I, II, and III, are not the ratios of the total amount of these oxides in the rock as shown by analysis, but of that part of these oxides assigned to molecules of orthoclase, leucite, albite, nepheline, sodalite, noselite, and anorthite. In other words, the ratios are the ratios of these mineral molecules, in three groups. It is a concise and convenient way of indicating the character of the silicate molecules the proportions of which, in the groups called felspar and lenad (felspathoid), enter largely into the division of Orders. The same explanation applies to the ratios of oxides used in making rangs and subrangs in Classes IV and V. They stand for certain mineral molecules.

The view that magmatic molecules correspond to simple mineral molecules has been expressed by many petrographers. While testing the 'Kernhypothese' of Rosenbusch in its application to laurdalite and its descendant rocks, Brögger came to the conclusion that magmas consist of simple compounds ordinarily found in rock-minerals, and that their number exceeded not very greatly the assumed 'Kerne' of Rosenbusch. He specifies orthoclase, albite, anorthite, nepheline, as molecules in which alumina is combined with silica and alkali or lime.[1]

In his recent work (1909) on igneous rocks, Iddings says :—

'They [the compounds in solution] are mostly silicates, with a few oxides, SiO_2, Fe_2O_3, Al_2O_3, and other non-silicates in some cases. The components do not exist as uncombined oxides, with limited exceptions.' (Vol. i, p. 268.)

The dichotomous principle on which the Quantitative System is worked out is a practical necessity, as I venture to think will be the conclusion of Mr. Harker—who objects to it—or any one else attempting to deal with a number of variables in a quantitative scheme. That the result in the Quantitative System is unfortunate is not, I believe, the general opinion of those who have applied it. Its primary effect is certainly to give appropriate form and bounds to five vague magmatic divisions ordinarily referred to as ultra-acid, acid, intermediate, basic, and ultra-basic. The course of magmatic differentiation is commonly conceived as tending to separate the femic (basic) from the salic (acid or alkalic) magmas. In this first division of common use Mr. Harker would surely not put corundum, a molecule which he recognizes as existing in some magmas, with the femic or basic constituents, although he criticizes our placing it in the salic group.[2]

The assertion that a unit of a quantitative system should bring together things which are alike, must have regard for the basis on which that unit is made. Mr. Harker criticizes the Quantitative System in this way by reference to the subrang Toscanose.[3] The citation of the names which petrographers have given to rocks found under Toscanose in Washington's tables is not, as Harker uses it, proof of the heterogeneous character of the assemblage belonging to this subrang. The larger number of different names assigned by the current system to rocks under Toscanose were given on account of texture or occurrence, features not entering into the chemico-mineralogical definition of Toscanose. Other names cited by Mr. Harker are not properly applied to the rocks in question. Thus the 'trachytes' have a notable amount of free silica and of lime-felspar: they should be called quartz-latite in most cases. The 'hypersthene-andesite' has in its norm 7·8 per cent. of femic molecules, 8·3 per cent. of anorthite, and 25·6 per cent. of quartz, the balance being alkali felspar; and its mode can vary from this to no great extent. The 'granites' were named before quartz-monzonite came into use, and are rich in the anorthite molecule. The 'rhyolites' all carry more anorthite than typical rhyolites should.

Instead of showing the heterogeneity of Toscanose, this list of rocks illustrates the lax and inappropriate use of terms under the

[1] 'Die Eruptivgesteine des Kristianiagebietes, III: Das Ganggefolge des Laurdalits' 1898, p. 332.

[2] 'The Natural History of Igneous Rocks' 1909, p. 364. [3] *Ibid.* p. 363.

old system. And, as Mr. Harker points out, the names of rocks found under other subrangs have the same significance as those under Toscanose. Washington[1] found that rocks called 'granite' belong to 20 different subrangs, 'trachytes' to 23 subrangs, 'andesites' to 27 subrangs, which is neither an argument for the homogeneity of the old group nor for the heterogeneity of the new units of definite bounds!

Mr. Harker remarks that

> 'the manner in which the various oxides are actually combined in the minerals —in the author's terminology, the "mode" of the rock—finds no place in the classification.' ('The Natural History of Igneous Rocks' 1909, p. 365.)

The mode naturally finds no place in the magmatic classification expressed by the new systematic nomenclature. But it is not true that the authors of the Quantitative System did not provide, by many definite suggestions, ways of stating in any given case the actual mineral and textural characters found in a given rock-unit. It is undesirable to enlarge on this subject here, but the idea of the authors of the Quantitative System may be repeated. It is that mineral composition and texture are each variable qualifying features of any consolidated magma. The ends of systematic petrography will be best met by using these characters as qualifiers in the ways which experience may show to be most effective. By these means, and only by them, I think, can the appropriate descriptive terms needed for the illimitable variations possible for each magmatic unit be connected with the fundamental chemical character.

The foregoing review of principles, of facts of nature, of points of view, will, I hope, assist in directing discussion towards the vital question, Is a natural classification of igneous rocks possible? Mr. Harker outlines the 'Desiderata in an Ideal System.' I can quite agree with him in this statement. In the abstract I should also agree with the forceful final comments on the Quantitative System embodied in these sentences:—

> 'The strongest objection to the Quantitative Classification is, however, that it is planned entirely on *a priori* lines......As von Richthofen aptly remarked, in order to establish a more natural system, we have not to make groups, but to find them......The scheme of Nature (is) based not on arithmetical but on physical and chemical principles.' (*Op. supra cit.* p. 366.)

But these truisms and ideal characters of a natural system do not make the system. What are the physical and chemical principles practically applicable to petrographic system? Who shall find the natural groups? If the groups do not exist, if the principles are unfortunately not suitable to systematic use, then must we not come to an *a priori* basis for that classification on which specific nomenclature must rest?

[1] 'Chemical Analyses of Igneous Rocks' Prof. Paper No. 14, U.S. Geol. Surv. 1903, p. 61.

VIII. Summary.

(1) A 'natural' system of classification is one giving expression to facts of nature, the plan of the system being demanded by the laws of the origin of the principal characters of the objects to be classified. Natural laws are established by facts, not by process of reasoning.

(2) No current classification of igneous rocks is, in any of its main features, in accord with the facts of nature.

(3) It is questioned whether petrographic system for igneous rocks can be strictly natural, because all their important characters are gradational within a group, and are due to complex geological conditions.

(4) The scientific logical classification of igneous rocks must apparently be based on the quantitative development of fundamental characters, and the divisions of the scheme must have sharp artificial boundaries, since none exist in nature.

(5) Chemical composition is the fundamental character of igneous rocks, but it may be advantageously expressed for classificatory purposes in terms of simple compounds, which represent either rock-making minerals or molecules entering into isomorphous mixtures in known minerals. It is probable that the magmatic solution consists of such molecules and that the norm of the Quantitative System is a fairly representative set of these compounds.

(6) The actual mineral and textural characters of igneous rocks are variable qualifiers of each chemical unit, and should be applied as such to terms indicating magmatic characters.

Discussion.

Mr. Harker welcomed this paper as a clear statement of the Author's position. He took a more hopeful view than the Author of the ultimate prospects of a natural classification of igneous rocks, and believed that in Vogt's conception of 'anchimonomineralic' and 'anchieutectic' types we had already the germ of such a system. He was content to await in patience the gradual development of a more rational classification with increasing knowledge. The conviction that this development would be seriously impeded if a rigid artificial taxonomy and terminology came to be generally adopted, was one ground for his objection to the Quantitative Classification.

The speaker thought that the authors of this system had been decidedly, if unconsciously, influenced by the now obsolete conception of a rock-magma as a mixture of free oxides, which might be arbitrarily linked together for purposes of convenience. He pointed out that, since such constituents as lime and alumina enter into ferromagnesian as well as into felspathic minerals, the choice of the 'standard' molecules may affect even the class to which a given rock is to be assigned. Thus the 'hornblendite' of Brandberget, which on general mineralogical grounds would be ranged in Perfemane, appears in Washington's Tables in Salfemane.

Dr. J. W. Evans believed that a natural classification of igneous rocks must be founded on genetic principles, but admitted that our knowledge of the processes involved in the differentiation of igneous magmas was still too incomplete to enable us to frame a satisfactory permanent system of classification on these lines. It might, he thought, be possible to demonstrate the existence of rock-types which occurred with greater frequency than the intervening links, and might serve as the centres of natural groups that would prove to have a genetic significance; but the necessary detailed information as to the composition and extent of rock-masses was as yet insufficient for the purpose. In the meantime, what might be called an arithmetical classification, with arbitrary lines of division based on the proportions of different constituents, might, he thought, be of considerable value as a kind of pigeon-hole arrangement of analyses for convenience of reference. The silica percentage had in fact been widely employed in this way. In that case there was only one substance employed as an index. If, on the other hand, the proportions which one group of constituents bore to another were adopted as the basis of the classification, it was important that the increase or decrease of the associated substances in the differentiation of rocks should be determined by similar conditions. Even if it were admitted that crystallization was the predominant process in the differentiation of a magma, the eutectic theory would give us little assistance except in the more basic rocks, for up to the present it had been worked out only in anhydrous magmas. The presence of water profoundly affected the order of crystallization of the rock-forming minerals, and the succession enunciated by Rosenbusch was, he believed, an expression of the differences in the affinity of rock-constituents for water. Those with the greatest attraction for water, the 'hydrophil' constituents, if the expression might be allowed, were the last to separate from a water-bearing magma: they included silica, and the alkali felspars and the felspathoids. The two last-named groups, however, probably existed in the magma, in the form of silica and the alkaline aluminates which were highly soluble in water. This selective action of water appeared to operate, both in segregation by crystallization and in magmatic differentiation in the fluid state. If the hydrophil constituents had been grouped together by the American Quantitative Classification, it might have been of some service to petrologists. Unfortunately the 'salic' minerals of its authors included, not only these substances, but anorthite and any molecular excess of alumina over the alkalis. Anorthite, however, played a part totally different from that of the alkali felspars, though it occurred in solid solution with albite as a result of community of crystalline structure. It was, as a matter of fact, essentially a basic silicate, which, unless it was present in very small amount or was 'brought down' by albite, crystallized out before augite, and in some cases even before olivine. Anorthosite (which consisted mainly of anorthite) was more closely allied to a peridotite than to a quartz-orthoclase rock, with which the American classification associated it. Similar considerations applied in the case of an excess of alumina, which usually appeared as a constituent of augite or hornblende,[1] and should have been classed with the femic minerals. The salic group was in fact a collection of minerals which had nothing essential in common, and the fundamental lines of division of the classification were accordingly practically meaningless. Its general adoption in the description of rocks would, therefore, hinder rather than advance our recognition of their relation to one another.

Mr. T. Crook contended that the primary requirement of a system of classification of igneous rocks was, that it should be natural. The formation of igneous rocks took place by differentiation, and was essentially an evolutionary process. Experience proved that differentiation-products required to be classified qualitatively and not quantitatively, since it was only by this means that the natural order could be reflected in a scheme of classification. Classifications based on mineral composition and structure were admittedly imperfect; but they were natural, inasmuch as they sacrificed sharpness of grouping in their attempt to copy the natural order of arrangement. It was in this sense that the quantitative-chemical system was rightly stigmatized as unnatural when compared with mineral-textural systems, since it insisted upon the essentiality of 'sharp artificial boundaries' which did not exist in Nature. The chemical composition of an igneous rock, which the Quantitative System treated as the most fundamental character, was less fundamental than mineral composition. The chemical composition of any given few grams of a holocrystalline rock was determined by the minerals actually present, and at no period of differentiation could it be truly said that this chemical composition was an inherent feature of the magma. On the other hand, the mineral composition was not determined by the chemical composition of the particular piece of rock analysed, but by that of the magma during the various stages of crystallization. By a development of this argument it could be proved that the natural mineral composition of a rock was more fundamental than its chemical composition or any artificial norm calculated therefrom, and was therefore a sounder basis of classification.

Dr. L. L. Fermor said that most of the previous speakers had spoken disapprovingly of the Quantitative Classification of igneous rocks. He did not advocate its adoption, but drew attention to one good feature, namely the idea of the norm. In dealing with a rock the speaker found it very helpful to be able to compare one rock with another, not on the basis of their actual mineral composition, nor even of their chemical analyses, but preferably by converting the

[1] [Mica might also have been mentioned in this connexion.—*J. W. E.*]

chemical analyses into the standard mineralogical composition known as the norm: thus comparing the rocks mineralogically, but yet without reference to their actual mineral composition and physical structures, which after all were in a way accidental features dependent not merely on the original composition of the magma, but on its treatment during and after solidification.

Dr. Teall thanked the Society on behalf of his friend the Author for the way in which they had received the paper. There appeared to be general agreement on the main subject of the paper, for the criticisms had been almost entirely directed to the Quantitative System of classification. Much of this criticism seemed to him to be rather wide of the mark. Was the system of real utility as aiding thought? This, after all, was the important question, and on the answer that would ultimately be given to it depended the fate of the classification.

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[No. 264 of the Quarterly Journal will be published next November.]

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Part 4.

THE QUARTERLY JOURNAL OF THE GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

[With Eighteen Plates, illustrating Papers by Dr. F. H. Hatch & Mr. R. H. Rastall, Mr. R. G. Carruthers, Mr. A. Wilmore, Mr. E. B. Bailey, and Dr. Tempest Anderson.]

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SESSION 1910–1911.

1910.

Wednesday, December 21*

1911.

Wednesday, January .... 11*—25*
,, February (Anniversary, Friday, Feb. 17th) . 8*—22*
,, March..................... 8*—22
,, April .... 5*—26
,, May .... 10*—24
,, June 14*

[*Business will commence at Eight o' Clock precisely.*]

The dates marked with an asterisk are those on which the Council will meet.

21. Dedolomitization *in the* Marble *of* Port Shepstone (Natal).

By Dr. F. H. Hatch, M.Inst.C.E., F.G.S., and R. H. Rastall, M.A., F.G.S. (Read May 25th, 1910.)

[Plate XXXV.—Microscope-Sections.]

I. Introduction.

While on a visit to the marble quarries of Port Shepstone, the attention of one of the authors [1] was attracted by a block of granite, included in the dolomite and surrounded by a dark banded border, which was succeeded in order by a pale brown and a pale green zone. On closer examination these coloured rings were found to consist of a portion of the marble, containing a number of interesting minerals in zonal arrangement. Among these minerals a brown mica and a coal-black substance were the most conspicuous to the unaided eye, although a pale mica and a green serpentinous mineral could also be distinguished. On account of its obvious interest a photograph of the occurrence was taken (see fig. 3, p. 512), and a number of specimens were collected for microscopic examination.

The Port Shepstone marble is well known in Natal, on account of its beautiful white appearance and coarsely crystalline (saccharoidal) texture. Unfortunately for those interested in its commercial exploitation, it does not possess the uniformly fine and even grain of the celebrated marble of Carrara, a fact which militates against its employment for statuary purposes. It is first mentioned in geological literature by C. L. Griesbach,[2] who notes the occurrence of a 'crystalline limestone of enormous thickness, [but] whose position relative to the neighbouring strata is not clear.' In the year 1894, David Draper [3] described it in somewhat more detail,

[[1] Since this paper was read Mr. Rastall has also visited the locality, and his observations confirm those previously made by Dr. Hatch.]

[2] 'On the Geology of Natal' Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 56.

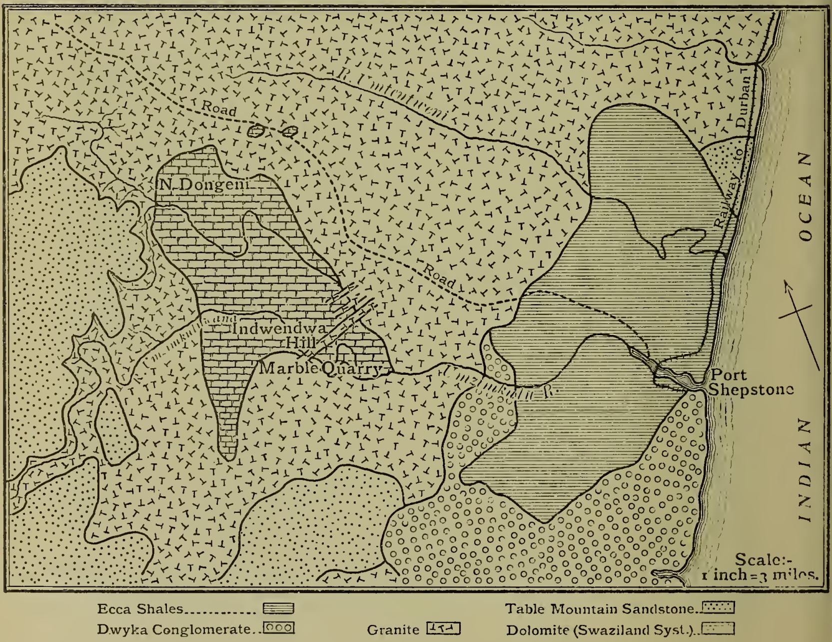
[3] 'The Marble Beds of Natal' *Ibid.* vol. li (1895) p. 51.

and stated that he had no doubt 'that the calcareous matter of which the marble was formed was deposited upon the granite' (*op. cit.* p. 55), although the sections accompanying the paper appear to indicate distinctly that the granite is of later age. Furthermore, the two sections are inconsistent with each other—the one showing the granite occurring as a sheet overlying the dolomite on Indwendwa Hill, while the other shows the granite intruded into the marble of Indwendwa Hill as a bathylith. The same occurrence was described in 1907 by Mr. William Anderson,[1] then Government Geologist for Natal. This author considered that the marble originated as a sedimentary deposit, and that by the intrusion of the granite 'it has been converted into a very coarsely crystalline limestone, consisting entirely of crystals of calcite' (*op. cit.* pp. 111–12).

II. Field-Relations of the Dolomite.

Mr. Anderson mapped the marble, and showed it as extending over an irregular area measuring 9 to 10 square miles, and surrounded

Fig. 1.—*Geological map of the district around Port Shepstone.*



on all sides by granite. In all probability, however, the area is larger than that indicated on Anderson's map: since, in the course

[1] Third & Final Report of the Geological Survey of Natal & Zululand, 1907, p. 109.

of the examination made by one of us, the marble was seen cropping out on the farm N'dongeni, about a mile north-west of the nearest point on Anderson's boundary; and an isolated outcrop was observed in Cherrywillingham Park, at a point a mile and a quarter north-east of his limit in that direction.

During the same visit a traverse was made along the right bank of the Umzimkulu River, and the marble was there seen to be cut by several big dykes of red granite, striking roughly east and west. The width of one of these was roughly measured by pacing, and found to be from 200 to 300 feet. The granite shown in Draper's section of Indwendwa Hill is evidently a portion of the outcrop of one of these big dykes. Whether they are to be considered as offshoots from the main mass, or as later intrusions, cannot be now decided. Their appearance is rather different from the general character of the main mass of granite, which has a prevailing grey tint. In any case, they must have had considerable influence on the metamorphism of the dolomite.[1]

The invading granite surrounds the dolomite on all sides, and covers a large area of country extending for many miles to the north. To the west of the dolomite area it is overlain unconformably by horizontally-bedded Table Mountain or Waterberg Sandstone,[2] and to the east and south-east it is covered by Dwyka Conglomerate and Ecca Shales. Since the Table Mountain Sandstone at the Cape underlies beds of Devonian age, the intrusion of the granite was certainly pre-Devonian. The dolomite and certain schists which accompany it presumably belong to the Swaziland System.

III. Petrographical Description of the Invading Granite.

Specimens of the invading granite were collected from a good exposure 2 miles north-east of the Marble Delta Company's Quarry, near Sinclair's house on the left side of the Umzimkulu River. It is a rather dark-grey rock of medium texture, and consists exclusively of quartz, alkali-felspar, and brown biotite. Under the microscope the most abundant constituent is seen to be microcline, which, together with quartz, makes up the bulk of the rock. A little orthoclase is present, but no plagioclase can be identified. Some of the microcline crystals show indistinct perthitic structure. The mica when fresh is bright yellowish brown and strongly pleochroic, but in places it is partly altered to chlorite. The structure is typically granitic, the microcline and the quartz having crystallized almost simultaneously. In places there is even a tendency to graphic intergrowth.

[1] A specimen of one of the dykes of red granite was collected, but no thin section has been prepared, as this specimen was included in the collection presented by Dr. Hatch to the Pietermaritzburg Museum.

[2] This Natal sandstone formation constitutes an important link between the Table Mountain Sandstone of the Cape and the Waterberg Sandstone of the Transvaal. Its correlation with the Cape formation is generally admitted; but the resemblance to the Waterberg formation, especially in regard to its highly developed basal conglomerate, is even more striking.

IV. Petrographical Description of the Dolomite, its Inclusions, and its Alteration-Products.

(1) The Dolomite.

The dolomite, away from the sphere of influence of the inclusions, is a beautiful white marble of very coarse texture: in the hand-specimens scarcely any coloured minerals are observable. The following chemical analysis of a typical specimen, made by Mr. Campbell Smith, shows that the rock is composed of 74·56 per cent. of dolomite and 21·43 per cent. of calcite, with 2·46 per cent. of insoluble matter and 1·34 per cent. of water:—

Calcium carbonate	61·95
Magnesium carbonate	34·04
Ferrous carbonate	0·21
Insoluble matter	2·46
Water and loss	1·34
Total	100·00

To gain an idea of the average composition of the dolomite in the Marble Delta Company's Quarry, a sample was taken by chipping off a great number of small pieces from the quarried material, of which a large stack had been accumulated. This sample was analysed in Pietermaritzburg by Mr. F. W. Penny, and was found to have the following composition[1]:—

Calcium carbonate	57·75
Magnesium carbonate	37·46
Ferrous oxide	0·50
Insoluble matter	3·16
Water and loss	1·13
Total	100·00

Ratio of $CaCO_3 : MgCO_3 = 3 : 2$.

An examination of a thin section shows that, besides carbonates, the rock contains a small quantity of a colourless augite (diopside) showing the characteristic high refractive index, strong birefringence (about ·02), and a maximum extinction-angle of 36°.

(2) The Granite Inclusion and its Reaction-Border.

(*a*) The granite inclusion.—The granite inclusion consists of a subangular block, the longest dimension of which is roughly 3 feet (see photograph, fig. 3, p. 512). The rock is of a light-grey colour and of fairly fine texture. Under the microscope it is seen to be a holocrystalline, even-grained aggregate of quartz, perthite, and a green ferromagnesian mineral, the felspar being the predominant constituent. Besides perthite, there is a very small

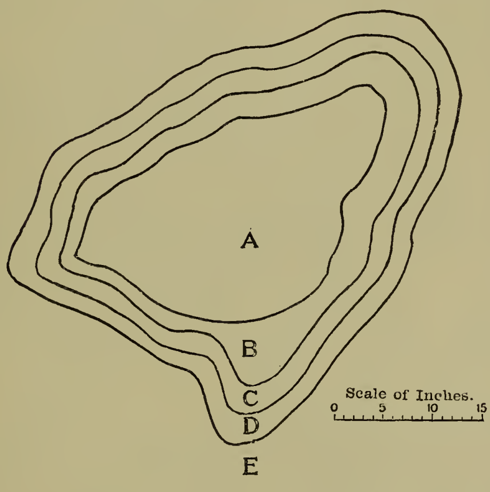
[1] F. H. Hatch, 'Report on the Mines & Mineral Resources of Natal' Published by order of the Natal Government, London, 1910, p. 99.

amount of plagioclase. The perthitic structure is rather peculiar: even in ordinary light the intergrown felspars can be distinguished by a slight difference in turbidity; between crossed nicols the intergrowth is marked by the different orientation of the alternating streaks, a wavy appearance being a conspicuous feature.

The ferromagnesian mineral is of a dark emerald-green, and shows distinct pleochroism; it has, however, the characteristic rectangular cleavage of a pyroxene, and its maximum extinction-angle is about 38°. There can be little doubt that it is an ægirine-augite.

From this composition it is evident that the rock belongs to the alkali-granites, being either a soda-granite or a soda-aplite.[1]

Fig. 2.—*Diagram of the granite inclusion and its reaction-zones* (cf. *fig. 3, p. 512*).



A = Granite inclusion; B = Dark-mica zone;
C = Light-mica zone; D = Ophicalcite zone;
E = Normal dolomite.

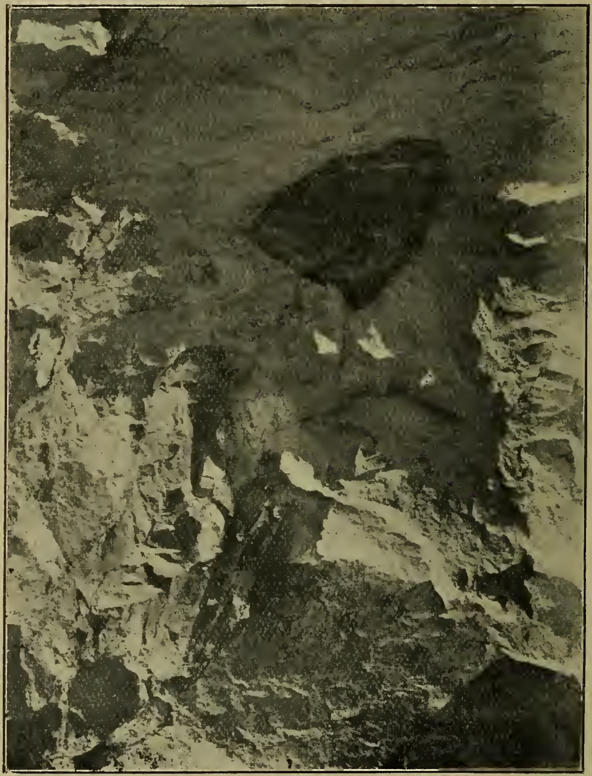
(*b*) The dark-mica-olivine zone.—This zone varies in width from 2 to 5½ inches, and averages about 4 inches. It owes its dark colour partly to the presence of a dark-brown mica, arranged in peripheral layers in alternation with white carbonate; and partly to a dark band consisting mainly of olivine, but with some spinel, both of these minerals having the coal-black appearance already mentioned. A section cut from a portion of this

[1] A mechanical separation made, with the aid of the electromagnet, by Mr. T. Crook, in the laboratory of the Imperial Institute, yielded 4·6 per cent. of the green augite, 0·2 per cent. of magnetite, and 0·2 per cent. of sphene, the remaining 95 per cent. being felspar and quartz.

latter band contains abundant olivine and a transparent, isotropic, very pale green mineral (spinel), with subordinate calcite and a few flakes of mica.

The olivine possesses the usual characteristics—high refractive index, strong birefringence, and irregular cleavage-cracks. The form is rounded. This mineral, although it no doubt contains a

Fig. 3.—*Photograph of the granite inclusion and the reaction-rim, taken in the Marble Delta Co.'s Quarry, near Port Shepstone.*



F. H. H., photogr.

[The longest diameter of the inclusion = 3 feet. The white patches are flecks of sunlight, the remaining portions of the quarry-face being in shadow.]

high percentage of magnesia, cannot be classed as forsterite, since chemical tests [1] indicate the presence of a considerable proportion of iron, and the microscope shows a separation of much powdery

[1] Mr. Campbell Smith isolated some of this mineral, and found that it dissolves readily in hydrochloric acid, leaving a residue of white silica. A qualitative analysis showed the presence of silica, ferrous iron, magnesia, and lime, the last-named being possibly due to attached calcite.

iron-ore (magnetite) in those grains which are most serpentinized. It is the presence of this finely divided iron-ore that gives to the olivine its coaly-black appearance.

The spinel occurs in well-formed crystals, which frequently show square or triangular sections. Although not present in every section made from the dark band, the spinel is in places quite abundant. It has a faint greenish tinge, and is perfectly isotropic. A conspicuous feature is a black margin, due to a coating of powdery iron-ore, which is probably derived from the decomposition of the olivine. Incipient alteration to a fibrous product is visible in places. To make certain that the mineral was really spinel and not periclase, the black material (which after crushing was retained on a 90-mesh, but passed a 60-mesh sieve) was digested for $2\frac{1}{2}$ hours in hot concentrated hydrochloric acid.[1] A product was obtained consisting almost entirely of isotropic crystal fragments freed from the iron coating. This material is pale purplish grey in reflected light, but possesses a faint green tinge in transmitted light. In methylene iodide it is nearly invisible, indicating a refractive index near to 1·74. A qualitative analysis showed that it contained a large proportion of alumina.

The mica, viewed in the slice, is pale brown with decided pleochroism (pale brown to colourless) and very strong birefringence. Flakes of this mica were picked out from the hand-specimen and examined by Mr. Campbell Smith with the following results:—The dark-brown flakes are quite brittle, and too small for the determination of the percussion figure. The refractive index was found by the method of Schroeder van der Kolk to be between 1·56 and 1·59. The mineral is biaxial ($2E = 24°$) and optically negative; the pleochroism on cleavage-flakes is dark brown to pale brown (light vibrating parallel to the plane of the optic axes giving pale brown).

Mr. T. Crook, of the Imperial Institute, isolated by means of the electromagnet about 2 grams of the mica, and, after cleaning this material with weak acid, determined its percentage of water to be 1·72 and its density to be over 2·85. The summation of these characters, with those determined by Mr. Campbell Smith, suffices for its identification as phlogopite.

In the course of the isolation of the mica, it was found to be associated with a considerable amount of pyrrhotite, which was separated by means of a heavy solution of a density of 3·34. An examination of a thin section in reflected light reveals the pyrrhotite grains embedded in the phlogopite.

(*c*) The light-mica-forsterite zone.—This zone, which is about 2 inches in width, consists of a pale mica (phlogopite), a pale-brown member of the olivine group, and a small amount of pale-green serpentine, derived from the last-named mineral, together with interstitial calcite.

An examination of a slide shows clearly the nature of the change

[1] Periclase is soluble in hot concentrated hydrochloric acid.

which has taken place; the original dolomite has completely disappeared, and is replaced by an aggregate of mica and forsterite, the interstices between the crystals being filled with secondary calcite, in plates which are optically continuous over large areas (see p. 518).

The reason for the difference in colour of the two mica-zones is clearly brought out under the microscope; the mica in this case is absolutely colourless, and the olivine mineral is serpentinized along cracks without separation of iron-ore, a fact which points strongly to its being the pure magnesian orthosilicate, forsterite.

Besides the calcite plates, which are evidently of secondary origin, there are a few rounded grains of carbonate enclosed in the forsterite; possibly these are unaltered remnants of the original dolomite.

Towards the outer portion of the zone the serpentinization of the forsterite grains increases rapidly, a few grains being more than half replaced by serpentine.

(*d*) The ophicalcite zone.—This zone consists of an aggregate of white carbonate and greenish-yellow serpentine, which, under the microscope, is, by its form, clearly recognizable as derivative from forsterite. It shows the characteristic mesh-structure in great perfection, and in one grain a core of the unaltered mineral was identified as forsterite by its high refractive index, strong birefringence, and absence of colour.

The serpentine in ordinary light is quite colourless, and is distinguishable from the carbonate by its more perfect transparency. Between crossed nicols it shows rather weak birefringence. Figs. 3 & 4 in Pl. XXXV illustrate the appearance of a section in ordinary light and between crossed nicols respectively.

(3) Other Inclusions in the Dolomite.

In other parts of the quarry, specimens were obtained showing interesting associations of magnesia and lime silicates, which, as in the instance already described, evidently owe their origin to action between the dolomite and enclosed pieces of foreign rocks. Two specimens merit detailed description: one a felspar-scapolite-diopside-rock, and the other a rock largely composed of forsterite and spinel.

(*a*) The felspar-scapolite-diopside rock.—This consists mainly of a pale bluish-grey aggregate of felspar, separated from the dolomite which encloses it by a zone of silvery mica about an inch wide; in this zone the mineral occurs in long narrow blades disposed radially, that is, at right angles to the boundary of the inclusion. Examined in convergent light, the mica is seen to have so small an optic axial angle as to be practically uniaxial. There is little doubt that it is the magnesian mica, phlogopite.

Examination of a thin section of the felspar-rock shows that it is, in the central portion, almost entirely composed of a plagioclase felspar. This felspar exhibits well-marked twin-lamellation, with an extinction-angle corresponding to oligoclase. The boundary edges of the felspar grains are irregularly crenulated, and occasionally a granular structure is to be seen.

In the marginal portion of the rock the felspar is associated with scapolite and diopside. The scapolite, which is fairly abundant, occurs in crystals which often have rectilinear boundaries. It shows a rather low refractive index, moderate birefringence, and, in suitable sections, rectangular cleavage-cracks parallel to the prism 100. Sections parallel to the principal axis show of course only one set of cleavage-lines, and in these sections the birefringence is at its strongest, giving reds and greens of the third order as compared with the greys and pale yellows of the sections that lie more transversely. A favourably oriented section enabled the optically negative character of the mineral to be determined.[1]

The diopside occurs in colourless, rather isolated grains, possessing a high refractive index, strong birefringence, well-marked prismatic cleavage-cracks, and oblique extinction.

(*b*) The spinel-forsterite rock.—A hand-specimen of this rock consists of a pale pink central core, a narrow grey band, and an outer white portion, the latter being part of the normal dolomite. The central core owes its colour to the abundant presence of a pink spinel in small octahedral crystals, which are embedded in a white carbonate (calcite). The latter occurs in very large crystals, in which the spinel is so embedded as to interrupt the reflecting cleavage-surfaces in the manner characteristic of the pœcilitic structure of igneous rocks. Besides the spinel there is present in isolated grains a dark red to black mineral of brilliant adamantine lustre; this mineral, as will be shown later, has been determined as rutile. The grey layer owes its colour to the presence of forsterite in round translucent grains of a dull grey colour and vitreous lustre.

The minerals of this rock were isolated, and the separated material examined by the following method:—The rock was treated with cold dilute hydrochloric acid until effervescence ceased; the solution was then filtered, and the residue washed and dried. The removal of the forsterite was effected by flotation in methylene iodide (of density 3·3), in which both the spinel and the black mineral (rutile) sank. The black mineral was separated from the spinel by hand-picking. Its density, determined by Mr. Campbell Smith on ·0448 gram by means of a small specific-gravity bottle, is approximately 5·0. The refractive index is greater than 2·0; the colour, reddish brown to black; the lustre, metallic to adamantine. The fragments are rather brittle, and translucent to opaque. In thin sections the mineral appears as irregular translucent grains of a light brown colour and strong birefringence. There are

[1] We have to thank Dr. J. S. Flett for assistance in the determination of this mineral as scapolite.

two cleavages approximately at right angles. The extinction is straight with reference to cleavages. A qualitative analysis by Mr. Campbell Smith shows that the mineral consists of titanium dioxide, no other element being found. The three minerals which consist of titanium dioxide are brookite, anatase, and rutile. The high density and the presence of a well-defined cleavage exclude brookite. Anatase is ruled out by the high density and the absence of a basal cleavage; consequently the mineral must be rutile.

A considerable quantity of the spinel was isolated. It consists of fairly well-formed crystals with predominant octahedral faces. Its density is approximately 3·6.[1] Its lustre is vitreous. In thin sections it occurs in grains, which are mostly bounded by straight edges. It has a well-marked but rather imperfect octahedral cleavage. The refractive index is high; in ordinary light there is no trace of colour, and between crossed nicols the mineral is perfectly isotropic. It is most probably the magnesian spinel corresponding to the formula $MgO . Al_2O_3$.

The forsterite in thin sections appears in grains which bear a superficial resemblance to the spinel, from which it is distinguishable by its more rounded contours and by its strong birefringence. Alteration to serpentine has only just commenced along the imperfect cleavage-cracks.

In addition to the above-mentioned minerals, there is very sparingly present a colourless mica which is biaxial (2E small) and optically negative. Under the microscope it shows one good cleavage, parallel to which it extinguishes, and the birefringence is seen to be strong. A few flakes of this mica, examined by Mr. Campbell Smith, were found to have a density of less than 3·7, and a refractive index of about 1·58. It is probably a phlogopite.

This association of minerals, namely, spinel, forsterite, and phlogopite, recalls the rock described by Mr. C. T. Clough & Dr. W. Pollard from Glenelg.[2]

V. Discussion of Results.

The chemical analyses quoted above show that the marble of Port Shepstone is a dolomite: whether originally deposited as such, or resulting from the alteration of a limestone, is not clear; at the time of its marmorization by the granite, however, it is certain that it was a dolomite. The character and extent of this marmorization indicate that the rock was subjected at the time of its metamorphism to a very high temperature, in the presence of water vapour under great pressure; and this is borne out by the nature of the minerals produced in the dedolomitized areas. The intrusive

[1] Determined by Mr. T. Crook, by immersion in fused silver-thallium nitrate.

[2] 'On Spinel & Forsterite from the Glenelg Limestone (Inverness-shire)' Quart. Journ. Geol. Soc. vol. lv (1899) p. 372.

granite, which forms the whole country for hundreds of square miles, completely surrounds the dolomite, and, in addition, the latter is traversed by broad dykes, which probably represent the last phase of the eruption.

The normal metamorphism of the dolomite produced a saccharoidal marble of very coarse texture, and, as a rule, free from minerals other than carbonates. It is noteworthy that our sections of the normal marble do not disclose the presence of brucite, as in the cases described by Dr. Teall and Mr. Harker in the Durness Limestone of the North-West of Scotland, and in the well-known instance at Predazzo in the Tyrol.

Where silica could be supplied from extraneous sources, as in the neighbourhood of the included blocks, dedolomitization took place, the following minerals being produced: olivine, forsterite, diopside, scapolite, phlogopite, all of which are silicates. In addition to these there is the non-silicate spinel. A noteworthy feature is the absence of minerals such as garnet and cordierite, which are specially characteristic of cases in which other considerations indicate the occurrence of low-temperature metamorphism. All the facts agree, therefore, in indicating the prevalence of a high temperature during the metamorphism of the dolomite.

The inclusions are blocks of rock that appear to have been deposited in the limestone or dolomite at the time of its original formation, and the large granite fragment especially bears out this view. While the grey granite of the district, which is responsible for the metamorphism of the dolomite, is a potash-granite, the inclusion is a fragment of soda-granite or soda-aplite of wholly different character. So far as our experience goes, no such rock has been observed among the South African granites. Since the dolomite belongs to the oldest group of rocks found in the country (the Swaziland System) into which the known granites are intrusive, this rock if a boulder must have formed part of an igneous complex older than anything yet discovered.

The occurrence of granite boulders in limestone is not unknown; they have been found, for instance, in the Carboniferous Limestone which crops out in the neighbourhood of Dublin (near Milltown) and south of Kimmage,[1] and Jukes suggested the possibility of these fragments having been transported by adhesion 'to the roots of plants which were drifted down the water-courses from the neighbouring granite land into the sea of the Carboniferous Period.' Again, a large boulder of granite, together with smaller blocks of greenstone, was found in a chalk quarry at Haling, south of Croydon, and described by R. A. C. Godwin-Austen.[2] In the same paper Godwin-Austen mentions the discovery of a boulder of syenite

[1] S. Haughton, Journ. Geol. Soc. Dublin, vol. v (1850–53) p. 113. See also 'The Geology of the Country around Dublin,' Expl. Sheet 112, Mem. Geol. Surv. Ireland (1903) pp. 76–77.

[2] Quart. Journ. Geol. Soc. vol. xiv (1858) p. 252. See also A. J. Jukes-Browne, 'Cretaceous Rocks of Britain: the Upper Chalk of England' Mem. Geol. Surv. vol. iii (1904) p. 178.

in the Chalk of Antrim. Mr. Whitaker[1] also refers to the occurrence of pebbles of various rocks in the Chalk near Gravesend; and mention may be made in this connexion of the well-known occurrence of boulders of igneous and other rocks, often of large size, in the Cambridge Greensand.[2]

During the period in which the dolomite and its included blocks were maintained at a high temperature, there must have been a molecular interaction between the latter and the former. The materials derived from the granite block are silica, alumina, and iron. The influence of the iron (derived, no doubt, chiefly from the pyroxenic constituent of the granite) did not extend beyond the innermost or dark-mica zone of the reaction-rim, where, together with silica and alumina, it is combined with the magnesia of the dolomite to form an iron-bearing phlogopite and olivine. In this zone the alumina has entered into combination also with magnesia alone, to form spinel. It also plays a part in the light-mica zone, in which it forms a non-ferruginous phlogopite; while forsterite has been formed in this zone by the union of silica with magnesia but without alumina. The influence of the silica alone extended to the outermost zone, where it forms forsterite.

The decomposition of the double carbonate of the dolomite liberated carbonate of lime, which crystallized as calcite in all three zones.

To test this inference, some of the white carbonate material was taken from the dark-mica zone, coarsely crushed, the fine dust removed by washing, and the residue dried. From this material the mica and olivine were removed by means of a powerful electro-magnet. The residue was shaken up with bromoform (diluted with benzine to a density of 2·79)[3]: the whole of the material immediately rose to the surface. On the other hand, material from the pure dolomite-rock, treated in a similar manner, separated into two distinct portions, the smaller part floating in the bromoform, the other sinking to the bottom. Since calcite has a density of 2·72 and dolomite one of 2·85, it is obvious from this experiment that the white material of the dark-mica zone is almost entirely calcite. A similar result was arrived at by the use of the Lemberg staining test. It was found that the whole of the carbonate in a section of the dark-mica zone acquired the stain, while in a section of the pure dolomite-rock, treated simultaneously, the bulk of the carbonate remained uncoloured.

The nature of some of the chemical reactions which took place between the dolomite and the silica, alumina, and iron of the inclusions may be theoretically represented by the following equations:—

[1] 'Guide to the Geology of London' Mem. Geol. Surv. 6th ed. (1901) p. 31.

[2] W. J. Sollas & A. J. Jukes-Browne, Quart. Journ. Geol. Soc. vol. xxix (1873) p. 11; P. F. Kendall, Final Rep. Roy. Coal Commission, 1905, pt. ix, App. 3.

[3] A heavy medium suggested for the purpose by Mr. T. Crook, of the Imperial Institute.

(I) $CaMg(CO_3)_2 + Al_2O_3 = MgO.Al_2O_3 + CaCO_3 + CO_2$.
Dolomite. Alumina. Spinel. Calcite. Carbon dioxide.

(II) $2CaMg(CO_3)_2 + SiO_2 = 2MgO.SiO_2 + 2CaCO_3 + 2CO_2$.
Dolomite. Silica. Forsterite. Calcite. Carbon dioxide.

The formation of the phlogopite can be explained theoretically by the following somewhat simplified equation, in which the presence of alkalis and water is ignored :—

(III) $CaMg(CO_3)_2 + Al_2O_3 + 2SiO_2$
Dolomite. Alumina. Silica.

$= MgO.Al_2O_3\ 2SiO_2 + CaCO_3 + CO_2$.
Phlogopite. Calcite. Carbon dioxide.

The spinel-forsterite rock is a perfect example of dedolomitization. In this case the magnesia of the dolomite combined with alumina to form spinel, and with silica to form forsterite, the residual carbonate of lime re-crystallizing as calcite. Whence the alumina and silica were derived in this particular case there is no evidence to show, since no unaltered fragment of the foreign rock is present in the collected material. The reaction which probably took place assumes the addition of silica and alumina to the dolomite, and can be represented by the following equation :—

(IV) $3CaMg(CO_3)_2 + Al_2O_3 + SiO_2$
Dolomite. Alumina. Silica.

$= MgO.Al_2O_3 + 2MgO.SiO_2 + 3CaCO_3 + 3CO_2$.
Spinel. Forsterite. Calcite. Carbon dioxide.

The fact that neither periclase nor brucite is found in the normal marble points to the metamorphism having been conducted under such high-pressure conditions that the dolomite molecule was unable to part with any of its carbon dioxide, thus differing from the conditions under which the metamorphism of the Durness Limestone took place, as described by Dr. J. J. H. Teall [1] and Mr. A. Harker.[2] In the latter instance, the dolomite, where free from silica, was converted into an aggregate of calcite and brucite; but where silica, in the form of chert, was present, silicates of magnesia and lime, such as forsterite, diopside, and tremolite, were formed. In the marble of Port Shepstone, on the other hand, the normal dolomite crystallized without decomposition, while the formation of silicates of magnesia, lime, and alumina was restricted to areas in which a considerable amount of foreign material was present. This foreign material consisted, in many cases, of the granite and other blocks above

[1] Geol. Mag. 1903, p. 513; see also 'The Geological Structure of the North-West Highlands of Scotland' Mem. Geol. Surv. 1907, p. 453.
[2] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 144.

described; in others, the position and arrangement of the newly-formed silicates appear to indicate the original presence of layers of impurities along bedding-planes, which have been disturbed and contorted by earth-movements prior to the thermal metamorphism by the granite.

To conclude: in the Port Shepstone rocks we have a well-marked instance of dedolomitization, in essential features similar to those described by other authors, but differing in its determining factors. So far as we are aware, in no previously described case was the introduction of new material derived from included boulders.

We have to express our indebtedness to Mr. W. Campbell Smith, of Corpus Christi College, Cambridge, and to Mr. T. Crook, for careful work carried out by them on some of the isolated minerals in the laboratories of the Mineralogical Museum at Cambridge and of the Imperial Institute respectively.

EXPLANATION OF PLATE XXXV.

[All the figures, except fig. 6, are magnified 20 diameters.]

Fig. 1. Olivine-spinel band in the 'dark-mica zone.' O=Olivine; S=Spinel; and C=Calcite. Ordinary light.

2. 'Light-mica zone.' F=Forsterite; M=Phlogopite; and C=Calcite; Ordinary light.

3. Ophicalcite zone. Serpentine (light part) and calcite (dark part). Ordinary light.

4. The same slice as the preceding, between crossed nicols.

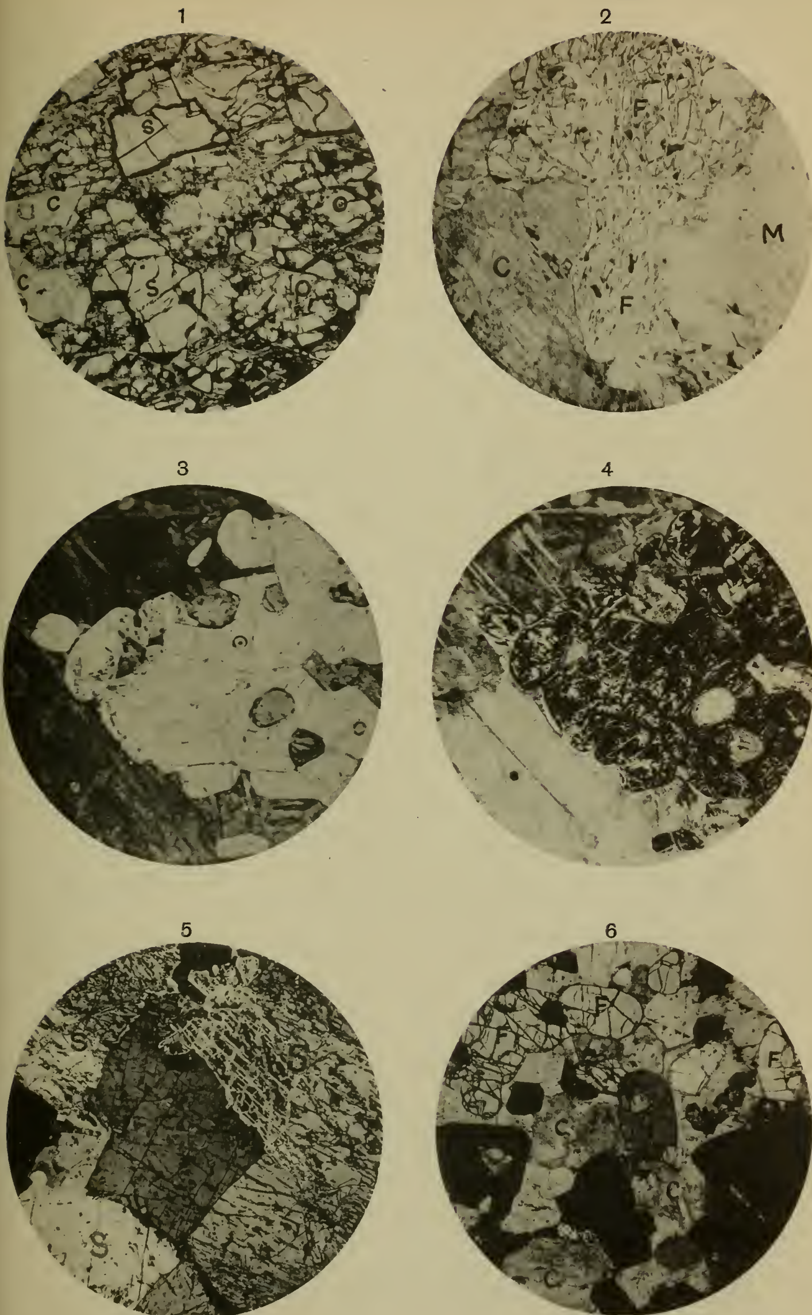
5. Reaction-rim of felspar-rock. S=Scapolite in transverse and longitudinal sections. Between crossed nicols.

6. Spinel-forsterite rock. Spinel (black); F=Forsterite; and C=Calcite. Between crossed nicols. Magnified 15 diameters.

Discussion.

Prof. Sollas remarked on the extreme interest of the mineral changes described by the Authors, but found a difficulty in understanding how these changes had been brought about. He had imagined that the word inclusion must have been substituted by an oversight for intrusion, but evidently this was not the case. The assumed transference of silicon dioxide and alumina from the granite to the dolomite required further explanation: it could hardly be supposed that these substances migrated in the free state. Something also in the nature of an exchange was to be expected, affecting the mineral composition of the granite, and giving rise to basic felspars; yet the Authors had observed, evidently not without surprise, that the characteristic felspar was not anorthite but oligoclase.

Dr. H. J. Johnston-Lavis wished to know whether the granite inclusion also showed zoning from chemical interaction with its calcareo-magnesian matrix. The speaker had always maintained the mutual interaction between two such rocks, which in fact



R. H. R., *Photogr.* Bemrose Ltd., *Collo.*, *Derby.*

REACTION-RIMS OF INCLUSIONS IN DOLOMITE OF PORT SHEPSTONE.

constituted his osmotic theory of metamorphism. He was surprised that the Authors gave no account of the contacts of the dolomitic limestone and the great mass of granite. He combated the idea that this granite block was a sedimentary erratic in the ancient limestone. It might be in rare cases, but he had often seen evidence of such dolomitic limestones having been fused and injected; and as a dyke of igneous rock could detach and carry on pieces of its wall, this could do likewise. In fact, it was only in such a way that the eozoonal masses of Canada and Monte Somma could be explained.

The speaker likewise believed that the smaller inclusions were originally the same rock, but altered by paramorphism. At Monte Somma one could trace a piece of leucitite through a series of ultrabasic rock right on to masses or cavities lined with meionite, anorthite, and perhaps a little pyroxene.

He also enquired what was the insoluble residue of the dolomite analysis, which he thought of great importance.

Dr. J. W. Evans believed that the presence of the blocks of soda-granite might be accounted for by the breaking-up of an intrusive mass into lenticles by earth-movements and the removal of all traces of these disturbances from the limestone by its recrystallization. He also spoke of the power, which crystalline limestone possessed, of accommodating itself to pressure like a fluid, as a result of movements along the gliding-planes of individual grains.

Mr. T. Crook remarked that the fundamental cause of dedolomitization was to be found in the fact that magnesium carbonate had a much lower dissociation-temperature than calcium carbonate. It was for this reason that magnesia took precedence over lime in the reactions which accompanied the thermal metamorphism of dolomite. It was noteworthy that the secondary minerals of contact-metamorphosed dolomites were usually rich in magnesia, lime often taking no vital part in the reaction; as, for example, spinel, the olivine-group, and phlogopite. Presumably, these secondary minerals could form at a lower temperature than those requiring the interaction of lime.

Perhaps the most novel and interesting feature of the paper was the Authors' contention that the absence of garnet and cordierite proved high-temperature metamorphism in this particular case. The speaker was unable to agree with this conclusion, which seemed to him quite untenable. The garnets of metamorphic limestone belonged to the lime–alumina–iron-oxide group, and were typically void of magnesia. Therefore they could not be expected to form under conditions of metamorphism in which the reaction of magnesia preceded that of lime. Similar reasoning applied to cordierite, which was comparatively poor in magnesia. The facts of paragenesis led to the same conclusion.

Dr. Hatch, in replying for the Authors, said that the main facts were indisputable, namely: blocks of granite in the dolomite were surrounded by rings of silicates and other minerals, which were formed at the expense of the dolomite and confined to the immediate vicinity of the blocks, although the dolomite everywhere else was converted to a coarsely crystalline marble under the influence of a later granite invasion—and, however novel the Authors' interpretation might be, it was the simplest explanation of the facts. Dr. Evans's view that the granite fragments had been formed by the breaking-up of an intrusive vein in the dolomite during earth-movements, all trace of which had been obliterated by a later metamorphism, was ingenious and possibly correct. Even if correct, it would still have to be admitted that chemical interaction had taken place between the fragments of the earlier granite and the dolomite, under the influence of the intense metamorphism of the later granite-invasion, since each fragment was completely surrounded by a reaction-rim. The speaker further drew attention to the fact that the two granites belonged to distinctly different petrographical provinces.

In reply to a question put by Dr. Johnston-Lavis, he said that the interior of the granite blocks showed no zonal arrangements of minerals. Mr. Crook's criticism of the high-temperature question was more relevant, and would be considered by the Authors; but it was immaterial to the main issue whether the metamorphism of the dolomite took place at a high, or at a low, temperature.

22. *On the* Evolution *of* Zaphrentis delanouei *in* Lower Carboniferous Times.[1] By Robert George Carruthers, F.G.S. (Read April 27th, 1910.)

[Plates XXXVI & XXXVII.]

Contents.

I. Introduction.

An attempt is made, in the following communication, to demonstrate the evolution of a small Zaphrentid coral, belonging to a gens[2] of common occurrence in the Lower Carboniferous rocks of Scotland.

The simple rugose corals seem to have been strangely neglected by workers on phylogenetic problems. Although suggestions as to the lines of evolution of certain species have been advanced from time to time, no direct proofs have, apparently, been forthcoming.

Yet, in some respects, few of the Invertebrata are so well adapted for investigations of this nature. In most of these corals, all the growth-stages of the skeleton are retained intact, and can be studied by means of serial sections cut across the corallum. The one serious difficulty arises from the remarkably sporadic distribution of such fossils or, indeed, of the Rugosa in general—a fact only realized to the full after one has engaged in the systematic examination of a wide area, in search of some particular gens. As a matter of fact, the corals here dealt with are the only ones that range through most of the Lower Carboniferous rocks of Scotland. Even then, they are found on horizons often somewhat widely separated in time and unproductive for long distances. Fortunately, the stratigraphy of the Scottish rocks is so well known, that collections can be made all over the country, from horizons the position of which in the sequence is fixed more or less definitely. Although, therefore, section after section of some particular limestone may be searched in vain, the same bed can often

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

[2] This useful term was originated by Dr. A. Vaughan, and defined by him as follows:—'A gens or species-group may be considered to be the aggregate of all the species which possess, in common, a large number of essential properties, and are continuously related either in space or time' (Quart. Journ. Geol. Soc. vol. lxi, 1905, p. 183).

be identified elsewhere, and may then yield a large number of specimens. Accordingly, by spreading the investigation over a wide area, a considerable amount of data has been got together. In the end, the evolution of the gens has proved to be so slow and gradual, that the separation of the various fossiliferous horizons by considerable vertical intervals of barren strata has offered no material check to the completion of the chain of evidence.

II. Sequence of the Strata.

It is as well to preface an account of the palæontological results by briefly noting the general stratigraphical succession (see general section, fig. 1, Pl. XXXVI).

The Lower Carboniferous rocks of Scotland, when fully developed, show a conformable passage from the Upper Old Red Sandstone. The lower two-thirds of the whole sequence is occupied by Calciferous Sandstone strata, composed of a Cementstone Group, succeeded, in the East of Scotland, by the Oil-Shale Group, or, along the English Border, by the Fells Sandstone, and the Lawston coals and limestones. Throughout the Central Valley corals are absent in this great Calciferous Sandstone Series, excepting in the uppermost beds. Near the Border, however, the Cementstones become more distinctly marine, and not infrequently contain brachiopods, polyzoa, etc., and occasionally small corals. The Lawston Limestones[1] are thoroughly marine, although the variety of species or genera which they yield is not great.

Above the Calciferous Sandstone comes the Carboniferous Limestone Series, divided into (1) the Lower Limestone Group, (2) the Coal & Ironstone Group, and (3) the Upper Limestone Group. The limestones in (1) and (3) occur in thin beds, separated by sandstones and shales, and most of them are of purely marine origin, with abundant fossils. Marine bands are extremely rare in the intervening Coal & Ironstone Group (2).

This tripartite division of the Carboniferous Limestone Series holds good throughout the country. The presence of a group of workable coals between the two Limestone Groups is of incalculable value to the stratigrapher, for it has given rise to extensive mineral prospecting, by means of which individual beds of limestone can frequently be traced for scores of miles. So much attention has been paid to the Series in the Central Valley of Scotland, that in this part of the country the horizon of any fossil locality can usually be given within narrow limits.

The upper limit of the whole succession may be said to be reached at the abrupt break in the Carboniferous flora, which has been shown by Dr. Kidston to take place about one-third of the way up in the Millstone Grit (Roslin Sandstone of the East of Scotland).

[1] By this term are indicated the two limestones, separated by a group of thin coals, which appear in Liddesdale above the Fells Sandstone; the upper bed is known as the Lawston Linn Limestone.

III. Palæontology.

General Remarks.

The gens of *Zaphrentis delanouei* is marked by several characters that remain unchanged (except in the case of *Z. lawstonensis*) throughout Lower Carboniferous times. These peculiarities lend an unmistakable aspect to members of the group; they may be tabulated as follows:—

(1) Average size and shape.
(2) An epitheca with clearly marked longitudinal ribbing.
(3) Situation of the cardinal fossula on the concave side of the corallum.
(4) Spacing and character of the tabulæ, which are arched upwards and strongly depressed into the fossula.
(5) Stout septa, thickened at the inner end.
(6) Curvature of the septa convex to the cardinal fossula.

In my experience, immature members of the gens of *Zaphrentis enniskilleni* are the only forms which could be confused with the *delanouei* gens. In the former case, however, the septa, as seen in transverse sections, are usually thin, and are not thickened at the inner end; they do not exhibit a general curvature convex to the fossula; and the fossula itself is wide and irregular in outline.

The evolutionary changes that arise are confined to the shape of the cardinal fossula and the length of the major septa; in these respects there are striking differences between typical members of the mutations.[1] There is a tendency for these corals to become cylindrical in their late growth-stages. In this cylindrical part, all the mutations, in common with most Carboniferous Zaphrentids, usually develop short and amplexoid septa.[2]

A possible explanation of this fact may be sought in the common occurrence of such fossils in soft calcareous shales. It may be conceived that during growth the increasing weight of the polyp and its skeleton would sink the whole organism continuously farther into the mud. A necessity was thereby occasioned for some mode of growth which would raise the animal rapidly above the invading sediment; the cylindrical habit was therefore assumed. In this condition growth in an upward direction would be relatively much more rapid than when lateral expansion was taking place. Consequently the septa might be unable to develop fully before the formation of the tabulæ intervened and stopped the further increase.

The change does not seem to have ontogenetic significance, and compels a restriction of observation to the conical part of the corallum.

Evolutionary Stages observed.

The earliest record of the gens in Scotland is in the Cementstone Group of Liddesdale, where the predominant form is *Zaphrentis delanouei*; transverse sections of this species show septa meeting in

[1] Throughout this paper, unless otherwise stated, the word mutation is used in Waagen's sense, and not in that of De Vries.

[2] By this term are meant septa which are only fully developed on the upper surface of the tabulæ, and above that position retreat rapidly towards the wall.

the centre of the corallum, and a large cardinal fossula expanded towards the inner end[1] (Pl. XXXVII, figs. 3*a*–3*c*).

The lowest horizon from which specimens have been obtained is the thin bed of limestone exposed at the fork in the stream below Hartsgarth Farm, New Castleton. This limestone lies about the middle of the Group, and only yielded a single specimen.

After a prolonged search by Mr. Macconochie, of the Geological Survey of Scotland, certain beds in the neighbourhood of Larriston, Staneshiel, and Thorlieshope were discovered, from which a considerable number of determinable specimens (108 in all) were obtained. These beds lie towards the top of the Group, 300 or 400 feet below the base of the Fells Sandstone.

About two-thirds of the assemblage here found can be referred to *Zaphrentis delanouei sensu stricto*, but the remainder are of a slightly different type. In their neanic (or adolescent) stage these latter forms agree with *Z. delanouei*, the fossula being large and expanded inwardly (Pl. XXXVII, fig. 4 *d*). As the ephebic (or adult) state is attained, however, the walls of the fossula become parallel (Pl. XXXVII, figs. 4 *b* & 4 *c*) and finally show a tendency to constriction at the inner end (Pl. XXXVII, fig. 4 *a*).

Had these modifications of the original *delanouei* type of fossula been observed only in a few isolated cases, they might be considered as abnormalities, of no special significance from an evolutionary point of view. But, as they have been noticed in a very considerable number of instances, and, further, recur in the early ontogeny of members of the gens found at higher horizons, they evidently belong to a true mutational form, marking an advance on the parent stock. This mutation may be called *Zaphrentis parallela*, in allusion to the characteristic fossular outline.

In Liddesdale, the next coral-bearing horizon above the Cementstones is the Lawston Linn Limestone, which lies some hundreds of feet above the Fells Sandstone. The limestone overlies a group of thin coals, and is equivalent to either the Dun or the Woodend Limestones of Northumberland, which come above the Scremerston Coals. From the Lawston Linn horizon a large number of small corals have been collected. They are so small and irregular in shape, that it is questionable whether any great reliance can be placed on the disposition of the septa (which are usually very thin). The cardinal fossula is often parallel-sided throughout growth, although in many cases there is a marked constriction of the inner end (Pl. XXXVII, fig. 10 *b*). The reference of these forms to the *delanouei* gens is by no means a matter of absolute certainty. Pending a discussion of this question, all that need be stated here is that they are assigned to that gens with some hesitation, and regarded as a side branch from the direct line of evolution. The name proposed for them is *Zaphrentis lawstonensis*.

[1] A full description of the species is given in Geol. Mag. dec. 5, vol. v (1908) pp. 63 *et seqq.* & pl. v, figs. 5–7.

After a considerable vertical interval, the gens undoubtedly reappears in the Lower Limestone Group (Carboniferous Limestone Series), and in that position can be found all over Southern Scotland, developed in a highly characteristic manner.

Since the Lower Limestones lie some 2000 feet above the coral-bearing beds of the Liddesdale Cementstones, it is in accordance with expectation that in the Group as a whole there is but a very small percentage of adult forms belonging to the parent species, *Zaphrentis delanouei.* The *parallela* mutation, also, has fared little better. A new mutation, the presence of which is foreshadowed in the Cementstone assemblages, now becomes predominant, and in its ontogeny presents features of considerable interest.

Serial sections of a typical representative of this new mutation show that, in the neanic stage, the fossula retains little or no trace of the typical *delanouei* character. But the parallel-sided, though still relatively wide, outline, found in adults of *Zaphrentis parallela*, is clearly visible (Pl. XXXVII, fig. 5 *d*). As growth proceeds, the inner end of the fossula narrows (Pl. XXXVII, figs. 5 *b* & 5 *c*); and in sections across the ephebic region the constriction becomes pronounced (Pl. XXXVII, fig. 5 *a*): the septa are still joined together in the centre of the corallum. On account of the fossular character, this mutation may be termed *Zaphrentis constricta.*

Although within the Lower Limestone Group *Z. constricta* is almost invariably the predominant member of the gens, forms representing a further advance in evolution are also present in some force. These new forms, as a rule, do not pass through a *parallela* stage in neanic life, but develop instead the *constricta* type of fossula (Pl. XXXVII, figs. 6 *e* & 7 *e*). On further growth the septa shorten, until in ephebic life they become amplexoid in character, and separate at the centre of the corallum (Pl. XXXVII, figs. 6 *a*, 7 *a*, & 7 *b*). The amplexoid septa lend a very distinctive appearance to this mutation, which may accordingly be termed *Zaphrentis disjuncta.*

It is worthy of note that the less advanced forms of *Z. disjuncta* frequently present, in their fossular character, a great resemblance to *Z. parallela* (Pl. XXXVII, figs. 6 *b* & 6 *c*), due to the shortening of the septa in the cardinal quadrant being insufficient to cause a separation of their inner ends. No confusion with the older mutation need arise, if the striking difference between the neanic stages of the two forms be considered (compare Pl. XXXVII, figs. 6 *e* & 4 *d*).

Passing on to the Upper Limestone Group, it is found that *Zaphrentis delanouei* is now altogether absent, *Z. parallela* extremely rare, and that *Z. constricta,* although by no means uncommon, is quite subordinate to *Z. disjuncta*, which becomes easily the dominant form. Many specimens of the last-named species, especially in the upper part of the Group, present a further advance in type, the septa becoming amplexoid even in the neanic stage (Pl. XXXVII, fig. 8 *c*) and being extremely so in the ephebic period (Pl. XXXVII, figs. 8 *a* & 8 *b*). When the gens is last seen, not far above the base of the Millstone Grit, these advanced types of *Z. disjuncta* are abundant, but no further change in ontogeny can be recorded. In the Millstone Grit forms there is an absence of spines or other characters usually taken to indicate phylogenetic old age. Unless such a state be indicated by the rudimentary condition of the septa, the extinction of the gens at this position (above which no corals of any kind are recorded in Scotland) must be ascribed solely to the incoming of unfavourable physical conditions.

General Conclusions.

Reviewing the evolution as a whole, one is struck by the prevalence of tachygenesis. It rarely happens that the ancestral traits seen in the neanic stage go back farther than the immediately preceding form. Indeed, in a few cases, the adult fossular character may be assumed in the neanic stage, and persist unchanged to the close of the ephebic period. 'Skipping of stages'[1] is remarkably rare.

The development of amplexoid septa in *Z. disjuncta* may indicate catagenesis (or simplification of characters). It is, of course, impossible to ascertain the raison d'être of the progressive changes observed, since the soft parts of the animal are missing. In cutting sections, however, it is noticed that there is a very appreciable gain in structural strength when the *constricta* type of fossula is assumed. One learns by painful experience how the large open fossula of *Zaphrentis delanouei* weakens the corallum.

Little can be said yet regarding the line of descent of *Z. delanouei* itself. Among the earliest specimens of that species (for instance, those from Hartsgarth in Liddesdale, and from horizon β in the Avon Gorge) the neanic cardinal fossula is sometimes constricted at the inner end. It is possible, therefore, that the Devonian ancestor of the gens was of the *constricta* type, and that the fossula of the Viséan *Z. constricta* illustrates the return of an old character.[2]

Determination of Specimens.

The difference between these mutations is obviously not great, and, as a matter of fact, so intimate is their relationship, that any considerable assemblage will always contain a number of forms the classification of which is no easy matter. In these cases the problem

[1] Recently termed saltative palingenesis by S. S. Buckman, in his 'Yorkshire Type Ammonites' pt. i (1909) Introduction, p. vii.

[2] A Devonian ancestor of the gens may perhaps be found in *Zaphrentis guillieri*, Barrois ('Recherches sur les Terrains Anciens des Asturies & de la Galice' Mém. Soc. Géol. Nord, vol. ii, No. 1, 1882, p. 197 & pl. vii, fig. 3), which has many characters of the gens, and in which the cardinal fossula is decidedly constricted; I have not yet been able, however, to examine specimens of this interesting species.

of specific delimitation, only too familiar to every palæontologist, is presented in an acute form. Some way out of the difficulty must necessarily be devised if there is to be any attempt at dealing with questions of stratigraphical distribution. Accordingly, in the preparation of the fossil list (§ VII, p. 535) certain arbitrary distinctions have been drawn between the various mutations.

Attention has been paid solely to cross-sections cut below the floor of the calyx and in the conical part of the corallum. Taking size to be a test of age (although it can only be a rough one at best), the critical section has been about 7 mm. in diameter, unless the septal characters are so pronounced that reliance can be placed on sections of smaller type (as, for instance, in *Z. disjuncta*).

In very many cases sections across the neanic region have also been made; this has been done wherever the adult characters admitted of a double interpretation (as in the resemblance between *Z. parallela* and the early, or pseudo-*parallela*, forms of *Z. disjuncta*).

The nomenclatorial difficulty is greatest in the case of *Z. disjuncta*, owing to the amplexoid septa developed in this species. If the section happens to coincide with a tabula (that is, if it is a 'tabular section'), some, or all, of the septa may be long, and joined together in the centre of the section by the rising of the floor of the tabula into the plane of section. These tabular sections, therefore, may present the septal disposition of *Z. constricta*; in such cases the question as to which species the specimen should be assigned has to be decided by grinding down the section, in order to pass below the floor of the tabula. When this is done, it can be seen at once whether the septa are, or are not, of an amplexoid type, since in the former case the septa are shortest immediately underneath the tabulæ. As a matter of fact, *Z. disjuncta* is frequently identifiable even in tabular sections, the adult septa of this mutation being usually thinner and more irregular than in *Z. constricta.*

Stratigraphical Distribution of the Mutations.

A list is appended to this paper giving the mutational assemblages met with in various parts of Scotland (§ VII, p. 535). Most of the Lower Carboniferous areas are represented, the fossil localities having been distributed as widely as possible. The latter are grouped together in districts, in each of which percentages are calculated for both Upper and Lower Limestone Groups, wherever the number of specimens is sufficiently great to yield approximately accurate results. The exact horizon is added in each case where the position within the local stratigraphical sequence is known.

Sufficient material has been collected from the Carboniferous Limestone Series to justify an analysis of the assemblages found therein, and to notice very briefly the relationships of these assemblages to the stratigraphical lines. Before taking up this matter, the general sequence of strata in the two Limestone Groups may be briefly outlined, the leading datum-lines among the limestones being pointed out. No reference will be made to the Liddesdale development of the Carboniferous Limestone Series, the material collected therefrom being quite insignificant in amount, although it is satisfactory as far as it goes.

IV. General Succession in the Carboniferous Limestone Series (Central Valley of Scotland).

Upper Limestone Group.—The strata are largely arenaceous, the whole thickness varying from 500 to 900 feet (Ayrshire excepted). Four to five seams of limestone, or calcareous shale, are found, dividing the sequence into approximately equal parts (see Pl. XXXVI, fig. 1). These limestones are, in descending order:—

(4) Castlecary Limestone.
(3) Calmy Limestone.
(2) Extra Limestone.
(In the West of Scotland two limestones are found hereabouts; the upper is known as the Orchard, and the lower as the Lyoncross Limestone.)
(1) Index Limestone.

The Calmy Limestone (3) can beyond doubt be traced throughout the Central Valley, from the west coast to the east; the other limestones can also be followed nearly as far. Our knowledge of the distribution of these beds is unusually good, on account of the innumerable bores put down to reach the coals below.

Quarry-sections are few, the limestones being, as a rule, of little economic value.

Lower Limestone Group.—The total thickness varies from 100 to 400 feet, the strata being, on the whole, argillaceous. In the western half of the Central Valley there are two marked limestone horizons, which define the upper and lower limits of the group. These are, in descending order:—

(2) Hosie Limestones (one to four seams, all close together).
(1) Hurlet Limestone and coal.

These two horizons can be followed throughout the West of Scotland, their outcrop round the west and south sides of the Lanarkshire Coal-Basin being traceable for upwards of 54 miles.

In the East of Scotland the seams have not yet been definitely recognized, owing to the abrupt change that takes place in the character of the limestones near Bathgate, in the heart of the Central Valley. Nevertheless, the general facies in the East of Scotland is similar to that in the West, the strata consisting largely of shaly material with several thin limestone-bands. On general stratigraphical grounds, it appears highly probable that the whole group was continuously deposited throughout the Central Valley. Any homotaxial difference between the eastern and the western facies must be comparatively slight, if, indeed, it exists at all.

Quarry-sections in the group are numerous, the limestones forming the chief source of supply from the Scottish Carboniferous rocks.

It will be noticed that both the Limestone Groups are of considerable thickness, but by far the greater part of the component strata consist of sandstones and shales, the deposition of which probably occupied no great interval of time.

A consideration of the assemblages from the Lower Limestone localities shows that the three East of Scotland districts (Dunbar, West Fife, and Midlothian) agree fairly well in their mutational percentages. They have about 1 per cent. of *Zaphrentis delanouei*, 4 to 6 per cent. of *Z. parallela*, about 78 per cent. of *Z. constricta*, and about 16 per cent. of *Z. disjuncta*.

In the middle of the Central Valley, in the Linlithgow district, there is a decided increase in the proportion of *Zaphrentis disjuncta*, which rises to 23 per cent. Going farther westwards (where all the localities are known to be from the Hurlet horizon) the whole assemblage is seen to become of a more advanced type. In the East Kilbride district *Zaphrentis delanouei* is unknown, there is only 2 per cent. of the *parallela* mutation, while the proportion of *Z. disjuncta* rises to 48 per cent., almost equalling that of *Z. constricta*.

Still farther west, in the North Ayrshire district, the *parallela* mutation entirely disappears, and for the first time the percentage of *Zaphrentis disjuncta* exceeds that of *Z. constricta*.

It is clear, therefore, that on considering assemblages from the Lower Limestone Group as a whole, the percentage of *Z. disjuncta* rises considerably in crossing the Central Valley from east to west (although the amount is always much smaller than in the Upper Limestone Group). There would seem to be three possible explanations of this fact, namely:—

(1) The western limestones may be of slightly later date than those in the east.
(2) The assumption of the *disjuncta* habit may have arisen, not so much from an inherent cause, as from some change in the physical environment (for instance, a shifting ocean-current) advancing slowly from west to east.
(3) The forms defined as *Zaphrentis disjuncta* may in reality belong to two branches, that prevalent in the west diverging from the original *constricta* stock more rapidly than the eastern form.

The question involved is of fundamental importance to the stratigrapher, as it deals with the relative value, as chronological indices, of lithological and evolutionary faunal lines.

Now, it is evident that a precise solution of this problem is to be obtained in one way only—by the examination of a large amount of material collected from a wide area (500 or 600 square miles at least) from a single fossiliferous horizon. The Scottish limestones undoubtedly offer a most promising field for such an enquiry, but the data are as yet insufficient. Nevertheless, the facts so far obtained are given, in the hope that they may serve as a basis for future work; in all probability, a close examination of such well-known datum-lines as the Hurlet and Calmy Limestones would eventually yield good results.

To summarize: the map (Pl. XXXVI, fig. 2) and fossil lists appended to this paper bring out the fact that assemblages from the two great Limestone Groups are everywhere separable on an evolutionary basis; while, for some reason or other, the proportion of *Zaphrentis disjuncta* increases within the Lower Group in crossing the Central Valley of Scotland from east to west.

The questions involved in this last fact are of great interest, but they do not affect the main thesis, that a gradual evolution of the whole gens occurred during Lower Carboniferous times.

V. Occurrence of the Gens in other Areas.

Zaphrentis delanouei seems to be common at Tournai, and also in the South-Western Province, where Dr. Vaughan has found that the species is an abundant and characteristic fossil in the Z_1 subzone. Above that position the gens seems to have been extinguished by unfavourable conditions.

Some half-dozen specimens which I collected from the Z_1 subzone at Burrington are all referable to *Z. delanouei sensu stricto*.

On account of the prevalence of the *parallela* mutation in the Upper Cementstones of Liddesdale, I should place the latter rather higher in the zonal sequence—perhaps in the C zone. The distance of the limestones from the base of the Carboniferous, as well as other lines of evidence that need not here be discussed in detail, lend some support to that opinion.

Z. constricta has been found by Prof. Garwood at the top of the massif (D_2?) in Westmorland. The species also appears to occur in Derbyshire, since it is represented by a syntype of M'Coy's species *Zaphrentis costata* (described as *Cyathaxonia costata* in 'Brit. Pal. Foss.' 1855, pl. iii c, fig. 2).[1]

Zaphrentis disjuncta is represented in internal casts from the Millstone Grit of Congleton Edge (Cheshire). These specimens are in the Geological Survey Collection at the Museum of Practical Geology, Jermyn Street, London.

Zaphrentis lawstonensis is found at Woodend Quarry (Northumberland) and at Biteabout, a mile and a quarter south-west of Lowick; and I have also obtained a single specimen from the Dun Limestone on the coast south of Berwick-on-Tweed. Both of these localities are close to the Lawston Linn Limestone in stratigraphical position.

Most of the specimens examined in this investigation have been personally collected in the field. A good number, however, were

[1] I am much indebted to the authorities of the Sedgwick Museum, Cambridge, for permission to cut this specimen, previously whole. In view of the latter fact, I have taken the other syntype, which showed the septal disposition characteristic of M'Coy's species, and was figured by him (*loc. supra cit.* fig. 2 *a*) for that purpose, as the holotype of *Z. costata*.

collected many years ago by the late Mr. James Bennie, of the Geological Survey of Scotland.

I am indebted to Mr. James Neilson for his kind permission to cut several specimens from Campsie and Orchard, in his well-known collection.

Dr. Horne has granted every possible facility during the progress of the work, and I owe him my sincere thanks for his continued encouragement. To other colleagues of mine I am indebted for much advice and assistance; while Mr. Macconochie's invaluable discovery of the Liddesdale *delanouei*-beds is deserving of especial mention.

VI. Specific Descriptions.

The parent species, *Zaphrentis delanouei*, has been fully described elsewhere (Geol. Mag. 1908, pp. 63 *et seqq.* & pl. v, figs. 5–7); but as the characters are preserved in a more or less modified form throughout the gens, a condensed diagnosis is appended as a basis for notes on the new species.

Zaphrentis delanouei, M.-Ed. & H. (Pl. XXXVII, figs. 3 *a*–3 *c*.)

(For synonymy, see Geol. Mag. *loc. supra cit.*)

Corallum conical or slightly curved. The epitheca has well-marked longitudinal ribbing.

The major septa are stout, thickened at the inner end, and have a characteristic curvature convex to the cardinal fossula, which is situated on the concave side of the corallum, and in transverse section is large and widely expanded at the inner end.

Minor septa quite rudimentary.

Average dimensions of adult: height = 2·5 cm.; diameter of calicinal rim = 1·3 cm.; number of major septa to above diameter of calyx, 27; depth of calyx = 1 cm.

Tabulæ 1 to 2 mm. apart, arched in the centre and strongly depressed into the cardinal fossula.

Zaphrentis parallela, sp. nov. (Pl. XXXVII, figs. 4 *a*–4 *d*.)

All characters as in *Z. delanouei*, except that, in transverse sections, the ephebic cardinal fossula is parallel-sided, or even slightly constricted towards the inner end; in the neanic stage the typical expanded *delanouei* outline is usually, but not necessarily, seen.

Zaphrentis lawstonensis, sp. nov. (Pl. XXXVII, figs. 9–10 *c*.)

Corallum small, of a more narrow cono-cylindrical form than other members of the gens, and often exhibiting strong concentric rugæ; wall usually very thick.

Average dimensions: height = 10 to 20 mm.; diameter = 4·5 mm.; depth of calyx = 5 mm.

Major septa usually very thin; the cardinal fossula is constricted at the inner end, although not to such an extent as in *Z. constricta* (see below, p. 534).

The species is included in the gens of *Zaphrentis delanouei*, since it possesses the following characters in common with all members of the gens :—

(1) Strong longitudinal ribbing on the epitheca.
(2) Cardinal fossula on the concave side of the corallum.
(3) Curvature of septa convex to the cardinal fossula.
(4) Tabulæ of the same nature and spacing as in other members of the gens.

Nevertheless, the septa are usually much thinner than in other members of the gens, and they are not markedly thickened at their inner ends.

The species is entirely unknown from higher beds. Neither can it be said that any of the higher mutations pass through a *lawstonensis* stage in neanic life, if the very thin septa usually found in the latter species be regarded as an essential character; but many specimens of the pre-existing form, *Z. parallela*, do develop very thin septa in their late ephebic stages.

All these facts, therefore, point to *Zaphrentis lawstonensis* as a short-lived side-branch from the direct line of evolution.

ZAPHRENTIS CONSTRICTA, sp. nov. (Pl. XXXVII, figs. 5 *a*–5 *d*.)

All characters as in *Z. delanouei*, except that in transverse sections the ephebic cardinal fossula is strongly constricted at the inner end; in neanic life the fossula is usually of the *parallela* type, although in a few cases, probably of advanced forms, the characteristic constricted outline is assumed at a very early stage.

It is possible that this species may be synonymous with Thomson's *Zaphrentis pachysepta* (see Proc. Phil. Soc. Glasgow, vol. xiii, 1881, pl. iv, fig. 9). I examined his type in the Kilmarnock Museum, but was unable, from the one section available, to satisfy myself as to its relation to *Z. constricta*. Since then practically the whole of Thomson's magnificent collection has been destroyed by fire—an irreparable loss to Scottish palæontology.

ZAPHRENTIS DISJUNCTA, sp. nov. (Pl. XXXVII, figs. 6 *a*–8 *d*.)

Zaphrentis cyathina, J. Thomson, Proc. Phil. Soc. Glasgow, vol. xiii (1881) pl. iv, figs. 16–16 *c*, & *ibid.* vol. xiv (1883) pl. vi, fig. 2.
Zaphrentis intermedia, J. Thomson, *ibid.* vol. xiii (1881) pl. iv, figs. 17 & 17 *a*, & *ibid.* vol. xiv (1883) pl. vi, fig. 1.

All characters as in *Z. delanouei*, with the following exceptions:—In transverse sections the neanic stage is of the *constricta* type, but in the ephebic stage the septa become amplexoid; in that condition, unless the section happens to pass over the floor of a tabula, the major septa are short and disconnected in the centre of the corallum. This separation of the septa may take place at varying periods, according to the evolutionary stage of the species (see Pl. XXXVII, series 6, 7, & 8), and is usually preceded by a relatively broad, parallel-sided fossula of the *parallela* type (Pl. XXXVII, figs. 6 *b* & 6 *c*).

VII. Locality List.

Ho = Hosie Limestones.
H = Hurlet Limestone.
C = Calmy Limestone.
E = Extra Limestone.
E¹ = Orchard Limestone.

District.	Number (see map, Pl. XXXVI, fig. 2) and description of locality.	Number collected.	*Zaphrentis delanouei.*	*Z. parallela.*	*Z. constricta.*	*Z. disjuncta.*
	(*e*) Millstone Grit.					
Glenboig	(40) Gain Qy., Glenboig, impure limestone	20	...	...	1	19
	(*d*) Upper Limestone Group.					
Midlothian	(30) Morrison's Haven, Prestonpans. Shaly limestone C	13	...	...	2	11
Mid-Fife	(31) Ravenscraig shore, shale over limestone. C	18	...	...	4	14
Linlithgow...	(32) R. Avon, 100 yards below Kinneil Mill, shale over limestone .... E	10	...	...	3	7
Carluke	(33) Middlehope Hill Qy., shale over limestone C	155	...	...	19	136
	Average percentage	...	...	...	12	88
East Kilbride...	(34) Limekilnburn Qy., shale over limestone. C	14	...	...	3	11
Shettleston......	(35) Hogganfield Loch, shale over limestone. C	7	...	...	1	6
Muirkirk.........	(36) Garpel Water, shale over limestone ...... E	23	...	...	4	19
Thornliebank	(37) Dubs Qy., shale over limestone C	32	...	...	5	27
	(38) Orchard Qy., shale over limestone ...... E¹	40	...	1	10	29
	Average percentage for district	...	...	1	21	78
Canonbie......	(5) R. Esk, 200 yds. below Gilnockie Bridge. Shaly limestone	3	...	...	...	3
	(*c*) Lower Limestone Group.					
Dunbar	(8) East Barns Qy., Dunbar, shale above Middle Skateraw Limestone .... H ?	138	2	5	106	25
	(9) Catcraig shore Qy., do. do. .... H ?	44	...	...	35	9
	(10) Skateraw, do. do. .... H ?	22	...	...	17	5
	(13) Burlage Qy., do. do....................... H ?	7	...	...	5	2
	Average percentage for district	...	1	3	77	19
Midlothian...	(11) Cousland Qy., Dalkeith, shale between limestones	23	...	1	18	4
	(12) Carlops Qy., shale over limestone	12	...	1	10	1
	Average percentage for district	...	...	6	80	14
West Fife ...	(14) Duloch Qy., shale over limestone	93	2	6	73	12
	(15) Lathalmond Qy., shale over limestone	19	...	...	16	3
	(16) Woodend Qy., shale over limestone	23	...	2	18	3
	Average percentage for district	...	2	6	79	13

Locality List (*continued*).

District.	Number (see map, Pl. XXXVI, fig. 2) and description of locality.	Number collected.	*Zaphrentis delanouei.*	*Z. parallela.*	*Z. constricta.*	*Z. disjuncta.*
	(*c*) Lower Limestone Group (*continued*).					
Linlithgow...	(17) Galabraes Qy., Bathgate, shale over limestone ... Ho ?	76	...	4	54	18
	(18) Silvermine Qy., do. do. ... Ho ?	20	...	...	15	5
	(19) North Mine Qy., do. do. ... Ho ?	18	1	2	12	3
	Average percentage for district	...	1	5	71	23
Campsie	(20) (*a*) South Hill, Campsie ... H	9	...	...	8	1
	(20) (*b*) Lennoxtown, shale over limestone. H	2	...	...	1	1
Carluke	(21) Auchenheath, shale over limestone...... H	6	...	...	4	2
East Kilbride	(22) Thorntonhall Qy., shale over limestone. H	34	...	1	17	16
	(23) Shiels Qy., shale over limestone ... H	9	...	...	4	5
	(24) Crosshouse Qy., shale over limestone ... H	22	...	...	12	10
	Average percentage for district	...	...	2	51	48
Muirkirk......	(25) Ashlawburn Qy., shale over Hawthorn Limestone ... H ?	2	...	...	2	...
North Ayrshire.	(26) Auchenskeith, shaly limestone, top bed. H	68	...	...	32	36
	(27) Beith, shale over top limestone ... H	12	...	...	5	7
	(28) Gameshill, shale over top limestone ... H	6	...	...	3	3
	(29) Auchenmade, shale over top limestone. H	11	...	...	4	7
	Average percentage for district	...	...	...	45	55
West Liddesdale.	(39) R. Liddel, 100 yards below Penton Bridge. Calcareous shale ...	3	...	...	3	...
	(*b*) Lawston Limestones.					
West Liddesdale.	(6) R. Liddel, at the bend a mile and a half below Kershopefoot (Lawston Linn Limestone)	30	All *Zaphrentis lawstonensis.*			
	(7) R. Esk, $\frac{1}{5}$ mile below Glencartholm ...	25				
	(*a*) Cementstone Group (Liddesdale).					
East Liddesdale.	(1) Limestone at junction of streams below Hartsgarth Farm ...	1	1	...	...	...
	(2) Top band of limestone, Larriston Qy. ...	63	44	19	...	...
	(3) Limestone in Staneshiel Burn, 300 yds. above main road ...	25	16	8	1	...
	(4) Thorlieshope Qy., shale between limestones.	21	15	6	...	...
	Average percentage for district	...	69	30	1	...
	Total ...	1179				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e Great Glen, showing the
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Fig. 1.

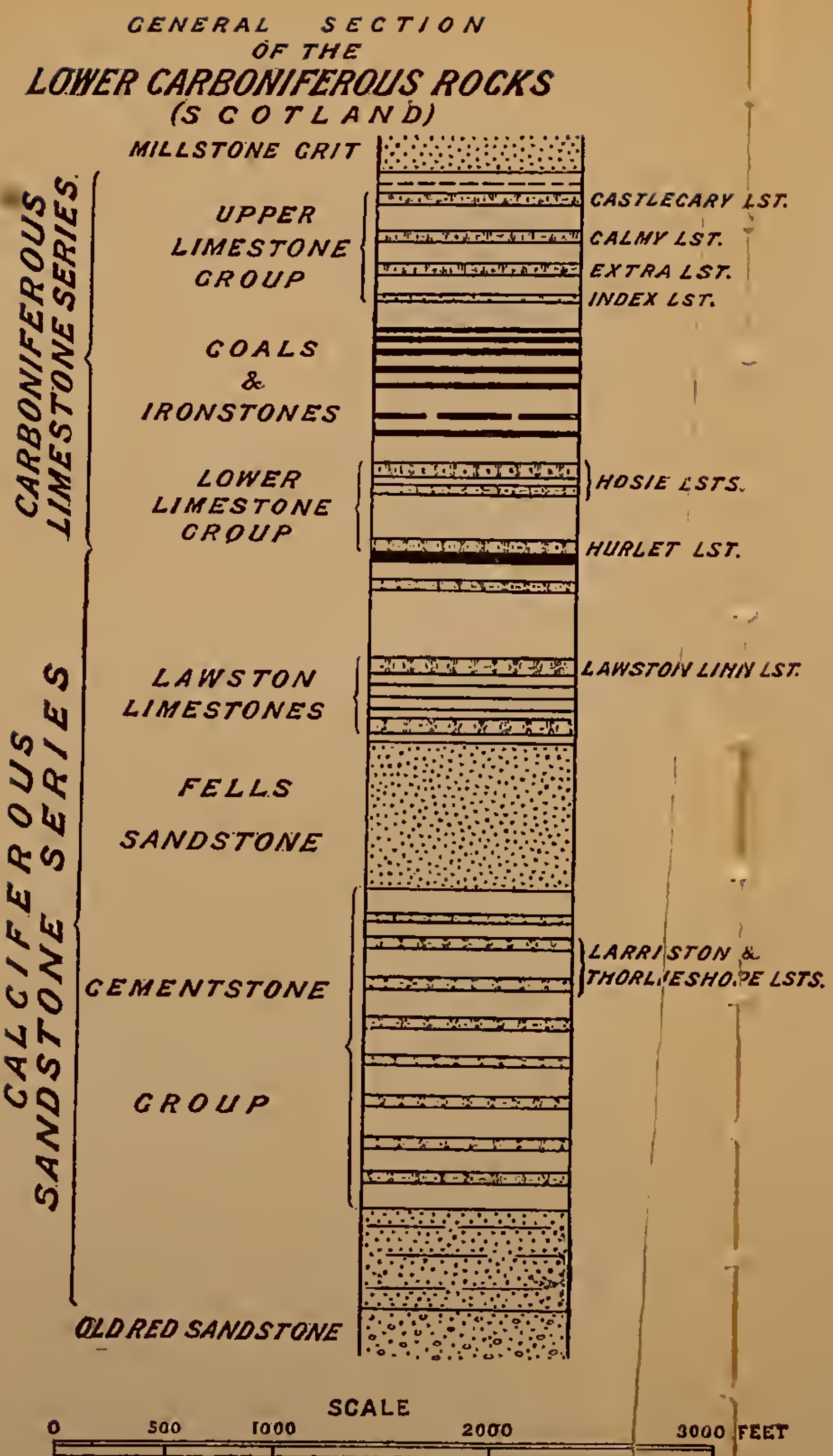
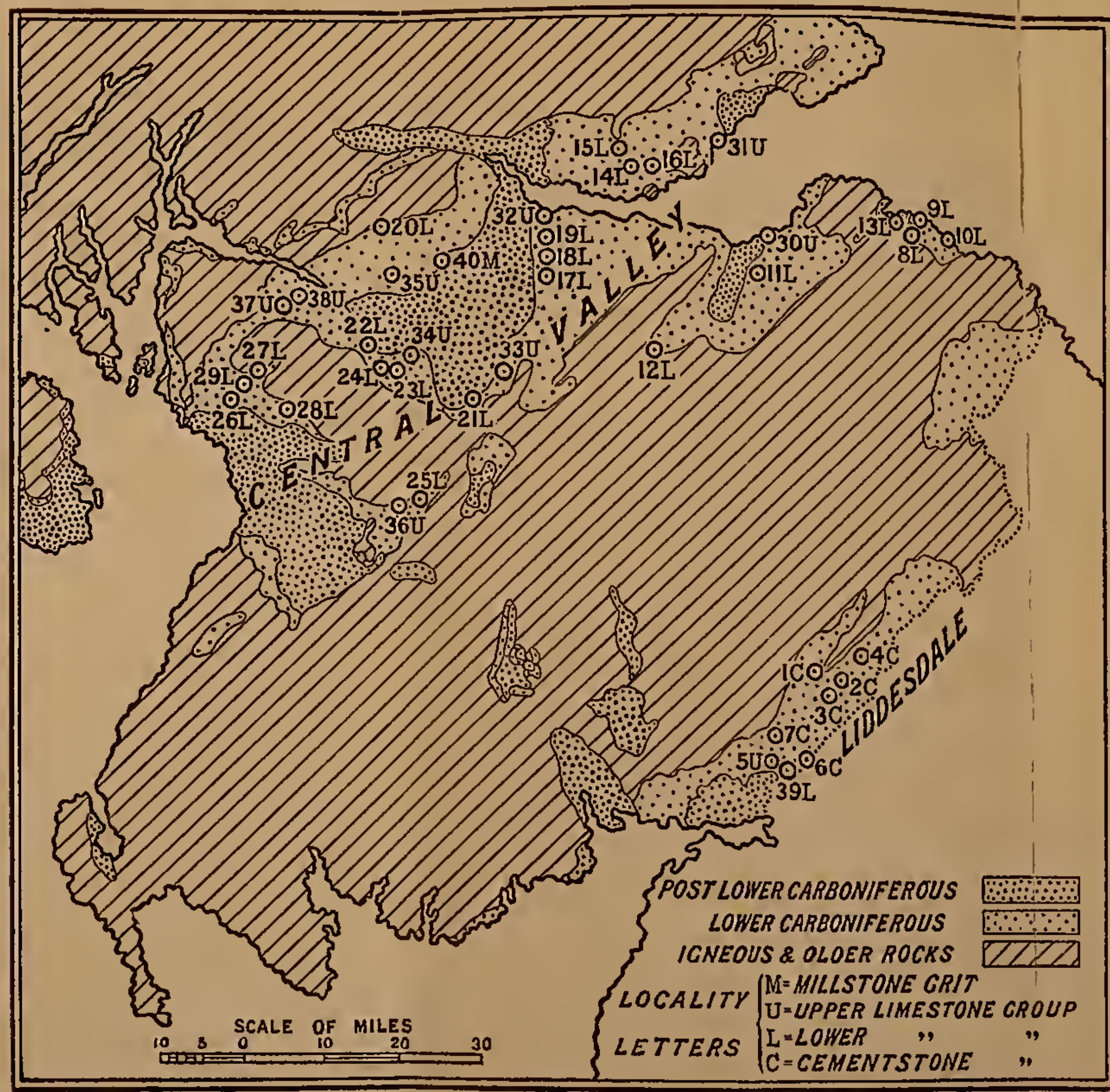
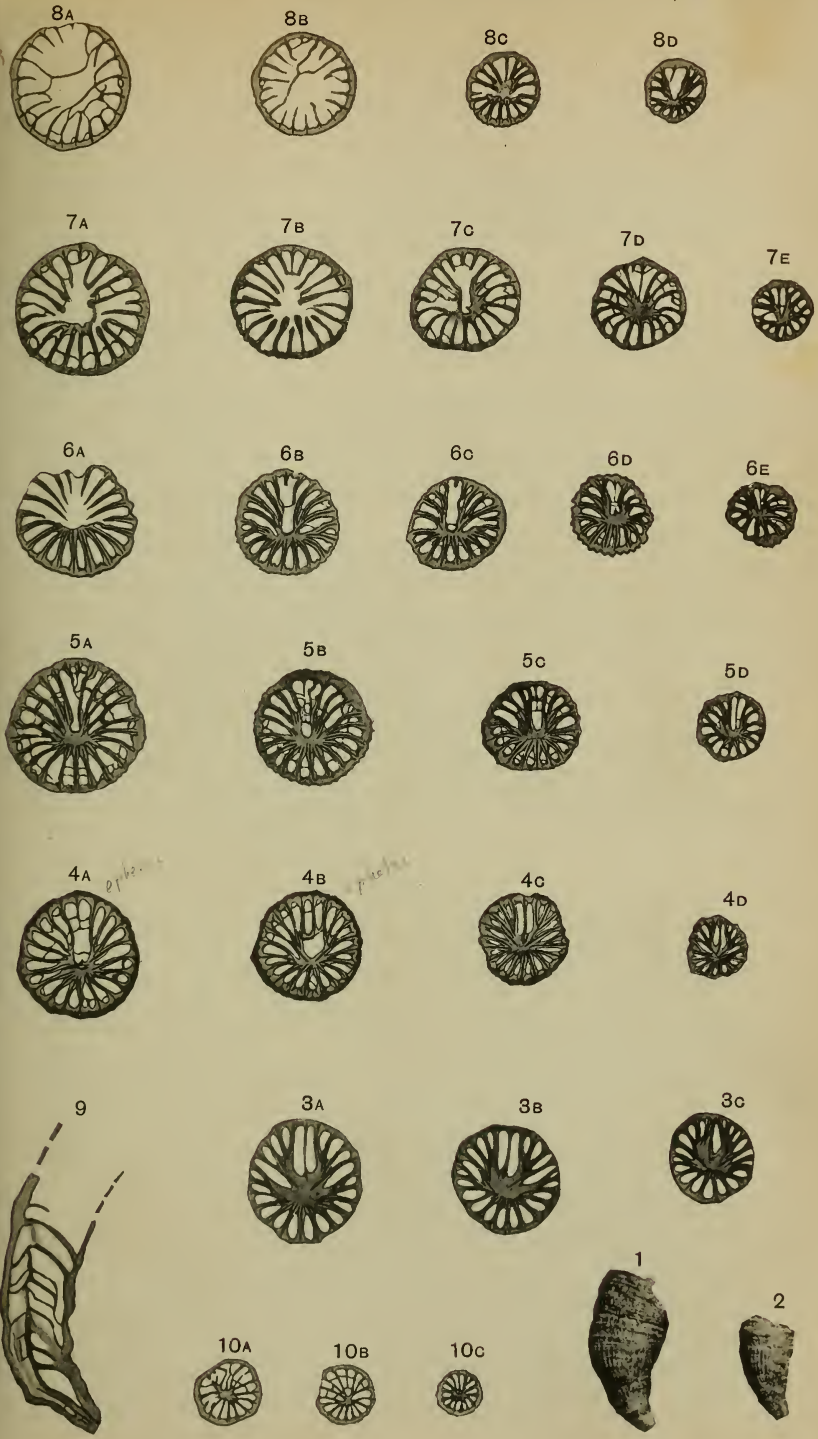


Fig. 2.—*Geological sketch-map of Scotland south of the Great Glen, showing the distribution of Carboniferous fossil localities.*





R. G. C., Photogr. *Bemrose Ltd., Collo., Derby.*

EVOLUTION OF ZAPHRENTIS DELANOUEI.

EXPLANATION OF PLATES XXXVI & XXXVII.

Plate XXXVI.

Fig. 1. General section of the Lower Carboniferous rocks of Scotland.
2. Geological sketch-map of Scotland south of the Great Glen, showing the distribution of Carboniferous fossil localities, on the approximate scale of 26 miles to the inch.

Plate XXXVII.

[All figures, except figs. 1 & 2, are from camera-lucida drawings, × 2·5 diameters. Figures with the same numeral represent serial sections from one corallum.]

Fig. 1. A typical member of the gens, showing the external characters. Auchenskeith Quarry, Ayrshire (Lower Limestones, Hurlet horizon). Natural size.
2. Another specimen. Middlehope Hill Quarry, Fauldhouse (Upper Limestones, Calmy horizon). Natural size.
Figs. 3 *a*–3 *c*. *Zaphrentis delanouei.* Thorlieshope Quarry, Liddesdale (Cementstone Group).
4 *a*–4 *d*. *Zaphrentis parallela*, sp. nov. Larriston Quarry, Liddesdale (Cementstone Group).
5 *a*–5 *d*. *Zaphrentis constricta*, sp. nov. Duloch Quarry, Dunfermline (Lower Limestones).
6 *a*–6 *e*. *Zaphrentis disjuncta*, sp. nov. Early form (pseudo-*parallela*). Crosshouse Quarry, East Kilbride (Lower Limestones, Hurlet horizon).
7 *a*–7 *e*. *Zaphrentis disjuncta*, sp. nov. Typical form. Orchard Quarry, Glasgow (Upper Limestones).
8 *a*–8 *d*. *Zaphrentis disjuncta*, sp. nov. Advanced form. Middlehope Hill Quarry, Fauldhouse (Upper Limestones, Calmy horizon).
Fig. 9. *Zaphrentis lawstonensis*, sp. nov. Vertical section. Lawston Linn Limestone, R. Liddel, a quarter of a mile below Kershopefoot.
Figs. 10 *a*–10 *c*. *Zaphrentis lawstonensis*, sp. nov. Lawston Linn Limestone. Same locality as above.

Discussion.

Dr. A. Vaughan heartily congratulated the Author upon the completion of an exceptionally fine piece of work, demanding the highest powers of observation, combined with the exercise of untiring patience. The variation in the gens of *Zaphrentis delanouei* might now be regarded as definitely known in the Lower Carboniferous of Scotland; in other parts of the British Isles, the facts, so far as they were yet known, were in agreement. It did not admit of question that the determination of a considerable number of such genetic series for the coral gentes of commonest occurrence in the Lower Carboniferous would form the base of an ideal time-scale or zonal series. The Author had shown that this ideal was attainable in a gens whose very simplicity of structure constituted its great difficulty; the more complex gentes would probably yield more readily to less effort.

The system of zoning at present in use was based upon such obvious characters as first establishment and dominance of certain species (pretending in no way to genetic relationship) and, ultimately, upon the identity or similarity of faunal assemblages. Such a system had admittedly the defects of its simplicity. It had been found to work satisfactorily for large zones, but the probable error of the method forbade small subdivisions.

A question of some theoretical interest, quite unessential however to the main issue of the paper, arose as to the nature of the variation concerned in the formation of the genetic series that the Author had established. The final demonstration of continuous variation as a function of time seemed to demand an unbroken sequence of identical deposits, containing, throughout, abundant representation of the gens under examination. These conditions were satisfied by the rocks in which Waagen and Dr. Rowe demonstrated continuity of variation, but the Scottish sequence could not be said to fulfil the same requirements.

Dr. F. A. Bather, considering the paper from the standpoint of a palæontologist rather than from that of a zonal stratigrapher, regarded it as important for the following reasons:—(1) It offered a clear example of the most gradual kind of mutation, as opposed to saltation; even the form from the Lawston Limestones, though called a 'sport' by the Author, seemed to have arisen quite gradually. Although there was no break between the extremes of the series, still the necessity of having names justified the Author in drawing arbitrary lines of division. (2) The assumption that the type dominant in a lower bed was nearer the ancestor than was the type dominant in a higher bed, an assumption hitherto supported mainly by *à priori* considerations, was greatly strengthened by the proof of this particular instance. (3) While comparable to Dr. A. W. Rowe's classic paper on *Micraster*, the present communication upset the metaphysical and (to the speaker) unintelligible conception of an 'horizonal influence.' Different stages of development co-existed at the same horizon in a single area, while the same stage came in at different horizons in separate areas. Physiological processes and needs doubtless produced changes of organization more or less adapted to a changing environment, and so originating new species through natural selection; but what either the internal or the external factors might be in the case of the Scottish *Zaphrentis*, they hoped to learn from the Author.

Mr. E. E. L. Dixon, in adding his congratulations to those of previous speakers and remarking on the great value of the Author's work to both the stratigraphist and the evolutionist, regretted, in connexion with an observation made by Dr. Bather, that in most rock-sequences the forms which were dominant at successive horizons were not genetically connected.

The Author, in reply to Dr. Vaughan, said that he considered that the employment of the word 'mutation' in the paper was certainly in accordance with Waagen's use of the term. He agreed with Dr. Bather as to the inadvisability of referring to the form from the Lawston Limestones as a 'sport,' if by that term individual abnormalities were implied. He regarded the species as a lateral branch of narrow vertical range, although having a considerable horizontal distribution. In conclusion, the Author expressed his gratitude to the Fellows present, and especially to those who had spoken in the discussion, for their cordial reception of the paper.

23. *On the* Carboniferous Limestone South *of the* Craven Fault (Grassington-Hellifield District).[1] By Albert Wilmore, B.Sc., F.G.S. (Read April 27th, 1910.)

[Plates XXXVIII–XLI—Corals.]

Contents.

I. Introduction.

South of the great Craven Fault is a district which may well be termed the Craven Lowlands. It lies between the limestone scars of Settle, Malham, and Grassington on the north and the grit hills of the Pendle Range on the south. The district thus defined may be held to include all that part of Craven which extends from Clitheroe to Skyreholme, and from the so-called 'middle branch' of the great fault-system, to the grit hills of Simon's Seat, Burnsall Fell, Flasby Fell, Carleton Moor, and westwards to Pendle.

The Carboniferous Limestone and Pendleside Beds, which occupy almost the whole of the district under consideration, are everywhere very much folded and faulted.

The greater part of the region is much obscured by drift. With the exception of a good section at Troller's Gill (which does not, however, show any considerable thickness of beds) there are no long continuous sections, and the geologist must remain perforce content with the numerous isolated exposures which are scattered over the whole district. Owing to the continually changing dips, it is not easy to make out the sequence of the beds.

This paper will be confined to a description of the Carboniferous Limestone, as it may be seen in the various exposures between Swinden Moor on the west and Skyreholme on the east. I have previously discussed other parts of the Craven Lowlands.[2]

The lithological character of the limestone varies considerably in different parts of the district, the most widely different types being the greyish-white, irregularly-bedded shelly limestone of Elbolton

[1] Thesis approved for the Degree of Doctor of Science in the University of London.

[2] Proc. Yorks. Geol. Soc. n. s. vol. xvi (1906–08) pt. i, pp. 27–44; *ibid.* pt. ii, pp. 158–70; and *ibid.* pt. iii, pp. 347–71.

and Swinden Quarry (Swinden, near Grassington) on the one hand, and the dark, evenly-bedded foraminiferal limestone of Swinden Gill on the other. Between these extremes there is a complete series of gradational types.

The greyish-white very fossiliferous limestone occurs in the knoll regions of Cracoe, Thorpe, and Linton (as also those of Clitheroe, Slaidburn, etc., outside the region here discussed); and it appears occasionally in other places, as, for example, at Fogger near Coniston Cold, at Crag Laithe near Bell Busk, and at Slack near Newsholme. The rock at Fogger is known as the 'white rock' by the quarrymen and roadmenders of the Coniston district.

I have been working at the limestone of the Craven Lowlands for several years, in the hope that some contribution may be made to our knowledge of the vertical and lateral distribution of the commoner fossils. It has seemed advisable that much patient and careful collecting should be done, in order that comparisons may be instituted between this complicated district and other Carboniferous Limestone districts in which the sequence can be readily determined.

Many of the fossils in our museums, and some of those figured in memoirs and monographs, have no very definite locality assigned to them, but are described as from Clitheroe, Bolland, or Craven, as the case may be. In any good zonal work it is manifestly necessary that the exact quarry or other exposure should be specified.

The area under discussion falls within the 1-inch Geological Survey map, Sheets 60 & 61 (southern part of the maps). It must, however, be pointed out that the deep blue and the lighter blue colouring have not been uniformly used by the officers of the Survey. In the neighbourhood of Grassington, the deep blue is used for the very fossiliferous grey limestone. In the Hetton and Winterburn district it represents dark blue flaggy limestone with *Caninia gigantea*, *Syringopora*, and other fossils which are found in the limestones of Coniston Cold and Swinden Moor. These latter limestones are coloured light blue. In the adjacent district dark limestones with abundant shales are coloured dark blue (see Thornton, Rain Hall, and Gisburn on the 1-inch map, Sheet 68).

The rock at or near the dip-mark 30° N. east of Owslin Barn is apparently of exactly the same type as the rock at the dip-mark 65° N. immediately north of Hetton village, but the colouring is different. So also the rock at Swinden Moor Head is in no way different from that of Swinden Gill Head and in other exposures in the 'rolling' ground near the Skipton-Hellifield Road: yet the former is coloured on the map deep blue, the latter light blue. The limestones of Warrel Quarry and Bell-Busk cutting are lithologically the same as the beds near Winterburn Chapel: yet, again, the Survey map-colouring is different, the beds at Winterburn Chapel being coloured dark blue, and those of Warrel and Bell-Busk cutting light blue.

In the present paper, as in my paper on Thornton, Marton, and Broughton district, I shall describe the various exposures, giving some account of the lithology of the beds, and specifying the fossils which I have found. So far as it may seem possible and desirable, I shall attempt to deduce the sequence of the beds, and so make some contribution to further exact zonal work which I or others may be able to carry out. I propose, moreover, to add some brief notes on the quantitative relationships of many of the commoner fossils, as also some notes on certain of the genera and species met with. Some new species or varieties will be described.

II. Description of the Chief Exposures.

(1) The Coniston Cold District.

Warrel Quarry.—Near Ingber House is an old quarry called Warrel Quarry (dip-mark 17° N., on the 1-inch Geological Survey map). It is about halfway between Bank Newton and Coniston Cold. Much of the cutting is now overgrown. The rock was evidently quarried for the walls of the pastures and meadows, and those walls that have been built in the immediate vicinity of the quarry show various stages in the weathering of the massive dark limestone. The rock is perfectly well bedded. Shales are quite subordinate. The limestone rock weathers to a brownish-yellow mud, in which small and fragmentary fossils may be seen.

The dip is about 15° to 18° almost due north; but, as in nearly all the exposures in the district, there is some variation. Some of the rock-surfaces show slickensiding.

There is an interesting breccia which may be studied in some of the fragments that have been long exposed on the floor of the disused quarry; but it may be better seen in some of the walls. It consists of a mixture of angular and rounded fragments of limestone held together by a calcareous mud. Fragments of *Caninia*, *Amplexus,* and of brachiopods may be seen among the irregular pieces.

Fossils are not very numerous. The talus of calcareous mud at the foot of one face of rock yields crinoid stems and plates, and small brachiopods, among which are *Rhipidomella michelini* and a small *Athyris*.

List of Fossils obtained.

Amplexus coralloides, J. Sow.
Caninia aff. *cornucopiæ*, Mich.
Caninia aff. *gigantea*, Mich.

Rhipidomella michelini (L'Éveillé).
Athyris sp.
Productus semireticulatus, Mart.
Productus humerosus, Sow.
Productus giganteus, Mart.
Productus scabriculus, Mart.
Chonetes papilionacea (Phill.).
Chonetes comoides (J. Sow.).
Orthotetes crenistria (Phill.).

Euomphalus sp.
Flemingia spiralis (De Koninck).

[See § III, p. 566, for notes on some of the corals.]

Fogger.—At Fogger, on the main road from Skipton to Hellifield, is a knoll-like mass of white or grey limestone. It is bisected by the road. This rock has all the characteristics of the knoll limestone of Cracoe and Thorpe. The upper beds are irregularly stratified, and it is not easy to make out the precise dip. This is often the case with the limestone of these knolls.

The rock is now being quarried close to the road, and in the small knoll on the east: it has also been quarried in the small knoll immediately to the west. It is clear that a considerable cutting was necessary in making the road.

The dip varies considerably in the different exposures. The officers of the Geological Survey marked dips of 10°, 15°, 17°, and 55° almost due north, and one southward dip. Dr. Wheelton Hind & Mr. J. A. Howe record a dip of 30° north-north-eastwards.[1] The beds have been considerably disturbed, and slickensided surfaces are seen. One newly exposed surface on the northern side of the hill shows very hummocky bedding, far too much so to permit of the amount of the dip being definitely ascertained: its direction is north-north-westerly. Brecciation is quite common, as well as slickensiding.

A fault is mapped on the 1-inch Geological Survey map, just at the northern end of the exposures.

The fossils are, generally, those of Swinden and Elbolton. They are not easy to extract, but occasionally one weathers out clearly.

List of Fossils obtained.

Amplexus coralloides, Sow. (Common.)
Caninia sp. (Indeterminable.)
Zaphrentis sp.

Productus fimbriatus, J. Sow.
Productus martini, Sow.
Productus humerosus, Sow.
Productus pustulosus, Phill. (Towards *scabriculus* in type.)
Spirifer bisulcatus, Sow.
Martinia glabra (Mart.).
Pugnax acuminata (Phill.).
Rhynchonella pugnus, Mart.

Gasteropods and cephalopods are seen, the cavities of the latter being filled with calcite. Specimens are difficult to extract.

Crinoidal débris is quite common; occasionally a 'cup' or a 'head' may be seen, but I have not been able to extract one.

I think that these beds are the same as those of Slack, near Newsholme, and the upper beds of Crag Laithe (to be described later). The lithological character of the limestone is absolutely the same, and the fossils are almost identical.

Quarry near Fogger.—There is a small quarry near the high road, a little west of the Fogger cutting. The strata are here well bedded, and dip north-north-westwards: not more than 20 feet of them are exposed. The strata are lithologically quite unlike the Fogger beds. There is crinoidal débris; but it is hard and splintery, and in parts is converted into chert. I regard these beds as intermediate between those of Warrel Quarry and Fogger Rock, both in lithology and in stratigraphical sequence. There can be little doubt that they are well up in D_2 at least.

[1] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 359.

List of Fossils obtained.

Caninia aff. *cornucopiæ*, Mich.
Caninia aff. *gigantea*, Mich.
Campophyllum caninoides, Sibly.
Cyathaxonia cornu, Mich.
Syringopora cf. *reticulata*, Goldf.
Michelinia aff. *megastoma* (Phill.).
Lophophyllum, sp. nov. (?).
Productus pustulosus, Phill. (One large weathered-out specimen obtained.)
Productus giganteus, Mart.
Spirifer bisulcatus, Sow.
Spirifer striatus, Fischer.
Rhipidomella michelini (L'Éveillé).

Swinden Gill Head Quarry.—This quarry lies a little south of the Blackburn & Hellifield Railway, near the head of the eastern branch of Swinden Gill. Here massive limestone dips north-north-westwards at an angle of 20°. Shale bands are somewhat more abundant than at Warrel; still they are quite subordinate. Chert is fairly common. Fossils are tolerably common, and there is plenty of loose rock lying in the cutting.

List of Fossils obtained.

Michelinia aff. *megastoma* (Phill.).
Syringopora cf. *reticulata*, Goldf.
Caninia gigantea, Mich.
Cyathaxonia sp.

Productus semireticulatus, Mart.
Productus martini, Sow.
Productus fimbriatus, J. Sow.
Productus giganteus, Mart.
Productus humerosus, Sow.
Chonetes papilionacea (Phill.).
Chonetes comoides (J. Sow.).
Orthotetes crenistria (Phill.).
Rhipidomella michelini (L'Éveillé).

Euomphalus sp., and other small gasteropods not yet determined.

Trilobites are occasionally seen.

NOTES.—*Syringopora* is not very common. *Caninia gigantea* is quite common. (It has been identified for me by Mr. R. G. Carruthers.)

Productus giganteus is the *Chonetes*-like form common at Warrel Quarry. *Chonetes papilionacea* has a characteristic purplish colour, which is also seen at Warrel and at other exposures that appear to be on nearly or quite the same horizon. *Orthotetes crenistria* is the most abundant brachiopod; it seems to be exactly like the Warrel form. *Rhipidomella michelini* is fairly common.

There are two other small cuttings close at hand, which show the same massive limestones, with approximately the same dip.

Across the small stream, and about 40 yards away, are three small exposures of shales, which Dr. Wheelton Hind unhesitatingly put down as Pendleside Shales.[1] The dip is still the same, and there is no indication of faulting. Accepting the dip as 20°, the thickness between the massive limestones and shales of the quarry and the shale beds will be about $120 \times \sin 20°$ (41 feet); consequently the limestones would seem to be nearly at the top of the 'massif.'

The shales contain *Cyathaxonia* sp. nov. and *Caninia cornucopiæ*, mut. nov. (*fide* R. G. Carruthers). Pygidia of *Phillipsia* sp. are common. Brachiopods are rare and dwarfed. I found fragments of a small *Orthoceras*.

The same shales, with the same general dip and strike, are seen in Swinden Gill, and they seem to be undoubted Pendleside Beds.[2]

[1] Dr. Wheelton Hind visited this quarry, in company with the author, in the spring of 1906.
[2] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 359.

There is no great thickness exposed, as the stream runs along the strike for the most part. Fossils are not numerous. I have obtained *Rhipidomella michelini* (L'Eveillé), *Strophomena analoga* (Phill.), *Posidonomya becheri*, *Orthoceras* sp., and a single coral, probably *Zaphrentis omaliusi*, M.-E. & H.

A quarry near the Gisburn-Hellifield Road shows the same massive limestone as at Swinden Gill Head, with a slightly higher dip. Hence there is little doubt about the general sequence.

Bell Busk Cutting.—There are two quarries close to the railway, immediately north-west of Bell Busk Station. In the eastern quarry are massive dark-grey limestones, almost black in places, with very little shale. The bedding is very definite, with some slightly hummocky surfaces. The dip is almost due north, at an angle of 10° to 12°. *Syringopora* cf. *reticulata* is exceedingly common. A small *reticulata* form, with very little tendency to irregular ramulose branching, occurs in masses ranging up to a foot in maximum diameter. The corallum starts from a somewhat elliptical or circular base, and grows into a sub-ovoid mass. It is noteworthy that some of the masses have the small end upwards and some are lying sideways. Did the masses float into the calcareous mud in which they now occur?

A ramulose *Syringopora* with wide tubes, somewhat like *S. gigantea*, Thomson, is apparently rare. *Michelinia* sp., with thin walls and with corallites 3 to 4 millimetres wide, occurs; but I have not succeeded in obtaining anything like a complete corallum. It appears, however, to agree with the description of *Michelinia tenuisepta* (Phillips), as given by Dr. Vaughan in the Loughshinny paper.[1] (It is noteworthy that his form is common in D_3.)

Near the top of this exposure *Caninia* aff. *gigantea*, Mich., is occasionally found, but it seems to be very rare. Brachiopods are scarce and fragmentary, *Orthotetes crenistria* and *Productus semireticulatus* being the only good specimens that I obtained.

Across the railway is the second exposure. Here the beds have approximately the same dip and are higher in the sequence. Shale beds are more abundant towards the top of the cutting. There is some disturbance shown, slickensided surfaces being plentiful and some rolling being seen. The fossils are:—

Caninia aff. *gigantea*, Mich. (Common.)
Zaphrentis sp. (Only one specimen.)
Syringopora cf. *reticulata* (Goldf.). (Not so common as in the other quarry.)
Orthotetes crenistria (Phill.). (Fragmentary.)
Athyris aff. *royssii* (L'Éveillé).

NOTE.—*Caninia gigantea*, specimens often crushed, as at Swinden Gill Head, at Hetton, and elsewhere.

The sequence of these beds is interesting when compared with those of other exposures, such as Warrel and Swinden Gill, already described, and Crag Laithe, Winterburn, and Hetton, to be described.

[1] Quart. Journ. Geol. Soc. vol. lxiv (1908) pp. 455-56.

Old Quarry 400 yards west of Bell Busk Viaduct.—Here the beds dip south-eastwards, with some rolling, at an angle varying from 15° to 20°. Hard, dark, splintery limestone occurs, with very little shale. There are not many feet of beds now exposed, the quarry being overgrown. Fossils seem rather rare.

List of Fossils obtained.

Productus semireticulatus, Mart. (With spines attached.)
Orthotetes crenistria (Phill.). (In fragments.)
Chonetes papilionacea (Phill.).
Pygidium of *Phillipsia* sp.
Crinoid stems and plates.

Dr. Wheelton Hind & Mr. J. A. Howe [1] record *Spirifera lineata*, *Syringopora geniculata*, and *Cyathophyllum* sp., in addition to some of those enumerated above.

It is remarkable that the dip is not in accordance with the general dip of the beds south of the southern branch of the Craven Fault.

The strata which have now been described are coloured pale blue on the 1-inch Geological Survey map, Sheet 60, with the exception of the Fogger rock. There is no doubt, however, that beds yielding the fauna described—with the probable exception of the Swinden Gill shales—belong to the Carboniferous Limestone; and the colouring might well be the same as that employed for the Eshton Moor strata, to be described later. Dr. Wheelton Hind & Mr. J. A. Howe wrote in 1901 (*op. cit.* pp. 357–58):—

'Examination of the ground and numerous small quarries seem to show much more limestone than is accounted for on the map, and we are inclined to believe that the Carboniferous Limestone occupies nearly the whole area.'

It is of some importance to make out the relation of these beds to the general systems of anticlines and synclines which occupy most of the Craven Lowlands. Commencing at or near Stainton Cotes (see 1-inch Geological Survey map, Sheet 60), and extending to north of Otterburn, the beds occupy 'rolling country' in which the remarkable rounded hills show much uniformity of height in well-defined groups and lines. The dips are fairly persistent northwards or north-north-westwards. The angle of dip varies somewhat, but it is usually between 15° and 30°, the average being possibly, say, 24°. As the fairly steady dips continue for a distance of at least 3 miles, we should have a thickness of about 15,000 feet × sin 24°, that is, over 6000 feet, which is, of course, inadmissible. All the beds are well up in D probably.

There must consequently be repetition of beds by one or more faults or folds; and it is interesting to note in this connexion the few dips, as at Fogger and near Bell Busk, and the remarkably folded beds in Otterburn Brook, which do not accord with the general direction. Also there is the considerable difference in the amount of dips. The southern branch of the Craven Fault cuts off these beds, with their northward dip, from the irregular anticline of Eshton Moor, Hetton, and Winterburn.

[1] Quart. Journ. Geol. Soc. vol. lvii (1901) p. 358.

From Warrel Quarry to the first beds of Fogger is about half a mile. The height in the two cases is almost the same. The dip varies between 15° and 18°. Hence, the possible thickness of strata between the *Caninia gigantea* beds of Warrel and the white crinoidal limestone of Fogger may be about 700 feet. The similar beds of Swinden Gill Head, however, with an all but identical fauna, seem to come very near to Pendleside Beds, which in their turn usually begin almost immediately above the shelly crinoid breccia that so often forms thick beds at the very top of the Carboniferous Limestone.

But, of course, in a drift-covered country, with exposures scattered here and there, with so much change in the observed dips, and with so many direct evidences of disturbance, any such estimates as the above must be received with great caution.

(2) The Eshton-Hetton Anticline.

Under the above heading I propose to describe all the exposures which I have noticed on Eshton Moor, near Winterburn, and near Hetton and Rylston.

The exposures near Crag Laithe and Throstle Nest (Eshton Moor).—About half a mile east of Bell Busk village, and on the left bank of the River Aire, are small scars of limestone culminating in a knoll-like hill in which is an old quarry. A very interesting series of beds is shown in the Crags, in the quarry, and in the pastures immediately east and north-east of the Crags and the quarry.

In the Crags the beds are well-bedded and relatively undisturbed, with a south-south-easterly dip at an angle of about 8°. The Crag Laithe Quarry beds come at the top of the series. The succession is as follows:—

		Thickness in feet.
Top Beds of Quarry.	Shales with crinoids, Zaphrentids, *Cyathaxonia*, *Cyathophyllum*, *Rhipidomella michelini*, etc. ..	
Middle Beds of Quarry.	Shales and limestone beds, with much crinoidal débris, *Clisiophyllum*, *Campophyllum caninoides*, *Amplexus*, *Beaumontia*, *Michelinia*, etc.	40?
Lowest Beds of Quarry.	Crinoidal and shelly limestone with knoll characters; *Productus giganteus*, *Pr. martini*, *Spirifer bisulcatus*, *Terebratula* sp., etc.......................	
	Gap, of about 17 to 19 feet of strata	18
Upper Crags.	Crinoidal débris, irregularly bedded, with shells as at Fogger	30
	Gap, of about 13 or 14 feet of strata	13
Middle Crags.	Well-bedded crinoidal limestone, with bands of black limestone	20
	Well-bedded limestone, with abundant *Caninia*, *Campophyllum (?)*, and a *Clisiophyllum*; *Productus giganteus*, and other Productids common.	7
Lower Crags.	Massive, well-bedded, 'fine-grained' limestone with occasional specimens of *Caninia gigantea*, and an immense profusion of *Syringopora* cf. *reticulata*. Brachiopods are not common, and are not easily extracted	22
	Approximate thickness	150

With regard to the beds of the quarry, any estimate of the thickness involves some difficulty. The general dip is south-south-eastward. There is, however, considerable disturbance of the beds. They are in parts much folded, and there is a frequent squeezing-out of the shale bands (compare Draughton, Foxley Bank, etc.). Slickensiding is quite common, and a small fault is seen near the north-western end of the quarry, where earthy shales lie sharp against limestone of the Fogger type. On the whole, the quarry has been worked along the strike, and there is no great thickness of beds seen, probably not more than 40 feet at most. That is, therefore, the maximum which I have allowed in my estimate of the total thickness.

The shelly and crinoidal limestone found in the lower part of the quarry (the whitest type observed here) is like the white rock of Fogger, and approaches closely some of the beds of the Knoll region, as, for example, those of Carden, Butterhaw, Appletreewick, and Troller's Gill; but it is not so fossiliferous as some of the Elbolton and Swinden beds.

The southern branch of the Craven Fault is mapped close to these Crag Laithe beds. The latter and the beds of the Crags themselves evidently form part of the Eshton-Hetton anticline. This anticline is clearly cut off from the beds which have a steady northward dip, as already described; hence the fault runs across country north-east of Bell Busk and Otterburn, as shown on the 1-inch Geological Survey map (Sheet 60).

The little exposures in the hilly pastures north-east and east of the Crags help to corroborate the sequence already described. These smaller cuttings have been opened to obtain stone for the walls, and are now to some extent grown over.

The first is a small cutting some distance north-east of the quarry, and in a field not far from Throstlenest Farmhouse. The beds strike in line with the upper Crags. The dip is the same, and the beds are of the same character. Some 8 to 10 feet of strata, partly overgrown, may be seen. Fossils found:—

Syringopora cf. *reticulata*, Goldf. (Small corallites.)
Syringopora cf. *gigantea*, Thomson. (With very large corallites.)
Productus semireticulatus, Mart.

The second is a much better exposure; it occurs north of the first and lower in the sequence. A thickness of about 15 feet is exposed. The dip is still approximately the same.

List of Fossils obtained.

Syringopora reticulata, Goldf. (Average form.)
Syringopora cf. *ramulosa*, Goldf. (The small ramulose form.)
Syringopora gigantea, Thomson. (Rare.)
Amplexus coralloides, Sow. (Tabulæ 10 inches long by half an inch wide, extending across from wall to wall and about a quarter of an inch apart. Septa very short.)
Caninia gigantea, Mich. (Of apparently Warrel type.)

Rhipidomella michelini (L'Éveillé).
Orthotetes crenistria (Phill.). (Of exactly Warrel type.)
Chonetes papilionacea, Phill. (Again exactly as at Warrel.)

The third is a good exposure, a little farther north-west and in the line of strike with the lower Crags. Dip again about the same. *Syringopora* cf. *reticulata*, Goldf., is here exceedingly abundant, the débris simply swarming with it, just as in the lower Crags. Hence the whole sequence seems to be as follows :—

(4) Quarry beds with *Zaphrentis*, *Cyathophyllum*, etc.
(3) Crinoidal beds.
(2) *Caninia* Beds.
(1) *Syringopora* Beds.

It is noticeable that the succession of (1) and (2) is the same as at Bell-Busk cutting half a mile away, but across the line of fault.

Fossils of Crag Laithe Quarry.

(Mr. R. G. Carruthers has been good enough to identify very many of the corals for me.)

Syringopora cf. *reticulata*, Goldf. (Comparatively rare.)
Syringopora gigantea, Thomson. (Rare.)
Michelinia cf. *favosa*, De Kon.
Beaumontia sp.
Cyathaxonia cornu, Mich.
Cyathaxonia rushiana, Vaughan. } (Both quite common.)
Lophophyllum aff. *retiforme*, Nich. & Thomson.
Lophophyllum sp.
Clisiophyllum sp. (1).
Clisiophyllum sp. (2).
Carcinophyllum sp.
Campophyllum caninoides, Sibly. (Fairly common.)
Caninia cornucopiæ, Mich.
Caninia sp.
Amplexus coralloides, Sow.
Zaphrentis omaliusi, M.-E. & H. (Common.)
Zaphrentis densa, R. G. Carruthers.
Zaphrentis delanouei, M.-E. & H. (Common.)
Zaphrentis delanouei mut. *parallela*, R. G. Carruthers.
Zaphrentis enniskilleni, M.-E. & H.
Zaphrentis costata, M'Coy.
Zaphrentis amplexoides, sp. nov.
Zaphrentis, sp. nov. (2).
Cyathophyllum aff. *murchisoni*, M.-E. & H. (Quite common.)

Serial sections are necessary to determine more exactly many of the species. This is obviously a matter of considerable expense and time. I hope to proceed with the work as opportunity arises.

Chonetes hardrensis, Phill. (Common.)
Chonetes aff. *papilionacea*, Phill.
Productus semireticulatus, Mart. (Common.)
Productus martini, Sow. (Of Knoll type.)
Productus scabriculus, Mart.
Productus pustulosus, Phill. (Common.)
Productus giganteus, Mart. (Of somewhat Chonetid type.)
Schizophoria resupinata (Mart.). (Very common.)
Rhipidomella michelini (L'Éveillé). (Very common.)
Martinia glabra (Mart.).
Spirifer bisulcatus, Sow. (Common.)
Terebratula sp. (A very small form ; rare.)
Athyris aff. *royssii* (L'Éveillé).
Athyris aff. *planosulcata* (Phill.).
Orthotetes crenistria (Phill.). (Not common.)

Gasteropods and cephalopods occur occasionally.
Phillipsia sp. (Pygidia occur frequently.)

Farlands Quarries.—Near the country lane which leads from Airton to Winterburn are some cuttings now almost completely overgrown. Beds may be seen on each side of the road at one point, but they are almost covered with vegetation. It is difficult to make out the relationship of the strata. The dip is at a low angle, almost due south-eastwards, and so there is some irregularity in the anticline here, as at Owslin Barn. I obtained *Syringopora* cf. *reticulata*, Goldf., *Caninia* aff. *gigantea*, Mich., and *Orthotetes crenistria* (Phill.).

Winterburn Chapel Quarry.—This cutting is in the hillside, east of Winterburn Chapel. We are here on the northern side of the anticline.

The rocks are chiefly a blue-black limestone in fairly thin beds, extremely fissile and breaking with a splintery fracture. There are very thin shaly partings between some of the limestones. The bedding is remarkably well seen. The strata remind one of Bell-Busk cutting, the Crags (already described), and Warrel Quarry. Dip north-north-westwards at about 55°; but there is some change apparent, and the Survey officers—who probably took the dip when the quarry had not its present aspect—obtained 60°. The thickness exposed is about 60 feet. The fossils which I obtained are:—

Syringopora cf. *reticulata*, Goldf. (Plentiful.)
Syringopora gigantea, Thomson. (Rare.)
Michelinia tenuisepta (Phill.). (Common.)
Michelinia cf. *megastoma* (Phill.). (Quite common.)
Caninia aff. *subibicina*, M'Coy. (Rare.)
Caninia aff. *gigantea*, Mich. (Common.)
Campophyllum aff. *caninoides*, Sibly. (Rare.)
Productus pustulosus, Phill.
Productus scabriculus, Mart.
Productus semireticulatus, Mart.
Productus giganteus, Mart., or a 'Chonetiproductid.'
Chonetes aff. *hardrensis* (Phill.). (Very small, rather rectangular, and very finely striated.)
Orthotetes crenistria (Phill.). (Reminding one of Warrel.)
Athyris aff. *royssii* (L'Éveillé).

As in all these dark limestones, the brachiopods are not readily obtained complete.

Caninia gigantea occurs here in great profusion: I have a specimen of it from this quarry, which illustrates in a remarkable manner the movement of these beds one over the other. A stout well-developed coral has been broken, and one part of the coral pushed up along the upper part, which shows slickensiding very clearly. The broken pushed part is now cemented to the upper part very firmly by a deposit of calcite, just as one often finds along slickensided surfaces.

Owslin Barn.—There are a few small exposures in the pastures north-north-west of Skelda Gate, between Hetton and Winterburn. Most of them are much overgrown, but it can be seen that there is here some roll in the beds, and that consequently the anticline is not a simple one. The only exposure worthy of the name of quarry is a small cutting close to Owslin Pasture, where thinly bedded limestone with shale dips north-north-westwards at a high angle. There are not more than 15 or 16 feet of beds exposed at this place. The beds are, however, fossiliferous, and I obtained the following specimens:—

Syringopora aff. *reticulata*, Goldf. (Exceedingly common.)
Syringopora ramulosa, Goldf. (Not so common.)
Caninia hettonensis, sp. nov. (Very common, see § III.)
Productus pustulosus, Phill. (Common.)
Productus semireticulatus, Mart.
Productus martini, Sow.
Productus giganteus, Mart.
Chonetes papilionacea (Phill.).
Chonetes aff. *hardrensis* (Phill.).
Athyris sp.
Orthotetes crenistria (Phill.). (In fragments.)

Quarry near Hetton Village.—This is an old quarry, now partly overgrown, immediately north of Hetton village. These beds are again on the northern side of the anticline. Dark muddy limestone, with thin shaly beds, very similar to the Winterburn-Chapel beds. The dip is 68° or 69°, slightly east of north. The thickness, including the overgrown beds, is about 135 feet. There is again evidence of movement in the abundance of slickensided surfaces.

On the whole, these beds seem to be most like those of the Middle Crags near Bell Busk.

List of Fossils obtained.

Syringopora sp. (A form which is not common elsewhere.)
Syringopora cf. *ramulosa*, Goldf. (With small corallites.)
Amplexus aff. *coralloides*, Sow.
Caninia hettonensis, sp. nov. (Very similar to the form described from the last quarry.)
Caninia gigantea, Mich.

Rylston Railway Quarry.—This is an important cutting which shows the Carboniferous Limestone of the anticline nearly at the top of the series. The grits cannot be far away. It is not very distant from the dip-mark 20° S.S.E. (Geol. Surv. 1-inch map), about half a mile south of Rylston and a little north of Low Wood. It is close to the down side of the line from Skipton to Grassington. The dip is about 13° south-south-westwards. The beds are of varied character, and it is well to specify them exactly. The section, in descending order, is as follows:—

	Thickness in feet	*inches.*
Coarse crinoidal débris, with shells and corals	16	5
Thin shale-parting	0	6
Finer crinoidal limestones	5	0
Coral-bearing muddy shale	0	8
Massive blue limestone, with corals	3	5
Calcareous muddy shale	0	6
Fine-grained massive limestone	1	8
Black shale	2	0
'Blue' limestone	1	8
Shale	0	4
Rapidly changing succession of thin beds, limestone and shale, with predominant shale, to bottom of quarry	12	0
Total thickness seen	44	2

List of Fossils obtained.

Cyathaxonia rushiana, Vaughan.	*Michelinia* cf. *tenuisepta* (Phill.).
Lophophyllum costatum (M'Coy).	
Zaphrentis, sp. nov.	
Zaphrentis amplexoides, sp. nov.	*Spirifer bisulcatus*, Sow.
Zaphrentis costata, M'Coy.	*Spirifer trigonalis* (Mart.).
Zaphrentis ambigua, R. G. Carruthers.	*Martinia glabra* (Mart.).
Zaphrentis omaliusi, M.-E. & H.	*Productus pustulosus*, Phill.
Caninia sp.	*Productus semireticulatus*, Mart.
Clisiophyllum sp.	*Productus martini*, Sow.
Diphyphyllum sp.	*Productus giganteus*, Mart.
Syringopora cf. *ramulosa*, Goldf. (Rare.)	*Rhipidomella michelini* (L'Éveillé).

Also some gasteropods and cephalopods which have not been determined.

The shales and some of the limestones are very rich in corals. In the face of one block of stone, rather less than 2 feet in area, I counted over 120 individuals of *Cyathaxonia*, *Lophophyllum*, *Zaphrentis*, and *Caninia*. It is obvious that among such a wealth of material there is considerable work for the future. I may point out here that there is some similarity between the general faunal assemblage of these beds and that of Crag Laithe Quarry.

(3) The Knoll Region of Cracoe, Thorpe, and Linton.

Much has been written concerning this famous region, famous alike for its peculiar topography and for the beauty of its fossils. There has been a long controversy concerning the origin of the prominent knolls of limestone which are found in the district. It is not necessary to repeat the theories of Mr. Tiddeman and of Dr. Marr, because these are now well known and have been so often summarized. I propose, however, to submit some remarks on those theories, and to offer a contribution towards the solution of the difficulties (in my opinion more apparent than real) which have brought these knolls into greater prominence in geological literature. My remarks will best follow a detailed account of some observations made in the district during the past few years.

I propose to describe some of the exposures in the separate knolls, more especially those of Elbolton and Swinden, the latter being now dissected by quarrying operations and presenting a fine opportunity for the study of the internal structure of a knoll.

A series of these knolls may be seen along a line which is roughly parallel to the grit fells of Cracoe and Thorpe. In order from east to west they are Keal Hill, Elbolton, Stebden, Butterhaw, Carden, and Skelterton. Stebden stands back from the rest, nearer to the grit fells. Carden is only a small knoll, but ought to be included in the series. It forms a small dissected mass of limestone, separated from Butterhaw and Skelterton on either side by small streams, which coming down from the grit moors so close at hand, have tremendous erosive power.

Elbolton Knoll.—This is the largest of the knolls, and forms a fine hill west of the hamlet of Thorpe. The hill has been explored for lead-ore, and there are several adits, one of which on the south-west side is still open. Near Thorpe village is a heap of débris, at an old adit which is now closed. Close at hand, masses of rock *in situ* may be studied. Here the limestone is of the following types:—

(A) Coral limestone, with *Lithostrotion martini* in a fine-grained calcareous mud; in places, a small brachiopod or gasteropod is found between the corallites.
(B) Crinoidal débris, in which stems, plates, and arms are scattered in all directions, with again in places a shell-fragment.
(C) A shell-débris, with all sorts of odd valves and occasional whole shells cemented together by a calcareous cement.
(D) A shell-débris consisting of larger shells, less perfectly cemented together. The shells come out readily.

Of course, there are intermediate types between B, C, and D.

The dips are towards the grit fells, and the beds of limestone clearly pass under the Pendleside Series and the grits. The rocks are very roughly bedded here.

Farther westwards the dip is very well seen; it is south-south-easterly and straight towards the grit fells. Shell-breccia, very much like the well-known breccia of the Downham Knoll, is seen here. At the western end, towards Esker House, dips are again seen. At one point, close to an adit, the beds (quite well-bedded) are almost vertical. At the point nearest to Esker House the dip is clearly into the hill. On the northern face of the hill, on the slope facing Linton, there is again a dip-slope, several minor exposures being visible. At the upper end of Thorpe village, in the lane, it is almost due east. Thus the dips are not in keeping with the theory of quaquaversal dips, but are such as one finds in the other districts, where much folding of the flaggy limestone has taken place and where the dips can be well seen (which is not the case at Elbolton).

Elbolton has long been noted for the beauty of its fossils, and certainly it is a collector's paradise. It would be a mistake, however, to allow the conception to prevail that every part of Elbolton is good collecting-ground: such is not the case. Some beds are very disappointing, and in other instances a good deal of limestone has to be broken up in order to obtain a few good specimens. On the other hand, there are in places bands where shells can be had for the picking up. Especially is this the case with *Martinia glabra*, with *Schizophoria resupinata*, and to a less degree with other brachiopods and mollusca.

Stebden Knoll, as I have already observed, stands well back from the line of knolls. It consists of the same limestone as Elbolton Knoll. The grits are here close to the limestone, and there is not much room for the normal sequence of Pendleside Beds. There is probably an overthrust fault or an overfold, and thus the limestone of the knolls is brought right against the grit.

Dips are somewhat irregular in the knoll itself, and they are not quaquaversal. On the south side the dip is into the hill; on the summit of the hill is a dip-mark (1-inch Geological Survey map) 40° N.W. There are other westerly or north-westerly dips on the west side. On the north-east side the dip is north-north-easterly. All the beds are coarsely bedded and often somewhat hummocky, and the dips are consequently not readily ascertained.

The fossils here are of exactly the Swinden and Elbolton type. The general similarity is at once shown by the presence of *Lithostrotion irregulare*, *L. martini*, *Productus fimbriatus*, *Pr. punctatus*, *Pr. giganteus*, *Pr. striatus*, *Spirifer bisulcatus*, *Martinia glabra*, *Rhynchonella pleurodon*, and *Pugnax acuminata*.

Butterhaw Knoll.—This knoll is much like Elbolton in many respects, but is smaller. At an old lime-kiln at the south-south-western corner fossils may be got plentifully. The limestone is of the same type as at Elbolton, and the dips are towards the grits again. The valley is very narrow between the grits and the limestones, leaving little room for Pendleside Beds. The same suite of fossils is obtained: namely, *Productus martini*, *Pr. fimbriatus*, *Pr. striatus*, *Pr. humerosus*, *Martinia glabra* (very common again), *Spirifer alatus*, *Sp. bisulcatus*, *Rhynchonella pleurodon*, and *Dibunophyllum* sp.

North of Butterhaw towards Linton, and near Esker House, is a cutting in the roadside for road-metal. Here folding is clearly evident in the fairly well-bedded limestone. The dip is almost due east, that is, towards the south-western slope of Elbolton. Hence there is probably a fold or a fault between here and that knoll.

Fossils are fairly good and again of the same general facies. Cephalopods and gasteropods are seen, in addition to brachiopods and polyzoa. Of course, crinoids are plentiful. The brachiopods include *Productus pustulosus*, *Pr. scabriculus*, *Pr. fimbriatus*, *Pr. martini*, *Pr. striatus*, *Pr. giganteus* (a deeply fluted or ribbed form, ribs very irregular), *Spirifer bisulcatus*, *Spirifer* sp. (?), and *Martinia glabra*.

Still going westwards, the next knoll is the small hill named Carden, which is separated from Butterhaw by a transverse stream, as already mentioned. Here scars face the Swinden-Linton Valley, and the dip seems fairly regular at some points towards the grit hill. The Pendleside Beds must be very thin again, as the limestones come very near to the grits. Brachiopods and corals are the same as before, excepting that I obtained one small Zaphrentid here.

Skelterton is the next and the last knoll in the series. Its beds again dip, on the whole, towards the grits. There is some lithological change evident, however, for there are not the same shell banks, but crinoidal limestone with beds made up for the most part of finely comminuted material. There are such beds in Elbolton Knoll, but here they form the bulk of the strata. In consequence, the stratification is much more evident, and it is possible to make out the dips quite readily On the northern side, between the limestone and the Millstone Grit, the dark shales are seen. They are quite normal Pendleside Beds, consisting of dark shales and thin earthy limestones, containing such fossils as *Posidonomya becheri* and *Pterinopecten papyraceus*. There is not a continuous section visible; but the limestone with abundant corals and brachiopods is only a few yards away from the Pendleside Beds, and the sequence seems to be a normal one.

Between Skelterton and the little knoll called Carden is another transverse stream, which provides some interesting sections, and throws some light on the tectonics of the district. Beginning at the north-western end of Skelterton, just where the small brook (Threapland Gill) reaches the lane, there is well-bedded limestone dipping slightly west of north. Small corals (*Caninia* and *Zaphrentis*) are seen in this limestone. A little farther up the hill the beds have turned over, and dip nearly due south; they are evidently the same beds. After an interval of about 20 feet, black shales make their appearance, associated with thin dark-blue limestones of Pendleside type, the beds appearing quite regular in succession: these shales dip south-south-eastwards. A little higher up the black shales are seen dipping northwards again, and then the limestones continue for some time. Evidently a roll in the beds here shows a small syncline of probable Pendleside Beds.

Some distance below the road are small exposures in the fields, which show well-bedded limestone dipping at a high angle towards the grit fells again. Hence there is still further folding. Here is well exposed a breccia, which is often seen interbedded in the limestones. Shells and crinoids are cemented together by a cement of calcareous mud, which easily disintegrates and allows the shells and other megascopic fossils to weather out. The shells include most of the well-known Elbolton types.

A little farther east, near a well-marked vein with abundant calcite and some fluor, is more evidence of disturbance, and the dips change again. Thus, here, as in the other cases, we have abundant evidence of intense folding, in and near the well-known knolls which are so marked a feature in this part of Wharfedale.

Farther west from Skelterton the peculiar knoll character dies out, while the shell-beds and crinoidal breccias diminish in thickness, passing laterally into the black and 'blue-black' well-bedded limestones described in the preceding section (p. 550).

There are many exposures in the pastures situated between the line of knolls already described and the obviously silted-up lake-beds of Linton; but they are very small and, the limestone being of the coarsely-bedded character, it is not advisable to rely much upon any dips such as may be with difficulty made out. On the whole, there seems to be no difference in the fauna, the brachiopods, gasteropods, and cephalopods which have been obtained being exactly the same as those found in the knolls.

Swinden Knoll.—On the opposite side of the alluvial flat of Linton rises the important knoll of Swinden, now being worked by Messrs. P. & W. Spencer (to whom, as also to their manager, Mr. Todd, I tender my thanks for permission to visit the quarry at any time, and for help on the spot). There are other cuttings near, notably the railway and road-cuttings near Catchall Inn.

Swinden Hill is a fine and quite typical knoll, and it is very fortunate that it is thus being dissected. It is an excellent collecting-ground for fossils, and scarcely inferior to Elbolton in that respect. I have collected extensively from both knolls, and I am able to say with some confidence that there is very little difference in their general fauna. At Elbolton it so happens that in making drifts for lead-workings a '*glaber*' band was hit upon, and that consequently enormous numbers of that species (*Martinia glabra*) may be obtained.

At Swinden it occurs in equally large numbers, and I have also seen vast numbers of other shells. In the summer of 1908 I was shown a deposit of *Pugnax acuminata*. The shells occurred about 3 or 4 feet from the top of the then face of rock, and it was possible simply to scrape out perfect specimens. A quarryman got me a series of handfuls by letting himself down by a rope. I have seen the fossils from this band lying in profusion at the foot of the face of rock. Sometimes there are similar rich finds of *Schizophoria resupinata*, and I have seen them about equally in both Elbolton and Swinden. I have collected a considerable number of corals from both knolls, and they are, again, generally the same.

The remarks on the lithology of the Elbolton beds will apply equally well to Swinden. Some of the beds are barren of megascopic fossils, but consist of finely comminuted calcareous débris mingled with abundant foraminifera.

The beds are much disturbed. Quite clear folds may be seen, and slickensided surfaces are common. The bedding-surfaces are of the usual very irregular character, so common in these limestones; but there are exceptions, and sometimes the bedding is well-defined and regular.

The whole appearance of the quarry reminds one of the folding of the well-bedded limestones at Draughton, Hambledon, Foxley Bank, Skipton Castle, and elsewhere, but of course the folding is more clearly seen in the dark limestone than in the irregularly and coarsely bedded rocks of the Elbolton and Swinden type.

East and south-east of this big knoll are a few exposures of some significance. In the fixing of the telegraph-posts, between Catchall Inn and the railway-cutting, excavations had to be made in the limestone, and I was able to examine the material. In one of them a fossil band of the usual type was struck, and scores of specimens of Rhynchonellidæ might be obtained from the small heap of débris.

The railway-cutting is very interesting. The same shell and crinoidal débris are interbedded with so-called 'non-fossiliferous' limestone. The general dip is almost across the cutting, that is,

Fig. 1.—*View of Swinden Knoll, near Grassington: the quarry on the northern slope of the hill is clearly seen.*

Fig. 2.—*A small part of Swinden Quarry, showing one of the numerous folds which are exposed from time to time as the quarrying proceeds. In the middle of the picture the beds are brecciated.*

south-eastwards, but there is much disturbance. Some poorly developed and irregular shale-bands with clayey concretions help to

Fig. 3.—*Railway-cutting, near Swindon End, known as 'Catchall Cutting,' showing folded beds of white 'knoll limestone.'*

show up the folding of the strata. At one point the beds seem to become almost vertical.

The fossils here are again quite indistinguishable from the Elbolton and Swinden fossils. Except that I have not been able to

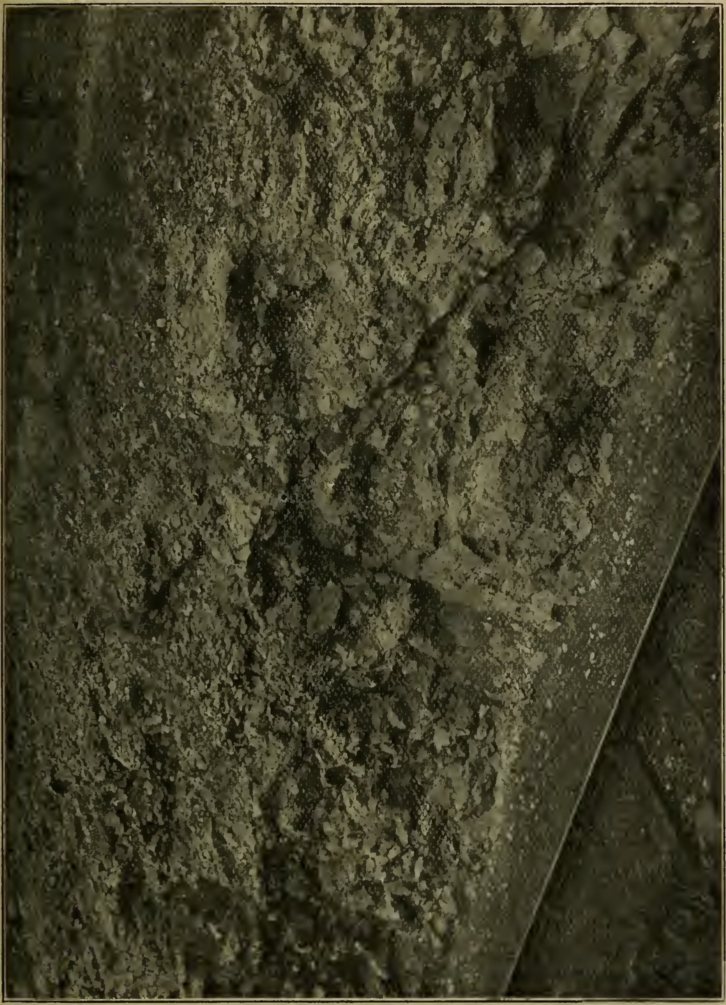


Fig. 4.—*Another part of the same railway-cutting as that seen in fig. 3, showing a second fold in the beds of white 'knoll limestone.'*

obtain from a comparatively small cutting the same extensive list as I have obtained from the large knolls, there is no difference whatever to be recorded.

Summary of Evidence of Intense Folding in the immediate Knoll Area.

(*a*) Cracoe Gill, at the western end of the area, shows much folding, the beds in the lower part of the Gill being much disturbed.

(*b*) Threapland Gill (already mentioned) shows folding and probable faulting.

(*c*) Small Gill, which empties itself into the Wharfe near Hebden Swing Bridge. This again shows a complete turnover of the beds in the upper part of the Gill.

(*d*) Roadside cutting near Esker House, old road from Thorpe to Cracoe.

(*e*) Railway-cutting, near Catchall Inn (already mentioned).

(*f*) Folds seen in Swinden Knoll, as it is being dissected by quarrying operations. This is the only knoll in this district that has been thus dissected, and its internal structure shown.

(*g*) Folds clearly seen in the bed of the Wharfe at Loup Scar, Burnsall.

Fauna of the Knolls and the intervening Limestone Exposures.

Cyathophyllum sp. (Probably aff. *murchisoni.*)
Cyathophyllum regium, Phill.
Caninia hettonensis, sp. nov.
Caninia cf. *subibicina*, M'Coy. (Two varieties.)
Caninia aff. *gigantea*, Mich.
Zaphrentis sp. (Rare.)
Amplexus coralloides, Sow.
Clisiophyllum sp.
Carcinophyllum aff. *kirsopianum*, Thomson.
Carcinophyllum sp.
Lophophyllum sp.
Lithostrotion portlocki (Bronn). (Common.)
Lithostrotion m'coyanum, M.-E. & H. (Common.)
Lithostrotion aranea (M'Coy).
Lithostrotion cf. *martini*, M.-E. & H. (Very common.)
Lithostrotion affine (Flem.).
Lithostrotion irregulare, M.-E. & H.
Lithostrotion junceum (Flem.). (Rare.)
Michelinia cf. *tenuisepta* (Phill.).
Syringopora reticulata, Goldf. (Rare.)

Spirifer bisulcatus, Sow. (Common.)
Spirifer lineatus, Phill. (= *Reticularia lineata*, M'Coy). (Common.)
Spirifer trigonalis (Mart.).
Spirifer ovalis, Phill.
Spirifer integricosta, Phill.
Spirifer pinguis, Sow.
Martinia glabra (Mart.). (Exceedingly common in places.)
Rhynchonella pleurodon (Phill.). (Common.)
Rhynchonella pugnus (Mart.).
Pugnax acuminata (Mart.). (Exceedingly common in places.)
Orthotetes crenistria (Phill.). (Common in places.)
Strophomena analoga, Phill.
Strophomena rhomboidalis (Wahl.).
Productus martini, Sow. (Very common everywhere.)
Productus semireticulatus (Mart.).
Productus pustulosus, Phill.
Productus scabriculus (Mart.).
} Some specimens show the characters of two or more of these species.
Productus cora, d'Orb.
Productus corrugatus, M'Coy.
Productus punctatus (Mart.).
Productus fimbriatus, Sow. (Common at Elbolton and Swinden.)
Productus aculeatus (Mart.).
Productus giganteus (Mart.). (Very common everywhere.)
Productus striatus, Fischer. (Very common at Elbolton and Swinden.)
Schizophoria resupinata (Mart.). (Very common at Elbolton.)
Schizophoria resupinata, var. *connivens* (Phill.). (Very common at Elbolton.)
Rhipidomella michelini (L'Éveillé). (Not common.)
Chonetes papilionacea (Phill.). (Not common.)
Chonetes hardrensis (Phill.).
Athyris planosulcata (Phill.).
Athyris royssii, L'Éveillé.
Dielasma hastatum (Sow.). (Common, especially at Swinden.)

Some notes on the origin of the knolls.—It is quite evident from the accounts of the individual knolls, and from the notes on the other exposures, that there is a good deal of folding, with probably much faulting in this knoll region. It would certainly appear, *à priori*, that there ought to be much disturbance. The knolls occur in the folded region, south of the great fault; and all the other beds, which are similarly situated with respect to the fault, are sharply folded, faulted, and slickensided. The dark fine-grained limestone shows the evidence of disturbance to perfection, and in the following anticlinal region it may be seen over and over again:—Thornton-in-Craven, Skipton, Draughton and Bolton Abbey, Hetton and Eshton Moor. The beds are very sharply arched over at Rain Hall, and again at Skibeden, east of Skipton, and there are many minor folds.

It is, then, quite in keeping with expectation when we find Swinden, Elbolton, and Stebden showing much evidence of great disturbance. Dr. Marr was quite right in insisting on the fact that the knoll beds are much disturbed.[1] The great knolls of Elbolton and Swinden are probably homologous with the Skibeden Hill in the next valley and with the rounded hills of the Rain Hall region; but the great difference in the lithology of the folded beds has been the cause of great difference in the way in which they have weathered. I have, in an earlier paper, pointed out how the beds at Downham and Chatburn have been dissected by longitudinal and transverse streams into prominent knoll-like masses. The same general results of weathering must, *cæteris paribus*, have been produced in the district under consideration. But at Downham and Chatburn the coarsely bedded limestone dips steadily to the south; here the same limestone (with the same assemblage of fossils) is much more sharply folded. Hence some of the difference in the aspect of the knolls.

The coarsely-bedded limestone, especially when it is largely made up of masses of shells, is very permeable, even when it is not conspicuously jointed, and thus such masses resist denudation, and I think it is demonstrable that the evenness of the erosion and the lowering of the folded beds of the whole of the Craven Lowlands is proportional to the fineness of the structure of the limestone.

I submit that the 'quaquaversal dip' theory as due to original deposition can no longer be maintained. If, in any given hill, the dips seem to be of that nature, it is due to folding and not to deposition, and there would seem to be as little call for such a theory to explain the sharp dips of these highly folded beds as there would be to adopt it for the fine-grained foraminiferal limestones of the neighbouring districts.

In the whole district the general nature of the folding is the same, but the lithology of the beds varies greatly; hence the folding and the subsequent denudation have produced results so markedly different.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 331-38.

The great Elbolton Knoll is part of a dissected anticline, in which there are subsidiary folds and faults (just as similar subsidiary folds and faults complicate, for instance, the Rain Hall anticline). On the south side the Pendleside Shales are seen dipping off the limestone mass; on the north side the dip-slope is a comparatively gentle one, and extends nearly to the Wharfe, a distance of half a mile. Here again the Pendleside Shales, with their characteristic fossils, are seen at several places, dipping northwards. Swinden is also a disturbed and complex anticlinal fold, dissected by erosion somewhat irregularly. It is separated from Elbolton by a valley which is now full of alluvium, and in which is the silted-up lake-bed previously mentioned. It is, however, significant that shales of Pendleside type were cut through in one part of the western end of the valley in the making of the Dales Railway. It is thus probable that the valley along which that railway now passes, from Rylstone Station to the neighbourhood of Catchall Inn, is a former synclinal fold which ended abruptly against the fault at Linton, just as the obvious folds do all along that fault.

The Butterhaw, Carden, and Skelterton knolls are obviously partly separated portions of the same general mass of limestone. The transverse streams which separate them show limestone similar to that of which the knolls are composed; and, in the lower land in the immediate neighbourhood, as already pointed out, there are numerous exposures of the same beds of limestone. Minor folds again introduce complications, as in the case of those in Threapland Gill, already described.

The knolls continue eastwards, across the Wharfe; it is, indeed, most instructive to stand on the top of Elbolton and to see how the line of rounded limestone hills continues in a modified form to the grit hills beyond Skyreholme. There is a striking likeness in the series as seen thus from Elbolton, beginning with that hill and following to Keal Hill, Hartlington Raikes, and on to Appletreewick Hill. They are the same general limestone, part of the same general anticlinal fold, but dissected into several masses by the Wharfe and its tributaries.

In the eastern part of the district, the beds, as will be pointed out later, are quite evenly bedded; this has already been shown to be the case in the western part. There is less disturbance, too, in the nature of the folding and faulting, though the beds are by no means free from it. In the middle part of the district now included as the knoll region, the folding and the faulting, as well as the 'coarseness' of the bedding of the limestone, seem to have attained their maximum. Here, consequently, are found the most remarkable knolls: Elbolton, Stebden, Butterhaw, and Swinden.

It is not without significance that precisely at this point the Wharfe leaves the 'tabular' country of the Craven Highlands, with its almost horizontal limestone strata, and cuts its way across the fault and the anticline of Linton and Burnsall already mentioned. High-level drifts—apparently river drifts—of enormous dimensions abound here, and there has evidently been rapid river-erosion and much change in direction of both the main stream and its tributaries, while the permeable limestones have been well adapted to resist atmospheric denudation.

(4) The Burnsall and Appletreewick Exposures.

It will not be necessary to treat this section at so great a length, but rather to refer to it in amplification of the observations made on the district just described. The limestone forms a well-defined anticline with fairly consistent dips.

The Burnsall exposures.—Near a lane leading from Hebden to Hartlington, along the hill-slope which overlooks Burnsall across the Wharfe, are three small quarries. In all these the same general type of limestone is exposed. There are exposures in the bed of the Wharfe not very far away, and also in the small gill which enters the Wharfe near the Hebden Suspension Bridge.

The upper beds in this district are much more coarsely bedded than the lower; in the latter, blue limestones with some thin shales are well bedded. The beds exposed in the quarries mentioned above are the upper limestones, and yield all the fauna of Elbolton and Swinden. I have visited two of these quarries (which are occasionally worked for road-metal) many times, and have thus succeeded in sifting a considerable amount of broken-up material. I have been unable to detect any difference between the general fauna of these beds and that of the knolls proper, as regards either the corals, or the brachiopods, or the mollusca. Only occasionally are they as easy to extract; but at Swinden and Elbolton, as already pointed out, fossils are sometimes difficult to extract.

Among the commoner fossils I may quote fine specimens of *Productus martini* with the long 'anterior skirt' excellently shown, and also good specimens of *Productus scabriculus* and *Pr. pustulosus*. Cephalopods and gasteropods are quite common.

There is more of the fine-grained evenly-bedded limestone, however, at this locality than at either Elbolton or Swinden; but the same hummocky bedding is seen in the coarser upper beds, involving the same difficulty in determining the dip.

The general strike of the beds is the same as on the south side of Elbolton, and it is quite clear that the River Wharfe has cut through the anticline here. All the dips on each side of the Wharfe, and in the patch of low country between Burnsall and Keal Hill (Knoll), can be explained by assuming that the Wharfe has here cut somewhat obliquely across a sharp anticline, the continuation of the Elbolton anticline to the east.

The Appletreewick exposures.—Here is another great knoll, with the Wharfe flowing close to its southern side and the River Dibb separating it from the knoll at Hartlington Raikes.

Close to the New Inn, at Appletreewick, is well-bedded crinoidal limestone, dipping steadily southwards. The strata are exactly like the crinoidal limestone of Downham and Clitheroe, and probably occupy much the same geographical position, that is, near the top of the massif.

The River Dibb does not show many exposures in its lower part. There is, however, limestone dipping northwards at Dibbles Bridge, but this is north of the fault.

At Dowscar Nook, near the sharp bend of the river, there is the grit of Fancarl pasture, which forms grit-scars farther east, but is not mapped near the River Dibb. The relationships are much obscured by drift; but the patch of grit mapped at the upper end of Troller's Gill should apparently be continued westwards to join the patch mapped at Hebden.

Troller's Gill and Skyreholme.—Here a river has cut right across the anticline, forming a narrow gorge of great beauty. There is an almost continuous section for over half a mile.

At the southern end of the Gill the Pendleside Beds must be very thin. The grit is not seen in the glen; but on the hillside, not very far away, is a grit-quarry showing a dip and strike consonant with that of the limestone beds. There is also a well-defined narrow lateral depression, which no doubt coincides with the outcrop of the Pendleside Shales. The refuse of an old lead-mine close at hand probably marks the junction of the Carboniferous Limestone with the overlying beds. As the cutting of the Gill is not very deep, there is no very great thickness of strata exposed.

Commencing at the southern end, grit overlooks the entrance to the valley. There is limestone in the field not far below the grit. Here it is like the Lower Limestones of Pendle, Salterforth, and Elslack. Crinoidal débris occurs, containing dwarfed forms of crinoids and small shells.

At the bottom of the glen, at Middle Skyreholme Dam, the dip 18° southwards. Here is well-bedded fine-grained limestone, with very few fossils. I obtained *Lithostrotion m'coyanum*, and fragments of the ribbed, fluted form of *Productus giganteus*.

A little farther on are small exposures with almost all the knoll fauna, including *Productus cora*, *Pr. giganteus*, *Martinia glabra*, and *Pugnax acuminata*; many gasteropods and cephalopods; also *Caninia subibicina* and species of *Lithostrotion*.

The dip now lessens considerably, and, in the narrow part of the gorge, becomes very low. Farther up the Gill the beds have turned over, and the strata are traversed in inverse order.

I have studied the limestone of the Gill at many points, but have discovered no exception to the fauna of the knoll region of Thorpe and Linton.

At the top end the shales, the presence of which can only be surmised at the lower end, are well seen just below the upper dam. These shales are the same as those of Swinden Gill, and there are beds with concretions like those of the Pendleside Beds of Pendle, Weets, Salterforth, and Elslack. Clearly, the Pendleside

Series is here very thin, for the grits come on in the dam side a little farther up.[1]

In the impure limestone bed above the concretionary shales occur, among other fossils, *Productus* aff. *pustulosus*, *Spirifer bisulcatus*, *Rhipidomella michelini*, and a species of *Lithostrotion* (*? m'coyanum*). A crushed *Caninia* or *Campophyllum* is also present, but it is not possible to identify it from the material that I have seen.

The distance from the point at the entrance to the Gill, where the highest limestone probably occurs, to the turn-over of the beds is 1800 feet. The average dip may be taken at about 12° to 14°: hence the thickness of the beds may be approximately 400 feet. Measured in the opposite direction, the thickness does not seem quite so great, perhaps about 300 feet. It is not, however, easy to determine where to locate the centre of the anticline, and how much precisely to allow for diminishing dip as the middle is approached.

Some General Notes.

The change in lithology.—There is a marked change in the lithology of beds on or near the same horizon, as they are traced laterally. From Troller's Gill, through Appletreewick, to near Burnsall, most of the strata are distinctly well-bedded and fine-grained, with a tendency towards coarser bedding in the upper strata as we get nearer to Burnsall. The comparatively coarse crinoidal limestone of the upper beds of Appletreewick gradually gives place to mixed crinoidal and shell breccias towards Elbolton and Swinden. Here the coarseness of the bedding and the difficulty of determining the dip is accompanied by the profusion of loosely cemented shells which makes these knolls so excellent a collecting-ground.

As the beds are followed westwards, the finer-grained lower white and grey limestones of Appletreewick become well-bedded bluish-black limestones at Burnsall. Farther west, beyond the knoll region, the whole of the beds are of this character, with the exception of a comparatively limited, but variable bed of crinoidal and shell breccia, such as is seen at Crag Laithe and Fogger. This occurs near the top of the limestone massif, and seems to be homotaxial with the muddy crinoidal limestone of the Thornton and Broughton region, and with the famous crinoidal limestone of Clitheroe.

The remarkable change in the lithology of the upper beds is well seen, as one traces them from the comparatively thin shell-and-crinoid beds in the upper part of the Rylstone Railway Quarry, to the richly fossiliferous beds of Elbolton, the richness of which in fossils (and also the apparent thickness) is somewhat augmented, as I believe, by folding. Midway between these extremes, at Skelterton Knoll, near Cracoe, the upper crinoidal and shell breccias occur at the top of beds which are, for the most part, composed of

[1] See Wheelton Hind & J. A. Howe, Quart. Journ. Geol. Soc. vol. lvii (1901) p. 363.

finely comminuted calcareous débris, and are, in consequence, fairly well bedded.

In strata which vary so remarkably in lithological character as they are traced laterally, it may be expected that any attempt to assign them to precise zones and sub-zones will meet with some difficulty. The fauna of the Elbolton and Swinden Knolls (the knoll phase) is generally regarded as D_2 or D_3,[1] yet some of the common forms suggest much likeness with D_1 or even S_2; witness, for example, the very common *Lithostrotion*, the common *Caninia subibicina*, the occasional *Caninia gigantea*, and such fossils as *Productus cora*. The Pendleside Beds seem to succeed the knoll-beds normally.

In the Hetton and Eshton Moor districts beds containing *Clisiophyllum*, *Cyathophyllum*, also numerous species of *Zaphrentis* and *Cyathaxonia*, come in below the Pendleside Series.

At Swinden Gill Head, near Hellifield, as pointed out before, the Pendleside Beds seem to follow very closely on massive limestone with *Caninia gigantea*.

At Crag Laithe that fossil occurs plentifully in beds some 60 feet below the shales and limestones containing the *Zaphrentis-Cyathaxonia* fauna. As the Pendleside Beds do not appear to come on immediately (they are seen in the old lane leading to Gargrave), the relation of the *Caninia* beds to the Pendleside Series is not the same here as at Swinden Gill Head.

It may be pointed out that the Pendleside Series increases in thickness very rapidly, as one proceeds from the Wharfedale knoll region westwards. We may therefore expect some considerable change in the beds which immediately underlie the Pendleside Series; but it is not easy to determine the precise nature of that change in a region which affords no continuous sections, which is complicated by so many folds and faults, and presents such rapidly changing lithology.

I hope to devote time to the study of these relationships, but it must be a work of some years.

III. Notes on some of the Corals.

Caninia, Michelin.

For discussions of the characters of this genus, the following, *inter alia*, may be consulted :—

F. M'Coy : 'Brit. Pal. Fossils' 1851–55, p. 28.

A. Vaughan : 'The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area' Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 272 *et seqq.*

R. G. Carruthers : Geol. Mag. dec. 5, vol. v (1908) pp. 158 *et seqq.*; and Trans. Roy. Soc. Edin. vol. xlvii (1909) pt. i, pp. 149–50.

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[1] See 'Faunal Succession in the Lower Carboniferous (Avonian) of the British Isles' Table iii, Rep. Brit. Assoc. 1909 (Winnipeg) p. 4.

I recognize four species from the area under discussion, namely:—*Caninia gigantea*, Mich., *C. hettonensis*, sp. nov., *C. subibicina*, M'Coy, and *C. cornucopiæ*, Mich.

CANINIA GIGANTEA, Mich. (Pl. XXXIX, figs. 4, 5 & 7.)

[For synonymy, see papers quoted above, p. 566.]

The general characters of this species, as I know it from this area, are as follows:—The maximum diameter is a little over 3 inches. I have not obtained a complete specimen, but many individuals more than a foot in length may be seen.

Characters seen in transverse sections.—There is a peripheral area of rather large vesicles, then an area of smaller dissepiments, reaching to a fairly well-defined inner wall. The major septa reach to the outer edge of this zone of smaller dissepiments, and are occasionally continued as thin plates into the peripheral vesicular area. The minor septa form slight projections into the medial area, but are irregularly and incompletely developed in the dissepimental area. The major septa in a full-grown specimen number from 70 to 80. They are thickened in the medial area, but taper somewhat towards their inner ends. They are usually a little thicker in the neighbourhood of the fossula. There is a distinct fossula, but no great break in the septa.

Characters seen in longitudinal sections.—The tabulæ are numerous and somewhat close together. They are nearly flat in the middle of the cylindrical corallum, and dip sharply as they reach the inner wall, but more especially into the fossula. The outer zone of vesicles and the inner zone of smaller dissepiments are distinguishable. There is no tendency to vesicular Cyathophylloid characters in the tabulæ.

The central area with bare tabulæ usually occupies over a third of the width of the corallum in the cylindrical part. The length of the septa, as seen in transverse section, of course depends upon the plane of section. In the young conical stages, the septa reach nearly or quite to the centre of the corallum, and there is little or no dissepimental zone in the very young stage.

This species occurs abundantly in the dark limestones of the western part of the district, and much more sparingly in some of the white limestones of the knolls. I have found several specimens in the Elbolton Knoll and in the well-bedded limestone of the Wharfe Valley close by. In the Elbolton Limestones I have found a variant which has large bubbly dissepiments. In the well-bedded dark limestones the species seems to be characteristic of the middle horizon of the beds exposed there. (See notes on Crag Laithe and Bell Busk, and other exposures.)

CANINIA HETTONENSIS, sp. nov. (Pl. XXXIX, fig. 6.)

This may be a variant of *C. gigantea*, Mich., but I am of opinion that it deserves recognition, provisionally at any rate, as a distinct species. It occurs as long coralla, often reaching 8 or 9 inches in length, and the width reaches about 2 inches. Constrictions of growth are frequent, and thus the corallum expands and contracts continually.

A transverse section shows four areas :—

(1) Central area showing tabulæ only, which varies in width with the plane of the section.

(2) A medial area occupied by the major septa. These are often greatly thickened towards the inner wall, but taper to a thin plate as they end off on the tabulæ. There are about sixty major septa in the large specimens. The septa are thickened very unequally, some specimens having nearly all the major septa thickened, but others showing clusters of such thickened septa. These clusters are not always near the distinctly marked fossula. The septa vary considerably in length, according as the section has been near the upper surface of a tabula or at some distance from it.

(3) A narrow zone of dissepiments, through which the prolongations of the major septa pass. There is thus an inner wall, and the short and irregular minor septa project from this wall for a short distance into the medial area.

(4) A narrow peripheral zone of larger, laterally elongated vesicles, without any septal prolongations.

A longitudinal section shows that the tabulæ are exceedingly irregular, both in distance apart and in manner of growth. Two or three often unite as they approach the inner wall (the inner edge of the dissepimental zone) and these dip sharply together. Usually there is a wide gap above such a grouping of tabulæ.

The irregular tabulæ and the narrower zone of dissepiments, as well as the irregular growth of the corallum, distinguish this coral from the true *Caninia gigantea*, Mich. Hence I propose to constitute it a new species, provisionally, and to name it *Caninia hettonensis*, from the village of Hetton, near the Yorkshire Dales Railway.

I have found this coral at Owslin Barn, near Hetton; at Winterburn; at Farlands, near Airton; at Crag Laithe; and in Swinden Knoll. It is not so common as the normal *C. gigantea*.

Caninia cf. subibicina, M'Coy. (Pl. XXXIX, figs. 1–3.)

This is fairly common in the knolls, and I have found it in the well-bedded limestones of the knoll region. It is especially common at Swinden Quarry. A variety (recognized for me by Mr. R. G. Carruthers) has closer septa and closer tabulæ, with the dissepimental zone fairly normal; another variety has normally spaced septa, but with an outer area of decidedly irregular character. The dissepiments are much larger, and are often in the form of large vesicles. In this respect it approaches *Caninia gigantea*. This variety I have only found at Elbolton.

ZAPHRENTIS, Rafinesque & Clifford.

Several species of this genus have been found in the area here described, and in some cases individuals are exceedingly common. The genus is quite rare in the white knoll limestones.

ZAPHRENTIS AMPLEXOIDES, sp. nov. (Pl. XXXVIII, figs. 1–9.)

This is a remarkable coral which exhibits a number of features associated with different genera. It is very common in Rylstone Railway Quarry, and there is thus plenty of material available for study. I have, therefore, had quite a large number of specimens cut and a considerable number of thin sections made.

I was at first inclined to include it in *Caninia*, and Mr. Carruthers suggested that it might be an *Amplexus*. I have, however, provisionally assigned it to *Zaphrentis*, for reasons which will appear later. It may, of course, be eventually transferred to one of the other genera mentioned, or to *Calophyllum*, but meanwhile the description of the coral as it occurs at Rylstone may be useful.

In discussing its structure and possible relationships, I have followed the diagnoses of the writers named below. Four closely related genera are concerned, namely:—

(a) *Zaphrentis*, Rafinesque & Clifford; as re-defined by Mr. R. G. Carruthers, in his recent discussion of some species of this genus, Geol. Mag. dec. 5, vol. v (1908) pp. 24 *et seqq.*

(b) *Caninia*, Michelin; following the revised diagnosis, as given by Mr. Carruthers in the Geological Magazine (*tom. cit.* pp. 158–59).

(c) *Amplexus*, Sowerby; as re-defined by Nicholson & Thomson, Ann. & Mag. Nat. Hist. ser. 4, vol. xvi (1875) p. 424.

(d) *Calophyllum*, Dana; as re-defined by Thomson, Proc. Phil. Soc. Glasgow, vol. xiv (1882–83) pp. 358–59.

It seems very doubtful whether the last genus will be retained, as most or all of the forms assigned to it seem to fall within *Amplexus* or *Zaphrentis* as usually defined.

Diagnosis.—Corallum simple, turbinate, conical and cylindro-conical. Very variable in external outline, in this respect being somewhat like *Caninia cornucopiæ* (see the diagram given by Mr. Carruthers, *op. supra cit.* p. 160). When the growth is regular, the coral is sharply and evenly curved until the cylindrical stage begins. The latter is not very highly developed as a rule, fully-grown specimens being the exception. The limits of variation in form which I have seen are represented in fig. 5 (p. 570).

The calyx is very different in different examples, owing to the great changes in septal development as growth proceeds. Usually, however, the septa are Amplexoid, and a large tabular area is seen. In younger specimens a well-marked fossula is present.

The development of the coral can, of course, only be satisfactorily studied by means of serial sections, and I have had several series made. In the very young stages, the septa are comparatively few in number and very much thickened. They reach the centre in the earlier stages. In these young specimens there is a cardinal fossula, and sometimes traces of three other fossulæ. The cardinal fossula is, at first, bounded by two short irregular thickened septa. Later on, a short cardinal septum appears, and as this grows in length the enclosing septa open out, the whole appearance of the fossula being decidedly Caninoid. The cardinal fossula is barely traceable in the cylindrical Amplexoid stages.

There is nothing like uniformity in the development of the cardinal septum and its fossula as seen in different examples, and the development of the other fossulæ is exceedingly variable.

Fig. 5.—*Variations in form of* Zaphrentis amplexoides, *sp. nov.*

[The figures are about two-thirds of the natural size.]

Sometimes one alar break is quite conspicuous, without the other being more than barely perceptible. Sometimes a counter fossula is quite obvious; while at other times there is little to distinguish even a counter septum. I have not been able to discover any rule in the appearance and disappearance of these fossulæ.

With respect to the septa generally, they are usually much thickened, especially in the cardinal quadrants, in the earlier stages of growth. They are sometimes remarkably irregular in direction, the free ends in the Amplexoid stage being often bent in a capricious fashion. There is rarely the square-cut end noticed in some species of *Amplexus*. Some of these irregularities in the direction of the septa are well seen in the sections figured: one specimen, however, shows remarkably uniform septa, but it is noteworthy that a lower section of the same coral showed less regular septa. In this respect it is again somewhat like *Caninia cornucopiæ*, as described by Mr. R. G. Carruthers. Minor septa are rarely seen; only in the latest growth-stages have I been able to detect them, and then they are usually small.

The tabulæ generally extend from wall to wall, occasionally, however, coalescing one with the other. They are fairly flat in the middle part, dipping sharply at each end. Occasional large dissepiments rise irregularly from the upper surfaces. These dissepiments and the tabulæ are intersected by the transverse sections, and originate the irregular lines which are so marked a feature in sections of the Amplexoid stages of the coral. There does not seem to be, even in the latest stages of growth, any tendency to the development of an external zone of dissepiments.

The reason why I have provisionally included this remarkable and variable coral in the genus *Zaphrentis* will appear from the descriptions given and from an inspection of the figures. It may be well now to summarize those reasons.

I have excluded it from *Caninia*, because there is no external zone of dissepiments in any specimens that I have examined; also, in a minor degree, because of the presence of three (or even four) fossulæ in certain specimens and in certain stages of growth. In the earlier stages the cardinal fossula is completely enveloped by two or more septa which wrap round its inner end. The coral has, however, affinities with *Caninia* in its general septal development.

I have excluded it from *Amplexus*, because of the great length of its septa in the early stages, and also because of the well-developed fossula or fossulæ. There are, too, more dissepiments than are common in most species of *Amplexus*. It has affinities with *Amplexus* in its short septa of the later stages and in its tabulæ; many of the latter extend almost horizontally from wall to wall, and they are sometimes a considerable distance apart from each other.

From *Calophyllum* it is separated by the very rudimentary development of its minor septa.

The reasons for its inclusion in *Zaphrentis* follow from the foregoing statement: its well-marked cardinal fossula in the earlier stages; the counter and alar fossulæ which are often seen; the way in which the septa enclose the cardinal fossula; the extension of the septa to the middle of the coral in the earlier stages; and, finally, the scattered dissepiments, are all in keeping with its inclusion in *Zaphrentis*.

The specific name which I have provisionally attached to it recalls its pronounced Amplexoid characters.

I have found one specimen at Crag Laithe which seems to be the same, and one at Otterburn; otherwise I have not met with it elsewhere. It is, as already pointed out, exceedingly common in the Rylstone high-level beds. The horizon is probably D_3 or P.

Zaphrentis, sp. nov. (Pl. XXXVIII, figs. 10 & 11.)

I have only two specimens of this coral in the material which I have had cut. The transverse section shows the following distinctive features:—Four well-developed fossulæ. The cardinal fossula (if I have orientated the coral correctly) is long, bounded by two parallel septa. There is a short cardinal septum and a long thickened counter septum. The major septa in the cardinal quadrants join together before reaching the middle of the coral. The minor septa are well developed. The tabular intersections are nearly circular. I have found this 'species' at Rylstone and at Crag Laithe.

Zaphrentis omaliusi, M.-E. & H.[1]

The two 'varieties' recognized by Mr. Carruthers, as well as the normal 'species,' are common in various parts of Craven. The characters of these varieties are so distinct, that I suggest that they may well be regarded as 'species.' Of course, there are transitional forms, but such is the case with many recognized species of corals.

Zaphrentis ambigua, R. G. Carruthers.

This occurs at Crag Laithe, at Rylstone, and at Otterburn, as well as in the Clitheroe area. For a description of this interesting species or variety, see Geol. Mag. dec. 5, vol. v (1908) p. 28. *Z. ambigua* seems to be almost confined to dark shales in which there is a large amount of pyrite, both in the rock itself and in the fossils. Very often the visceral cavity of the coral contains good cubic crystals of the mineral. This species is often found fossilized, partly in pyrite, partly in calcite.

Zaphrentis densa, R. G. Carruthers.

This is not at all common in the district under consideration, but in the Thornton-Broughton District it is very common. It seldom or never occurs in the pyritous shale mentioned under *Z. ambigua*, and is always, so far as I have seen it, fossilized in calcite.

Densiphyllum bradbournense, Vaughan *in litt.*

This is again very common. It seems to be identical with a coral described by Dr. Vaughan in the Loughshinney paper.[2]

The exterior of the coral is smooth, with few or no constrictions of growth. It has a sharply curved part followed by a cylindrical part of almost uniform thickness. The calyx is rarely well seen in my specimens.

[1] See R. G. Carruthers, Geol. Mag. dec. 5, vol. v (1908) p. 25.
[2] Quart. Journ. Geol. Soc. vol. lxiv (1908) p. 459 & pl. xlix, fig. 2.

The septa, as Dr. Vaughan points out, are straight and closely approximated, and fuse together in a dense central mass. The minor septa are well developed, especially those on each side of the counter septum. The somewhat inconspicuous fossula is shown by a shortened cardinal septum. The number of the septa is the same in Dr. Vaughan's illustration as in my typical example, namely, thirty.

In the specimens that I have examined I do not find the alar fossulæ so well shown as in Dr. Vaughan's figured specimen. The coral is very common in Rylstone Railway Quarry.

Lophophyllum, Michelin.

Lophophyllum costatum (M'Coy). (Pl. XL, figs. 1–4.)

This is probably the same coral as that which was figured by Dr. Vaughan as '*Cyathaxonia*' aff. *costata*, M'Coy,[1] from Bradbourne (Derbyshire). It has been found abundantly by Dr. Sibly in 'the shaly limestones overlying the Derbyshire massif.' Following the revised diagnosis of the genus *Lophophyllum* recently given by Mr. Carruthers,[2] the coral under consideration would fall within that genus. It is exceedingly common in the Rylstone Railway Quarry, where, in some shaly bands between beds of dark limestone, it may be picked up by scores.

The corallum is simple and often turbinate, sometimes having, however, a cylindrical portion of some length. The maximum length is about $2\frac{1}{2}$ inches, and the maximum diameter about 1 inch. The columella stands up, in the weathered specimens more particularly, as a laterally compressed helmet-shaped boss, showing a well-marked series of vertical striæ.

The external surface of the coral is marked with a series of fine annular striations, through which, in specimens that show the slightest sign of weathering, the traces of the septa may be seen. 'Growth-constrictions' are common, and thus the coral often becomes somewhat irregular in shape.

I have had a considerable number of these corals cut transversely and some sections made. There is very great variation in the development and mutual relationships of septa, dissepiments, tabulæ, and columella. It becomes increasingly obvious that serial sections are necessary in the study of these variable corals, but such sections seem to be more than usually necessary in this case.

The septa reach the columella throughout the greater part of the coral. In the latest growth-stages they begin to retreat in groups, usually those nearest to the cardinal fossula earlier than those nearer to the counter septum. The septa in the cardinal quadrants are often very much thicker than the others, especially in the earlier stages of growth. When the septa have become clearly detached from the columella, they often develop club-shaped inner ends. At the same time the minor septa, which are but

[1] Quart. Journ. Geol. Soc. vol. lxii (1906) pl. xxix, fig. 5.
[2] Trans. Roy. Soc. Edin. vol. xlvii (1909) pp. 152–53.

poorly developed in the earlier stages, and are often connected to the major septa by thin extensions, now stand out boldly from the inner boundary of the retreating dissepimental zone.

The columella persists throughout in all the specimens which I have had cut. It is usually somewhat oval, and is often obviously a thickening of the inner end of the counter septum. It frequently becomes curiously irregular in shape, and, on the other hand, is sometimes almost circular. In those examples where the columella is strongly compressed, having a cardinal-counter extension about twice that of the lateral extension, a mesial line is often clearly seen, reminding one of the similar appearance in *Cyathaxonia rushiana*, Vaughan.

The dissepiments are somewhat variable in their nature and mode of occurrence. In an average specimen they are somewhat as follows:—In the earlier strongly cornute parts of the coral there are very few. In the middle growth-stages they are freely developed, and are more regularly tangential in their orientation. In the later stages they retreat, and form a well-marked dissepimental zone, through which the major and minor septa extend. In the final Amplexoid stages they have disappeared.

The tabulæ are irregular in their development, often some distance apart, and varying much in the degree to which they are arched up as they approach the columella.

Cyathaxonia, Mich.

Two species are fairly common in the shaly beds, namely:—*Cyathaxonia cornu*, Mich., and *C. rushiana*, Vaughan.

The occurrence of *C. cornu* at comparatively high levels seems to be quite regular in Craven; I have found it in several exposures. As pointed out by Dr. Vaughan, the type-specimen of Michelin was found at Tournai.[1] The two species occur in the same beds at Crag Laithe, as also at Marton School and Gledstone Kennels in a neighbouring district.

IV. Irregular Distribution of some of the Corals.

A somewhat remarkable phenomenon is the occurrence of colonies of corals in various parts of the district studied. Some species swarm in one particular place, and are only found sparingly elsewhere. In quoting instances I will refer also to contiguous districts which have been described in previous papers.

Zaphrentis ambigua occurs in great numbers in Horrocksford Quarry, Clitheroe, but is much rarer elsewhere.

Zaphrentis densa is exceedingly plentiful in the shales of Thornton Quarry; it occurs in several other exposures, but is not common.

Cyathaxonia rushiana is very common in the shales of Crag-

[1] Quart. Journ. Geol. Soc. vol. lxii (1906) p. 317.

Laithe Quarry; several species of *Zaphrentis* are common in the same quarry; the *Cyathophyllum* figured is also very plentiful, but I have rarely found it elsewhere. (Pl. XL, fig. 6.)

Caninia hettonensis, which occurs at Owslin Barn, and at Hetton and elsewhere, is very common in the former very small cutting. Two bands of muddy shale are, in places, crowded with specimens.

Cyathophyllum regium is common at Dibble's Bridge, but is rarely found elsewhere in the whole district described.

The most remarkable example of this localized abundance is that of the corals from the Rylstone Railway Quarry, mentioned in the description of that quarry and in the notes on the corals.

Small forms of *Caninia* (as, for example, *cornucopiæ*), *Zaphrentis*, and *Cyathaxonia* seem to be almost wanting in the white limestone of Elbolton and Swinden district; on the other hand, *Lithostrotion* and larger forms of *Caninia* are quite common.

The genus *Syringopora* occurs in countless masses in the Hetton, Eshton, and Bell Busk districts; it seems to be comparatively rare in the limestone of the Knolls.

With respect to such cases as the Rylstone 'colonies,' it may be that if other exposures could be obtained on precisely the same horizon, we should get at least most of the species that occur there in such numbers. Mr. Carruthers wrote (Geol. Mag. dec. 5, vol. v (1908) p. 170):—

> '. . . In Scotland, certainly, small rugose corals of this type are noticeably local in their distribution. In a bed whose position is accurately known over a wide area, they appear and disappear in a remarkable manner, as if they were very sensitive to conditions of deposit and food-supply.'

For a further admirable discussion of this subject, see a more recent paper by Mr. Carruthers.[1]

Another feature of importance in the distribution of the corals is the association of species and varieties which are, in some other provinces, characteristic of different horizons.

Caninia gigantea evidently occurs at a higher horizon here; at Crag Laithe and at Swinden Gill Head it is found plentifully in beds which are only separated by some 40 to 60 feet or so from calcareous shales containing *Cyathaxonia*.

The coral fauna of Crag Laithe Quarry is somewhat mixed, including forms which are suggestive of D_3 or even P, as well as forms like *Carcinophyllum* and *Zaphrentis delanouei* which suggest D_1 or D_2. The brachiopod fauna is suggestive of a high horizon, probably D_3. It would seem that the horizons D_1, D_2, D_3 are not represented by a great thickness of beds here.

In the neighbouring region of Rain Hall the *d* mutation of *Caninia cornucopiæ* is found in the same beds as the true species.

The association of *Cyathaxonia cornu* with *C. rushiana* has been already mentioned as being of some interest.

[1] Geol. Mag. dec. 5, vol. vii (1910) p. 171.

V. Notes on the Genus *Syringopora*.

The generic name *Syringopora* was first used by Goldfuss in 1826; see 'Petrefacta Germaniæ' vol. i, p. 75, etc. & pl. xxv.

Four species were defined by him, and the following brief diagnoses given of two of them:—

S. ramulosa (*op. cit.* p. 76):—'*Syringopora* tubis subdichotomis, tubulis connectentibus sparsis.'

S. reticulata:—'*Syringopora* tubis subflexuosis parallelis vel divergentibus, tubulis connectentibus subalternantibus.'

These original characters have been more or less departed from, and hence much confusion has arisen. Especially is this the case with *S. ramulosa*, which has been most variously interpreted by subsequent workers. It would seem desirable that we should revert to the diagnosis of Goldfuss, and remember his specific name '*ramulosa*' and his comprehensive though brief description. 'Tubi subdichotomi' as well as 'tubuli connectentes sparsi' are characteristic of certain coralla of *Syringopora* in an unmistakable manner, and to such coralla the name *ramulosa* should be applied. In the nature of things, much dichotomous branching and the occurrence of few connecting-tubes must accompany each other.

In 1828 Fischer de Waldheim[1] described two new 'species' under the names of *Harmodites distans* and *H. parallelus*, which have been accepted by many subsequent workers. His species *stolonifera* and *ramosa* have generally been merged into one or the other species already recognized.

Phillips[2] recognized four species of *Syringopora*: *ramulosa*, Goldf.; *reticulata*, Goldf.; and two new species which he instituted—*geniculata*, Phillips, and *laxa*, Phillips. He gave figures of *geniculata* and *ramulosa*. His diagnosis of *geniculata* reads as follows:—

'Radiating, often flexuous, branching, round tubes, united by very numerous small transverse subverticillate tubules.' (*Op. cit.* p. 201.)

Most subsequent writers have emphasized 'very numerous' and 'subverticillate' in the recognition of this species. Phillips's figure (*op. cit.* pl. ii, fig. 1) is not a very good one.

His *ramulosa* is like a specimen, with his name attached, in the British Museum (Natural History), but he did not follow Goldfuss in his characterization of the species. He gave 'parallel or flexuous tubes, irregularly united by the tubuli' (*loc. cit.*).

He did not figure *reticulata*, but he mentioned the small tubes which have been often held by subsequent geologists to be a fundamental character of *reticulata*. Goldfuss's *reticulata* was not necessarily a form with small tubes, and I think that it is evident to any one who has worked at abundant material that the size of corallites and of coralla (as Dr. Vaughan has recently pointed out) depends upon environment.

[1] 'Notice sur les Pol. Tubip. Foss.' pp. 19–25.

[2] 'Illustrations of the Geology of Yorkshire, pt. ii: The Mountain Limestone District' London, 1836.

Phillips, unfortunately, did not figure his *Syringopora laxa*. He gave its characters (*op. cit.* p. 201) as

'Very loosely branched, variously coalescing with few or no connecting tubuli.'

Surely, this is very nearly the *ramulosa* of Goldfuss. Whatever may be the ultimate conclusion as to the validity of the usually recognized species, it would seem unnecessary to retain *S. laxa*.

Lonsdale in 1845 [1] gave revised diagnoses of the species *parallela* and *distans* of Fischer. Of *parallela* he said:

'Tubes slender, nearly parallel, closely fasciculated, rarely branched; outer surface rugose, inner furrowed longitudinally; furrows exceeding twelve; connecting processes very short, unequally disposed; internal, funnel-shaped plates very irregular; medial pipe variable in position and form; terminal cup deep; sides furrowed; intermediate ridges tubercled; edge smooth, sharp.'

The foregoing admirable description emphasizes, for the first time so far as I know, the inner furrows. These evidently mean the almost aborted septa, the discovery of which was afterwards claimed by Milne Edwards & Haime.

Most subsequent authors have accepted *parallela* as a species, but I fail to see anything in Lonsdale's admirable description that is incompatible with its place in *reticulata*. The closeness of the tubes is a most variable feature in *Syringopora* as I know it.

Lonsdale's diagnosis of *S. distans* was:

'Tubes not closely fasciculated, slightly bent; branches few; connecting processes distant; funnel-shaped plates irregular; medial pipe generally excentric.' (*Op. cit.* p. 592.)

And in his comparison of it with *parallela* he said (*loc. cit.*) that in *S. distans* the tubes were greater, the outer walls thicker, smooth (so far as could be observed), or very slightly traversed by lines of growth, and that the disposition of the internal funnel-shaped plates was exceedingly irregular.

An excellent specimen of *S. distans* (Fischer) is exhibited in the British Museum (Natural History), from the Carboniferous Limestone of Skidrova (Urals); it has large tubes, and is much like the common Craven and Bolland form which is sometimes classified as *S. distans*.

The funnel-shaped tabulæ and the central or excentric tube are the only points of difference from fairly large forms of undoubted *reticulata*. In a great number of small coralla of *S. reticulata*, which I have examined, the tabulæ have been fewer in number, and some of them nearly horizontal. Obviously, with very few tabulæ there will be no interior tube.

On the whole, I should be inclined to retain *distans*, along with *reticulata*, *ramulosa*, and *geniculata*. The four species thus instituted up to 1845 would be: *S. reticulata*, Goldf., 1826; *S. ramulosa*, Goldf., 1826; *S. distans* (Fischer), 1828; and *S. geniculata*, Phillips, 1836.

[1] In Murchison, De Verneuil, & Keyserling's 'Geology of Russia in Europe & the Ural Mountains' 1845, Appendix to vol. i, p. 591, &c.

The great French actinologists, A. Milne Edwards & J. Haime, described *Syringopora* in their two important works ('Polyp. Foss. des Terr. Palæoz.' Paris, 1851, vol. v, Arch. Mus. Hist. Nat., and 'Monograph of the British Fossil Corals' pt. iii, 1852, Palæontographical Society).

In the former work they gave a revised diagnosis of the genus, and in the following discussion they called special attention to the septa :—

'Il est moins facile de s'assurer de la présence des cloisons, qui le plus souvent sont complètement détruites, et jusqu'à présent aucun auteur n'en a fait mention ; aussi ce genre a-t-il été regardé comme voisin des Tubipores, et par conséquent comme faisant partie de l'ordre des Alcyonaires. Pourtant, nous avons observé de la manière la plus nette, chez un grand nombre d'exemplaires bien conservés, des traces non équivoques de l'appareil septal.' (Pp. 285-86.)

They recognize the following Carboniferous species :—*distans*, *parallela*, *ramulosa*, *reticulata*, *geniculata*, *conferta*, and *laxa*. Of these, I submit that *parallela* may be included in *reticulata* or *distans*, *conferta* with *reticulata*, and *laxa* with *ramulosa*.

In the British Monograph there is an excellent example of what I understand the *ramulosa* of Goldfuss to be (pl. xlvi, figs. 3 & 3*c*). Dichotomous branching is shown very well, and there are few connecting-tubes (see Goldfuss's original description).

In 1851 M'Coy re-introduced another species, *S. catenata* (Martin), and also gave descriptions of some of the other recognized Carboniferous species ('Brit. Palæoz. Foss.' p. 83). His description of *S. catenata* (Mart.) reads as follows :—

'Corallum forming large masses of nearly equal, subparallel, very slightly diverging tubes, averaging half a line in diameter and about their diameter apart, connected by nearly equal, transverse tubuli, slightly more than the diameter of the tubes apart, the origin of each producing a slight angular flexuosity in the main tube ; tubular central opening rather large.'

This seems to be a small form of *reticulata*, and there does not appear to be anything in the diagnosis given by M'Coy that is incompatible with the inclusion of *S. catenata* [1] in the *S. reticulata* of Goldfuss.

In discussing *S. ramulosa*, M'Coy (*loc. cit.*) refers to the mode of branching as resembling 'dichotomous fission,' and points out that the parent and the young are of nearly equal size and almost equally deflected from the original direction. This is more in keeping with the original description of Goldfuss than is the description of Phillips.

M'Coy, in describing *S. reticulata*, mentions funnel-shaped diaphragms, and also connecting tubuli arising in irregular whorls. These points are of importance, as the latter was expressly referred to by Phillips as a distinguishing characteristic in *S. geniculata*, and many small reticulate forms have nearly horizontal rather than funnel-shaped tabulæ.

We now come to L. G. de Koninck's important work 'Nouvelles Recherches sur les Anim. Foss. du Terr. Carb. de la Belgique,'

[1] Martin's name in 1809 would be *Erismatholitus (Tubiporites) catenatus*.

published at Brussels in 1872. This contains a long synonymy of the genus, and also one for each well-known species. He seems to have been one of the first to point out that some forms which have been classed as separate species may be 'individus plus ou moins modifiés par l'âge ou par le milieu dans lequel ils ont vécu' (*op. cit.* p. 121).

The four species described by him were *S. distans*, *S. reticulata*, *S. ramulosa*, and *S. geniculata*. These are admirably clear descriptions, as may be expected, but there is a strange mistake in the figures on pl. xii. Probably by a printer's error, there is a transposition of *geniculata* and *ramulosa*. Figs. 1 & 1 *a* are undoubtedly *S. ramulosa*, Goldf.; figs. 2, 2 *a*, 2 *b*, 2 *c*, & 2 *d* are undoubtedly a reticulate-geniculate form. Fig. 1 is given as *geniculata*, fig. 2 as *ramulosa*. This mistake has probably misled some subsequent workers: hence we find, described as *S. ramulosa*, coralla which have all the characters of loosely fasciculate forms of *S. reticulata*. I do not think that De Koninck followed Goldfuss sufficiently when he wrote of *S. ramulosa*:—

'Polypierites très-allongés, flexueux, subparallèles, distants entre eux d'environ 2 millimètres.' (*Op. cit.* p. 126.)

This would be an excellent description of *S. distans*, but not of *S. ramulosa*, as described by Goldfuss, and later by M'Coy.

As this is a discussion dealing more with the question of the Carboniferous species than with the systematic position of *Syringopora*, I propose to omit anything more than a mere mention of three most important papers. These are:—

(A) G. Lindström: 'On the Affinities of the Anthozoa Tabulata' Ann. Mag. Nat. Hist. ser. 4, vol. xviii (1876) p. 1; see especially p. 14.
(B) F. W. Sardeson: 'Ueber die Beziehungen der fossilen Tabulaten zu den Alcyonarien' Neues Jahrb. f. Min. Beilage-Band x (1896) p. 249.
(C) W. Weissermel: 'Sind die Tabulaten die Vorläufer der Alcyonarier?' Zeitschr. Deutsch. Geol. Gesellsch. vol. l (1898) p. 54.

Dr. Sardeson had argued for the close relationship of *Syringopora* and its allies with the Alcyonaria, but Weissermel (as Lindström and Nicholson had done long before) argued against this disposition of the Syringoporidæ. Lindström had argued in favour of the relationship of *Syringopora* with *Lithostrotion* and *Diphyphyllum*, while Nicholson declared in favour of relationship with the Favositidæ.[1] Nicholson (*op. cit.*) emphasized the two methods of increase in the number of corallites, namely dichotomous branching and the production of new corallites as offshoots from the transverse tubuli. He also gave excellent figures of a longitudinal and a transverse section of a specimen from Kendal, which he referred to *S. reticulata*, Goldfuss.

It is most instructive to take his diagnoses of *S. reticulata* and *S. geniculata*, and to compare them closely. It will be seen how

[1] 'On the Structure & Affinities of the "Tabulate Corals" of the Palæozoic Period' Edinburgh & London: Blackwood & Sons, 1879, pp. 204 *et seqq.*

difficult it is to distinguish these species, unless we go back to Phillips's definition of *Syringopora geniculata,* and arbitrarily refuse to recognize as that species any forms other than those that have closely fasciculate coralla and the connecting tubuli very numerous and coming off in subverticillate whorls.

In 1883 Thomson [1] described some of the *Syringopora* found in the Carboniferous rocks of Scotland. He recognized *S. laxa,* Phillips, *S. geniculata*, Phillips, *S. catenata* (M'Coy), *S. distans* (Fischer), and also mentioned *S. ramulosa* and *S. reticulata.*

He also instituted a new species, *S. gigantea,* for specimens found at Langside, Beith (Ayrshire). His description is as follows :—

'Corallum compound, and composed of long cylindrical and distant corallites, and united by distant horizontal tubes, through which there is free communication throughout the colony. The epitheca is moderately stout, and there are faint annulations of growth. There is a system of elongated convex cellular tissue around the periphery, and there is a central tube extending throughout each of the corallites. There are twenty minute septa, which are hardly recognizable. Diameter of corallites, 2 lines.'

I have already remarked that, in my opinion, *S. laxa* and *S. catenata* may be included in other species, but I think that there is a place for Thomson's new species, *S. gigantea.* I find in Craven occasional specimens of a corallum which has wide and more distant corallites than the usual coralla to which I should apply the names *S. distans* or *S. ramulosa.* To these rarer specimens I think that the name *S. gigantea* may well be applied.

We now come to the quite recent contribution of Dr. A. Vaughan. In his Bristol paper,[2] he remarks, 'It is very doubtful whether the so-termed "species" of this genus are anything more than circuli.'

In the Rush paper [3] he writes :—

'Stated broadly, dimensional variation is a function of environment, whereas the degree of structural complexity is dependent on the earlier history of the gens, and is, consequently, a function of the time.'

Dr. Vaughan recognizes forms which are similar to *S. distans*, *S. geniculata*, *S. ramulosa*, and *S. reticulata.* He also describes a 'species' under the name *Syringopora* θ, Vaughan, which is somewhat like *S. laxa*, Phillips. It will be noticed from his description that this species is closely allied to *S. gigantea*, Thomson ; but the corallites are not so widely apart as in Thomson's diagrams, nor so widely apart as in the coral which I class as *S. gigantea* from Craven.

As I have already pointed out, *Syringopora* is exceedingly plentiful in some parts of Craven, and I think that there is sufficient material to justify some conclusions bearing on the various questions which have been raised by the writers whose work I have briefly summarized.

[1] Proc. Phil. Soc. Glasgow, vol. xiv (1882–83) pp. 328–32.
[2] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 268.
[3] *Ibid.* vol. lxii (1906) p. 313.

In the first place, I conclude from the examination of hundreds of specimens that the three species, *reticulata*, *geniculata*, and *ramulosa*, should be regarded as passing by insensible gradations one into the other. Whether on this account they should be included in a 'circulus,' or whether they should still be classed as species, will no doubt be decided by the test of general convenience in this, as in other cases.

The central type in the Craven Lowlands is a somewhat loose reticulate form, tending slightly towards the *S. laxa* of Phillips. The corallites measure about a millimetre and a half in average thickness, and are rather more than that distance apart. The connecting tubuli are somewhat irregularly distributed, and they are seldom appreciably verticillate in their origin. There is a very small amount of dichotomous branching, the new corallites arising from the transverse connecting tubes. The amount of geniculation is extremely variable, but there is often a distinct bending towards the neighbouring corallite at the point of origin of the cross-tubes.

This central type occurs in the beds below the common *Caninia* aff. *gigantea*, in the Eshton-Hetton anticline. It seems to vary laterally, that is, at or about the same horizon, so far as I can make out, in two directions. On the one hand, in the direction of Hetton, the corallites become smaller, rather more closely packed, and more inclined to open directly into each other. Thus the sections and surface-views of weathered specimens show a somewhat *Halysites*-like appearance.[1] I have seen as many as nine corallites opening one into the other, forming a sort of chain. In some cases a common visceral cavity of some considerable relative size is formed.

On the other hand, in the direction of Bell Busk and Swinden Moor, there seems to be an increase in the number of coralla, which are made up of rather smaller corallites with much thicker walls. The corallites in these examples are more irregular in their distance apart, but the distance is usually greater. The number of connecting-tubes become less, and the amount of dichotomous branching increases. Thus the tendency is towards a ramulose form at this horizon, but I think that no one would class the coralla as belonging to *S. ramulosa*, as defined by Goldfuss.

In those beds which are, in all probability, higher in the series, another mutation is seen. In the beds of the knoll region which are sometimes classed as D_3, *Syringopora* is comparatively rare; but the specimens which I have found exhibit very sharply defined characteristics. Without exception, the ramulose character is now less evident, and the reticulate character more developed. Most of the specimens have parallel tubes, showing remarkable regularity of distribution. Specimens from Swinden and Elbolton have much of the appearance that led to the adoption of the species *S. parallela*.

[1] *Cf.* Dr. Vaughan's *Syringopora* cf. *reticulata* in Quart. Journ. Geol. Soc. vol. lxi (1905) p. 268.

From Troller's Gill and Appletreewick I have collected specimens which have very closely packed corallites, but the verticillate character is not sufficiently developed to adopt the name *S. geniculata*, Phillips. Still, there is a definite tendency towards *geniculata* (Pl. XL, figs. 7 & 8, and Pl. XLI, figs. 1–4).

In the other direction geographically, there is a marked tendency towards variation in another definite direction. In the district of Rain Hall, Thornton, and Broughton, the ramulose character becomes predominant. The number of transverse tubuli decreases, and the amount of dichotomous branching increases to such an extent that the latter is almost the only method of increase seen.

Thus *S.* aff. *reticulata* seems to vary in a well-defined manner both laterally and vertically. It is obvious, however, that much more work will be necessary before these tentative conclusions can be considered as finally settled. The expense and time involved in the preparation of the necessary sections—both transverse and longitudinal—are considerable, and the writer hopes to continue to devote himself to this and to the other problems mentioned.

In the Swinden Moor district—that is, west of the district dealt with in this paper—a coral which I regard as *S. distans* (Fischer) is plentiful. It has corallites measuring approximately 2 millimetres in width, and 3 to 4 mm. apart as a rule. There are pronounced geniculations at the origin of the transverse tubuli, and these are a considerable distance apart. There is very little dichotomous branching. The funnel-shaped tabulæ are beautifully seen in some weathered specimens; they are somewhat irregularly developed, and the medial tube is not of so pronounced a character as it is in the strongly reticulate forms found at Swinden, Elbolton, and Appletreewick.

There is also the somewhat rare form which I have classed as *S. gigantea*, Thoms. This occurs chiefly at the lower horizon, that is, below the *Caninia-gigantea* beds. Its coralla measure $2\frac{1}{2}$ mm. in width, and are sometimes as much as 6 mm. apart. Connecting-tubes are few, and dichotomous branching is not common. The walls are thick, and there is a deposit of peripheral tissue in most of the specimens that I have seen. I hope to collect more material, and to obtain more particulars of this interesting 'species.'

Finally, as to some points of internal structure. There is seldom a well-developed axial tube, except in the forms with large corallites, and then not always. The strongly reticulate coralla from Elbolton and the knoll region generally show a medial tube fairly well (Pl. XLI); the coralla which I have included in *S. distans* show it less perfectly, but still it may usually be seen. The small reticulate forms from Hetton and Bell Busk rarely show a medial tube; their tabulæ are much fewer in number, and are often approximately horizontal, hence no medial tube can be developed by their union.

Imperfect traces of septa are seen in all the 'species,' but again they are best observed in the regularly developed larger reticulate forms (Pl. XLI) and in *S. distans*. They are not easily made out in coralla of the ramulose type.

The 'species' which I should be prepared to recognize from my acquaintance with the abundant material available in Craven are:—

(1) *S. reticulata*, Goldf. (2) *S. geniculata*, Phillips.
(3) *S. ramulosa*, Goldf. (4) *S. distans* (Fischer).
(5) *S. gigantea*, Thomson.

The first-named three seem to be more closely related to each other than they are to the others.

Under *S. reticulata*, Goldf., I should include also *Harmodites parallelus*, Fisch., and *Tubiporites catenata*, Mart.

Under *S. ramulosa*, Goldf., I should include also *H. stolonifer*, Fisch. (*pars*), *H. ramosus*, Fisch., and *S. laxa*, Phill. (*pars*).

Under *S. distans* (Fischer) I should include also *S. ramulosa*, Phill. (*pars*), and *S. ramulosa*, De Kon. (*pars*).

EXPLANATION OF PLATES XXXVIII–XLI.

Plate XXXVIII.

[All the figures are of the natural size.]

Figs. 1–4. *Zaphrentis amplexoides*, sp. nov. Serial transverse sections of one specimen; showing irregular septal development and occasional irregular dissepiments. (See p. 569.)

5–7. Serial transverse sections of another specimen, with regular septa and fewer dissepiments.

Fig. 8. Longitudinal section, taken through the middle cylindrical part of an average specimen.

9. Transverse section of a larger specimen, taken just below the calyx. All from Rylstone Railway Quarry.

Figs. 10 & 11. *Zaphrentis*, sp. nov., transverse sections. Fig. 11 cuts the lower part of the calyx. Rylstone Railway Quarry. (See p. 572.)

Plate XXXIX.

[All the figures are of the natural size.]

Figs. 1 & 2. *Caninia* cf. *subibicina*, M'Coy. Swinden Quarry. Transverse and longitudinal sections. (See p. 568.)

Fig. 3. *Caninia* cf. *subibicina*, M'Coy. Elbolton. Transverse section.

Figs. 4 & 5. *Caninia gigantea*, Mich. Swinden Gill Head. Transverse and longitudinal sections. (See p. 567.)

Fig. 6. *Caninia hettonensis*, sp. nov. Owslin Barn, Hetton. Transverse section. (See p. 567.)

7. *Caninia gigantea*, Mich. Warrel Quarry, Coniston Cold. Transverse section of an average specimen.

Plate XL.

[All the figures are of the natural size.]

Figs. 1 & 2. *Lophophyllum costatum* (M'Coy). Rylstone Railway Quarry. Transverse sections of the same specimen. (See p. 573.)

Fig. 3. *Lophophyllum costatum*. Transverse section of another specimen.

4. Do. do. Longitudinal section of another specimen.

5. *Lophophyllum* aff. *retiforme*, Nich. & Thoms. Rylstone Railway Quarry. Transverse section.

Fig. 6. *Cyathophyllum* aff. *murchisoni*, M.-E. & H. Crag Laithe Quarry. Transverse section. (See p. 575.)

Figs. 7 & 8. *Syringopora reticulata*, Goldf. Troller's Gill. Fig. 7. Section transverse to the extension of the corallites. Fig. 8. Longitudinal section. (See p. 582.)

PLATE XLI.

Fig. 1. *Syringopora reticulata*, Goldf. Troller's Gill. Longitudinal section, × 12; to show axial tube and aborted septa. (See Pl. XL, fig. 8.)

2. *Syringopora reticulata*, Goldf. Troller's Gill. Transverse section, × 12; to show aborted septa. (See Pl. XL, fig. 7.)

3. *Syringopora reticulata*, Goldf. Elbolton. Longitudinal section, about two-thirds of the natural size. (See p. 582.)

4. Same section, × 8, to show the axial tube.

DISCUSSION.

Dr. A. VAUGHAN expressed the pleasure that the Author's account of a difficult region had afforded him. Confining his attention to the palæontological portion of the paper, he remarked that the small number of fossils that he had seen from the limestone-massif suggested something below D, but were insufficient to fix the age. On the other hand, the forms figured from Rylstone left no doubt that the beds were of *Cyathaxonia* (D_3) age. It seemed therefore probable that there was a non-sequence between the massif and D_3. Concerning the identification of corals by slicing, he remarked that although, for full acquaintance with a species, it might be necessary to enquire into its early life, yet, for mere identification, single sections of the adult were usually quite sufficient; cases of really deceptive identity, especially among the more highly-developed corals, were relatively of uncommon occurrence. He further congratulated the Author on the photographs of corals thrown on the screen.

Mr. COSMO JOHNS remarked on the many difficulties that attended any attempt to investigate the area which the Author had described, and commended him for his courage in facing them. Not only were the rocks shattered and folded, but the thick mantle of Drift added to the complexity. It was not clear, from the account given, how the occurrence of S_2 beds had been determined. The speaker, during his visits to the district, had found great difficulty in recognizing with certainty any of the subdivisions that he had worked out in the area north of the faults. He considered that the estimate of thickness given, though much less than that of previous workers, was still excessive. He would ask the Author whether he considered the 'reef-knolls' of Cracoe to lie on the horizon of the Pendleside Limestone, and strongly insisted on that term being retained for the thick limestone that occurred below the grit of Pendle Hill and Longridge Fell. He had satisfied himself that this Pendleside Limestone was the equivalent of the Main or Upper Scar Limestone of Ingleborough, and was therefore of Upper Yoredale age.

Mr. R. G. CARRUTHERS said that, during a brief visit under the guidance of the Author to a part of the area described, he had been much impressed with the structural complications and the unusual nature of the coral assemblages. One of the most interesting

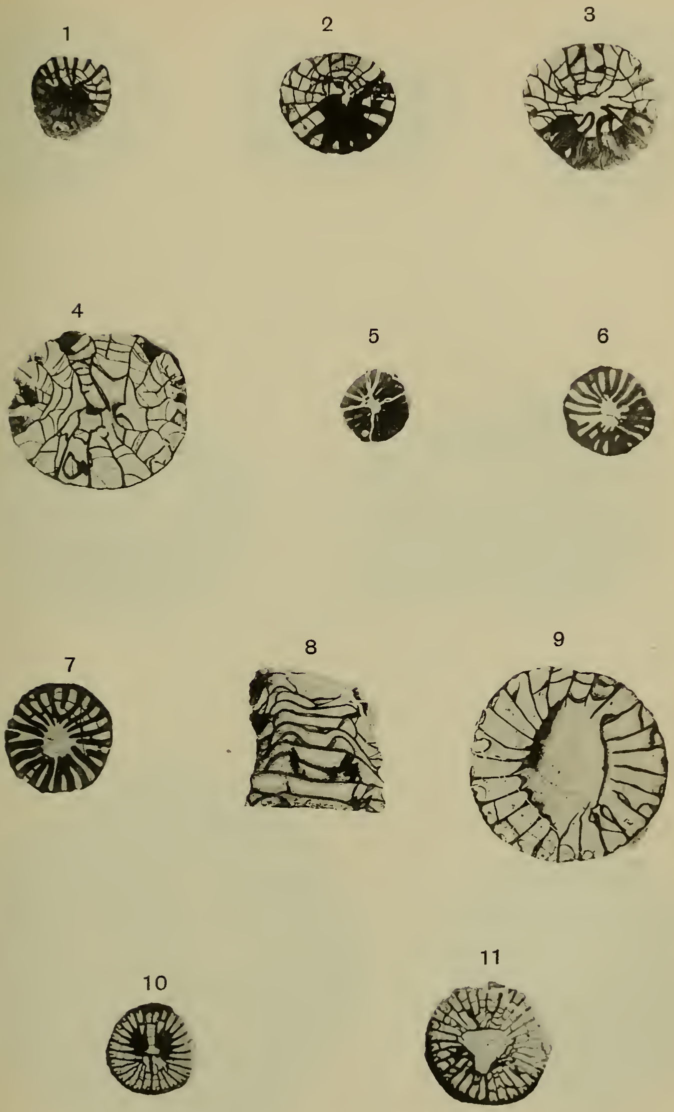
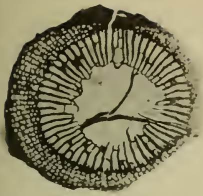


Photo.: Palæobotanical Co., Bolton. *Bemrose Ltd., Collo., Derby.*

CARBONIFEROUS LIMESTONE CORALS (ZAPHRENTIS).

1



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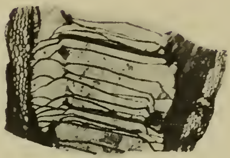

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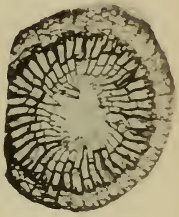

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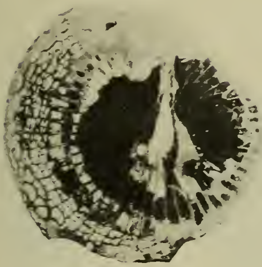

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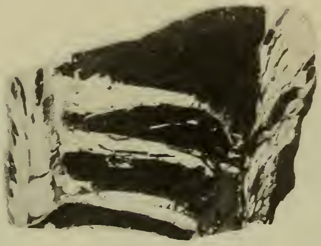

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7

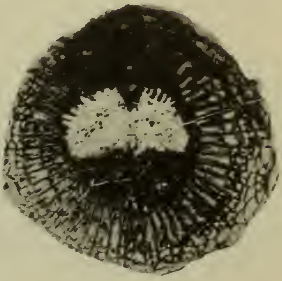


Photo.: Palæobotanical Co., Bolton. *Bemrose Ltd., Collo., Derby.*

CARBONIFEROUS LIMESTONE CORALS (CANINIA).

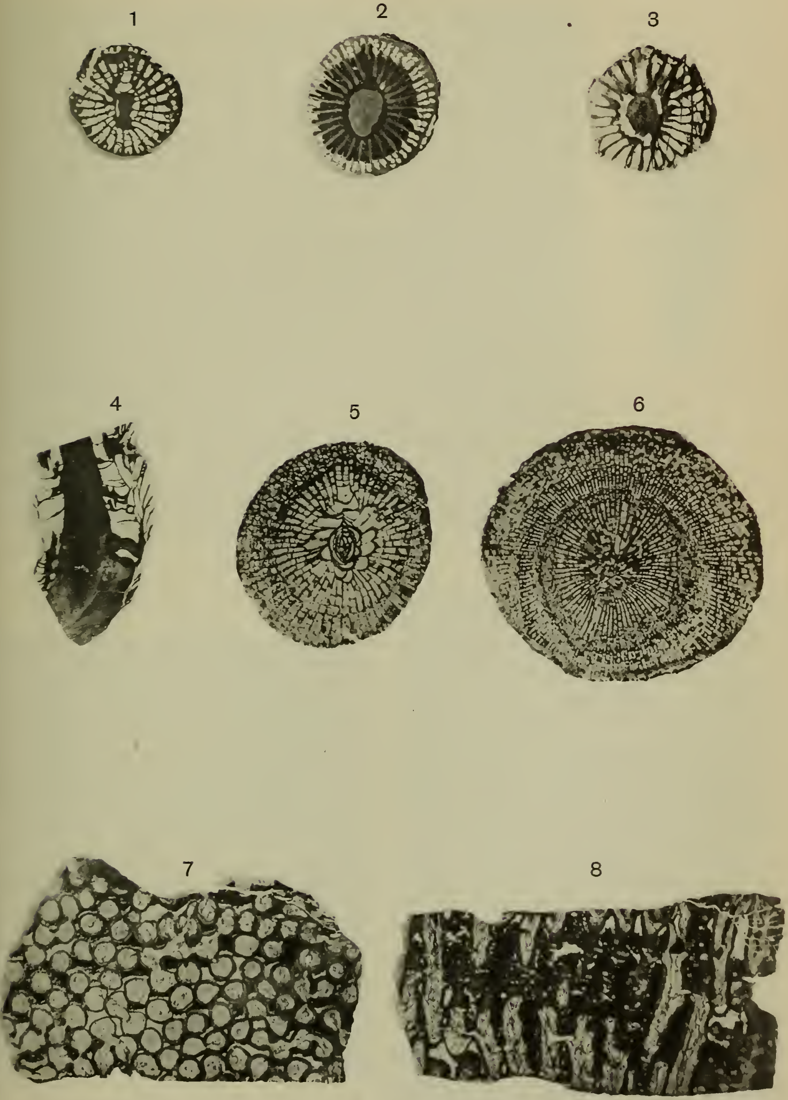
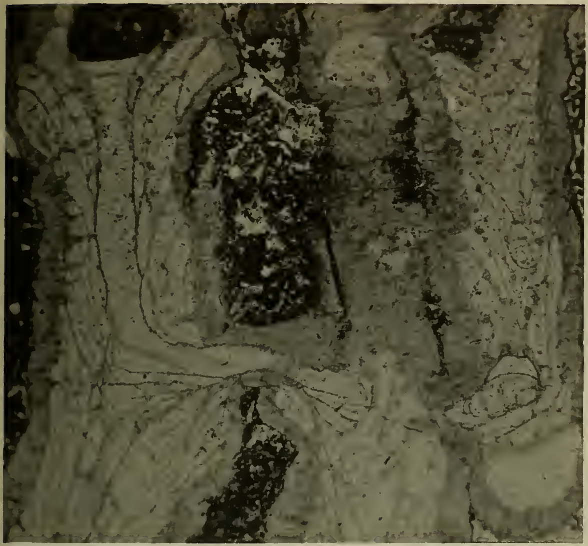


Photo.: Palæobotanical Co., Bolton. *Bemrose Ltd., Collo., Derby.*

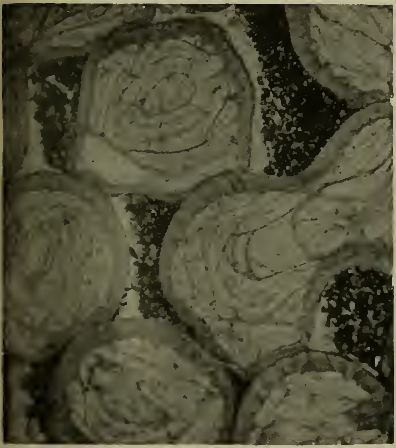
CARBONIFEROUS LIMESTONE CORALS.
(LOPHOPHYLLUM, CYATHOPHYLLUM, SYRINGOPORA.)

1



3

2



4

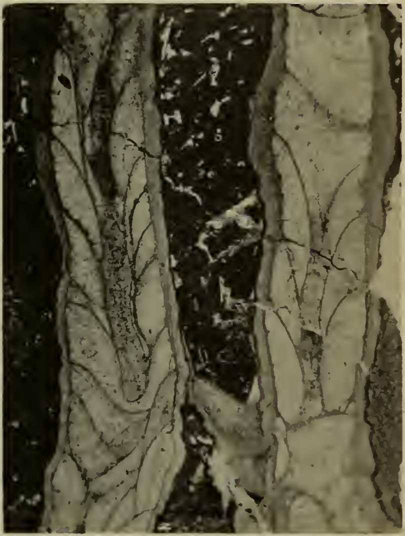


Photo.: Palæobotanical Co., Bolton. *Bemrose Ltd., Collo., Derby.*

CARBONIFEROUS LIMESTONE CORALS (SYRINGOPORA).

problems that remained for solution was the relationship of the Pendleside facies to the limestone massif. At the Thornton Quarry, Pendleside Beds apparently succeeded limestones containing an assemblage of the gens of *Zaphrentis omaliusi* that was only known elsewhere in the C zone of the Bristol district; again, at Elbolton, the Pendleside facies seemed to succeed limestones with *Carcinophyllum* and other corals that elsewhere characterized the D_1 or lower levels. Hitherto, of course, the Pendleside facies had not been recorded below the top of the D_2 zone, although there seemed to be no valid reason why it should not be found at lower levels. He had listened to the paper with great pleasure, and congratulated the Author on the energy and enthusiasm with which he was pursuing his investigations in this remarkably interesting district.

Mr. G. W. Lamplugh mentioned, with respect to the 'knolls,' that dome-like structures were very prevalent in the Magnesian Limestone between Pleasley and Langwith in Derbyshire. These domes of massive limestone, bordered by flaggy beds, were clearly due to conditions of deposition. They deserved notice in the discussion, although it would be unsafe to affirm positively that they were analogous to the Carboniferous knolls.

Prof. E. J. Garwood remarked that he had listened to the paper with especial interest, as he had made extensive collections from the district 20 years ago. He commented on the horizons from which the Author had obtained *Chonetes* cf. *comoides* and *Caninia subibicina*, as these forms only occurred in Westmorland in C, and M'Coy's type-specimen of the latter undoubtedly came from C_2. He expressed regret that no further light had been thrown by the Author on the cause of the marked change in the character of the fauna on the north and south sides of the Craven Faults.

The Author, in reply to Prof. Garwood, pointed out that the *Chonetes* cf. *comoides* mentioned was apparently the same as that figured by Davidson in pl. xlv of his Monograph of the British Carboniferous Brachiopoda. It accompanied *Productus pustulosus* and *Orthotetes crenistria*. The *Caninia subibicina* ought to be 'cf. *subibicina*,' and had been identified by Mr. R. G. Carruthers. He was much interested in the statement made by Prof. Garwood as to the marked difference in the character of the brachiopod fauna north and south of the faults, and would take care to avail himself of every opportunity for comparing the faunas.

In answer to Mr. Cosmo Johns, he held that the name 'Pendleside Limestone' should be applied to the limestone or limestones of very well-marked character which occurred in the Bowland Shales of Phillips and at the base of these shales. It was, however, sometimes used for another limestone in the Grassington District, which, in his opinion, was at a different horizon. In connexion with the knolls, he did not deny that there was a considerable thickening of the shell and coral deposits, in fact he had called special attention to that thickening as the beds were traced eastwards from Rylstone and Cracoe. Owing to the lateness of the hour, he asked to be excused from dealing with the other points raised, and thanked the Fellows for their reception of his paper.

24. Recumbent Folds *in the* Schists *of the* Scottish Highlands.[1]

By Edward Battersby Bailey, B.A., F.G.S. (Read May 25th, 1910.)

[Plates XLII–XLIV—Map & Sections.]

Contents.

I. Introduction.

The district discussed in this paper includes a considerable portion of two typical Highland counties, Inverness-shire and Argyllshire. It lies in the main between Loch Linnhe, on the north-west, and a chain of granitic intrusions which, on the south-east, connect the Moor of Rannoch with the upper portion of Loch Etive. It extends northwards to the River Spean, and southwards to Appin and Loch Creran.

The region thus defined is dissected by an intricate system of deeply cut glens, flanked by some of the loftiest mountains of Great Britain, including the giant Ben Nevis itself, 4406 feet high. The rock exposures on the mountain sides are remarkably clear, owing to the comparative absence of morainic material.

The detailed mapping of this district has recently been completed by the Geological Survey, and the results of the work will shortly be published in an official memoir. In the present paper an outline is given of the complicated tectonics of the crystalline schists.

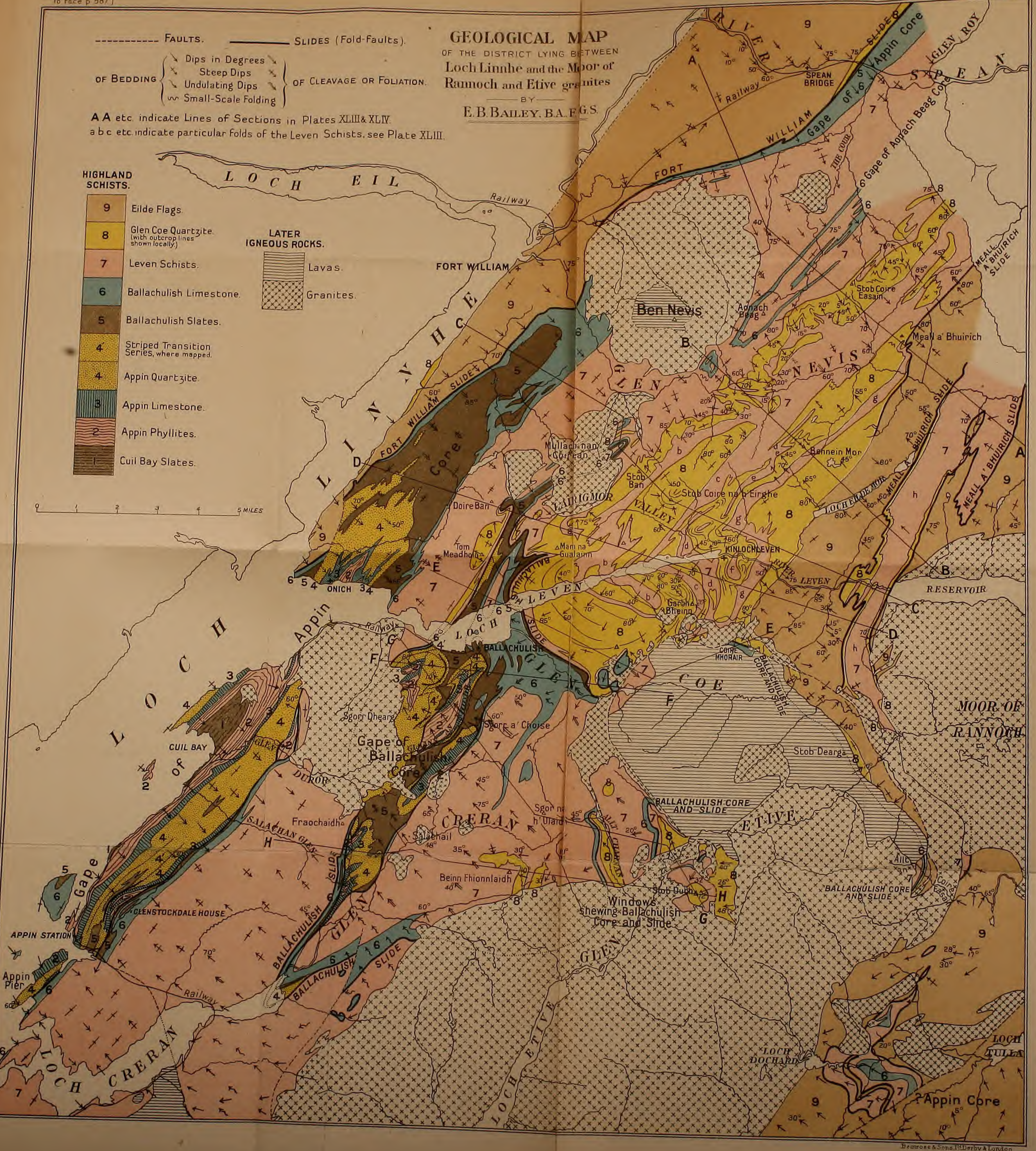
Before entering on this description brief reference may be made to the results obtained by other workers along similar lines of enquiry.

(*a*) Historical Review.

Geologists are now familiar with the researches of James Nicol [1],[2] who showed that the gneisses, which Sir Roderick Murchison had described as conformably overlying the fossiliferous strata of the North-West Highlands, are in reality separated from the latter by a powerful dislocation.

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

[2] These numerals in brackets refer to the Bibliography, § V, p. 617.


GEOLOGICAL MAP
OF THE DISTRICT LYING BETWEEN
Loch Linnhe and the Moor of Rannoch and Etive granites
BY
E. B. BAILEY, B.A. F.G.S.
Faults.
Slides (Fold-Faults).
of Bedding
Dips in Degrees
Steep Dips
Undulating Dips
Small-Scale Folding
of Cleavage or Foliation.
A A etc. indicate Lines of Sections in Plates XLIII & XLIV.
a b c etc. indicate particular folds of the Leven Schists, see Plate XLIII.
HIGHLAND SCHISTS.
9 Eilde Flags.
8 Glen Coe Quartzite. (with outcrop lines shown locally)
7 Leven Schists.
6 Ballachulish Limestone.
5 Ballachulish Slates.
4 Striped Transition Series, where mapped.
4 Appin Quartzite.
3 Appin Limestone.
2 Appin Phyllites.
1 Cuil Bay Slates.
LATER IGNEOUS ROCKS.
Lavas.
Granites.
5 MILES
LOCH EIL
LOCH LINNHE
LOCH OF CUIL BAY
FORT WILLIAM
Ben Nevis
GLEN NEVIS
RIVER SPEAN
SPEAN BRIDGE
GLEN ROY
KINLOCHLEVEN
RIVER LEVEN
LOCH LEVEN
RESERVOIR
MOOR OF RANNOCH
GLEN COE
GLEN ETIVE
LOCH ETIVE
LOCH CRERAN
GLEN CRERAN
LOCH DOCHARD
LOCH TULLA
ONICH
APPIN STATION
Appin Pier
GLENSTOCKDALE HOUSE
DUROR
SALACHAN GLEN
Fraochaidh
Salachail
Beinn Fhionnlaidh
Sgorr Dhearg
Sgorr a' Choise
Gape of Ballachulish Core
BALLACHULISH
BALLACHULISH SLIDE
BALLACHULISH CORE AND SLIDE
Windows shewing Ballachulish Core and Slide
Stob Dubh
Stob Dearg
CORE MHORAIR
FORT WILLIAM SLIDE
Fort William Core
Gape of Fort William
Appin Core
? Appin Core
Gape of Aonach Beag Core
Aonach Beag
Stob Coire Easain
Meall a' Bhuirich
MEALL A' BHUIRICH SLIDE
Beinnein Mor
Stob Coire na h-Eirghe
LOCH EILDE MOR
Stob Ban
Mullach nan Coirean
Doire Ban
LAIRIGMOR VALLEY
Tom Meadhoin
Mam na Gualainn
Garbh Bheinn
Sgor na h Ulaidh
Coire Easain
Railway
Bemrose & Sons, Ltd. Derby & London

Dr. Callaway was the first, however, to appreciate clearly that this dislocation is of the nature of a gently inclined reversed fault. He boldly applied the result of his observations, and in a section drawn to illustrate the structure of the hillside above Loch Glen Coul [2] he showed a reversed fault bringing forward gneisses for a distance of fully a mile over quartzites, fucoid beds, and limestones belonging to the Assynt Series.

During the third year of Dr. Callaway's researches, 1882, Prof. Lapworth [3] attacked the North-West Highlands, fresh from his victories in the Southern Uplands. In the latter district he had elucidated a complex system of small-scale isoclinal folding and reversed faulting, and now in the Durness-Eriboll area he found a further development of similar structures on a larger scale. He pointed out their essential similarity with those already recorded by Rogers, Suess, Heim, and Brögger in extra-British mountain regions. The names here mentioned are representative, but reference might equally well have been made to certain other workers, such as Cornet, Briart, and Gosselet, who, a few years previously, had published striking sections in illustration of the structure of the over-ridden Franco-Belgian coalfield [4].

Dr. Peach and Dr. Horne [5] began work in the North-West Highlands in 1883; they confirmed and greatly extended the results of Callaway and Lapworth, and were even able to show that one of the thrust-masses has travelled from the south-east a distance of more than 10 miles—how much more no man can say. Thus the researches of Callaway, Lapworth, Peach, and Horne raised the subject of Highland structure into the realm of large-scale tectonics.[1]

In Scandinavia, Dr. Törnebohm [7] obtained even more wonderful results. As early as 1883 he had recognized thrusting as a local phenomenon; but the main step was taken in 1888, when he adopted the conception of large-scale thrusting as a principle in the explanation of the tectonics of the Swedish Highlands. In 1896 he gathered together the results of his researches, which by this time had received the powerful support of Prof. Högbom [8], and published a comprehensive account of the great thrust which forms the eastern boundary of the highland range. Except in regard to the direction along which movement has taken place, this Scandinavian Thrust is essentially similar to the Moine Thrust of Scotland; but denudation happens to afford a fuller insight into the displacement involved, for which the astounding minimum of about 90 miles has been established.

A brief account may now be given of contemporaneous developments in the study of Alpine regions—developments with which the name of Marcel Bertrand [9] will for ever be associated. The career of this French savant runs strangely parallel with that of

[1] Thrusts have now been described on the south-eastern border of the Highland mass by Mr. George Barrow [6].

his British colleague Prof. Lapworth. During the years in which the latter was largely concerned in unravelling the facies problem presented by the Southern Uplands of Scotland, Bertrand was performing a like task in the Jura mountains, following the lead there given by 'le "sauvage" mais génial Gressly de Soleure.' Both Lapworth and Bertrand in the course of their researches were thus introduced at about the same time to the complications incident upon small-scale isoclinal folding and reversed faulting. Then turning to new fields of enquiry in 1882, both investigators came face to face with the phenomena of large-scale overthrusting, the one in the North-West Highlands, the other in Lower Provence [10].

The inconstancy of facies of sedimentary groups, which early attracted the attention of both Lapworth and Bertrand, has up to the present proved nothing else than an impediment in the development of tectonic ideas so far as Britain is concerned. In Alpine regions, however, this apparent difficulty has been, not so much surmounted, as actually turned to advantage. Suess [11] in 1875 contrasted the sediments, driven forward to build the outer folds of the Eastern Alps and Carpathians, with their time equivalents, where such exist, in the over-ridden foreland regions beyond. Bertrand, too, in his well known paper of 1884 [12], alluded to the Alpine (as opposed to Helvetian) facies of the Rhæticon thrust-mass lying in front of the Alps. Suess and Mojsisovics [13] had previously recognized the marginal superposition of the Rhæticon Alp on the neighbouring masses of Helvetian facies, but interpreted this relation by faulting and back-folding: Bertrand saw in it evidence that the entire Rhæticon is a masse or lambeau de recouvrement. His object in writing this paper was to extend the notion of large-scale thrusting to the solution of Alpine problems in general. He indicated that the blocs exotiques of the Alps may be fragments of nappes de recouvrement, and in especial he gave a new interpretation on more generous lines of the wonderful Glarus inversion, so long rendered famous owing to the researches of Escher and Heim. Bertrand's suggestions were neglected by Swiss geologists for many years, probably because he had not seen for himself the Glarus, Rhæticon, and other sections which he thus boldly re-interpreted.

In 1892 Bertrand [14] visited the North-West Highlands in the expectation, he tells us, of finding that an important difference of detail, distinguishing the sections drawn by Dr. Peach and Dr. Horne from those with which he was himself familiar in the exposures of the Alps and Provence, would vanish on closer enquiry. The feature which at the time seemed so peculiar in the North-West Highland thrusts was the complete suppression of the lower inverted limb of each recumbent anticline to which, according to Prof. Heim's idealization, the various individual thrusts should correspond.

Bertrand found that this difference was real so far as research had, at that time, revealed the structure of the two countries compared.

In the following year, however, Schardt [15], in his wonderful interpretation of the pre-Alps, made it apparent that clean-cut thrusts, similar to those of the North-West Highlands, play a very important part in the tectonics of the Alps. Schardt's researches in this connexion have furnished what is perhaps the most picturesque development of modern tectonic theory. He has shown, in fact, that the pre-Alps are a complex foreign mass of southern facies, resting upon and folded with an autochthonous foundation of local Helvetian character. Lugeon [16] in particular and many others, including the veteran Heim, have been busy of late years extending the scope of Alpine interpretation, and in their sections we may recognize every connecting link between clean-cut thrusts of North-West Highland type and others which merely modify, without definitely replacing, the lower limbs of recumbent anticlines.

But the convergence has not been all from the one side. The Scottish Highlands, now that the schists have come to be minutely studied, are yielding examples of recumbent folds which may well be compared with those of the Alps. Mr. Clough [17] has suggested the existence of flat folds with an amplitude of a mile and a half, near Lochgoilhead, in the Cowal district of Argyllshire. He has also discovered near Carrick Castle [18], farther to the south-east in the same district, another important fold which probably belongs to this category, although the sections do not suffice to indicate its true proportions. A more extensively exposed example has been described by Dr. Horne [19] from the Fannich Forest in Ross-shire, where a gently inclined core of gneiss of the Lewisian type is overlain and underlain by sedimentary schists or gneisses of the Moine type. The amplitude of the recumbent fold in this case is estimated at not less than 3 miles. Turning now to the region at present under discussion, we find the first indication of its complex structure in a description written by Mr. Maufe [20] as a result of his work in 1905. 'The structure of the district,' he says, referring to Glen Etive, 'is evidently that of a huge overfold, the limbs of which dip gently westwards and are at least 3 miles in length (from trough to crest). The quartzite which caps the hills, also forms the floors of the glens' (*cf.* Section H, Pl. XLIV).

My own work, which has been dependent at all stages upon the cordial co-operation of my colleagues, has extended Mr. Maufe's results: it has shown that structurally the whole district is an assemblage of recumbent folds, broken and entire, in certain cases not less than 12 miles in amplitude; and that these folds are by no means always in the position in which they were formed, since many of them have been subsequently rucked up and bodily involved in other isoclinal folds, which, though of minor importance, are still of considerable amplitude [21]. The fold-faults which accompany these recumbent folds, where the latter are broken, are not confined to the lower limbs of anticlines. This is a peculiar feature, which may have a considerable bearing upon the tectonic problems presented by crystalline schists in other regions besides Scotland.

I may now attempt to indicate, to some extent, my indebtedness to my colleagues.

The late Mr. Grant Wilson mapped much of the western portion of the district described. In so doing he separated several of the various lithological subdivisions referred to later, establishing among other points the existence of two distinct limestones [22]. He [23] also gave an account of the puzzling metamorphism which the schists undergo in the neighbourhood of the granite masses of the district, and, in addition to this, he drew attention to the remarkably fine folding of the quartzite exposed in Stob Ban near Glen Nevis [24]; see Pl. XLIII, Section C.

Mr. Wilson's work marked a very important advance, but one cannot pass unnoticed the results previously obtained by Macculloch. This great pioneer [25] of Scottish geology had already indicated the approximate positions of several outcrops of 'quartz-rock' 'mica-slate,' 'clay-slate,' and 'primary limestone' in the district under consideration. He had also given a detailed account of the transition zone linking the quartzite (Appin Quartzite) and slates (Ballachulish Slates) of the Ballachulish exposures. This transition zone consists, as Macculloch [26] states, of

> 'fine sandstones .... striped in endless alternations by black clay .... These belong to that quartz rock which alternates with clay slate, and show the transitions between these two substances.'

This observation of Macculloch was forgotten for a time, when other considerations led to the view that the quartzite of the Ballachulish sections rests unconformably upon the black slates; of late years, however, the reality of the passage-zone which he described has been fully confirmed. It was Macculloch, too, who first recorded the contact-alteration of the schists at the margin of the Ballachulish Granite [27].

But, to return to the recent work of the Geological Survey: Mr. Wright mapped a considerable tract of the region lying north-east of Kinlochleven, which affords in Binnein Mor especially clear examples of minor folding (Section B, Pl. XLIII). He also fixed the position of the line drawn between the Eilde Flags and the Glen Coe Quartzite near Kinlochleven (Pl. XLII), and found a pebbly horizon close to the junction of these two groups.

Mr. Anderson has continued Mr. Wright's mapping, and has traced the northward extension of the Leven Schist outcrop shown as (*h*) on the map, where it assumes a much more complex form than in the district farther south.

At an earlier date, Mr. Clough mapped a small part of the Glen Etive district. He also detected the two fold-faults bounding the Sgorr a' Choise fold (Pl. XLII), and introduced me to the sections which had been mapped by Mr. Wilson in Glen Creran. During a joint excursion [28] into districts bordering the map upon which we were primarily engaged, Mr. Clough detected the true nature of the Loch Dochard limestone and mapped the Allt Coire an Easain section.

Dr. Peach had a very brief association with the district, but with Mr. Maufe and the writer he realized the separate existence of two quartzites, pebbly and non-pebbly respectively [29]. Of these the pebbly quartzite (Appin Quartzite) was correlated by Mr. Wilson and Dr. Peach with the Schiehallion Quartzite of Perthshire [30], and was regarded by them as unconformable, owing to the fact that in certain sections it comes into transgressive contact with several distinct rock-groups. The Appin Quartzite is not peculiar in this respect, however, since all the other groups of the district are, on occasion, equally transgressive in their behaviour, and the present writer holds that the observed phenomena are due entirely to the intervention of fold-faults. It is not clear what bearing this new interpretation has upon the theory of 'the unconformable quartzite' advocated by several authors elsewhere in the Highlands, but it may be recalled that this theory of unconformity, as applied to Perthshire, has been opposed for many years by Mr. G. Barrow. It is not only in this matter that uncertainty exists. In the Summaries of Progress of the Geological Survey, correlations have been suggested between the rock-groups of the district now described and those of other parts of the Highlands (for instance, Ardrishaig and Loch Fyne). But the views expressed are certainly premature: since, until the fold-faults came to be recognized, there was great confusion even in such matters as involved strictly local correlation. Thus, for instance, the Appin Phyllites and the Leven Schists were regarded as one and the same group, and as such were correlated with the Ardrishaig Phyllites. This resulted from the extraordinary complications introduced by fold-faults in what was for some years regarded as the typical stream-section afforded by the lower part of Gleann an Fhiodh (near Ballachulish), and the tributary of this glen which lies on the north-east of Sgorr a' Choise.

Mr. Maufe has assisted me perhaps more than anyone else; in fact, this paper is the outcome of a joint traverse which we undertook last autumn to see the more important sections together. The result of this trip was the clearing up of various uncertainties, thus permitting a directness and confidence of description hitherto impossible. The main advance was the establishment of the anticlinal nature of the fold of Ballachulish Slates separating the Beinn Bhan and Gleann an Fhiodh synclines (Pl. XLIV, Sections F & G). At an earlier date I was indebted to Mr. Maufe for the identification of the Appin Quartzite outcrop at the head of Loch Creran, and the discovery of an obvious discordance along its south-eastern margin. The district actually mapped by Mr. Maufe is a large one, extending from Glen Etive to Glen Coe, and including the great recumbent fold already mentioned as the first to be recognized in this region.

In conclusion, I wish to thank Dr. Horne and Mr. Clough for the facilities which they have afforded during the investigation of this complicated tectonic problem.

(b) General Statement of the Problem.

Before entering into a detailed account of the stratigraphy and structure of the district, the main features will be set forth in outline.

The following stratigraphical sequence has been established, but whether it should be read upwards or downwards is a matter for future enquiries to decide :—

9. Eilde Flags (commonly classed with the Moine Gneisses of the Central Highlands).
8. Glen Coe Quartzite (fine-grained).
7. Leven Schists (grey phyllites and 'Banded Series').
6. Ballachulish Limestone (dark grey, with a thick cream-coloured margin against the Leven Schists).
5. Ballachulish Slates (black).
4'. Striped Transition Series (separately mapped in certain localities only).
4. Appin Quartzite (pebbly).
3. Appin Limestone (cream-coloured).
2. Appin Phyllites (with a large proportion of flaggy quartzite).
1. Cuil Bay Slates (black).

No exact measurements can be given in regard to the groups enumerated above; but even the thinnest of them, the Appin Limestone, is probably not less than 100 feet thick, while the Leven Schists, Glen Coe Quartzite, and Eilde Flags must each of them reach about 1000 feet: the other members of the sequence should doubtless be reckoned in hundreds of feet. These rough estimates refer to original thickness of deposition. Now, over wide areas, various groups are reduced to mere films, or may be entirely missing from the sequence as a result of the intensity of the folding movement to which they have been subjected; elsewhere, again, their dimensions have been mightily increased by reduplication—another aspect of the same folding process.

The details of stratigraphy, the consideration of which is deferred for the present, vouch for continuity of sedimentation during the formation of the great pile of deposit included in groups 1–8, for all these groups are linked by passage-beds. The Eilde Flags (9) also appear to be connected by a passage-zone with the Glen Coe Quartzite (8); but, in this case, it would perhaps be premature to come to a definite conclusion in regard to the nature of the junction until a larger area has been surveyed.

No feature of the stratigraphy affords a hint as to the original order of superposition of the groups tabulated above, nor does the degree of metamorphism assist in solving this difficult question. As a matter of fact, there is increasing regional metamorphism in a south-easterly direction, which affects all groups alike, so that the Eilde Flags, in the Loch Eilde Mor district, are much more highly altered than the same flags in the Fort William district. While referring to metamorphism, it is important to bear in mind that an aureole of marked contact-alteration surrounds each granite boss. In these aureoles many of the subdivisions assume very special characteristics, so much so that their definite correlation with the equivalent groups beyond the range of the granites' influence might well have proved impossible, had it not been for the wealth of connecting exposures. The limestones suffer most from this type of metamorphism, and are altered to calc-silicate hornfelses for distances ranging from a quarter to 2 miles, measured from the various granite margins.

The rocks included in Groups 1–6 occupy the gape of a great fold which has been traced from the River Spean to Appin. This fold may be conveniently termed the Appin Fold, and the rocks specified may be described as constituting the Appin Core. It will be realized at once that the definition of a fold-core by reference to any particular group of rocks is essentially arbitrary, but the convention adopted here will be found very serviceable in the description of the structure of this complicated region.

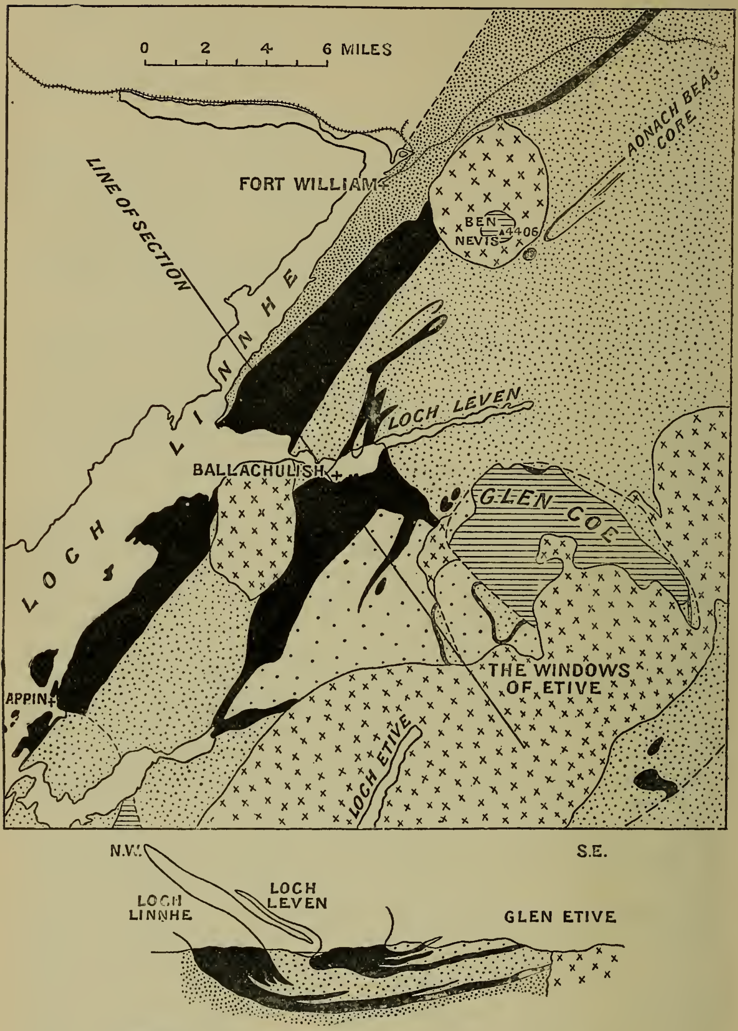
The lower limb of the Appin Fold is in large measure replaced by a very important fold-fault, or slide, as it may be called for brevity, which constitutes the north-western boundary of the Appin Core from Spean Bridge to Onich, where it goes out to sea. The evidence for this slide is most clearly displayed in the neighbourhood of Fort William, and the structure will accordingly be named the Fort William Slide.

A word of explanation is necessary, perhaps, to justify the introduction of this new term 'slide.' If there were only one type of fold-fault present in the district, one might be bold and call every fold-fault a thrust. But, as a matter of observation, it is sometimes found that complementary fold-faults have developed in the two limbs of one and the same recumbent fold (*cf.* the Fort William Slide and Meall a' Bhuirich Slide, Pl. XLIII, and several other examples, Pl. XLIV). The fold-faults, therefore, are some of them thrusts, some lags,[1] and here at present our knowledge ends. Hence a non-committal general term is unavoidable. 'Fold-fault' itself is too cumbrous for constant repetition, and accordingly 'slide' has been introduced to take its place.

Farther south-east, rocks included in Groups 2–6 are again encountered, where they form what may be termed the Ballachulish Core. The Ballachulish Fold, to which the core belongs, is in every sense analogous to the Appin Fold. Like the latter it gapes towards the north-west and closes towards the south-east, while its lower limb is in large measure replaced by a very powerful slide, known in this case as the Ballachulish Slide. The Ballachulish Core is structurally on a higher level than the Appin Core (see fig. 1, p. 594). It has a much more varied and interesting outcrop, and can be shown to behave as a highly persistent layer extending south-eastwards from its gape at Ballachulish as far at least as Allt Coire an Easain, a distance of 14 miles.

[1] Thrust is here employed in the sense of a fold-fault replacing the lower limb of an overturned anticline. Lag, based on the term lag-fault introduced by J. E. Marr [31] and A. Harker, is employed in the sense of a fold-fault replacing the upper limb of an overturned anticline. Lags have been shown in some sections illustrating the structure of Alpine regions, *cf.* L. W. Collet [32].

Fig. 1.—*Sketch-map showing the relations of the Appin and Ballachulish Cores.*



Lavas

Granites

Faults

Groups 1- 6 of the table in the text, included in the Appin, Aonach Beag and Ballachulish Cores.

Groups 7 - 9 where they structurally overlie the Ballachulish Core.

Groups 7 - 9 where they structurally intervene between the Ballachulish and Appin Cores.

Groups 7 - 9 where they structurally underlie the Appin Core.

Perhaps the most picturesque feature in connexion with this wonderful Ballachulish Core is the glimpse that we get of it through what, to borrow the illuminating Swiss expression, we may call the Windows of Etive (fig. 1 & Pl. XLII). Here, and in fact everywhere between Ballachulish and Allt Coire an Easain, the core is underlain by the Ballachulish Slide, which cuts out a great thickness of Leven Schists. This observation gives a minimum displacement of 14 miles for the Ballachulish Slide. How much greater the total displacement may be must remain a matter of conjecture for the present, and perhaps for all time: the proved displacement of the Moine thrust of the North-West Highlands is, it will be remembered, only 10 miles, but this is probably not more than a small fraction of the whole.

A third core, the Aonach Beag Core, crops out on the east of Ben Nevis (fig. 1). It occupies a structural position intermediate between that of the Appin and Ballachulish Cores, and is of quite minor importance, including in its gape the Ballachulish Limestone, alone of all the groups from 1–6.

II. Stratigraphy.

(1) The Cuil Bay Slates are preserved only in the heart of the Appin Core. Their outcrop is surrounded by an intermediate zone, characterized by intercalations of black and grey pelitic sediment, through which they merge into the Appin Phyllites. This is the only character as yet known which distinguishes the Cuil Bay Slates from the Ballachulish Slates (5) to be described presently.

Although the Cuil Bay Slates are not themselves met with in the Ballachulish Core, the marginal zone just described has been recognized in this position to the south-east of Fraochaidh, near Glen Creran.

(2 & 3) The Appin Phyllites and Appin Limestones are best considered together, as, in places at any rate, there appear to be two beds of Appin Limestone, one occurring at the margin of the pebbly Appin Quartzite (4), and the other at some little distance from this margin intercalated in the phyllitic series.

The name Appin Phyllites is used, for want of a better, to connote a group consisting of grey pelitic sediments, among which are intercalated, in many outcrops, numerous bands of flaggy fine-grained quartzite.

In the Appin Core the group is well exposed on the Onich shore, where the quartzite intercalations appear to be restricted to that portion which intervenes between the two beds of Appin Limestone already mentioned. The rest of the group at Onich consists of massive grey mica-slates. In the Cuil Bay district on the south the grey pelitic rocks are rather more sandy than on the Onich shore. Abundant quartzite intercalations are again met with as the Appin Limestone is approached, but the existence of two separate beds of the latter has not as yet been proved anywhere between Cuil Bay and Appin. Near the south-eastern margin of the core, however, for some distance south of Salachan Glen, the Appin Limestone is clearly in two distinct beds. In the Ballachulish Core the Appin Phyllites reappear in five or six independent minor folds. Though predominantly pelitic the group here, as in the Appin Core, contains a large proportion of flaggy quartzite.

The Ballachulish Granite reaches across from the Appin to the Ballachulish Core, and for a quarter of a mile on either side of this granite the more pelitic beds of the Appin Phyllites are converted into spotted cordierite-hornfelses, while the portions containing much flaggy quartzite are altered to a striped series well-nigh indistinguishable from the Striped Series (4′) intervening between the Appin Quartzite and the Ballachulish Slates.

The Appin Limestone was always suspected by Mr. Wilson to be a dolomite, as in some outcrops it does not effervesce with acids. Mr. Lightfoot has now shown that it varies in composition from a sandy magnesian limestone to true dolomite. In the field it generally weathers to a pale cream-colour with dark ribs, so that it has sometimes been called the 'tiger rock.' The dark ribs are often found to be pale in their interior when broken, but this is not always the case. Both of the beds exposed on the Onich shore (Appin Core) are of the 'tiger rock' type, and the beautiful exposures in and near the 'Marble Quarry' south of Ballachulish are also of this type. Another variety occurs, which weathers in massive beds with the faintest of blue-white tints. The bed occurring next to the Appin Quartzite near the south-eastern margin of the Appin Core, south of Salachan Glen, is of this type; while the second bed in this locality, lying farther south-east, is typical 'tiger rock.' The same massive unstriped type is also well represented in the Ballachulish Core, in proximity to the Appin Quartzite, on Sgorr a' Choise.

Where it approaches the Ballachulish Granite the Appin Limestone loses its characteristic appearance, being generally converted into a white crystalline marble or calc-silicate hornfels. In one locality it even assumes a grey colour, thus mimicking the Ballachulish Limestone (6). This phenomenon is exhibited at the southern end of the Sgorr a' Choise outcrop, in the neighbourhood of a tongue from the Ballachulish Granite, and the grey colour is found on examination to be due to finely disseminated crystals of forsterite, as in the case of some of the 'dedolomitized' Durness Limestones described by Dr. Teall from the North-West Highlands.

The repeated association of the Appin Limestone with the Appin Quartzite, in many minor folds included within the two major folds of Appin and Ballachulish, proves that the two zones are in natural conjunction. In addition to this, the limestone sometimes actually passes through a pebbly calcareous rock into the Appin Quartzite, a phenomenon which may be observed near Appin Station.

(4) The Appin Quartzite is a massive, white, false-bedded, pebbly quartzite, containing abundant pebbles of quartz and felspar.

This rock figures largely in both the Appin and the Ballachulish Cores, and everywhere its characters are the same.

The passage-zone, commonly known as the Striped Series (4′), links the Appin Quartzite with the Ballachulish Slates; it is perhaps as thick as the quartzite itself, and is certainly as widely distributed. About 500 feet of the Striped Series are seen in an unreduplicated section on the face of Sgorr Dhearg, in the Ballachulish Core south-west of the village. As the name implies, the Striped Series is characterized by an incessant alternation of white and grey quartzite and quartzitic material with dark-grey and black pelitic seams. At the one end quartzite predominates, and pebbly seams are not uncommon; at the other end black slate predominates, and pebbly seams are rare or absent. A few calcareous layers are locally found in the heart of the Striped Series.

(5) The Ballachulish Slates are black pyritous slates, generally in the condition of roofing-slates; in places, however, the slaty character is destroyed by strain-slip cleavage. They are widely developed in both the Appin and the Ballachulish Cores, where they have been extensively quarried, especially in the latter. It is interesting that these slates never show conspicuous mica-flakes, although the latter are common both in the Appin Phyllites (2) and in the Leven Schists (7). The group yields very sombre, spotted, splintery hornfelses in proximity to the Ballachulish Granite; the retention of the black colour is, however, sufficiently diagnostic.

(6) The Ballachulish Limestone consists of two parts—a black, or dark grey, sandy, banded limestone, merging into the Ballachulish Slates, and a cream-coloured sandy limestone merging into the Leven Schists.

Several clear sections showing the two parts of the limestone in natural relation are afforded by the Appin Core, and in all save the Spean section, at the northern extremity of our district, the two are continuous. In the Spean section there appears to be a partition of phyllite of the Leven Schist type. The more important sections are as follows:—East of Onich, on the hill-top above the road, the two parts of the limestone are found in contact in natural position between the Ballachulish Slates and the Leven Schists. West of Onich, on the sea-shore, the same features are repeated, save that here the cream-coloured edge of the limestone comes, through the intervention of the Fort William Slide, into contact with the Eilde Flags (9). Another excellent section, showing the passage from the grey into the cream-coloured limestone and from the latter into the Leven Schists, is afforded by the tributary burns south of Glenstockdale House, about a dozen miles south of the Onich sections just mentioned. Farther south again, on the mainland side of the hollow which almost makes an island of the Port Appin peninsula, the cream-coloured edge of the limestone is very typically exposed, passing into the Leven Schists on the one side and into the grey portion of the limestone on the other; but the latter is only partially seen.

In the Ballachulish Core the grey and the cream-coloured parts of the limestone occur together in the great spread of limestone east of Ballachulish; but in the narrow outcrop extending southwards past Sgorr a' Choise, perhaps continuously, to the Creran River near Salachail, the cream-coloured portion is alone exposed, having been dissociated from the grey as the result of sliding. This point will, of course, be dealt with further in the sequel.

No other group dons so complete a disguise in the hornfels aureoles as the Ballachulish Limestone. The character most frequently assumed is that of a flaggy, greenish-white calc-silicate hornfels. In all cases, however, save in the isolated outcrops near the border of the Etive Granite, the altered limestone may be followed beyond the hornfels zone and its identity established on the most direct evidence possible. No hesitation, therefore, need be felt in interpreting the outcrops bordering the Etive Granite in the light of their stratigraphical and structural relations, leaving their special metamorphism out of consideration.

The most extensive section of calc-silicate hornfels is afforded by the southern slopes of Glen Nevis. This is a section of very great importance in its bearing upon the tectonics of the district; and it is, therefore, satisfactory to find in it an interlaminated passage-zone developed between the main mass of altered limestone and the biotite-hornfels which, on the south-east, represents the Leven Schists.

(7) The Leven Schists.—The Leven Schists occur with two facies in the region dealt with. In by far the larger portion of the district, the main mass of the deposit is a homogeneous sandy grey phyllite or mica-schist, with a regular alternation of more and less sandy layers, resulting in a persistent but ill-defined colour-stripe. Little spangling biotites are very common, while garnets are abundant in a few localities, but elsewhere are scarce or altogether absent. Actinolite is also found, though with a far more restricted occurrence than even the garnets. Hornfelsing produces a hard spotted rock, darker in hue than the grey phyllites, yet at the same time unmistakable.

Between these phyllites and the Glen Coe Quartzite intervenes in almost every section a thick transition zone, often called the Banded Series, in which grey phyllites are intercalated with fine-grained quartzite bands and, what is more peculiar, with lead-coloured or black pelitic seams, and often with sandy calcareous beds, a foot or so thick.

In the other facies, to which reference has been made, the normal grey phyllite is restricted to a moderately thick zone in natural conjunction with the Ballachulish Limestone along the south-east side of the Appin Core; and beyond this the bulk of the deposit consists of an exaggerated banded series with an enormous development of quartzose intercalations and black pelitic seams. This peculiar facies is limited, within the region described, to a district bounded on the north by the Ballachulish Granite, on the west by the Appin Core, on the east by the Ballachulish Slide and the Etive Granite, and on the south by the edge of the map. The change does not come in suddenly, for in the road and railway-cuttings, along the shore of Loch Leven north-east of the Ballachulish Granite, there is already an unusual number of black seams. Moreover, the new characters are not strongly marked at first to the south of the granite, although they become more pronounced in this direction, until across Loch Creran they have so far developed that they would render correlation between the Leven and Creran districts impossible, were it not for the chain of intermediate exposures. In this southern region some of the black pelitic seams develop into definite beds of black slate, and some of the quartzose bands into regular pebbly quartzite; at the same time, thin beds of dark-grey limestone make their appearance.

(8) The Glen Coe Quartzite is a thick, fine-grained quartzite, non-felspathic as a rule, and free from mica. It is well bedded, and often false-bedded too. In some portions there appears to be a deficiency of siliceous cement, and the rock is then grey; more often, however, the quartzite is very white. The fine-grained character of this rock distinguishes it from the pebbly Appin Quartzite (4) described above.

(9) The Eilde Flags are gneissose quartzo-felspathic flagstones, rich in biotite and muscovite. Their great feature is their evenly-bedded structure, shown by the constant alternation of more and less micaceous layers. In the Fort William district this flagstone series is much less altered than in the type outcrop running past Loch Eilde Mor.

Pebbles are rare in the Eilde group, but Mr. Wright has recognized a quartzose pebbly zone near the western border of the Eilde outcrop. This zone contains large pebbles of quartz and felspar, and is well exposed on the two sides of the River Leven. The pebbly beds have a quartzose matrix, and, generally speaking, the flags in contact with the Glen Coe Quartzite in this neighbourhood are all markedly quartzose. The same feature re-appears in the Spean section, where the fine-grained quartzite, underlying the Appin Fold and correlated with the Glen Coe Quartzite, seems to merge into the flagstone series on the north-west. Here, again, pebbles of red felspar have been found in the quartzose beds near the junction, but they are not prominent.

In the Spean, away from the actual junction with the quartzite, there is a belt of flags with rather more pelitic material than is usual in the Eilde group. This belt continues to run south-southwestwards, alongside of the Fort William Slide, after the disappearance of the Glen Coe Quartzite, and finally goes out to sea west of Onich. In Fort William itself some beds of hard black schist occur in the flags—apparently as an integral portion of the group.

III. Tectonics.

(*a*) The Appin Core.

The Appin Core has been proved to be a fold-core, and not a mere stratigraphical intercalation, by the mapping of its component groups, 1–6. The evidence is especially clear between Onich, where the core is composed of all the groups from the Appin Phyllites (2) to the Ballachulish Limestone (6), and Glen Nevis, where the core consists of the Ballachulish Limestone (6) and nothing else. Mapping also renders it evident that the fold-core is of complex isoclinal structure, since the outcrops of the various subdivisions zigzag in and out of one another, although the dips observed are almost invariably directed towards the south-east at high or moderate angles.

Another point firmly established is that the Appin Core is synclinal in form along the course of its outcrop in the present district, since

(1) its synclinal form is clearly exposed on the steep southern face of Glen Nevis, where the Ballachulish Limestone (6) emerges from beneath the Ballachulish Slates (5)—see Pl. XLIII, Section C; and

(2) the filling-up of the fold-core between Glen Nevis and Onich is apparently determined by a constant gentle south-westerly pitch, which is indicated in the featuring of the hills everywhere between these two localities.

The application of the terms 'anticline' and 'syncline' in folded regions.—It is important to realize that the Appin Core has been proved to be synclinal in form only, as has been said above, along the course of its outcrop in the district here described. At a distance from this outcrop it probably is sometimes anticlinal and sometimes synclinal—for it is likely that the axial plane of the fold is undulatory, so that sometimes the core will gape downwards and sometimes upwards. This peculiarity of recumbent folds in general is clearly illustrated in several of the sections appearing in Pls. XLIII & XLIV: for instance, Section G.

In describing a folded region, therefore, the terms 'anticline' and 'syncline' must always be employed with a local qualification, although this latter need not be explicitly stated, except in cases where otherwise it would not be clearly enough implied in the context. As a larger and larger district comes under observation the minor ups and downs of the recumbent folds assume their true proportions, and appear almost as accidents in the great scheme of mountain-structure; but in the first instance the local details are all important, especially when, as in the Highlands, the work has to be done in the absence of fossils.

The Fort William Slide.—The regularity in the development of the Appin Core between Onich and Fort William fails at once, as soon as we pass beyond the outcrop of the Ballachulish Limestone (6). On the south-east this core is succeeded by a great thickness of Leven Schists (7), while on the north-west it is flanked by no less a thickness of flags which have been described already as belonging to the Eilde Group (9): see Pl. XLIII, Sections A & D.

In the Onich district, where the core is deep enough to include all groups from 2 to 6, it might be argued that the flags on the north-west are merely the disguised representatives of the Leven Schists, emerging from beneath the syncline with a new facies; but on the slopes above Glen Nevis no such explanation can be maintained, since the core here contains only the Ballachulish Limestone, and yet the contrast between the Leven Schists on the one side and the flaggy series on the other is as marked as ever.

We are thus driven to postulate a fold-fault or slide as the north-western boundary of the Appin Core between Fort William and Onich—a slide which cuts out the Leven Schists (7) and Glen Coe Quartzite (8), and brings the Eilde Flags (9) into conjunction with the Ballachulish Limestone (6). This inference is greatly strengthened by a detailed examination of the junction-line. It is found that

(1) the Leven Schists and Glen Coe Quartzite are not always entirely missing, for they are locally represented in a very attenuated, or, as Swiss geologists say, a 'laminated' form; and

(2) the Ballachulish Limestone itself, about 3 miles north of Onich, suffers a similar attenuation (Pl. XLIII, Section D), and for a space is entirely absent.

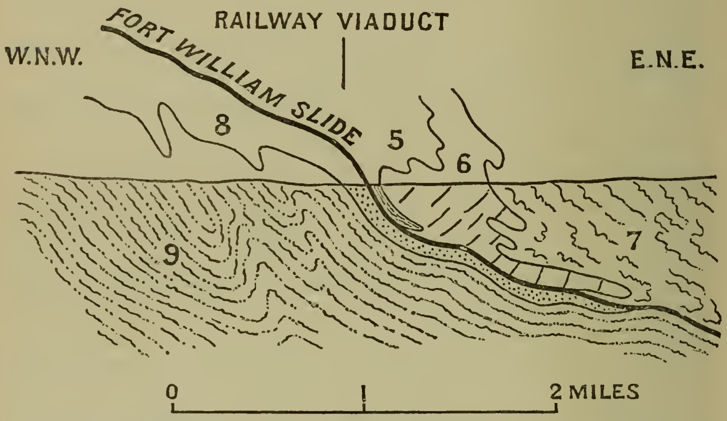
The type section of the Fort William Slide is afforded by the river that drains westwards from the Lairigmor Valley. The slide is twice exposed in the bed of this river, owing to normal faulting; but in the down-stream exposure the limestone is only just seen before it is cut out by the fault which is responsible for the repetition of the section.

Both Leven Schists and Glen Coe Quartzite, with a thickness of about 10 or 20 feet each, are here represented in their natural position between the limestone and the flags. The quartzite has a more flaggy structure than usual, and minute examination reveals three or four instances of very gradual transgression of one division-plane across another. But, although the whole of the attenuated quartzite, from its banded edge against the Leven Schists to its contact with the Eilde Flags, is laid bare in the river, there is no plane marked out by special signs of shearing, much less by any overt evidence of disruption.

It is, in fact, a feature, not only of the Fort William Slide, but also of by far the greater number of the slides of this district as a whole, that no one could possibly suspect their importance from a mere examination of the slide-plane itself. It seems probable, too, that in almost every case sliding has not been confined to a single isolated plane, but rather has been distributed over a host of close-set parallel planes; doubtless, too, sliding has been associated, to an important extent, with phenomena of plastic deformation. In this way we can account for the simultaneous thinning of neighbouring groups of rocks in connexion with these slides—a phenomenon often observed.

North of Glen Nevis the Fort William Slide suffers a local displacement to the west, obviously determined by movements[1] accompanying the introduction of the Ben Nevis Granite. For a short distance along the outcrop of the slide, thus displaced, the Ballachulish Limestone has almost disappeared from the section, permitting the Leven Schists to approach within a foot or so of the outcrop of the Eilde Flags. A little farther on, however, the Ballachulish Limestone re-appears in force, once more to separate the two (Pl. XLIII, Section A); then the Glen Coe Quartzite begins to show, intervening between the limestone and the flags; and finally in the Spean, where both limestone and quartzite are strongly developed, their outcrop is separated by a narrow strip of the Ballachulish Black Slates (fig. 2).

Fig. 2.—*Horizontal section showing the Fort William Slide in the Spean Valley.*



[5=Ballachulish Slates; 6=Ballachulish Limestone; 7=Leven Schists; 8=Glen Coe Quartzite; 9=Eilde Flags.]

The following section is met with in the Spean near the railway viaduct—from north-west to south-east—Eilde Flags (9), Glen Coe Quartzite (8), Ballachulish Slates (5), Ballachulish Limestone (6), and lastly Leven Schists (7). Were it not for the symmetrical development of the Appin Core between Glen Nevis and Onich, it would be hard indeed to realize that the Ballachulish Slates in this section occupy the heart of a synclinal fold, rendered asymmetrical through the operation of a fold-fault.

A slide complementary to the Fort William Slide has been detected near the south-eastern limit of the Appin Core, in

[1] Mr. H. B. Maufe points out that the displacement may perhaps be due to the local sagging down of the schists at the granite margin [33].

that portion of the outcrop of the latter which lies between the Ballachulish Granite and the southern limit of the map.

Near the margin of the granite local deflection of the outcrop of the Appin Core, as also intense contact-alteration of the sediments, renders the geologist's task one of unusual difficulty; but, on passing to the south of Glen Duror, these complications are soon left behind.

Suppose, then, that we enter the Appin Core somewhere in the vicinity of Glenstockdale House, about 2 miles north-east of Appin Station. After leaving the Leven Schists (7) we first meet with the Ballachulish Limestone (6), and after this with a narrow belt of the Ballachulish Slates (5). So far all is as regular as between Onich and Fort William, but progressing farther into the heart of the core we fail to encounter the Striped Transition Beds (4′), and instead step directly on to the massive pebbly Appin Quartzite (4), or, according to the locality, on to the Appin Limestone (3) or even the Appin Phyllites (2). We have, in fact, passed over an important slide, which has the effect of suddenly deepening the Appin syncline—in this feature agreeing with the Fort William Slide, although the latter occurs on the other side of the fold. It is obvious, then, that the two slides are complementary, and that they combine to give to the Appin Core increased freedom of advance, or relative advance, into the heart of the other sedimentary masses which lie above it, below it, and in front of it in a south-easterly direction.

Other examples of slides complementary to the Fort William Slide will be noticed in the sequel; the Meall a' Bhuirich Slide (Pl. XLIII) is a good example. The Ballachulish Slide is, however, homologous with the Fort William Slide (compare Sections C & H, Pls. XLIII & XLIV).

(*b*) The Aonach Beag Core.

In the district so far examined the Aonach Beag Core consists entirely of a thick limestone which is generally in the condition of a flaggy, greenish-white, calc-silicate hornfels. The limestone has, however, escaped contact-alteration in some of the sections east of the Cour, and is there found to be very sandy and impure in composition and anything from pale grey to cream in colour.

The limestone of the Aonach Beag Core is correlated with the Ballachulish Limestone for the following reasons:—

(1) It is linked with the Leven Schists through transition beds, and is of the same type as that portion of the Ballachulish Limestone which is similarly connected.

(2) It nowhere intervenes, structurally speaking that is, between an outcrop of the Ballachulish Limestone and one of the Glen Coe Quartzite. Thus the Leven Schists, in contact with the Ballachulish Limestone of the Appin Core, pass beneath the syncline holding the Aonach Beag Limestone, and connect directly with the Glen Coe Quartzite beyond (Pl. XLIII, Section A).

The main feature of the Aonach Beag Core is the degree to which it has suffered from secondary disturbance. The core has been treated as a bed and has been folded into a syncline, which descends with highly inclined sides to a depth of probably not less than 2000 feet (fig. 3 and Pl. XLIII, Sections A–C). Once a fold-core has been buckled in this fashion, it is obvious that its development, as a fold-core, must have come to an end. Henceforward its rôle in the scheme of mountain-building must have been entirely passive.

The secondary folding of the Aonach Beag Core has been accompanied by the production of a very striking vertical strain-slip cleavage, which affects a belt of country about a mile wide. This strain-slip cleavage cuts and displaces quartz-veins in the

Fig. 3.—*Looking up Glen Nevis from Stob Ban.*

[The Aonach Beag core of Ballachulish Limestone folded into a syncline is well seen in Aonach Beag, 4059 feet above sea-level, and also in the low hill in the middle distance.]

schists which it traverses; it is, therefore, analogous in behaviour to the secondary strain-slip cleavages described by Mr. Clough [34] and Mr. Wright [35] from Cowal and Colonsay respectively. In agreement with the views expressed by these authors, it would seem that the quartz-veins in the present instance were formed in connexion with the development of the Aonach Beag Core, and were buckled and broken when the latter suffered its subsequent corrugation.

(*c*) The Ballachulish Core.

In the ridge extending north-westwards from Stob Ban the continuation of the Aonach Beag syncline is clearly exposed, and is followed on the south-east by a second syncline involving a portion of the Ballachulish Core (Pl. XLIII, Section C)[1]; the distance

[1] The Ballachulish Core is here shown as distinct from the Aonach Beag Core, since it is fuller than the latter, although it lies farther to the south-east, in which direction it unquestionably closes.

between the two synclines is about half a mile, measured across the strike. In the second syncline, as in the first, a folded limestone (calc-silicate hornfels) is encountered, with Leven Schists above and below; in this case, however, the limestone itself is in two layers, separated by a parting of hornfelsed black slates. The section of the syncline on the hillside reads as follows:—

Thick Leven Schists in the heart of the syncline.
Upper layer of calc-silicate hornfels.—100 feet.
Black slate hornfels.—100 feet.
Lower layer of calc-silicate hornfels.—100 feet.
Basement of thick Leven Schists, in contact at both sides with Glen Coe Quartzite.

The black slates in the middle of this section are undoubtedly part of the black Ballachulish Slates (5), since their outcrop has been followed continuously from Stob Ban—save for the unimportant interruptions of the Mullach nan Coirean Granite and the waters of Loch Leven—to Ballachulish itself. Here, then, there can be no question but that a folded core of Ballachulish Slates, separated by Ballachulish Limestone from Leven Schists above and below, has been bent into a sharp secondary syncline.

It is with a feeling of rare exaltation that the geologist, after satisfying himself of the reality of this syncline, into which the Ballachulish Core is thrown, climbs back to the summit of the ridge and, map in hand, sits down to consider the consequences. This syncline, in fact, gives an insight at once into the synclinal disposition of the Ballachulish Core through all the district lying to the south. Its continuation can be recognized with certainty on the map south-west of the outcrop of the Mullach nan Coirean Granite (Pl. XLII). Beyond this it is joined by two other similar synclines on the slopes of Mam na Gualainn, and then crossing Loch Leven (fig. 1, p. 594) it expands into a great basin-shaped structure, measuring no less than 14 miles across.[1] The heart of this basin is occupied by Leven Schists; but the map shows how the Ballachulish Limestone appears from beneath this covering in the Windows of Etive (Pl. XLIV, Sections G & H), and how, too, the Leven Schists were themselves originally overlain by a great return fold of Glen Coe Quartzite, the remnants of which now cap the southern hills (Pl. XLIV, Section H). Throughout all this wide extent of country the Ballachulish Core persists: its gape crops out between Ballachulish and Loch Creran, while its taper end, not yet closed, is seen far away to the east in Allt Coire an Easain (Pl. XLII).

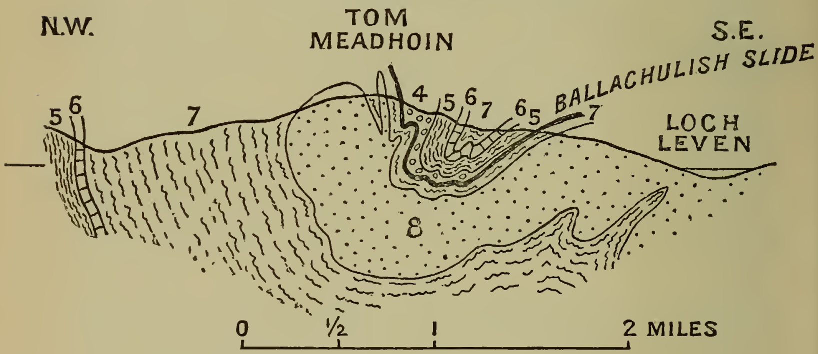
The Ballachulish Slide.—Once attention is given to details, it is found that sliding has played an essential part in the development of this wonderfully extensive and attenuated fold-core; several

[1] These 14 miles include the downthrown portion of the basin within the cauldron subsidence of Glen Coe. The latter is a great oval subsidence, which has been so recently described [36] that its existence is taken for granted in the following pages.

slides have been identified, but one of them—the Ballachulish Slide—is especially important. South of the Lairigmor Valley indeed, every section which shows the relations of the Ballachulish Core to the underlying rock-masses shows also the Ballachulish Slide at the base of the core. The effect by which this slide is recognized is the attenuation of a large part of the lower limb of the Ballachulish Fold, leading in many cases to the total disappearance of one or more recognizable subdivisions.

The best introduction to the study of slide phenomena is afforded in the district lying between the Lairigmor Valley and Loch Leven. Here it may be observed at once that the Ballachulish Slide certainly developed in the Ballachulish Fold before the latter was bent into the complex secondary syncline lying west of Mam na Gualainn (Pl. XLIII, Section D), since, in every section, the western and eastern outcrops of the lower limb of the Ballachulish Fold show precisely analogous phenomena of attenuation. Three groups are affected, to wit: the Leven Schists (7), the Ballachulish Limestone (6), and the Ballachulish Slates (5).

Fig. 4.—*Horizontal section showing the relation of the Ballachulish Slide to the Tom Meadhoin fold.*



[4=Appin Quartzite; 5 Ballachulish Slates; 6=Ballachulish Limestone; 7=Leven Schists; 8=Glen Coe Quartzite.]

The attenuation of the Ballachulish Limestone and Slates in connexion with the Ballachulish Slide in this district is especially evident where, for a space of about a couple of miles, the pebbly Appin Quartzite (4) occupies the gape of the fold. Between the outcrop of this quartzite and the Leven Schists on the north-west, the limestone and slates are reduced to a few feet in thickness, except where in certain places they have been entirely (see fig. 4, above) cut out. In striking contrast with this attenuation, the same divisions are strongly developed on the other side of the pebbly quartzite, where they enclose a small outlier of Leven Schists (fig. 4) in the heart of the secondary syncline to which reference has already so often been made.

In the eastern outcrop of the lower limb of the Ballachulish Fold, repeated by the syncline, the attenuation of the limestone is equally apparent in all sections. In most exposures of this outcrop, however, there is no chance of distinguishing Ballachulish Slates belonging to the lower limb from those belonging to the upper limb, until, close to Loch Leven, the taper end of the core of the Appin Quartzite peeps through; the quartzite here rests directly upon the diminished representatives of the Leven Schists: that is, at this point, both limestone and slate have been cut out entirely by the Ballachulish Slide (Section E, Pl. XLIV, shows this relation continued to the southern shore of Loch Leven).

The phenomena attendant upon the attenuation of the Leven Schists in connexion with the Ballachulish Slide are perhaps even more instructive than those just recorded with respect to the Ballachulish Slates and Limestone. On the north-west of the outcrop of the Ballachulish Core lies a thoroughly well-exposed anticline of Glen Coe Quartzite, forming Tom Meadhoin (fig. 4). The quartzite here is separated from the limestone, black slate, and pebbly quartzite of the Ballachulish Core by a mere fringe of Leven Schists, in one extreme case (Pl. XLIII, Section D) reduced to 30 feet in thickness. In spite of this, the same Leven Schists, where they sweep round the nose of the Tom Meadhoin anticline, occupy the surface of the country on the north-west for an uninterrupted distance of a mile, and build mountains measuring 2000 feet in height from base to summit. Clearly, if there were no other evidence, we should still have to postulate a slide along the south-eastern margin of the Tom Meadhoin anticline to account for so great a discrepancy.

A glance at Sections D–F (Pls. XLIII & XLIV) shows that the Tom Meadhoin (Doire Ban) fold of Glen Coe Quartzite, closing to the north-west under the Ballachulish Slide, is the precise complement of the Appin fold of Ballachulish Limestone, etc. (Pl. XLIII, Section C) closing to the south-east above the Fort William Slide.

The Ballachulish Slide traced from Loch Leven to Allt Coire an Easain.—Crossing Loch Leven, we find that the two outcrops of the Ballachulish Slide begin to diverge widely. The eastern outcrop sweeps up Glen Coe, following round the nose of a steeply pitching anticline of Glen Coe Quartzite (Pl. XLIV, Sections E & F), and only separated from the latter by the banded portion of the Leven Schists. This banded series (part of Group 7) is overlain directly by the Ballachulish Slates (5), except at the shore, where a thin band of Appin Quartzite (4) intervenes (Pl. XLIV, Section E).

The Ballachulish Slates dip south-westwards beneath a thick mass of Ballachulish Limestone, evidently much reduplicated by folding (Section F), and this in turn passes beneath a still thicker covering of Leven Schists extending away towards Glen Creran and Glen Etive. Farther up Glen Coe, beyond the boundary-fault of the cauldron subsidence, these overlying Leven Schists are encountered thrown down against the limestone and quartzite outside (Pl. XLIV, Sections E & F).

The schists are then hidden for a space beneath the Glen Coe Lavas, but reappear in Coire Mhorair 2 miles farther north-east (Section E). Here the Ballachulish Limestone (6) is well exposed. It is of considerable thickness, and dips steeply away from 10 feet of the black Ballachulish Slates (5), which in turn are separated by 50 feet of the grey Leven Schists (7) from a thick development of the Glen Coe Quartzite (8). The section here is at once so special in its characters, and so precisely similar to that which has been traced up Glen Coe to the boundary-fault of the cauldron, that there can be no hesitation in recognizing the Ballachulish Slide in the boundary-plane between the black and the grey pelitic rocks defined above as Ballachulish Slates and Leven Schists respectively.

Again the schists are hidden to the east beneath the lavas, and the first exposure of them in this direction belongs to the Eilde Flags (9), striking south-eastwards parallel to the outcrop of the base of the volcanic group. Now, outside the fault the Eilde Flags are next-door neighbours of the Glen Coe Quartzite (8); it is therefore reasonable to suppose that the continuation of the outcrop of the latter, seen in Coire Mhorair on the north-west, is just hidden beneath the base of the lavas. This view is confirmed at the foot of Stob Dearg, where the quartzite emerges, in good form, running side by side with the Eilde Flags until once more overstepped by the lavas still farther south-east. Beyond this overstep it reappears in Allt Coire an Easain, precisely in the position in which it might have been expected. Here the quartzite is very thin, and the section is as follows:—

Breccias of Volcanic Group.
Thick hornfelsed phyllites (Leven Schists, 7).
Thin calc-silicate hornfels (Ballachulish Limestone, 6).
Thin quartzite (Glen Coe Quartzite, 8).
Eilde Flags, 9.

It seems certain

(1) that the thick phyllites mentioned above belong to the thick covering of Leven Schists which overlies the Ballachulish Limestone in the Glen Coe section outside the fault;

(2) that the limestone is a continuation of the Ballachulish Core; and

(3) that the further attenuation of the rocks beneath this limestone, including a marked reduction of the Glen Coe Quartzite, is the result of the Ballachulish Slide.

The Ballachulish Slates are absent in this section, and the Ballachulish Limestone itself is much thinner than in Glen Coe; but these circumstances are scarcely surprising, considering that Allt Coire an Easain is 11 miles distant from even the nearest point of the gape of the Ballachulish fold at Ballachulish.

The Windows of Etive.—Glen Etive and its tributary valleys afford us a glimpse of the Ballachulish Core in its underground extension, midway between Ballachulish and Allt Coire an Easain (Pl. XLIV, Sections G & H). About 1500 feet of grey phyllites of the Leven Schist group (7) here overlie upwards of 100 feet of calc-silicate hornfels, representing the Ballachulish Limestone (6); directly beneath the latter comes a comparatively thin series consisting of the banded portion of the Leven Schists (7) —the thick phyllitic portion is entirely absent,—and then in natural sequence appears the Glen Coe Quartzite (8), forming the floor of the valleys where not cut out by granite.

When it became obvious, from work in the districts lying to the north, that through these Windows of Etive the Glen Coe succession[1] was again exposed to view, Mr. Clough and the writer set out for Allt Charnan, to see whether anything in the nature of an actual break could be detected where theory pointed to the existence of the Ballachulish Slide. The exposures are exceptionally good, and it was found, upon minute investigation, that a plane of discordance separates the calc-silicate hornfels from the banded series below. This plane is described by Mr. Clough as being less marked by any appearance of disruption than the well-known thrusts of the North-West Highlands, resembling rather an exaggerated plane of strain-slip cleavage. It runs for the most part parallel to the bedding and foliation-planes of the schists above and below, but sometimes it obviously transgresses these structures at a slight angle. Occasionally, too, small flat isoclinal folds occur, which affect the schists above the plane and not those beneath, and *vice versâ* (see fig. 5, p. 610). At other times, however, there is evidence for the isoclinal folding of the plane itself, which adds materially to the general complication.

It cannot be claimed that any appearance of excessive shearing characterizes this plane, along which, it will be remembered, a displacement of more than 14 miles is believed to have occurred. There is nothing, so far as we could see, to distinguish it from strain-slip planes elsewhere, which have a displacement at the most of a few inches or yards.

As has already been mentioned, Mr. Maufe [20] pointed out in 1906 that the Glen Coe Quartzite of the Etive district not only floors the valleys, but also caps the hills, being repeated in a great recumbent fold. This feature is illustrated in Sections G & H (Pl. XLIV), of which Section H is especially interesting, since it shows how in Beinn Fhionnlaidh the upper layer of quartzite is bent back upon itself and in turn overlain by yet another fold of the Leven Schists.

The gape of the Ballachulish Fold between Loch Leven and Loch Creran.—The Ballachulish Slide is probably

[1] The band of Ballachulish Slate is absent in Glen Etive, but otherwise the sections are essentially identical.

Fig. 5.—*Crag on the south-west side of the Allt Charnan glen.*

[Calc-silicate-hornfels (Ballachulish Limestone) lying discordantly, through the intervention of the Ballachulish Slide, upon the banded quartzo-phyllitic series of the Leven Schists. Redrawn by Dr. B. N. Peach, F.R.S., from a field-sketch made by the author.]

in no section a single isolated plane, and where its western outcrop is exposed on the Ballachulish shore of Loch Leven, about a mile west of Ballachulish, it is so conspicuously double that its position on the map has been indicated by two close-set parallel lines. Some 40 feet of the grey portion of the Ballachulish Limestone occur sandwiched in between the two planes of the slide thus separately shown. On the north-west the limestone is bounded by the banded edge of the Leven Schists and Glen Coe Quartzite (7 & 8), and on the south-east by the Striped Transition Series (4′) of the Appin Quartzite.

The gape of the Ballachulish Core is particularly wide in this neighbourhood, extending south-eastwards from the double slide just described to Sgorr a' Choise, a distance of about 3 miles. It is also highly complex, including three minor folds—the Beinn Bhan, the Gleann an Fhiodh, and the Sgorr a' Choise synclines. In the case of each of these three folds the pitch is so steep that it gives no clue in regard to the synclinal structure shown in Sections F & G (Pl. XLIV). Fortunately, however, the complementary fold separating the Beinn Bhan and the Gleann an Fhiodh synclines is cut obliquely across in Sgorr Dhearg, where its anticlinal structure is revealed as clearly as can be desired in the face of a cliff.

The anticline just mentioned brings up the Ballachulish Slates (5) in full force from beneath the Striped Series (4′). Thus a striking contrast is furnished between the two sides of the Beinn Bhan syncline: for, as already indicated, on the north-west side of this syncline the black slates are entirely absent, and the Striped Series (4′) comes into direct contact with Ballachulish Limestone (6) across one of the two main branches of the Ballachulish Slide.

The disappearance of the Ballachulish Slates against the Ballachulish Slide at this point (Pl. XLIV, Sections F & G) is, of course, merely a continuation of what has been described to the north of Loch Leven (Section E). It may advantageously be compared with the disappearance of the Leven Schists against the Fort William Slide (Pl. XLIII, Section C).

In its northern development the anticline separating the Beinn Bhan and Gleann an Fhiodh folds is an essentially symmetrical structure, throwing off on either side the Striped Series (4′), the Appin Quartzite (4), the Appin Limestone (3), and the Appin Phyllites (2) (*cf.* Section F in Pl. XLIV, with the map, Pl. XLII). Farther south, however, the south-eastern limb of this anticline is in part replaced by a slide which successively cuts out the Striped Series (4′), the Appin Quartzite (4), and the Appin Limestone (3). A glance at Section G shows that this slide (S′) is precisely homologous to the Ballachulish Slide (B.S.), since it occupies the same position in regard to the Gleann an Fhiodh syncline as the Ballachulish Slide holds with respect to the Beinn Bhan syncline farther north-west.

The next important slide encountered (S″, Section G) forms the south-eastern boundary of the Gleann an Fhiodh syncline. Its presence is very clearly manifested in an attenuation of the Appin

Quartzite and Striped Series, leading, in places, to an actual disappearance of these two groups. Reference to Section G shows that S″ is not homologous, but complementary, to its neighbours S′ and the Ballachulish Slide beyond.

Another slide (S‴, Sections G & H), belonging to the complementary series, bounds the Sgorr a' Choise fold on the south-east. This slide was first detected by Mr. Clough at the very beginning of our knowledge of the existence of such structures in the district. He found it in the burn section at the northern foot of the Sgorr, where its presence is indicated (1) by the direct conjunction of the cream-coloured portion of the Ballachulish Limestone with the Ballachulish Slates on the north-west; and (2) by definite, though none too conspicuous, evidence of shearing accompanied by disruption.

At the summit of Sgorr a' Choise Mr. Clough showed that the continuation of this slide (S‴) was further marked by the attenuation of both the Ballachulish Slates and the Appin Quartzite. These two groups, developed in force on the north-west side of the Sgorr a' Choise Fold, are reduced to about 3 feet each in thickness, where, passing round the nose of the fold, they intervene between the cream-coloured edge of the Ballachulish Limestone on the one side and the white Appin Limestone on the other.

Attention must now be directed to one of the main features characterizing the illustrations included in Pl. XLIV. In Sections F–H of this plate the various slides affecting the Ballachulish Core are indicated as sharing in the general folded structure of the core itself. Except in the case of the Ballachulish Slide, this assumption has not been justified by direct evidence, owing, probably, to the extreme difficulty of following the minor slides from point to point.

The Glen Creran development of the gape of the Ballachulish Core (Pl. XLIV, Section H) is very similar to that just described.

The Ballachulish Slide is again conspicuously double, including between the two planes which have been mapped a thick development of the grey portion of the Ballachulish Limestone, associated in places with outcrops of the Ballachulish Slates. On the north-west this grey limestone comes into direct contact with the banded portion of the Leven Schists; on the south-east its regular outcrop marches side by side with a folded complex of Appin Quartzite, Limestone, and Phyllite. The Appin Phyllites in many exposures contain thin black seams indicating the presence of the transition series which connects this phyllite group (2) with the Cuil Bay Slates (1).

The gape of the fold is narrower than it is farther north, and there is nothing in Section H to correspond with the Beinn Bhan syncline. The continuations of the Gleann an Fhiodh and Sgorr a' Choise synclines, or equivalent structures, are, however, clearly recognizable.

Farther south in Glen Creran the Ballachulish Core becomes still more restricted, and here the details of its constitution are not clearly understood.

The Ballachulish Core between Loch Creran and the margin of the Etive Granite.—On reaching Loch Creran the outcrop of the Ballachulish Core doubles back on itself, and continues thus in a north-easterly direction until lost sight of at the margin of the Etive Granite. In most sections in this part of its course, the core consists entirely of calc-silicate hornfels, representing the Ballachulish Limestone resting, through the intervention of the Ballachulish Slide, directly upon the banded portion of the Leven Schists beneath. Near the Loch, however, Ballachulish Slates and Appin Quartzite enter into the constitution of the core. The quartzite is separated from the banded Leven Schists outside by a thin layer of calc-silicate hornfels, on the two sides of which there is, in some sections, a definite discordance of strike. It should be pointed out that this is the only instance known of a conspicuous discordance in connexion with any one of the big slides of the whole district now under consideration.

It may be safely assumed that the return outcrop of the Ballachulish Core and Slide just described is determined by the same synclinal folding as that which is in large measure responsible for the reappearance of these structures farther east in Allt Charnan and the other Windows of Etive (Pl. XLIV, Sections G & H).

The apparent absence of the Ballachulish Slide in sections north of the Lairigmor Valley.—Now that the Ballachulish Core has been described in the whole of its known extent, it is obvious that everywhere south of the Lairigmor Valley it is underlain by the Ballachulish Slide. Further, in all sections between Tom Meadhoin and Allt Coire an Easain (14 or 15 miles distant from one another, measured across the strike) this Ballachulish Slide cuts out much the larger portion of the thick Leven Schist Group, so that the displacement along the slide must be fully 14 miles.

Under these circumstances, it is inconceivable that the slide suddenly dies out along the strike on the north side of the Lairigmor Valley. Rather, we must assume that it really continues, although in this direction it becomes unrecognizable. Fig. 4 (p. 606) shows that the fold of Glen Coe Quartzite, which in the sections south of the Lairigmor Valley displaces so large a portion of the Leven Schists from beneath the Ballachulish Core, closes in Tom Meadhoin (see also Doire Ban, Section D, Pl. XLIII, & Section E, Pl. XLIV). Now, if exposures were available, no matter how short a distance to the west of this hill, they would show the Ballachulish Core resting upon a thick mass of Leven Schists; and if, in addition to this, the main sliding happened to be confined to the Leven Schists, it might well become unrecognizable, just as in the actual sections lying north of the Lairigmor Valley.

The Ballachulish Limestone is in the condition of a calc-silicate hornfels in these northern sections; it is impossible, therefore, to say whether the grey and cream-coloured portions, distinguishable in complete sections of the limestone outside the hornfels aureoles, are both represented or not.

The quartzite (8) of Stob Ban, north of the Lairigmor Valley, is undoubtedly a continuation of the great quartzite fold which, on the south, underlies the Ballachulish Core. It appears, however, that the Stob Ban outcrop belongs to a lower lobe of this fold than that which in Mam na Gualainn and Tom Meadhoin occurs almost immediately beneath the Ballachulish Slide. The distinctness of these two lobes is not apparent farther south than Mam na Gualainn, for here their outcrops unite around the end of a fold of Leven Schists marked *a* on the map (Pl. XLII; see also Sections C & D, Pl. XLIII).

(*d*) The Folded District of Kinlochleven.

A wonderfully complicated folded region consisting of Eilde Flags (9), Glen Coe Quartzite (8), and Leven Schists (7) now falls to be described. Its features are illustrated in the south-eastern portions of the sections of Pl. XLIII. A comparison of these sections with those of Pl. XLIV shows how the quartzite fold, of the upper portion of which we obtained a glance through the Windows of Etive in the south (Sections G & H), comes boldly out of cover in Glen Coe (Sections E & F), and farther north is continually lifting up into the air and letting us see the Leven Schists beneath (Sections D to A).

Let us consider now Sections C & D of Pl. XLIII. In the earlier portions of this paper I have attempted to establish the essential features of these two sections as far east as the outcrop of Glen Coe Quartzite lying west of the Leven Schist fold, lettered *b* in the sections and on the map (Pl. XLII).[1] Looking at the map, it is seen that this quartzite outcrop communicates round the end of the fold *b* with a great tongue of quartzite extending northwards through Stob Coire na h' Eirghe almost to Glen Nevis. This great tongue of quartzite, bounded by the two folds of Leven Schists (*b*) and (*c*), is an obvious syncline, as may be seen in Garbh Bheinn (Pl. XLII) and less fully in Stob Coire na h' Eirghe (Section C, Pl. XLIII, & map, Pl. XLII). The synclinal structure of the quartzite between *c* and *b*, taken in conjunction with its mapped surface-connexion with the quartzite west of *b*, justifies the essential features of the sections drawn as far east as the outcrop of the Leven Schist fold (*e*).

The next important point to be noticed is the union of the Leven Schist outcrops belonging to the folds *c*, *d*, and *g* in the valley on the south side of Garbh Bheinn (Pl. XLII). Now, of these

[1] The letters *b* to *h* used in the sequel refer to definite folds of Leven Schist similarly lettered in Sections A–D (Pl. XLIII) and in the map (Pl. XLII).

three, the middle fold (*d*) is certainly an anticline, as can be seen on the hill-slopes above the termination of the Leven Schist outcrop (*d*) north-east of the Lairigmor Valley. Therefore, it is clear that the whole complex mass of quartzite, lying between the Leven Schist outcrops (*c*) and (*g*), rests upon a folded substratum of Leven Schist connecting these two outcrops (*c*) and (*g*) underground. This important fact is confirmed, since:

(1) the Leven Schist fold (*e*), shown in Pl. XLIII, Sections B & C, is anticlinal, as can be seen at both ends of its outcrop, especially on the western slopes of the Binnein Mor;

(2) the small isolated exposure of Leven Schists, mapped to the south-west of the termination of the outcrop (*e*), and almost on the same line of strike as the latter, also occupies the core of a clearly exposed anticline.

(3) The fold of Leven Schists (*f*) which develops into prominence south of Kinlochleven (Section D), furnishes in the hill-face above the village yet another example of an obvious anticline bringing the Leven Schists up from beneath their covering of quartzite. In addition to this, the hill-top definitely exposes the synclinal structure of the quartzite tongue intervening between the two anticlines (*f*) and (*d*)—the anticline (*e*) has dwindled out of recognition before reaching this side of the Leven Valley. Further, the synclinal structure of the quartzite extending down between *f* and *g*, although more complicated, can also be recognized on piecing together certain important artificial exposures at Kinlochleven with others afforded by the streams and hill-face south of the village.

Thus it may be claimed that the essential features of the sections drawn in Pl. XLIII have been established as far east as the outcrop of the Leven Schist fold (*g*). Such minor twists and turns as are indicated (Sections A & B) in the quartzite east of the outcrop of the Aonach Beag Core do not require individual discussion, as they are copied more or less directly from the mountain-slopes bordering Glen Nevis (see map, Pl. XLII). The thinning of the quartzite at one point in Section B is, it may be mentioned in passing, probably illusory, and due to the fact that the lower lobe of quartzite shown in this section is fed from the north rather than directly from above.

Let us now return to the Leven Schist fold (*g*): see map, Pl. XLII. Passing south-eastwards from this Leven Schist outcrop, we cross a broad band of Glen Coe Quartzite, and then reach the Eilde Flags. In so doing we have been ascending in the structural sequence, since, as already pointed out, the faulted continuation of the Eilde Flags at Allt Coire an Easain, within the cauldron subsidence of Glen Coe, is merely separated by a band of Glen Coe Quartzite from the Ballachulish Slide above.

Under these circumstances it is clear that

(1) the Leven Schist fold (*g*, Section D in Pl. XLIII) must close in an upward direction as indicated, and

(2) the fold of quartzite underlying the Ballachulish Core, which we have already seen close before our eyes in Tom Meadhoin (fig. 4, p. 606), has now, in its south-easterly extension, gaped widely enough to include a core of the Eilde Flags (*cf.* Sects. A–D, Pl. XLIII, & Sect. E, Pl. XLIV).

The Meall a' Bhuirich Slide and the limestone outcrop of Loch Dochard.—The outcrop of Glen Coe Quartzite, which intervenes between the Leven Schist fold (g) and the belt of Eilde Flags lying to the south-east, becomes exceedingly narrow towards Glen Nevis, and finally fails altogether on the slopes of Meall a' Bhuirich. Then, for a short distance, the Eilde Flags run on in contact with the Leven Schists of the fold g (see map, Pl. XLII); the latter, however, soon closes with a double termination, sending one lobe into the Eilde Flags, the other into an outcrop of Glen Coe Quartzite which forms the summit of Meall a' Bhuirich (Pl. XLIII, Section A, and map, Pl. XLII). This brings the Eilde Flags once more into contact with Glen Coe Quartzite; but it is not long before the latter, very gradually and, as it were, reluctantly, evacuates its position, and henceforward, as far as mapping has proceeded, the Eilde Flags march side by side with the Leven Schists. What makes this unnatural alliance all the more striking is the continued presence of the quartzite in strong force in the adjacent portion of the territory occupied by the Leven Schists.

In the light of what is known of the Fort William, Ballachulish, and other slides of the district, it is reasonable to regard the thinning and disappearance of the quartzite just described as evidence of an important slide, which has accordingly been mapped under the name of the Meall a' Bhuirich Slide.

On the east, close to the margin of the Moor of Rannoch Granite, the outcrop of the Eilde Flags is interrupted by a fold of the Leven Schists (h), bounded on each side by a narrow strip of Glen Coe Quartzite. The latter is rarely more than 100 feet or so thick, and is sometimes absent altogether.

It seems tolerably certain that this outcrop is the folded reappearance of the Leven Schists, which farther north-west pass beneath the Glen Coe Quartzite and the Eilde Flags; and that the thinning of the quartzite, here bordering the Leven Schists, is due to the south-easterly continuation of the Meall a' Bhuirich Slide in a highly folded condition (see Pl. XLIII). Otherwise, if we assume that this thick mass of Leven Schists overlies the Eilde Flags, as in Allt Coire an Easain, we are faced with a very grave difficulty in the absence of any suggestion of the intervention of a limestone in the position of the Ballachulish Core.

The fold h is lost sight of for a space in the Moor of Rannoch Granite, but appears again in a restricted exposure north-west of Allt Coire an Easain. Beyond this it may be recognized with fair certainty in a group of isolated folds of the Leven Schists near the mouth of Loch Dochard. These folds were originally mapped by Mr. Kynaston, whose lines have been to some extent modified by Mr. Clough during a subsequent visit to the district, to which reference has already been made. Mr. Clough showed that

(1) a few feet of clean white quartzite locally intervene between the Leven Schists exposed in these folds and the Eilde Flags outside, and

(2) the Leven Schists themselves include a core of highly metamorphic limestone.

It will be seen that this evidence, so far as it goes, strengthens the view that the Leven Schists here underlie the Eilde Flags. If the limestone mentioned above belonged to the Ballachulish Core, one would expect it to lie between the thick development of Leven Schists with which it is associated and the Eilde Flags, whereas the reverse is the case. On these grounds it is suggested that the limestone outcrop of Loch Dochard belongs to the Appin Core, although separated from the gape of the latter in Glen Duror by a distance of 17 miles.

IV. Conclusions.

1. The schists of the Highlands of Scotland are disposed in a succession of recumbent folds of enormous amplitude.
2. The limbs of these folds are frequently replaced by fold-faults, or slides, which have given freedom of development to the folds themselves.
3. The sliding is not confined to the lower limbs of recumbent anticlines, and is therefore due to something more than mere over-thrusting. It is a complex accommodation phenomenon, of a type peculiar perhaps to the interior portions of folded mountain-chains. In fact, the cores of many of the recumbent folds have been squeezed forward so that they have virtually reacted as intrusive masses.
4. In the growth of these structures many of the earlier-formed cores and slides have suffered extensive secondary corrugation of isoclinal type.

V. Bibliography.

[1] J. Nicol. 'The Structure of the North-Western Highlands, & the Relations of the Gneiss, Red Sandstone, & Quartzite of Sutherland & Ross-shire' Quart. Journ. Geol. Soc. vol. xvii (1861) p. 85.
[2] C. Callaway. 'The Age of the Newer Gneissic Rocks of the Northern Highlands' Quart. Journ. Geol. Soc. vol. xxxix (1883) fig. 7, p. 391.
[3] C. Lapworth. 'The Secret of the Highlands' Geol. Mag. 1883, p. 120; also 'The Close of the Highland Controversy' *Ibid.* 1885, p. 97.
[4] F. L. Cornet & A. Briart. 'Sur le Relief du Sol en Belgique après les Temps Paléozoiques' Annales Soc. Géol. Belgique, vol. iv (1877) p. 71; and J. Gosselet, 'Sur la Structure générale du Bassin Houiller franco-belge,' Bull. Soc. Géol. France, ser. 3, vol. viii (1879–1880) p. 505.
[5] B. N. Peach & J. Horne. 'Report on the Geology of the North-West of Sutherland' Nature, vol. xxxi (1884) p. 31. And with Survey Colleagues. 'Report on the Recent Work of the Geological Survey in the North-West Highlands of Scotland' Quart. Journ. Geol. Soc. vol. xliv (1888) p. 378; also 'The Geological Structure of the North-West Highlands of Scotland' Mem. Geol. Surv. 1907.
[6] G. Barrow. 'On the Occurrence of Silurian (?) Rocks in Forfarshire & Kincardineshire along the Eastern Border of the Highlands' Quart. Journ. Geol. Soc. vol. lvii (1901) p. 328.
[7] A. E. Törnebohm. 'Om Dalformationens geologiska Ålder' Geol. Fören. Stockholm Förhandl. vol. vi (1883) p. 622; 'Om Fjällproblemet' *Ibid.* vol. x (1888) p. 328; 'Grunddragen af det Centrala Skandinaviens Berg-byggnad' Kongl. Svenska Vet.-Akad. Handl. vol. xxviii, No. 5 (1896), with German summary.
[8] A. G. Högbom. 'Geologisk Beskrifning öfver Jemtlands Län' Sver. Geol. Undersökn. Afhandl. ser. C, No. 140 (1894).
[9] W. Kilian & J. Révil. 'Notice sur la Vie & les Travaux de Marcel Bertrand' Grenoble, 1908.

[10] M. Bertrand. 'Coupes de la Chaîne de la Sainte-Beaume (Provence)' Bull. Soc. Géol. France, ser. 3, vol. xiii (1884–85) p. 125.
[11] E. Suess. 'Die Entstehung der Alpen' Vienna, 1875, pp. 20–25.
[12] M. Bertrand. 'Rapports de Structure des Alpes de Glaris & du Bassin Houiller du Nord' Bull. Soc. Géol. France, ser. 3, vol. xii (1883–84) p. 318.
[13] E. Suess. 'Das Antlitz der Erde' vol. i (1885) p. 182.
[14] M. Bertrand. 'The Mountains of Scotland' (translated by G. A. Lebour). Geol. Mag. 1893, p. 118.
[15] H. Schardt. 'Sur l'Origine des Préalpes Romandes' Eclogæ Geol. Helv. vol. iv (1893–96) p. 129.
[16] M. Lugeon. 'Les Grandes Nappes de Recouvrement des Alpes du Chablais & de la Suisse' Bull. Soc. Géol. France, ser. 4, vol. i (1901) p. 723.
[17] C. T. Clough. 'The Geology of Cowal' Mem. Geol. Surv. 1897, fig. 52, p. 226.
[18] C. T. Clough. *Ibid.* fig. 47, p. 204, & pl. x.
[19] J. Horne. Summary of Progress of the Geological Survey for 1899 (1900) p. 10.
[20] H. B. Maufe. *Ibid.* 1905 (1906) p. 91.
[21] E. B. Bailey. *Ibid.* 1908 (1909) p. 51. *Cf.* also the Director's introduction.
[22] J. S. Grant Wilson. Annual Report of the Geological Survey for 1896 (1897) p. 21.
[23] J. S. Grant Wilson. *Ibid.* 1895 (1896) p. 25 & *ibid.* 1896 (1897) p. 21. Summaries of Progress of the Geological Survey for 1897 (1898) p. 66, for 1898 (1899) p. 46, & for 1904 (1905) p. 64.
[24] J. S. Grant Wilson. Summary of Progress for 1901 (1902) p. 123.
[25] J. Macculloch. A Geological Map of Scotland, published in 1840, several years after the author's death.
[26] J. Macculloch. 'Remarks on several Parts of Scotland which exhibit Quartz Rock, & on the Nature & Connexions of this Rock in general' Trans. Geol. Soc. ser. 1, vol. ii (1814) p. 483.
[27] J. Macculloch. 'Observations on the Mountain Cruachan in Argyllshire, with some Remarks on the Surrounding Country' Trans. Geol. Soc. ser. 1, vol. iv (1817) p. 117.
[28] C. T. Clough & E. B. Bailey. Summary of Progress of the Geological Survey for 1907 (1908) p. 63.
[29] B. N. Peach, H. B. Maufe, & E. B. Bailey. *Ibid.* 1903 (1904) pp. 66 & 67.
[30] J. S. Grant Wilson. *Ibid.* 1904 (1905) p. 63.
[31] J. E. Marr. 'Notes on the Geology of the English Lake District' Proc. Geol. Assoc. vol. xvi (1900) p. 449.
[32] L. W. Collet. 'Étude Géologique de la Chaîne Tour Saillère—Pic de Tanneverge' Matériaux pour la Carte Géologique de la Suisse, n. s. pt. xix (1904) pl. ii, fig. 7.
[33] H. B. Maufe. 'The Geological Structure of Ben Nevis' Summary of Progress of the Geological Survey for 1909 (1910) p. 85.
[34] C. T. Clough. 'The Geology of Cowal' Mem. Geol. Surv. 1897, pp. 9, &c.
[35] W. B. Wright. 'The Two Earth-Movements of Colonsay' Quart. Journ. Geol. Soc. vol. lxiv (1908) fig. 3. p. 302.
[36] C. T. Clough, H. B. Maufe, & E. B. Bailey. 'The Cauldron Subsidence of Glen Coe & the Associated Igneous Phenomena' Quart. Journ. Geol. Soc. vol. lxv (1909) p. 611.

EXPLANATION OF PLATES XLII–XLIV.

Plate XLII.

Geological map of the district lying between Loch Linnhe and the Moor of Rannoch and Etive Granites, on the scale of 2 miles to the inch.

Plate XLIII.

Sections A–D across the map (Pl. XLII), to illustrate the relations of the recumbent folds of Appin, Aonach Beag, and Ballachulish, on the scale of 1 inch to the mile.

Plate XLIV.

Sections E–H across the map (Pl. XLII), to illustrate the nature of the recumbent fold of Ballachulish and its attendant slides (fold-faults), on the scale of 1 inch to the mile.

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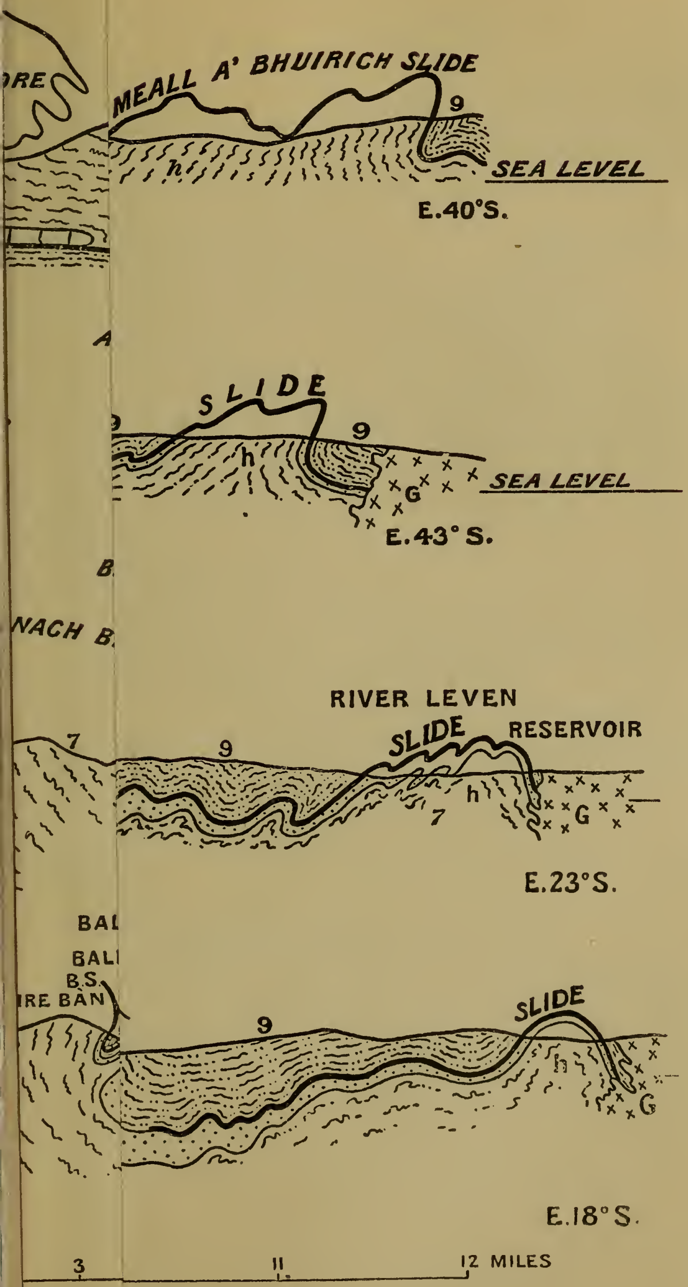

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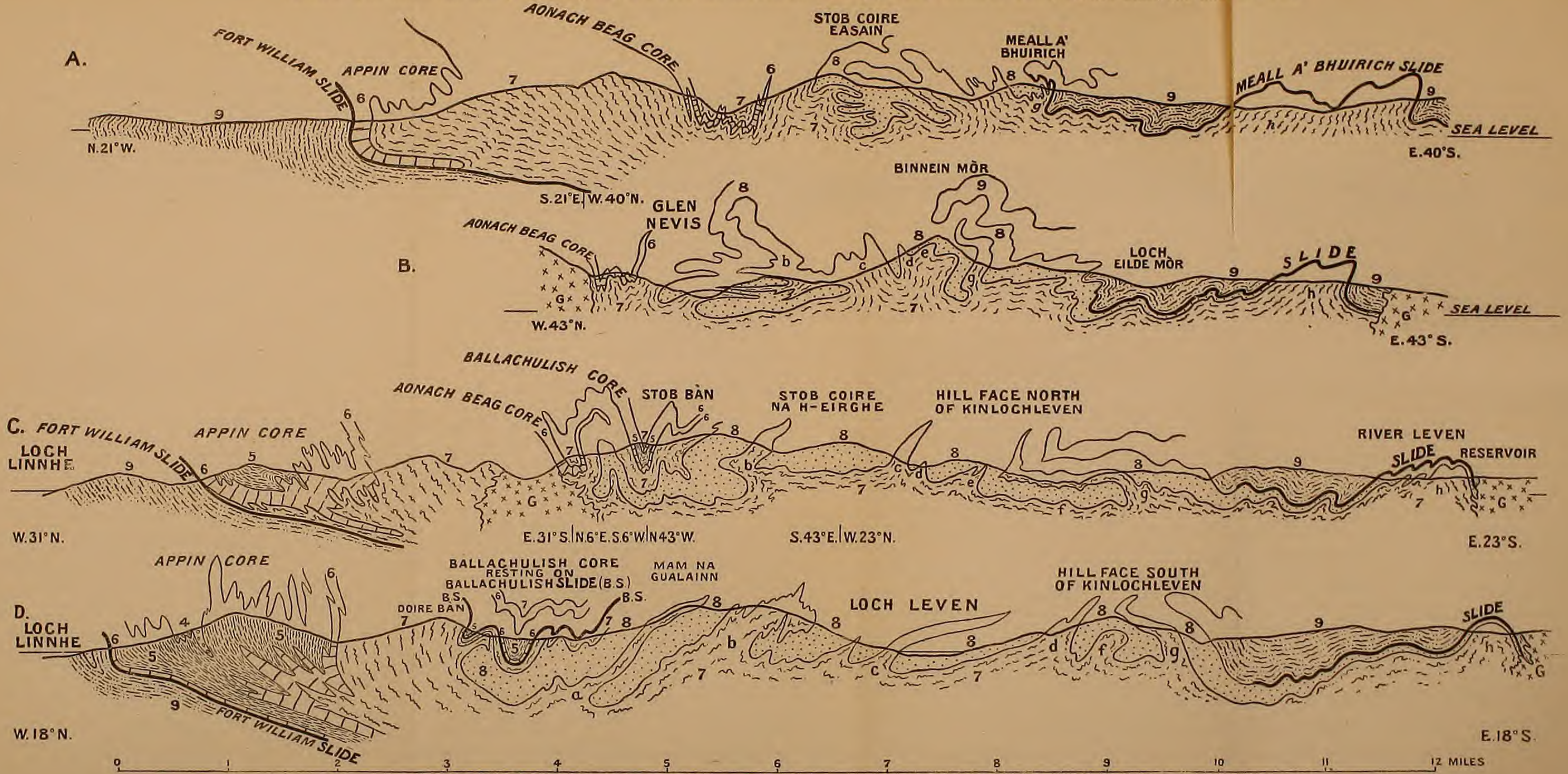
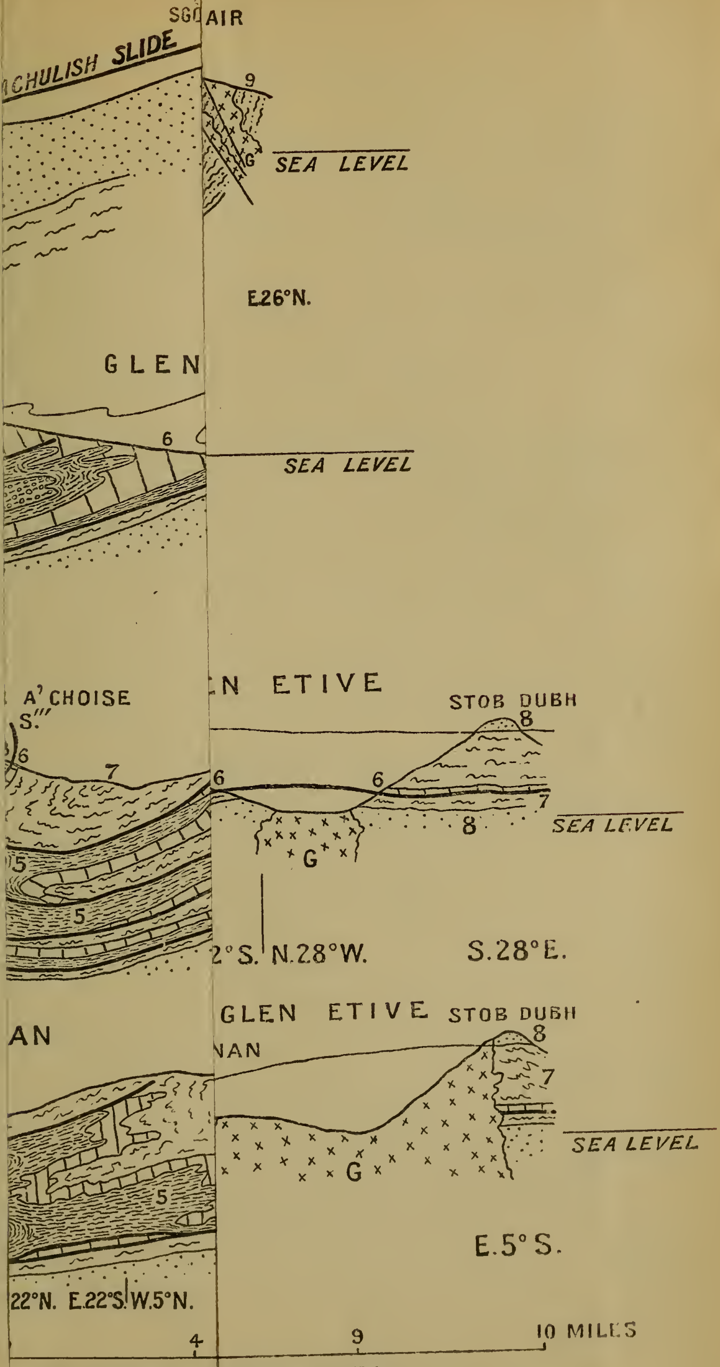
Sections A–D across the Map (Pl. XLII), to illustrate the Relations of the Recumbent Folds of Appin, Aonach Beag, and Ballachulish.



[The Fort William and Meall a' Bhuirich Slides (fold-faults) are complementary slides formed in connexion with the Appin fold. The Ballachulish Slide (B.S.) also appears in Section D. The scale, 1 inch to the mile, vertical and horizontal, is double that of the map.]

9 = Eilde Flags; 8 = Glen Coe Quartzite; 7 = Leven Schists; 6 = Ballachulish Limestone; 5 = Ballachulish Slates; 4 = Appin Quartzite. The letters *a–h* indicate particular folds of the Leven Schists similarly lettered on the map.

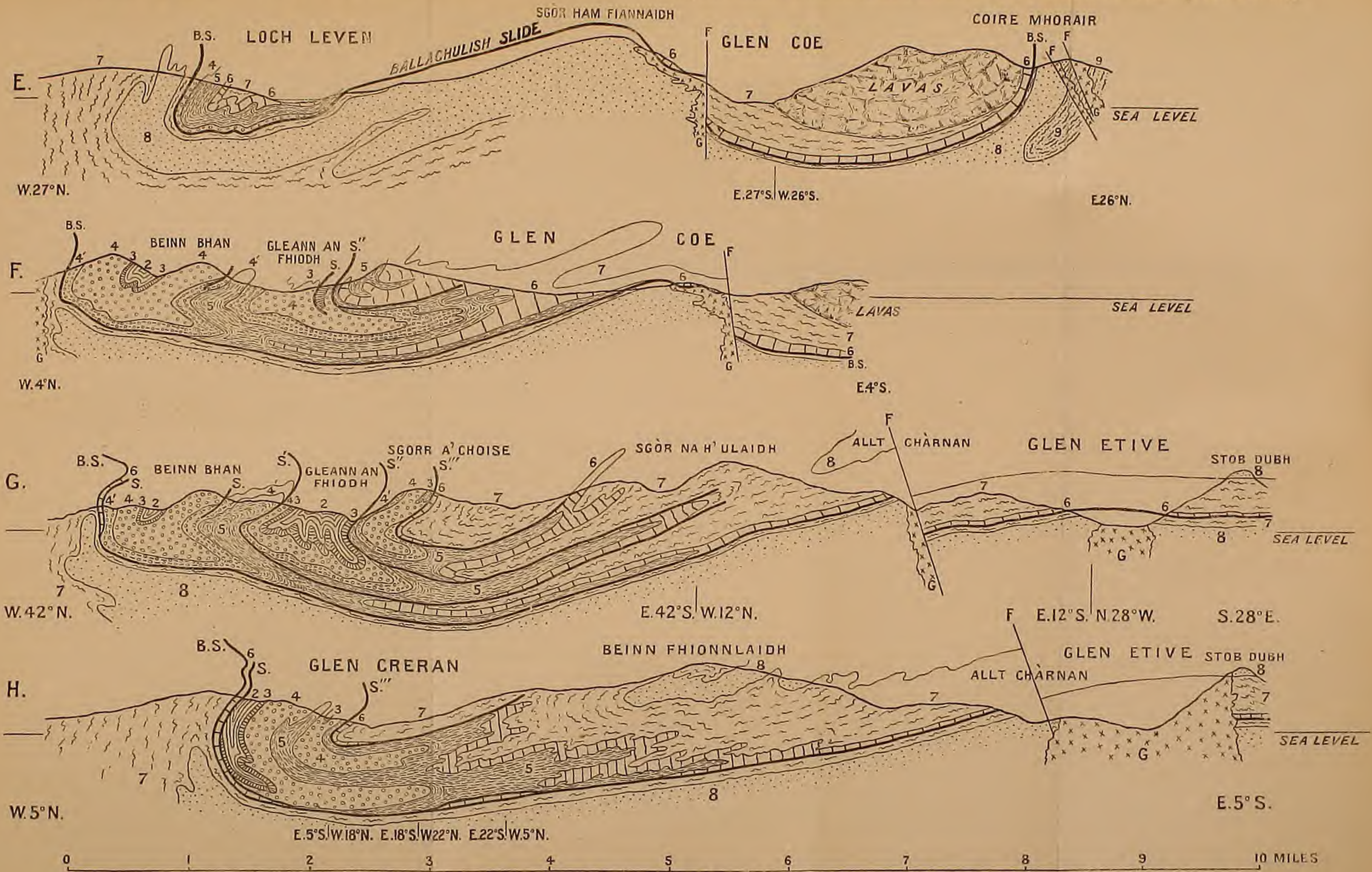
[T]O ILLUSTRATE TI[...]NDANT SLIDES (FOLD-FAULTS).



[...]rn part of these secti[...] Windows of Etive.
The scale, 1 inch [...]

[...], S''' = other slides sp[...]rtzite; 7 = Leven Schists;
[...]sh Slates; 4' = Stripe[...]ne; 2 = Appin Phyllites.

SECTIONS E–H ACROSS THE MAP (PL. XLII), TO ILLUSTRATE THE NATURE OF THE RECUMBENT FOLD OF BALLACHULISH AND ITS ATTENDANT SLIDES (FOLD-FAULTS).



[The downthrown region in the eastern part of these sections belongs to the cauldron subsidence of Glen Coe. Sections G & H cross the Windows of Etive. The scale, 1 inch to the mile, vertical and horizontal, is double that of the map.]

S=Slide; B.S.=Ballachulish Slide; S′, S″, S‴=other slides specially mentioned in the text. F=Fault. 9=Eilde Flags; 8=Glen Coe Quartzite; 7=Leven Schists; 6=Ballachulish Limestone; 5=Ballachulish Slates; 4′=Striped Transition Series (where separated); 4=Appin Quartzite; 3=Appin Limestone; 2=Appin Phyllites.

Discussion.

Prof. Sollas welcomed this as an important contribution to our knowledge of mountain-formation. It was a masterly paper, in which a very complicated structure had been explained in a clear and convincing manner. The task of establishing a sequence among highly disturbed rocks, not containing fossils, might well have deterred a less courageous investigator; but, as the Author unfolded the steps of his argument, they saw difficulty after difficulty disappear, and witnessed at length the final triumph of order over chaos. The only undetermined point was whether the sequence was normal or inverted, and in leaving this question undiscussed the Author had shown a wise reserve. The recumbent sheets and folds showed close analogies with many of those which had been described in Switzerland. Among the more interesting phenomena was the passage of folding movements into flows. In considering the flow of solid rocks, it was important to bear in mind not only the element of time, but also that of space. It was impossible to argue, from the physical constants of a rock examined in a hand-specimen, to those of the same rock buried deep within the crust and forming part of a flake 12 miles long or more.

The granitic intrusions, as the Author remarked, had no relation to the folding movement; but the granite before its intrusion may have played an important part: when the final attack is made on the explanation of mountain-formation, this will have to be taken into account.

Dr. Teall regretted the absence of the Author's colleagues, whose views on the paper would have been welcome. He believed that they were of opinion that the paper represented an important advance in our knowledge of the tectonics of the Central Highlands. It certainly introduced new ideas which were deserving of serious consideration.

Mr. M. M. Allorge commented upon the remarkable geometrical power shown by the Author in unravelling the complicated structures of this district, and grasping at the same time the strike, the dip, and the superimposition of the successive recumbent sheets, notwithstanding the partial obliteration produced by subsequent granitic intrusions; it was like reading a palimpsest half obscured by writing of a later date. The squeezing of the cores of some of the recumbent sheets and the bifurcating crystalline tongues thus formed reminded one of the 'carapaces' described by M. Argand in the crystalline zone of the Alps near Zermatt.

Any additional information concerning the following points would be gratefully welcomed:—(1) Were the thrust-planes underlain by thrust-breccias or not? (2) After the general 'mise en place' of the sheets, had they been subjected to one or to several subsequent epeirogenic movements? (3) Was there any information available concerning the amount of denudation undergone by these mountain-structures, and consequently the depth at which they originated?

The SECRETARY read the following extracts from a letter received from Mr. C. T. CLOUGH, who was unable to be present at the Meeting:—

'I think that special attention may be called to the similarity of the effects produced on all the beds in the attenuated limbs of the slide-folds; the hard massive quartzites, for instance, are not on the average any better preserved than the Leven Schists. This seems contrary to what we should expect *a priori*, and it is contrary also to what we find in some areas affected by the post-Cambrian thrusts of the North-West Highlands. For instance, near Ord in the Isle of Skye, just under the western limb of the folded Sgiath-bheinn an Vird thrust the Fucoid Shales become thinner as the thrust is approached, and are ultimately almost entirely squeezed away from between the Pipe-Rock on the one side and the Serpulite Grit on the other.

'It is interesting to consider what may be the relations in age between the slides described by the Author and the Moine Thrust. The Moine Schists had certainly been folded intensely, and were much in the same condition as they are now, before the actual snap of the thrust took place. The slides of the Ballachulish district seem much more closely connected with the folding. This difference suggests the question, whether, in the Moine Schists a little east of the Moine district, slides of the Ballachulish type may not also occur. It is certainly the case that the beds in the opposite limbs of some of the folds east of the Moine Thrust show a marked want of correspondence. The differences have hitherto generally been explained by the supposition that the folds concerned were of unusually great depth, so that they brought into proximity beds which originally were widely separated and were formed under different conditions of sedimentation. It seems very possible, however, that the differences may, in some cases, be due to the presence of slides accompanying the folds. If such slides do occur not far east of the Moine Thrust, as is thus suggested, we may be tolerably certain that they are somewhat older than it.

'In conclusion, I should like to express my high appreciation of the perseverance and enthusiasm with which the Author has carried out these investigations. I feel confident that his general conclusions may be accepted as correct, and that they mark a great advance in the study of the tectonics of the Scottish Highlands.'

The AUTHOR thanked the Fellows for their reception of his paper. He warned future workers against hasty correlations with the sequence worked out in the Appin and Ballachulish district. The Highlands of Scotland are probably divided into compartments by structure-planes of great importance, and in each compartment it will be necessary to determine the stratigraphical alphabet on independent evidence.

25. *The* VOLCANO *of* MATAVANU *in* SAVAII. By TEMPEST ANDERSON, M.D., D.Sc., F.G.S. (Read April 13th, 1910.)

[PLATES XLV–LII.]

THE Samoa or Navigator Islands are a group in the Western Pacific, lying in 13½° to 14° S. lat. and 168° to 173° W. long. They are some 350 miles north of Tonga, and between 400 and 500 miles north-east of Fiji. From Auckland (New Zealand) the sailing distance is 1560 miles, and from San Francisco about 4400.

The group consists of nine islands, in addition to rocks and islets, but only four are of any notable size, namely: Upolu, Savaii, Tutuila, and Manua. The two first-named belong to Germany and the two last-named to the United States. They are mountainous, but at the same time well wooded, and are all, with the exception of Rose Island, volcanic, and for the most part surrounded with coral-reefs. They are disposed in a linear direction from north-west to south-east, and a line drawn from the volcanic region of New Zealand and thence through White Island, Pylstaart, the Kermadecs, and the Tonga Islands, all of which contain volcanoes active or extinct, would pass through the group. It is probable that each of these lines marks a fold-fissure or line of weakness of the earth's crust. It is noteworthy that a volcanic eruption took place in the Tonga Group at the same time as the great eruption of Tarawera in New Zealand, in June 1886.

Savaii is the westernmost and also the largest of the group. It is 48 miles long and at least 25 miles wide, but the interior has never been surveyed. It has a backbone of volcanic mountains, all formed of different varieties of basalt.

One of these, Mauga Loa, rises to a height of 5600 feet. Another, 7 or 8 miles to the west, has the suggestive name of Mauga Afi (mountain of fire), and from it and its parasitic craters most of the extensive lava-streams in the west of the island appear to have proceeded. An eruption which destroyed Aopo, a town in this district, probably took place about 150 or 200 years ago, judging from information given to Mr. Williams [1] by an old man,

[1] For most of the information about the commencement and progress of the eruption, and for many other kindnesses, I am indebted to Mr. Richard Williams, Amtmann of Savaii. He allowed me access to his copious manuscript notes and official reports, and furnished me with a copy of a map of his own making, which shows the position of the volcano, and the extent of the lava-flows at various epochs.

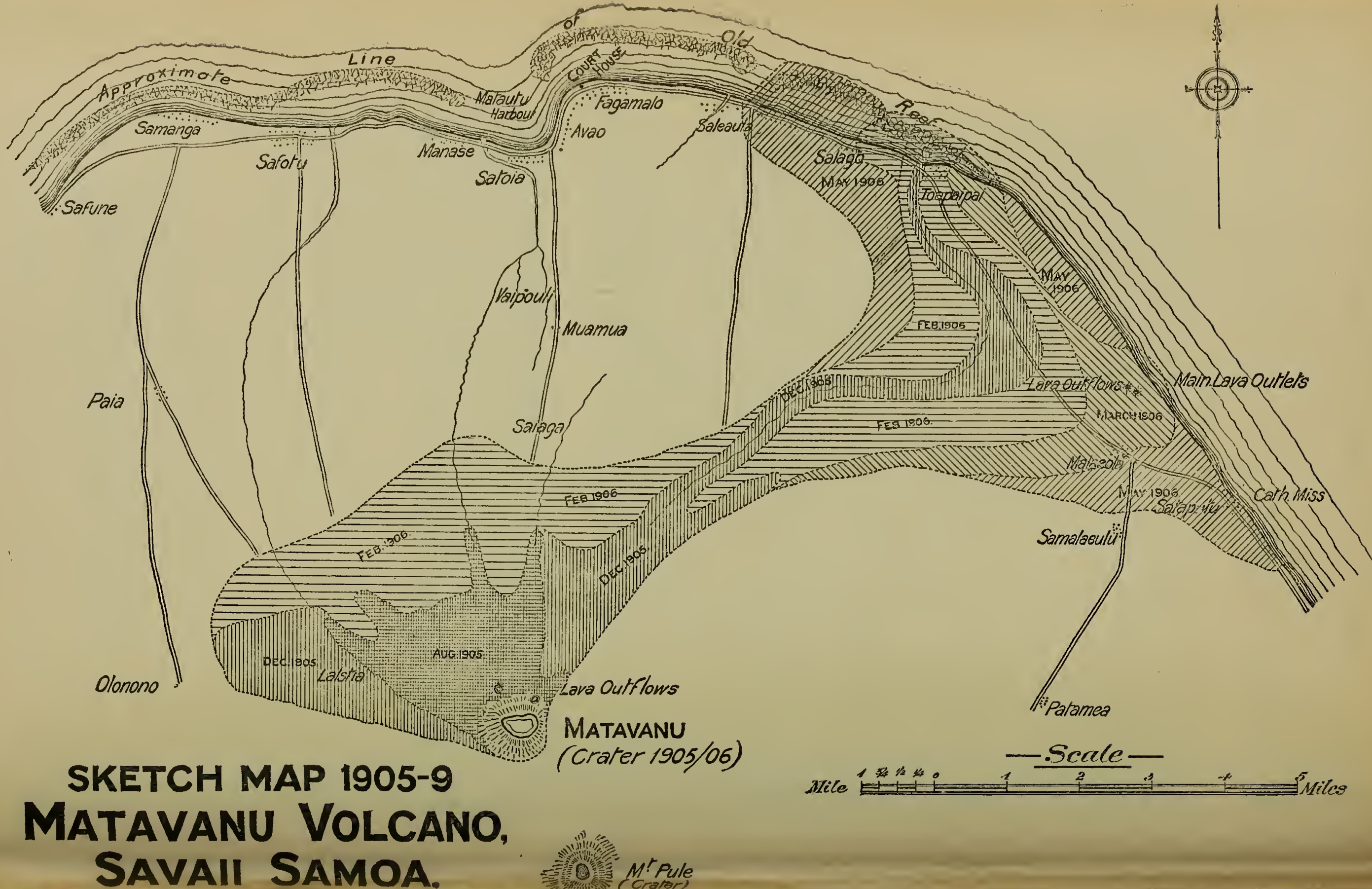
The following papers and articles have also been consulted, but are unfortunately not very accessible to English readers:—

H. I. JENSEN. Proc. Linn. Soc. N.S.W. vol. xxxi (1906) p. 641. This contains an early copy of Mr. Williams's map and some remarkable photographs by Capt. Allen, who in the ordinary course of his voyages regularly passes the volcano. It also contains a description of the petrology of the lavas.

W. VON BÜLOW. 'Vulkanische Tätigkeit auf Savaii' Globus, July 12th, 1906.

R. DEEKEN. 'Neuer Vulkan im Stillen Ozean' Deutsche Kolonial-Zeitung, 1906, p. 273.

KARL SAPPER. Zeitschr. f. Erdkunde, Berlin, 1906, p. 686. (A good compilation.)



SKETCH MAP 1905-9
MATAVANU VOLCANO,
SAVAII SAMOA.

whose grandfather had talked to him about the event, but could not himself remember it. The lava-fields of this eruption are more extensive and more rugged in character than those of the present eruption, and like them they reach the sea.

From a crater about 2 miles north-east of, and probably parasitic on, the volcano of Mauga Afi, and 4 miles south-south-east of Aopo, a small eruption took place in 1902. An indistinct crater was formed, and also a lava-stream nearly half a mile wide and 2 miles long. The lava is of the scoriaceous or 'aa' type. This eruption was accompanied by severe earthquakes, which was not the case in that of 1905.

More to the east is a large crater with a crater-lake, the name of which, Mauga Lapainé or Pule, is suggestive of Montagne Pelée in Martinique, and Pelé the goddess of the Hawaiian volcanoes. From it most of the flows near Papalaulelei (smooth lava), at the east of the island, have proceeded; while a little to the north of it and at a lower elevation, say 2000 feet above the sea, is the new cone of 1905, from which the eruption of that date took place and still continues.

I understand that, before the eruption, the place where the crater now is was a sort of elevated plain surrounded by mountains. It was almost level, and in fact a favourite camping-place for pig-stickers. It was near the now deserted plantation of Olonono. The name Matavanu is a native one, and was, I understand, first applied to the volcano by Herr von Bülow, a resident in the island and a cousin of the former German Chancellor. From near this place a deep and tortuous valley extended down to the sea, a distance of 10 or 11 miles, though that measured in a direct line to the sea at Matautu is only about 7 miles. The lower part of the valley was very fertile, and along the coast at, and on each side of, its mouth were prosperous villages. This part is now overwhelmed by the lava.

The western portion of the coast in question was protected by coral-reefs, and on it were situated the villages of Saleaula, Salago, and Toapaipai, and this district was called Le Ala Tele. Judging by the coast farther west about Matautu, these villages had been built on a bank chiefly formed of coral-sand raised not many feet above sea-level, and often with a swamp behind them. Farther to the east of Toapaipai came a stretch of iron-bound coast—that is, coast formed of old lava not protected by a coral-reef; a promontory here was called Asuisui, and this is near the point where the lava flows into the sea (1909). Farther east again was another region of coast protected by reef, and on it were situated the villages of Malaeola and Sataputu. A good buggy-road extended the whole way at varying distances from the coast, and led to the villages of Samalaeulu and Patamea, which still exist. There were also in the vicinity of the crater valleys leading in the direction of Safotu, the upper parts of which are now filled up.

The eruption began on August 4th, 1905. At first the ejecta were mostly solid, and the space covered was not large; but from

Saturday September 2nd to September 4th molten lava was poured out, which advanced 2 miles.

On October 28th the lava was at Saleaula, and on November 3rd the lava-stream at Saleaula was a quarter of a mile across, the side of the crater fell out, and a flood of lava issued therefrom.

On December 7th the lava reached the sea at Toapaipai. It filled up the lagoon between the shore and the reef, a space perhaps a quarter of a mile wide and of depth varying from 20 to 30 feet. It then took a turn westwards along the reef, leaving untouched a part of the lagoon which was not filled up until later.

From Sunday, January 28th, 1906, to the middle of February there was great increase of activity; the lava extended along the coast from Salago to Saleaula, a distance of 1130 yards, burnt Mr. Bartley's house, and filled the space between the shore and the reef. On the ironbound coast to the east of this, the lava-flow was about three-quarters of a mile broad, and still farther east half the town of Malaeola was destroyed.

On March 6th, 1906, the lava extended along the coast eastwards to within 200 yards of Sataputu, which village was destroyed somewhat later.

On March 3rd, 1906, the lava ceased running in the swamp behind Saleaula, this being the furthest extension of the lava to the west. Near the coast about half the town of Saleaula had been destroyed, the devastation reaching to about a mile and a half from the Government Offices at Fagamalo in the town of Matautu. Besides filling up the space between the shore and the reef at Saleaula, the lava has extended westwards along the summit of the reef for a considerable distance, and blocks up one of the entrances to the lagoon. The lagoon between the shore and the reef was not filled up until later.

The formation of the coast is little altered where it was previously 'ironbound,' as the lava there flows directly into deep water. Where, however, there was formerly a reef with a lagoon between it and the coast, the lagoon is generally filled up, and the coast-line correspondingly extended as far as the line of the old reef.

In the early part of the eruption the lava did not extend far from the crater, the longest streams not exceeding 2 or 3 miles, and these did not present the same heated appearance as subsequently, but were covered with moving scoriæ and stones, so that the whole mountain appeared to be in motion. Later on the lava was often very abundant and liquid: at times it flowed like a river of water 200 yards wide; at others as numerous small streams not above 10 feet wide, and in these cases was often so fluid that it nearly all ran away and only left a fresh crust less than 2 inches thick, over which it was safe to walk next day.

The large fresh lava-streams soon got crusted over on the surface with solidified lava, and the liquid lava continued to flow underneath. Even at the crater it seldom flowed over the lip, but generally entered holes and tunnels in the sides and flowed underground. The lava-field thus became honeycombed with channels of liquid or pasty lava, which occasionally came to the surface, and flooded it with fresh sheets of lava; at other times, the surface frequently floated up and was raised by the intrusion of fresh lava underneath, so that what had previously been the course of the valley now became the highest part of the field. Mr. Williams thinks that the lava must be in some places 400 feet thick.

In the beginning of September 1906 the lava-flows near the seacoast extended considerably farther eastwards, probably a mile. The mouth of the river was blocked, and the village of Sataputu, including a Catholic Church and Mission House, was overwhelmed. The lagoon, which was in places 30 feet deep, was filled up, the passage into it was blocked, and the coast-line pushed seawards about 300 feet. The total length of sea-front covered at different times by the lava was nearly 9 miles; and, from the westernmost point inland near Olonono to Sataputu the easternmost, not less than 15 miles.

On August 7th, 1908, Mr. Williams noted that the lava continued to run strongly into the sea, having only stopped for one day; it directed its course chiefly towards Le Ala Tele, in the former position of Toapaipai, and the promontory of Asuisui.

'Tidal' Waves.

It is interesting to note that several so-called 'tidal' waves have occurred during the eruption. The following were noticed at Matautu by Amtmann Williams:—

November 28th, 1906	5.30 P.M.
June 8th, 1907	at noon.
June 19th, 1907	3 A.M.
June 27th, 1907	between 6 & 7 P.M.
July 9th, 1907	6.45 P.M.
July 25th, 1907	11 A.M.

The tide usually rises and falls about 4 feet at Matautu. Most of these waves did not exceed 6 to 8 feet in height, and as many of them occurred at low or half-tide, and there was no heavy sea on at the time, little damage was done, although in several cases the main road of the town was flooded. The largest and most important of the series was that on Sunday, October 6th, 1907, about 5.30 P.M. It was just at the time of high water, but the sea was smooth. The wave was 10 or 12 feet high: it came from the north-east round the lava-point, as in fact the others had done, and at the Deutsche Handels & Plantagen Gesellschaft's place a boat-house was wrecked, a buggy in it smashed, and several boats were damaged; while, at a house a few score yards off, a 400-gallon tank of water was lifted bodily from its foundation and carried across the road. The wave appears to have spent itself here and, it was thought, probably rebounded out to sea. No damage was done at the Government Offices, 150 yards distant, nor in either direction along the coast.

The wave was noticed, but of smaller size, in some of the other islands. At Apia it had a height of only 1 or 2 feet. It was probably connected with the lava falling into the sea, but the exact cause was uncertain. Possibly it was due to a steam-explosion.

Present State of the Cone and Lava-Fields.

From the sea at night the view of the volcano is extremely striking.[1] The glare from the incandescent lava in the crater reflected on the clouds is visible for a distance of 50 miles or more, while on nearer approach the spectacle of a number of streams of red-hot lava descending into the sea and raising columns of illuminated vapour is very remarkable and at present probably unique. By day the view, though quite different, is equally interesting. The crater rising to a height of 2000 feet with a backing of hills, or rather mountains of double that height, and with several old cones of different ages dotted around, is surmounted by a magnificent canopy of white steam of the well-known pine-tree shape, often breaking out into the equally well-known cauliflower lobes. This frequently rises to a height of 8000 or 10,000 feet (Pl. XLV, fig. 1). Surrounding the crater for a distance of a mile or two in the shortest direction, and stretching down to the coast in the sinuous line indicated on Mr. Williams's map, are the great black lava-fields, which comprise an area of probably at least 20 square miles. At intervals along these lava-fields, and taking an equally if not more sinuous line, are several conspicuous clouds of vapour escaping from as many fumaroles, some of large size, which mark the line of a great lava-tunnel to the sea-shore, and there are some smaller ones in the other direction more to the west, which show the position of a smaller underground stream towards Safune. In the foreground again is the new coast-line formed of the wide-spread fresh lava-currents, with usually several magnificent columns of vapour rising some hundreds, or even thousands, of feet into the air from the places where the lava is for the moment falling into the sea. With a very good glass the observer may perhaps distinguish the towers or other parts of two churches, which are nearly all that mark the position of the destroyed villages of Saleaula and Sataputu; while a still more careful scrutiny will enable him to make out a few dead tree-trunks still erect among the lava and many more lying prostrate on its surface. Looking still farther afield are large areas where whitened tree-trunks are all that remain of the once dense tropical jungle, though in some places vegetation is beginning to return. Such is the view, some details of which call for a fuller notice.

The cone does not rise high above the surrounding lava-field. At the east side there is one point where the slope of the latter continues uninterrupted to within about 50 feet vertical of the lowest point of the lip of the crater, and even then the slope up to it is still very gradual, and probably does not exceed 15°. At other points the edge of the crater is somewhat more elevated,[2] and may reach an altitude 150 feet higher than the point referred to; and, as the lava-fields are in places lower, it is probable that

[1] At night I saw it once from the deck of a steamer of the Union Company of New Zealand, once from a German man of war, twice from a schooner, and also in the daytime from a boat.

[2] My aneroid reading made the height almost exactly 2000 feet.

there are points where the cone rises to a height of 350 feet above them.[1] The outside slope is in most places gradual; I did not notice any place where it appeared to exceed 33° (Pl. XLV, fig. 2). The crater itself is oval, and apparently about 400 by 200 yards in area; its long axis runs approximately south-west and north-east. Its inner walls are very steep throughout, and in many places precipitous and even overhanging. They are composed of the usual beds of lava and fragmentary material; but, except in the southern wall, where tuffs are abundant, the lavas predominate much more than in some other volcanoes that I have seen (Pl. XLVI). When on the spot, I estimated the depth down to the lava-lake to be mentioned presently at about 400 feet, possibly somewhat less; but, on subsequent comparison with Kilauea, I do not think that it exceeds 300 feet. At about half the depth is a well-defined bench on the walls showing a former height of lava.[2] The strata below this level are much obscured by this dense lava formation; there is also a less marked bench at a still higher level, say about a third of the depth from the lip (Pl. XLVII).

The bottom of the crater is of an oval form, proportionately narrower than the higher part, in fact with nearly parallel sides. I roughly estimate its length at 300 yards, and its breadth at 75 to 100. It is entirely occupied by a lake of liquid lava all in rapid motion from south-west to north-east, and of such extreme fluidity, that it continually beats in surging waves against the walls, where splashes retain their heat and brilliant colour for some time. The surface is in a constant state of ebullition, though not always to the same degree in different parts. Some of the boilings rise in veritable fountains of incandescent liquid basalt of 10, 20, or even, I think, possibly at times 50 feet high. The whole mass of the lava is at a brilliant white heat, visible as such even in bright sunlight, but a darker scum is continually forming on the surface, especially when the trade-wind blows strongly on it. These pieces of scum, like ice-floes, break up and flow down to the north-eastern end of the crater, where they and the liquid lava disappear down a hole, or rather tunnel, at the foot of the cliff. The tunnel is perhaps 30 feet wide. Its roof is quite low, and is nearly touched by the surface of the lava, which rushes under it at a steep slope with the velocity of a cataract. There is also another smaller hole at the foot of a cliff forming the north-western wall of the crater, down which a stream of lava seems constantly to flow; but this is small in comparison with the other. The wall forming the north-eastern end of the crater above the outflow of the lava is of a structure different from that forming the adjacent parts on each side, and seems to be a great chasm filled in with fragmentary material of a later date, and possibly partly with lava frozen on to the roof of the conduit.[3]

[1] See H. I. Jensen, Proc. Linn. Soc. N.S.W. vol. xxxi (1906) p. 653.

[2] This may have been the height of the lava in 1906, as mentioned by Jensen, *op. cit.* p. 653.

[3] I saw this clearly in the evening and night on two distinct visits; but, when I returned to photograph it by daylight, that part of the crater was so obscured by vapour that it was impossible to bring out the details. The chasm may have been formed when the side of the crater fell out on Nov. 3rd, 1905.

At the south-western end of the crater is also a tunnel larger and higher than that by which the lava escapes on the north-east. Its interior is incandescent, and its floor occupied by liquid lava. I am not at all sure that any lava goes out or comes in through it.[1] The whole bottom of the crater is, in fact, in such a turmoil, the lava boiling and surging up first in one place, then in another, that it is impossible to say definitely where the exact point of entrance is. On the whole, I am inclined to think that it is mainly towards the south-western end, in front of the entrance to the south-western tunnel. It is not unlikely that a fissure extends for the whole or greater part of the length of the bottom of the crater, and possibly for some unknown distance beyond each end of it.

The surface of the cone is mostly composed of a series of flows of basaltic lava, similar in type to that which forms the fields around. A considerable number of bombs or ejected blocks of lava of similar character are scattered over the surface; but beyond this the evidences of explosive action, at any rate in the later stages, are very few. In the earlier stages the action appears to have been more of the explosive type (Pl. XLV, fig. 2).

The lava-fields are extensive and irregular in shape, as may be seen from the accompanying map (p. 622). They comprise a considerable area round the cone, being most limited on its southern and eastern sides, where their further extension was prevented by the hills. They are somewhat more extensive towards the west and north in the direction of Safune and Safotu, where they have filled up the upper parts of several valleys. This part of the field shows a few fumaroles, and apparently receives the lava which enters the small north-western tunnel from the crater. The most extensive area, however, is towards the north-east in the direction of the sea. It is at first confined between hills, and becomes narrowed and sinuous in consequence, and lower down spreads out into the broad expanse near the coast. The molten lava which enters the tunnel at the north-eastern end of the crater flows under this part of the field. The surface is very rough and irregular, and presents large areas both of scoriaceous or cindery lava (locally called 'aa'), and slaggy, ropy, or corded lava (locally 'pahoehoe'). Of the latter variety there are large areas as regular as anything in Iceland, where the Odadhraun presents hundreds of square miles of such beds; or, again, like the less regular corded and festooned lavas on Vesuvius before they were covered up by the recent eruption; and there are fields composed of blocks of the surface-crust of such varieties broken up by subsequent movement, and forming some of the most difficult ground to traverse which it is possible to conceive (Pl. XLVIII, figs. 1 & 2).

One of the chief characteristics of these fields has been the great fluidity of the lavas at the time when they were poured out.

[1] I have seen caves and tunnels in Halemaumau, the 'working pit' of the crater of Kilauea, where the wall was being dissolved and undermined by convection currents of hot lava. They presented appearances quite comparable with this and the small lateral tunnel above mentioned.

Places are common where the surface is covered with fresh sheets of lava measuring an inch or even less in thickness; and the surface is honeycombed with channels along which the lava has flowed, channels which are occasionally deep and open, but often have a crust, sometimes thick, sometimes so thin as to give way under a man's weight, and form dangerous pitfalls for the unwary. There are, too, caves and bubbles of all sizes up to many feet in diameter, often also covered with only a thin roof equally liable to collapse (Pl. XLIX, fig. 1), and many areas, sometimes extensive, where the liquid lava beneath has found a vent lower down after a crust has formed on the surface, and the whole crust has subsided after the manner of the plain of Thingvalla. Tunnels can be seen by which the lava has escaped.[1]

This class of subsidence by lava flowing out from under a crust seemed to me common on the lower parts of the lava as well as on the upper, and there are two notable examples at the eastern foot of the cone (Pl. XLV, fig. 2). The lava-tunnels and evidences of rapid flow, superficial and deep, are numerous along the line of great fumaroles. On my ascent of the cone I had occasion to cross the line three times, in order to find a practicable route. From the causes named above, the surface, especially in the upper part, was so rotten that progress was extremely difficult; while the certainty that the river of molten lava was running somewhere below at an uncertain depth and under a crust of unknown thickness, combined with the approach of night, rendered delay undesirable. I was, therefore, unable to examine the fumaroles carefully[2]; but, so far as I could see, one of them was a large hollow with precipitous sides, apparently of the nature of a subsidence from the collapse of a crust of lava by combined remelting and withdrawal of fluid support below; and subsequent examination of similar places near Kilauea has confirmed this opinion. At Matavanu few of them appear to have been examined, and in still fewer was the liquid lava visible, but I understood that in one it had been seen flowing at a depth of 30 to 40 feet.[3]

The slope of these lava-fields is very gradual. The distance of the crater from the sea is about 7 miles as the crow flies; but, following the sinuosities of the underground current, it may be estimated as somewhat over 10 miles. If the foot of the cone be taken at a height of 1800 feet, this gives an average fall of one in 30, or about 6°, a slope which is of the same order of magnitude as that of many of the Icelandic streams. The slopes of some of the Hawaiian volcanoes formed of the same class of lava are stated by

[1] Compare T. Anderson 'Volcanic Studies' 1902, pls. lviii–lviii A & lxxii.

[2] The next day the wind blew the fumes against us, and prevented further examination.

[3] I have since received from Mr. Barts of Fagamalo a photograph of one such 'pit crater,' showing precipitous walls composed of very numerous thin layers of lava, presumably both surface-flows and intrusive sheets, comparable to those in the wall of the crater; also another photograph showing a pit with its walls coated with lava frozen on to them, somewhat like the wall of the crater shown in Pl. XLVII. This pit appears to have been an orifice by which lava rose and flooded the surrounding lava-field.

Dana[1] to be even less, sometimes not even more than 1°, an observation which I can personally confirm, in the case of the lavas of Kilauea. It is to be remarked that at Matavanu the lava-stream is highest in the centre over the line of the tunnel, and tends to become more so owing to frequent small flows of lava which, whenever the flow beneath is obstructed from any cause, rise to the surface and then spread out and solidify there. This class of flow is more common as the sea is approached, so that the surface nearer the sea is often higher than that inland, and the direction of the flows in the lower part is thus often away from the sea, and in the reverse direction to that of the flow underneath by which they are supplied. That the surface of the lava over the tunnels is higher than elsewhere is a matter of observation, and that the difference tends to increase is vouched for by careful observers like Mr. Williams and Capt. Allen. They think that this increase of height is also largely due to lava intruding from the tunnel into the surrounding lava and forming sills and dykes; and, although this is mainly a matter of inference, I see no reason to question its accuracy. On my first attempt to cross the lava and visit the outflow into the sea, our way was stopped by a fairly large flow of lava only a day or two old. It had originated in an opening of the lava-crust near the sea, and spread out inland as mentioned above. My men tried to cross it, and pronounced it impracticable; a dog tried it, and retreated howling. I found a hummock of cool lava near it, on which I established myself and took photographs of the steam-explosions and the intervening lava (Pl. L, fig. 2). This led me to notice particularly a crack in the hummock where the surface had risen apparently by the lateral compression of the surface-crust. When I made another attempt two days later, I succeeded in getting to the same spot, but a new lava-flow had covered a great part of the previous one and advanced even nearer the hummock. I noticed that the surface on which the new flow rested was pressed down and lowered for a distance of some feet in front of its edge; while the hummock itself was pressed up, and the crack materially widened. This shows that the lava below the surface was still plastic and capable of being squeezed into new positions, and the acuteness of the deformation or bending of the crust showed its small thickness. It is clear that a considerable amount of intrusive action might take place in such a mass, without leaving much subsequently recognizable alteration. On the lower part of the lava-fields there are also several considerable mounds (or perhaps they might even be called plateaux) formed of large angular blocks of broken compact lava. The mounds were flat-topped, and the blocks presented no trace of igneous action since they had been broken. I could not at the time think of any satisfactory explanation of their formation, but now believe that they have been probably formed by intrusion of lava under the previously consolidated crust, which was broken into pieces as it was pushed up (Pl. XLVIII, fig. 2).

[1] J. D. Dana, 'Characteristics of Volcanoes' 1890, p. 148.

The Outflow of Lava into the Sea.

This is one of the most striking features of the eruption, and it seems to have been going on, with the exception of one day, since 1905; but, like the flow of lava-streams elsewhere, it is never the same for many hours together.

The lava, on descending to the low ground, has spread itself like a fan, and by successive flows has covered the coast at different times for a distance of 9 miles, destroying four villages (Salago, Toapaipai, Malaeola, Sataputu), and the buggy-road between them, also the whole of the town of Saleaula except two houses. This part of the coast was collectively known as Le Ala Tele, and about half of it, reaching from Saleaula to Toapaipai, was encircled by a coral-reef. The lava has filled up the whole of the space inside this reef. Capt. Allen is quite clear that the lava first filled up part of the space between the shore and the reef,[1] and, on reaching the outer edge of the latter, did not continue to extend into deep water, but turned to the westward along the reef and continued to extend along it for some distance. The space between the shore and this part of the reef was not filled up until later. He agrees with me, however, that much of the reef farther west, which is now strewn with lava-blocks, has been so covered by the action of the waves and currents, and that the blocks are not *in situ*. He thinks that the reason why the lava spread along the reef rather than into deep water was that the lava-front exposed to the open sea was much more rapidly and effectually cooled than that which flowed only to the shallow water on the reef; this, I agree, is the probable explanation.

Having twice tried from the land to examine the place where the lava fell into the sea, and having been each time stopped by hot lava-flows, I determined to examine the coast from a boat. The reef was covered with breakers and consequently inaccessible. Its surface is certainly strewn with large basalt boulders, but, for some distance at the western end at any rate, these appear to be water-borne from the lava coast adjacent. Rowing farther eastwards, we came to the lava *in situ* forming a wave-washed, iron-bound coast of cliffs, 20 to 30 feet high and higher yet farther on. Though at sea the wind was slight and the surface smooth, the heavy low swell of the Pacific was breaking with tremendous force on the shore, the spray dashed nearly to the top of the cliffs, and a very steep beach of basalt-boulders at their foot was obviously undergoing rapid denudation. The cliff consisted of numerous irregularly bedded sheets of massive lava a few feet thick, with thin bands of the usual scoriæ and ash separating them at their joints. One or two small natural arches presented no special features, beyond showing the rapidity of the erosion. On coming nearer the point of entrance of the lava into the sea near the headland of Asuisui, the cliff rises to a height of 40 or 50 feet or more; while, close to the spot where the explosions occur, and

[1] See his photographs of this in H. I. Jensen's paper, Proc. Linn. Soc. N.S.W. vol. xxxi (1906) pls. lv–lvii.

especially to the west or leeward of the point, are beds of black sand capping the lava. This appears to be wind-borne and the product of the explosions. The streams vary much from day to day, and even from hour to hour. When I saw them for the first time at night from the steamship *Atua*, there were twelve visible by their own light; a second time, seen from a native schooner, they were fewer and quite different. On a third occasion, when I got as near as possible in a boat, the lava was flowing in four large and distinct streams, and more would probably have been visible at night (Pl. L, fig. 1). I was anxious to observe the formation of pillow-lava and we got as near as possible without melting the pitch-caulking of the boat. Where the discharges were most active explosions were almost continuous, and the whole was obscured by clouds of steam from which fragments of red-hot lava and showers of black sand were seen to fall (Pl. LI). Where the lava was flowing in smaller quantity explosions were much less noticeable, and the lava extended itself into buds or lobes. The process was as follows: an ovoid mass of lava, still in communication with its source of supply and having its surface, though still red-hot, reduced to a pasty condition by cooling, would be seen to swell, or crack, into a sort of bud with a narrow neck like a prickly pear on a cactus, and this would rapidly increase in heat, mobility, and size, till it either became a lobe as large as a sack or pillow, like the others, or perhaps stopped short at the size of an Indian club or large Florence flask. Sometimes the neck supplying a new lobe would be several feet long and as thick as a man's arm, before it expanded into a full-sized lobe; more commonly it would be shorter, so that the freshly-formed lobes were heaped together. They looked white-hot even in daylight, and, as the waves washed over them, the water seemed to fall off unaltered without boiling, owing probably to its being in the spheroidal condition.[1] I have

[1] The structure thus produced is analogous to that to which the term pillow-structure, originally applied to a peculiar and exceptional form of spheroidal jointing, has of late years been often extended.

It is very satisfactory to me to find that the mode of formation that I have observed is in accord with the views previously expressed as probable on other considerations by such careful observers as (in chronological order):—

- Cole, G. A. J., & Gregory, J. W. 'Variolitic Rocks of Mont Genèvre Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 311 (and *in litt.*).
- Teall, J. J. H. Trans. Roy. Geol. Soc. Cornwall, vol. xi (1893–95) pp. 562–64 & pl. facing p. 565. Also along with Dr. B. N. Peach & D. J. Horne. 'The Silurian Rocks of Scotland' Mem. Geol. Surv. 1899, pp. 84, 431, etc. & pls. iv, vi.
- Geikie, Sir Archibald. 'Ancient Volcanoes of Great Britain' vol. i (1897) pp. 25 & 193.

Foreign authorities on pillow-lava are:—

- Dana, J. D. Amer. Journ. Sci. ser. 3, vol. xxxiv (1887) p. 362; and 'Characteristics of Volcanoes' New York, 1890, pp. 9, 241, & 243.
- Platania, G., in Dr. Johnston-Lavis's 'South Italian Volcanoes' 1891, pp. 41–42 & pl. xii.
- Daly, R. A. 'Variolitic Pillow-Lava from Newfoundland' Amer. Geologist, vol. xxxii (1903) pp. 74–78, with a discussion and references.

watched the formation of ordinary corded lava on Vesuvius by a similar process of budding. When the hot lava of the interior has got vent and formed a pool, a soft scum forms on the surface, which is pushed forward by the fluid lava moving beneath, and is raised into a wrinkle or cord, then others are formed in the same way, until the surface is entirely solidified into a succession of cords (Pl. XLVIII, fig. 1). The same sort of process can often be watched on the surface of a slowly moving river when rubbish floating on the surface is stopped behind a log of wood. Here it was different: there was no trace of the formation of wrinkles and cords. The whole surface seemed to be chilled at once, as the waves rolled on and off, and examination of cooled specimens between high and low water-mark at the edge of the lava in the lagoon confirmed this. The surface at and below the water-level was roughly granular, like that of air-chilled bombs such as I have seen on Stromboli and Haleakalá, while higher up the ordinary corded or pahoehoe structure was seen (Pl. LII). I was vividly reminded of a section that I have seen at Aci Castello in Sicily.

Before the eruption a small river came down from the mountains, passed through the villages of Patamea and Samalaeulu, and fell into the sea at Sataputu. Both the higher and the lower reaches of the river have been covered over and filled up with lava, leaving the channel at Patamea and Samalaeulu unobstructed, but usually empty. The rain, which falls on the former gathering-ground, is soaked up by the lava and possibly percolates elsewhere, so that scarcely any water now comes down the channel except in very heavy rain-storms, which have only occurred once or twice since the eruption. On one such occasion the water could not get away owing to the obstruction near the old mouth, and the country round was flooded. The empty channel is a good example of a water-eroded gorge cut in geologically recent beds of lava, and shows the usual water-holes, as also small falls in its bed. At one place where I saw it, it was nearly 30 feet deep and not much wider. At others it was perhaps 3 or 4 times as wide.

The Destruction of Buildings.

The native houses in the villages destroyed consisted merely of thatched roofs supported on wooden poles. The churches of Saleaula and Sataputu were, however, substantial stone buildings,

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Clements, J. M., Monogr. U.S. Geol. Surv. xxxvi (1899) p. 124, thinks that pilow-lava is a form of aa, not pahoehoe. The aa referred to is not the common scoriaceous form, but one described by Dana as above.

Having now seen the actual formation of all three—aa, pahoehoe, and pillow-lava, I am satisfied that the scoriaceous form of aa is produced by watery vapour expanding from inside the pores of the lava; pahoehoe from the slow cooling of lava containing little vapour; and pillow-lava (at any rate one form) from the chilling action of water on the surface before it has time to assume the corded structure of pahoehoe. I have not seen the formation of aa as described by Dana.

as was also a house near Saleaula belonging to Mr. Bartley. In these three cases, although the interiors were burnt and gutted, the lava was fluid enough to surround the structures and bury them in various degrees without overthrowing the walls. Thus the body of the church of Sataputu was entirely buried under 30 or 40 feet of lava, and the only part remaining visible is the tower which still rears its head above the lava-field (Pl. XLIX, fig. 2). The walls were, in this case, substantial enough to cool the lava where it touches them, and so far to solidify it that subsequent flows were kept back, the upper part remaining uncovered in the middle of a depression which almost simulates a subsidence.

Mr. Bartley's house, though gutted, remains standing in the midst of a similar depression. The lava in this case was not so deep as in the first.

The church of Saleaula was near the edge of the lava, which was consequently of no great thickness; the lava was fluid enough to enter the building through the windows and cover the floor to a depth of several feet, without overthrowing the walls.

Damage to Vegetation.

All vegetation overwhelmed by the lava was, of course, killed; but much more damage was done by the Ua Sami, or poisonous gases, discharged from the crater, or formed by the action of the hot lava on the sea-water. The destruction of vegetation was naturally greater in the vicinity of the crater, and was especially severe on the high ground to the west, owing to the prevailing wind being easterly and north-easterly. On the descent from the crater in this direction the destruction of trees was complete, and to nearly as far as Olonono, a distance of 2½ miles, their bleached skeletons were all that remained. It was only in a few sheltered situations that the low undergrowth was beginning to return from the old roots, till this distance was reached, the trees having suffered more than the undergrowth. I heard from credible sources that the cocoa-nut palms had been killed as far as 5 miles to the west of the crater. On the low ground, both at Saleaula on the west, and Sataputu on the east, the damage was less. Trees close to and actually in the lava were killed, and I noticed many moulds where the lava had solidified round them, and the trunks had subsequently decayed[1] or been burnt out; but luxuriant tropical growth had returned right up to the lava, and was beginning to spread over it, especially near Sataputu. The plants that seem to be the pioneers were especially the creeping vines like *Ipomea*; and it is noticed that these were similar to, if not identical with, some of the commonest pioneer plants on the Soufrière of St. Vincent.

[1] In Hawaii I have seen this process carried a stage further. The lava has cooled and solidified so as to form a mould round a tree, but this solidification has only extended to a distance of a foot or two, the surrounding lava still remaining fluid. The flow has continued its course, and the still fluid part run away, so that a tube of solidified lava like a chimney 10 or 12 feet high remains standing and marks the position of the former tree.

At Matautu, 2 miles west of the lava, the damage was due to the Ua Sami formed by the action of the lava on the sea-water, which was considered even more poisonous than that discharged from the crater. Many cocoa-nut palms had been damaged and some had died, but most had recovered; while several breadfruit trees were killed entirely, and some recovered only with the loss of their upper branches.[1]

During the night of my visit to the crater some large frigate-birds of two kinds, black and white, with long tails, were constantly circling about the crater at a height of several hundred feet, and were clearly visible in the lurid reflected light. They have been noticed by others to whom I have spoken.

Mr. H. I. Jensen (*op. cit.* pp. 666–70) gives a full account of the petrology of the Samoan lavas: I quote only his conclusions. Petrologically the Samoan rocks are very like one another and the basalt near Auckland (New Zealand). The olivine content varies from *nil* to nearly 50 per cent. Most of the rocks are hypohyaline, if obtained from a depth beneath the surface of a flow; hyaline or hemicrystalline, highly vesicular or scoriaceous, when obtained near the surface. The earlier rocks erupted were probably augite-andesites, the later rocks being olivine-basalts. The new flow is richer in iron-ores than any of the old flows. Mr. Jensen does not discuss the reason of the high temperature and great fluidity of the lava at the moment of the eruption.

Comparison with Kilauea.

It may be well to discuss the many resemblances and few differences between the volcanoes of Matavanu and Kilauea in Hawaii, which latter I visited soon after the former. Both are of the effusive type, that is, characterized by the discharge of lava very slightly charged with steam and other volcanic gases, and hence little subject to explosive action: in which respect they contrast strongly with the volcanoes of the West Indies and Central America, where most of the recent eruptions have been highly explosive, and attended with the discharge of a vast quantity of ashes, lapilli, and pumice, but little or no lava. Not that explosions have been entirely absent in these Pacific volcanoes: I found in the walls of the crater of Matavanu some beds of tuff, that is, consolidated ash, but they were subordinate in thickness and importance to those of lava; and also on the flanks of the cone some bombs of basalt. Similarly on Kilauea I saw a bed of lapilli about a foot thick, but it was on the slopes of the old encircling cone comparable to Monte Somma, and there was no trace of such about the working crater. Moreover, its amount was strikingly different from the deposits of ash ranging up to 100 or 200 feet in thickness formed in 1902 on the Soufrière in St. Vincent, or on Montagne Pelée in Martinique, or on Santa Maria in Guatemala, or even those formed on Vesuvius in 1906.

[1] No human lives were lost by the eruption.

Then, again, there is the high temperature of the lavas and their power of remelting, dissolving, and carrying away previously solidified lava, and even surrounding rocks. At Kilauea this has been described by various observers, and I myself saw the incandescent molten lava in the 'working pit' eating into the walls and forming caves. Two of these, during my stay, undermined considerable portions of the so-called 'black ledge,' that is the most recently solidified portions of the lava-lake. The roofs of these fell in and formed recesses scores of yards across, which really deserved the name of bays. Prof. Daly, of the proposed observatory, told me that there was a cave in the walls of the working crater above the black ledge and pit evidently formed in the same way, and I saw landslides which by all analogy had been due to the undermining of the foot of the walls and their consequent subsidence. The vertical or overhanging walls of this crater had apparently been left standing in this manner. The exposed ends of the beds of lava were quite sharp except in places low down, where they showed signs of remelting, and there was no trace of ejected material round the lip of the crater. The same reasoning would apply to the landslides on the walls of the large encircling crater near the Volcano House, and even, I think, to the curious pit-craters (so called) in the neighbourhood, such as Kilauea Iki and several others.

Matavanu supplies abundant evidence of the same action. It is true that there is no old encircling crater with its landslides and subsidences; but the working crater has walls in many parts vertical or overhanging, and cracks about the lip showed that portions were ready to fall in, and rendered caution necessary in approaching the edge. The strata in the walls in the upper parts, where not obscured by recent lava-splashes, were broken off sharply like those in Kilauea. Caves and tunnels were visible in the walls, and especially the great tunnel at the western end appeared to be strictly comparable to the caves in the black ledge of Kilauea, and not a tunnel of outflow like that at the other end of the crater. Frozen ledges on the wall indicated former ledges of lava like the black ledge in Kilauea, and showed that the molten river was now flowing out at a lower level than during an earlier phase of the eruption. The mouth of the tunnel into which the lava flows on leaving the crater appears to have undergone a corresponding lowering. The crater-wall above it is much less regularly stratified than the adjacent parts, and appears to consist of agglomerate, or perhaps partly of material frozen on from below. I saw this process going on in one of the caves of Kilauea, where stalactites were forming from the roof. This may be the place from which the great outburst of lava took place in February 1906 (see map, p. 622).

This brings us to one of the most curious apparent differences, but perhaps real resemblances, between the two volcanoes. The lava in Kilauea, as is well known, is in constant motion; and, at first sight, it looks as if it were flowing out at one end of the crater. This appearance is certainly deceptive: the direction of the flow and level of the lava vary frequently; and the places where the lava appeared to flow out a few days previously can then be seen to be solid, and the caves into which it seemed to flow to have solid ends. The motion must be due at any rate to convection currents like those in a boiling pot or kettle, but it is still a question whether this is all.

The movement in Matavanu looks similar but much more active, the waves of liquid basalt are much larger, the splashes remain longer visible when they strike the walls, and the fountains are much larger and generally more active. The molten lava also can be seen to pour like a cataract into the tunnel, and visibly falls into the sea at the other end. Matavanu is therefore certainly a river. Kilauea may be a river, but is more probably a boiling pot. Does the lava of Kilauea at the times when the lake empties itself periodically, say once in five years, also discharge itself into the sea? This has been often supposed, but absolute proof has been wanting. The analogy of Matavanu now supports this hypothesis; and the appearances which I saw, along with Governor Frear of Hawaii, in some enormous cracks and subsidences between Kilauea and the sea give support to the idea.[1]

In conclusion, I wish to tender my thanks to Dr. Solf, Governor of German Samoa, for countenance and introductions; to Vice-Admiral von Cœrper of the Imperial German Navy, and to the Captain and Officers of S.M.S. *Leipzig*, especially Capt.-Lieut. von Luck and Ober-Lieut. von Sastrow for hospitable conveyance on their warship; and above all to Mr. Richard Williams, Amtmann of Savaii, whom I have so often quoted above, for much hospitality and practical assistance. Thanks are also due to Messrs. Ludwig Schrœder of Safune and Herbert Edwin Rae of Apia and to Serjeant Suisala (himself a native chief) for practical assistance of various kinds.

EXPLANATION OF PLATES XLV–LII.

Plate XLV.

Fig. 1. Matavanu from the sea.—A background of old volcanic mountains; then the new cone of Matavanu, surmounted and partly concealed by a cumulus and a lower stratum of condensed vapour. In front of this are seen the lava-fields covered with a little fleecy vapour, and themselves partly surrounding two old cones. Still nearer is the tropical jungle, and then the sea.

2. Matavanu: the cone and upper lava-field seen from the south.—In the distance is the cone. The lip of the crater extends from a point near the right of the plate to nearly the same distance from the left edge. The field in front is formed of slaggy lava (pahoehoe), and appears to have stood originally at a higher level, up to the ridge at the foot of the cone. After the formation of a crust, the lava beneath it has found a vent and the surface has subsided considerably, especially to the right and centre of the foreground.

[1] A discussion of these subsidences would, however, be premature until all the photographs are developed and can be examined.

Plate XLVI.

The southern wall of the crater.—On this side of the crater tuffs predominate over bedded lavas. Below the cloud of vapours on the right, and just outside the picture, is the tunnel mentioned as probably caused by remelting.

Plate XLVII.

The western end of the crater, from the same point of view as Pl. XLVI. (To the left the picture should join the last.)—On the right the lower part of the wall is covered with layers of lava which have frozen on to it. The western tunnel is almost concealed at the bottom of the column of vapour. On the right of this column (near the centre of the plate) is a rock which appears to be a dyke.

Plate XLVIII.

Fig. 1. Part of a lava-field.—A characteristic patch of slaggy lava (pahoehoe) showing the corded structure. Much of the scoriaceous lava (aa) is similar to that of Vesuvius or Etna. See T. Anderson, 'Volcanic Studies' 1902, pls. vii, viii, & xviii.

2. Lava-field with broken-up blocks, near the site of Toapaipai.—The greater part of the field is slaggy lava of the ordinary type. In the foreground, near the figure, the crust has been broken up by addition to or subtraction from the volume of the imperfectly consolidated lava beneath. In the middle distance on the right is a large bank of similar but bigger blocks, apparently due to the same cause. Farther away, at the foot of the hills, is the row of great fumaroles which mark the underground course of the lava on its way to the sea.

Plate XLIX.

Fig. 1. Lava with subsidences and a tunnel, near the site of Sataputu.—This is slaggy lava of the usual type. After the freezing of a crust the still liquid lava has found a vent and flowed elsewhere, leaving a cave or tunnel below. Towards the left end of the nearer subsidence are two small ledges, marking halting-places of the liquid lava during its fall. On the surface are dead trunks of trees and in the distance are trees, some killed outright, some recovering. The greater part of the country now buried under this lava-field was previously covered with similar forest.

2. The tower of the church of Sataputu.—This is all that remains to mark the site of that once flourishing village, which is now buried under about 30 feet of lava. It is chiefly remarkable for the depression round the tower, which simulates a subsidence; but the lava shows no marks of having been higher than it is at present.

Plate L.

Fig. 1. The lava flowing into the sea.—This photograph shows a place where the lava is flowing quietly into the sea, and producing a structure which appears to be a form of pillow-lava, as described on p. 632. The sea was boiling, and we did not approach nearer, for fear of melting the pitch-caulking of the boat.

2. Steam-cloud at Asuisui.—A view taken from the surface of the new lava. The foreground is corded lava of the usual type, and some of it had probably only been erupted the previous day. It was too hot to walk upon. The lava is falling into the sea just on the farther side of the ridge.

Fig. 1.

MATAVANU FROM THE SEA.

T. A , Photogr.

Fig. 2.

MATAVANU: THE CONE AND UPPER LAVA-FIELD SEEN FROM THE SOUTH.

T. A., Photogr.

Bemrose Ltd., Collo., Derby.

THE SOUTHERN WALL OF THE CRATER.

T. A., Photogr.

Bemrose Ltd., Collo., Derby.

THE WESTERN END OF THE CRATER. TO THE LEFT THE PICTURE SHOULD JOIN THE LAST (PL. XLVI).

T. A., Photogr. *Bemrose Ltd., Collo., Derby.*

FIG. 1.

SLAGGY LAVA (PAHOEHOE), SHOWING CORDED STRUCTURE.

T. A., Photogr.

FIG. 2.

LAVA-FIELD WITH BLOCKS BROKEN UP BY INTRUSION OF LAVA. FUMAROLES ARE SEEN ON THE LINE OF THE PRESENT UNDERGROUND FLOW.

T. A., Photogr.

Bemrose Ltd., Collo., Derby.

Fig. 1.

LAVA WITH SUBSIDENCES AND A TUNNEL.

T. A., Photogr.

Fig. 2.

THE TOWER OF THE CHURCH OF SATAPUTU IN A DEPRESSION IN THE LAVA-FIELD.

T. A., Photogr.

Bemrose Ltd., Collo., Derby.

Fig. 1.

THE LAVA FLOWING INTO THE SEA.

T. A., Photogr.

Fig. 2.

THE STEAM-CLOUD AT ASUISUI: IN THE FOREGROUND IS HOT LAVA.

T. A., Photogr. *Bemrose Ltd., Collo., Derby.*

AN EXPLOSION AS THE LAVA FALLS INTO THE SEA.

Capt. Allen, Photogr.

Bemrose Ltd., Collo., Derby.

LAVA IN THE LAGOON:

IN THE DISTANCE, ORDINARY PAHOEHOE; IN THE FOREGROUND, PILLOW-LAVA CHILLED BY SEA-WATER.

T. A., Photogr. — Bemrose Ltd., Collo., Derby.

PLATE LI.

An explosion as the lava falls into the sea.—This photograph, for permission to reproduce which I have to thank Capt. Allen, was taken by him from the cooled and solidified surface of the lava, near the spot where the still liquid mass from beneath was running into the sea, not far from the site of Toapaipai. Masses of red hot lava are seen in the air, each leaving a track of steam behind it. I saw many such explosions through the binocular, but did not get near enough to obtain a photograph equal to this.

PLATE LII.

Lava in the lagoon, near Saleaula.—The lava in the background above high-water mark has cooled slowly, and had time to assume the usual corded structure. In the foreground, between tide-limits, many of the lobes have flowed into the water and been chilled before they had time to do this. They present a structure resembling one variety of pillow-lava.

[NOTE.—The dates of the various lava-flows stated on p. 624 were taken in 1909 from Amtmann Williams's notes. The map on p. 622, with his latest corrections, was not received until the text was in type. The few small discrepancies will not, it is hoped, materially affect the general narrative.]

DISCUSSION.

Sir ARCHIBALD GEIKIE commented on the interesting character of the discourse to which they had listened, and on the instructive pictures which, as shown on the screen, had brought the details of a little-known volcanic region so vividly before their eyes. The type of volcanic action described by the Author belonged to that which had long been familiar as displayed by the Hawaiian volcanoes, but a special value attached to his observations on the end of the lava-stream where it enters the sea. The speaker believed that never before had the phenomena there presented been so closely watched and so instructively photographed. The Author deserved infinite credit for the courage and persistence which, in spite of a trying temporary lameness, had overcome all the natural difficulties of the place, and had enabled him to bring home so large an amount of material for the elucidation of various problems in the mechanism of volcanoes.

Mr. H. H. THOMAS, referring to the motion of fluid lava beneath a solid crust, mentioned an area of 200 square miles of lava in Central Iceland, which was covered with subsidiary vents or spiracles rising to heights of 10 or 15 feet above the average surface.

The PRESIDENT (Prof. WATTS) said that he was much impressed by the Author's description of the origin of pillow-lava. It had long been thought that this structure was the result of basic lava pouring into the sea, but this appeared to be the first case in which the actual production of it had been observed and described.

The AUTHOR, in reply, said that the spiracles mentioned by Mr. Thomas were very abundant in the Myvatn district of Iceland, and were generally, and he believed correctly, attributed to the hot lava flowing over mud or similar wet material. The steam generated made its way up through the lava, escaped through cracks in the crust, and blew out masses of pasty lava which fell round the orifice and built up the cones referred to.

26. *The* Denudation *of the* Western End *of the* Weald.

By Henry Bury, M.A., F.L.S., F.G.S., formerly Fellow of Trinity College, Cambridge. (Read June 15th, 1910.)

Contents.

I. Introduction.

The old 'sea-cliff' theory of Wealden denudation, which regarded the escarpments as the direct result of marine action, has long disappeared, and no one now doubts that the main physical features of this district have been produced by subaërial agencies. Beyond this, however, there is but little unanimity. Whether the subaërial process has been continuous since early Oligocene times; whether it can be divided into two cycles, with a peneplain between; or whether the removal of the top of the dome has been assisted by marine planation, are questions so undecided that, except on the one point already mentioned, geologists are perhaps in no closer agreement as to the physical history of the Wealden area than they were thirty years ago.

In the second section of this paper the older lines of evidence are reviewed, and in places supplemented by new arguments, tending to show that the theory of marine planation is the one which, on the whole best, embodies the observed facts. In the third section the history of the four western rivers (Wey, Mole, Arun, and Adur) is examined, and the same inference drawn. Whether this explanation holds good for other parts of the Wealden area must be left to future investigation.

The expression 'plane of marine denudation' is said by Foster &

Topley (5, p. 473, footnote)[1] to have been first used by Ramsay in 1847; but the words themselves are not to be found in the abstract of his paper to which they refer (20). It was not until 1863 that he definitely pointed to the Wealden area as showing traces of such a plain (21, 1st ed.); and in this he was anticipated by Jukes (8, p. 400), who, in 1862, expressed the belief that marine denudation had removed the Chalk from the centre of that area 'during or after the Eocene Period,' leaving subaërial agencies to complete the process. Some years later Topley (26) adopted the same hypothesis, and, by adding to Ramsay's very meagre evidence a table of heights along longitudinal and transverse lines, placed it on a more satisfactory footing: but even by Topley the arguments in its favour are not clearly defined, and I cannot help suspecting that its wide acceptance at that time may have been due, not so much to the strength of the proofs advanced, as to an unwillingness on the part of those who were compelled to give up the sea-cliff theory to abandon altogether their belief in marine action.

Dr. Barrois, in his classical paper on the English Chalk (1), found no evidence of this marine plain, which he thought was postulated by Ramsay solely to explain the courses of the consequent rivers. In his opinion the subaërial denudation of the Weald began before the Eocene beds were laid down, and continued at least until Pliocene times: how far the Diestian sea may have invaded the district is left uncertain, but it is expressly stated that it produced very little effect in denuding the Chalk.

Prestwich also rejected the hypothesis that the sea had played any important part in the removal of the Chalk from the Wealden area. According to him (17, 18, & 19) that area has formed dry land since Eocene, and perhaps since pre-Eocene, times; and although the early Pliocene sea has left deposits along its northern borders as far west as Dorking, yet it did not extend for any distance into the interior.

Prof. W. M. Davis (3), in 1895, put forward a suggestion which, so far as this region is concerned, seems to have been entirely new. From his study of the courses of rivers in the south and east of England he was led to the conclusion that they represented the product of two cycles of subaërial denudation. The first cycle ended in a peneplain, on which a mature system of drainage was already established; then a further elevation of the land initiated a second cycle, the rivers of which, instead of being developed *de novo* (as they must be on a marine plain), started with, and continued still further to mature, the system already established on the peneplain.

Though many others have expressed a passing opinion on the subject, practically the whole of the evidence until now adduced is to be found in the writings of the five great authorities already quoted—Ramsey, Topley, Barrois, Prestwich, and Davis. That evidence I shall now proceed to examine in detail.

[1] These numerals in parentheses throughout the paper refer to the Bibliography, § IV, pp. 691–92.

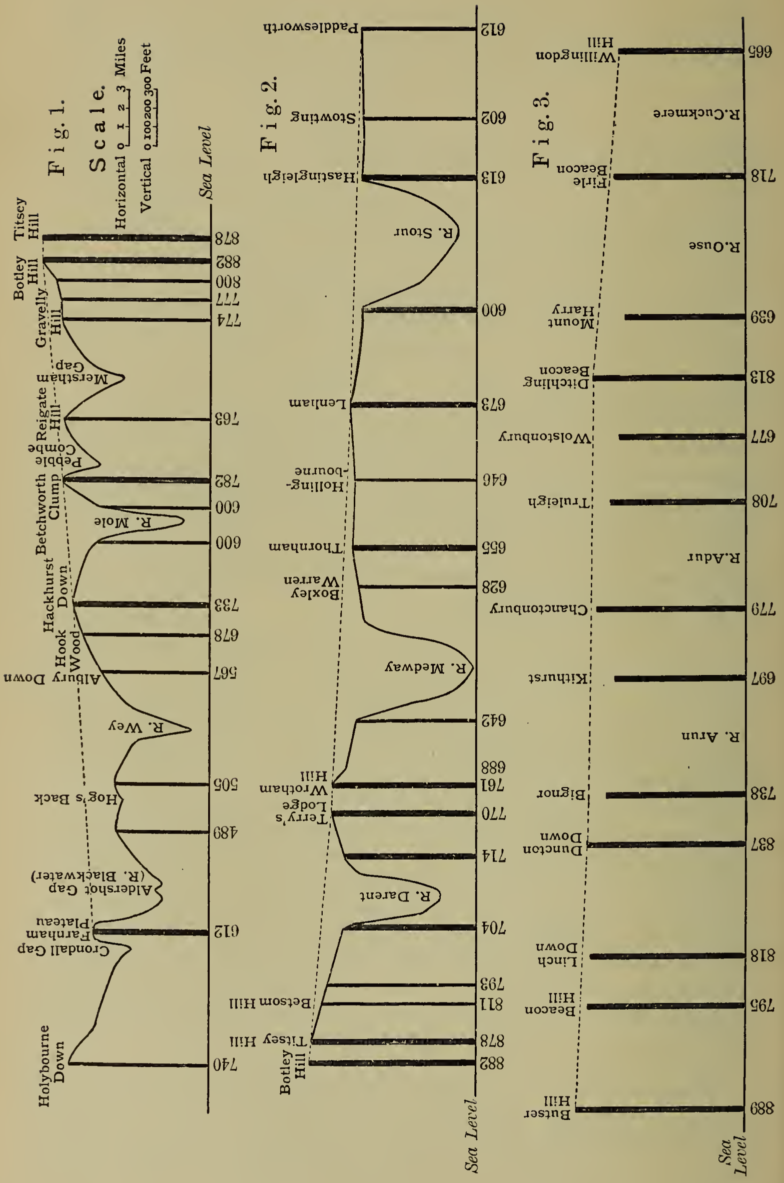


Fig. 1.
Scale.
Horizontal 0 1 2 3 Miles
Vertical 0 100 200 300 Feet
Sea Level
Titsey Hill
Botley Hill
Gravelly Hill
Merstham Gap
Reigate Hill
Pebble Combe
Betchworth Clump
R. Mole
Hackhurst Down
Hook Wood
Albury Down
R. Wey
Hog's Back
Aldershot Gap (R. Blackwater)
Farnham Plateau
Crondall Gap
Holybourne Down
878
882
800
777
774
763
782
600
600
733
678
567
505
489
612
740
Fig. 2.
Paddlesworth
Stowting
Hastingleigh
R. Stour
Lenham
Holling-bourne
Thornham
Boxley Warren
R. Medway
Wrotham Hill
Terry's Lodge
R. Darent
Betsom Hill
Titsey Hill
Botley Hill
Sea Level
612
602
613
600
673
646
655
628
642
688
761
770
714
704
793
811
878
882
Fig. 3.
Willingdon Hill
R. Cuckmere
Firle Beacon
R. Ouse
Mount Harry
Ditchling Beacon
Wolstonbury
Truleigh
R. Adur
Chanctonbury
Kithurst
R. Arun
Bignor
Duncton Down
Linch Down
Beacon Hill
Butser Hill
Sea Level
665
718
639
813
677
708
779
697
738
837
818
795
889

II. Review of Existing Hypotheses.

(A) General Evidence in favour of a former Plain (Marine or Subaërial).

(i) The coincidence of the highest levels throughout the area.—It is upon the evidence for this coincidence that Ramsay and Topley mainly depend; indeed it may safely be said that, in its absence, no one would have put forward a theory of planation at all: it is a different matter, however, to assert that the evidence can lead to no other conclusion. Following Topley (26, p. 240), I shall examine these coincidences along two lines, longitudinal and transverse. In the longitudinal series the Chalk Downs offer the most important evidence, and for that reason I give diagrams (figs. 1, 2, & 3, p. 642) showing their principal elevations, the measurements of which, taken from the most recent maps of the Ordnance Survey, differ somewhat from those of the old Survey used by Topley, but not to any important extent. In these diagrams a greatly exaggerated vertical scale has been used, in order to give prominence to certain features which would otherwise be obscure; but in spite of this it has been found possible to join together the principal summits by a line (dotted) which is almost straight. In figs. 1 & 2 I have also introduced a fine line showing a smoothed curve of the Downs as a whole, with their relation to the river-valleys; but, in the case of the South Downs (fig. 3), the numerous embayments made this practically impossible.

Topley claims that his figures (26, pp. 240–41) show a general fall from west to east. This may be true of the South Downs, although the fall is very small as far east as Ditchling Beacon, and beyond that it is due in some measure to the curve of the escarpment line towards the south; but in the North Downs this fall towards the east is certainly not conspicuous, even if it has any existence at all. In the first place, it is noticeable that Topley goes far to the west of the Wealden area for his starting-point, and that if he had done the same with the South Downs he would have arrived at very different results. Inkpen Beacon, with which he commences, rises to 1011 feet O.D., but the highest point in the Downs bounding the Weald is Botley Hill (882 feet O.D.). Between these two hills, nearly 70 miles apart, there are few points which rise above 800 feet, and for a distance of 60 miles absolutely none at all. Beyond Botley Hill (fig. 2) the fall to the east is evident enough, but on its other side (fig. 1), if we confine ourselves to the Wealden area, the diagrams suggest a similar fall

[*Note on figs. 1–3, p. 642.*—Figs. 1 & 2 are a diagrammatic elevation of the North Downs. The actual summit of the Downs, omitting minor irregularities, is represented by a fine line, and the theoretical summit of the plain by a dotted line. Fig. 3 is a similar elevation of the South Downs: owing to the greater unevenness of the crest of the escarpment and the complications introduced by the deep embayments, the actual summit-line is omitted.]

towards the west, at any rate as far as Farnham. Before, however, we conclude that the slopes thus indicated are due to warpings of a former plain, we must examine carefully the effects of the change of dip, which between Guildford and Farnham is very marked; and this may conveniently be deferred to a later stage of this paper.

If we turn next from the Chalk to the Lower Greensand escarpment, we again fail to find confirmation of Topley's contention. Here also, it is true, there is a fall from west to east on the south side of the central watershed, but not in a very convincing form. The highest point is Blackdown (forming part of the watershed), which reaches 912 feet O.D., and is therefore higher than any part either of the North or the South Downs; but to the east of that hill there is not a single point rising above the 500-foot contour, so that, even if marine planation is accepted, there is nothing here which is high enough to be regarded as a remnant of the plain: and I submit that this fall towards the east, to which Topley was inclined to attach importance (26, p. 240, note), is more closely connected with the diminution in hardness and thickness of the Hythe Beds than with any tilting of a former plain.

On the north side of the watershed Hindhead rises to 895 feet O.D.; some miles farther east are Pitch Hill (844 feet) and Holmbury Hill (800 feet), both higher than the adjoining Downs, and then comes Leith Hill (965 feet), the highest point in the series. It is only when we pass beyond the Mole that any fall towards the east can be admitted, and even there it is by no means clear that the lowness of the hills is a primitive feature. Since the Lower Greensand strata vary much in character, it is conceivable that they may once have been planed off to a fairly uniform level and then reduced unevenly; but, as evidence of planation, the hills of these strata are obviously inferior to the Chalk Downs.

Along the central axis Blackdown and Hindhead in the west rise higher than any hills farther east; but then there are no other points of observation, with the exception of Crowborough Beacon, which even approximate to the level of the Downs. Now Crowborough Beacon (792 feet O.D.) clearly owes its elevation in large measure to the upheaval of the Hastings Beds, the dip-slope of which radiates out from it in every direction. If it were as high as, or higher than, the Downs, or if any definite signs of planation were shown, we might perhaps accept it as a relic of a marine or subaërial plain, but as it stands I see no reason at all for doing so; indeed, assuming that a plain even existed, I doubt whether it was low enough for any part of the Hastings Beds to be uncovered.

We come next to the transverse series. Ramsay (21, 5th ed. p. 341) describes the uplifted plain as 'slightly inclined from the interior,' but his diagram (21, 5th ed. fig. 73, p. 343) leads us to infer that he regarded the inclination as scarcely perceptible. Topley is not quite consistent on this point: in one place (26, p. 274) he says that the existing dip-slope roughly represents the slope of the marine plain (a very doubtful proposition, since the dip-slope of the Chalk might, and sometimes does, correspond to a pre-Eocene plain); but elsewhere (fig. 59, p. 291) he gives a diagram of the River Medway on a much larger scale than Ramsay's, and in it he depicts the plain as absolutely horizontal over a distance of more than 40 miles. Again, in his table of heights (26, p. 241), although the rise from sides to centre is always evident, yet in most cases it is very small, and only in one instance does it exceed 50 feet; but in that one exception the whole of the rise, amounting to over 130 feet, takes place within 4 miles of the escarpment. It is pertinent, therefore, to ask how such a gradient is to be reconciled with Topley's other data and with his diagram of the Medway? The fact is that his figures are rather carefully selected, and point to conditions which are by no means universal; indeed he admits this when, in one of his series, he takes 812 feet as the height of the North Downs, whereas only 3 miles farther west they rise to 876 feet.[1] No safe inferences, therefore, are to be drawn from this part of Topley's tables, and if a plain is to be established at all, we must admit the existence of greater warpings, local if not general, than either Topley or Ramsay recognized; but a full discussion of this point must be deferred to a later stage of my paper.

Reviewing the general results of this line of enquiry, we see that the longitudinal coincidences of level in the lower beds (Hastings Beds and Lower Greensand) are few and unconvincing, but that those in the Chalk are very striking (figs. 1–3, p. 642) so long as we do not insist on Topley's belief in a fall from west to east. Yet even here we must be cautious in drawing conclusions. There can be no doubt that the Chalk in this region exhibited on the whole a very level surface before the Eocene beds were deposited on it, and that both have since been tilted up together; if then, rejecting the hypothesis of more recent (post-Eocene) marine planation, we imagine these strata to have been removed by subaërial forces alone, we can easily understand how the steady outward spread, like a centrifugal wave, of the crest of the Chalk escarpment would be accompanied by a good deal of correspondence in levels along the lines of the North and South Downs, although this correspondence would be due in the main not to post-Eocene, but to pre-Eocene causes. Transverse coincidences, however, between the summit-lines of different strata could not easily arise in this way, and we see therefore that it is by the degree of perfection which these exhibit that this line of argument must really be judged. Unfortunately, as already shown, the evidence on this point is hardly as strong as Topley's table (26, table iii, p. 241) might lead us to suppose: and it is not, therefore, surprising that although his figures have been before us for more than a generation, his inference from them has failed to meet with universal approval.

(ii) Even bevelling of the crest of the escarpment.—This is a line of argument not directly alluded to by the older

[1] These are Topley's figures; but the most recent maps exhibit the same fact, namely, that the sides are often higher than the centre.

writers, in part perhaps through its being confused with the previous one: but the essential distinctness of the two is recognized when we consider that, although the correspondence of the summits is seen in both North and South Downs, it is only in the former that even bevelling occurs (see 26, p. 265). Prof. W. M. Davis (3, p. 136) insists strongly on the importance of this feature as a sign of planation, and expresses the opinion that where it occurs, coupled with a mature river-system, the existence of two cycles of subaërial denudation can 'hardly be doubted.' If, on the one hand, the whole of the Chalk has been removed by subaërial agency in one prolonged cycle, the escarpment ought to be notched by the remnants of many temporarily successful consequent streams rising in the central axis and also, perhaps, by minor valleys which formerly scored the dip-slope of the Chalk (without extending so far inland), precisely as it is scored at the present day at a distance of only a few miles from the escarpment. If, on the other hand, the removal of the Chalk was mainly effected by marine planation, Prof. Davis (if I understand him rightly) thinks that the innumerable early consequent streams, and their obsequent offspring, would have destroyed all traces of the original bevelling before the present drainage-system, well adjusted to the structures, and consisting largely of subsequent rivers, had time to develop. This objection to marine planation evidently rests on Prof. Davis's individual judgment as to the rate at which a subsequent system is likely to be formed; and, despite the great weight attaching to his opinion, I venture to doubt whether he has made full allowance for the extremely soft character of the Wealden strata.

(iii) Straightness of the escarpments.—This is another feature pointed out by Prof. Davis (3, pp. 134–35) as likely to result from planation. According to him, in a mature system

'the crest of the escarpment turns inland and reaches greater height about midway between the consequent streams, but curves seaward and loses height on approaching the transverse valleys that are kept open by the successful consequent streams.'

In extreme old age, however, as in the peneplain stage, these escarpments, reduced almost to the level of the rivers themselves, straighten out again; and this straightness is likely to be noticeable for some time after the revival of activity in the second cycle.

It is evident that this feature is in some degree bound up with the last, for wherever the crest of the escarpment is deeply notched we find obsequent valleys interfering with the regularity of the outcrop: but I think that a very important factor in the Wealden area is to be found in the longitudinal folds. One of the straightest parts of the whole Chalk escarpment, between Dorking and Farnham, runs closely parallel to an anticline, and a similar parallelism is observable elsewhere, as, for example, in the South Downs, between Butser Hill and Duncton Down, and again between the Arun and the Adur; though in the latter case the curve of maturity has already begun to form.

The comparative absence of this feature from the Lower Greensand escarpment must also be taken into account: while the contrast between the straight parts of the Chalk just mentioned and the extremely indented region between Alton and Petersfield (which must, on any hypothesis, have been subjected to much the same influences) still further strengthens my conviction that straightness of the escarpment, in the region under review, cannot be due to planation alone.

(iv) Drifts.—Several different lines of argument may be deduced from the drifts, and it will be well, as far as possible, to keep them distinct.

(*a*) Flints.—Great stress is laid by the older writers on the distribution of flints over the Wealden surface. While almost entirely absent from the Hastings Beds, they are very scarce on the Weald Clay, but increase rapidly in quantity as we approach the Chalk escarpment; and this was taken by Ramsay (21, 5th ed. p. 344) and Topley (26, p. 290) to indicate that the Chalk had been removed by marine planation to within a few miles of its present position.

Prestwich (19, p. 158) rejected this inference, and although his reasons for doing so appear to me inadequate, and based in part on a misapprehension, yet his conclusion, that no decisive evidence of planation can be drawn from these facts, must, I think, be accepted. If we suppose that the present physical features are the result of prolonged subaërial denudation (with or without a peneplain), then probably the Chalk would be first removed from the central region, and any flint débris left there during the process will have had a longer time in which to disappear. Although, therefore, the distribution of flints presents some very interesting features, which might repay further analysis, it cannot, if taken alone, be held to prove planation.

But, while this destroys the value of Ramsay's inference, we must be careful not to attach too much importance to the converse argument, and infer from the occasional presence of flints close to the central axis (see 26, p. 200, and 4, pp. 637–38) that the sea has not touched this region since the Chalk was removed. If a marine plain ever existed, it must have left some deposits besides those of the North Downs; and although these are no longer recognizable, it is quite possible that the fragments of flint found at Horsham, Slinfold, etc. are remnants of such deposits gradually washed down to a lower level, and broken by atmospheric influences into angular fragments since their deposition.

(*b*) Pliocene beds.—As early as 1857, Prestwich (17) boldly assigned a Pliocene date to certain masses of sand and ironstone, difficult to separate from the Drift, which occur at intervals all along the North Downs from Folkestone to Dorking. Ramsay preferred to regard them as Eocene, but was prepared, if they should prove to belong to the Crag, to accept a Pliocene date for his marine plain (21, 5th ed. p. 345). The Pliocene (Diestian) age of the Lenham Beds, finally settled by Mr. Clement Reid (22), is now universally accepted; elsewhere, however, although there is a general tendency to assign a similar date to the other beds, no definite proof is forthcoming. On Netley Heath, between Guildford and Dorking, is a bed of sand (not included in Prestwich's list) in which Mr. Stebbing (25) has found casts of marine shells exhibiting a general resemblance to those of Lenham; but they are too imperfect for accurate determination, and opinion is still divided as to their true position.

Even, however, if we accept the Pliocene age of all these beds, they do not prove planation by the sea of the whole Wealden area. Prestwich and others who deny planation admit that the Diestian sea washed the northern fringe of that area, but perceive no reason for supposing that it spread much farther south than the line of the present Downs; and the absence of similar deposits from the South Downs, and from all the older Wealden beds, though by no means conclusive, affords some negative support to that position.

(*c*) Distribution of chert.—Scattered along the North Downs, sometimes as isolated pebbles or boulders, at other times in connection with the Southern Drift or the supposed Pliocene beds, are quantities of Lower Greensand chert. On the hypothesis of a marine plain these present no difficulty: but they offer so formidable an obstacle to Prof. Davis's suggestion of a subaërial peneplain, as to deserve more attention than they have hitherto received. It is only in the region of the Darent, where Prestwich and others have mapped it carefully, that the distribution of this chert is thoroughly known, and even there, as Prestwich's paper and the debate on it show (19), important facts were for some time overlooked. The following list, therefore, of the localities where it is to be found to the west of Wrotham Hill (the eastern boundary of the Darent region) cannot be regarded as at all complete, although it is sufficient for the purpose of the present argument:—

1. East of the Darent.—Prestwich found chert all along the Downs from the Darent to Wrotham Hill (19, pl. vi, fig. 3).

2. From the Darent to the Mole.—Prestwich traced Southern Drift only as far as Morant's Court Hill, but Crawshay (19, p. 162) mentions its occurrence (presumably with chert) on the summit of Botley Hill, about 7 miles farther west. So far as I know, no Lower Greensand fragments are to be found near the edge of the escarpment between this hill and the Merstham gap; but Dr. Hinde (6, p. 224) records chert as common rather below the summit of the Chalk Plateau to the east of that pass: how far east it extends is not clearly stated. I could find none in the supposed Pliocene beds at Alderstead, but it reappears to the west of the pass either in or on (I cannot from personal observation determine which) beds of the same age at Shabden Park. Near Walton-on-the-Hill and on Headley Heath it is fairly plentiful.

3. From the Mole to the Wey.—Lower Greensand fragments are found on Ranmore Common, and I obtained a few chert pebbles from a field about a mile west of Effingham Hill Lodge. It is comparatively plentiful on Netley Heath (overlying the sand), at Woodcote Lodge in beds associated by Mr. Monckton (13, p. 33) with the Southern Drift, and at Newland's Corner.

4. West of the Wey.—There is no Drift at all along the Hog's Back, but Lower Greensand fragments are found sparingly on the Farnham Plateau, under which name I shall, in this paper, include Cæsar's Camp, Hungry Hill,

Beacon Hill, and the high plain (now nameless) which connects them together. Chert is abundant in some Drift near Clare Park, to which more attention will be directed later; and, lastly, I have found a few pebbles on the summit of the Downs above Bentley.

These facts accord very well with the hypothesis of marine planation, whether we regard the sea or the rivers as the transporting agent of the chert; but how they affect the theories of Prestwich and Prof. Davis must now be separately considered.

(B) Hypothesis of a Subaërial Peneplain.

The general features of Prof. Davis's hypothesis have already been noticed, and it is unnecessary to repeat them here. What we have to examine is whether it affords any satisfactory explanation of the distribution of chert along the North Downs.

In the maturity of the first cycle there might be much transference of this material across the Chalk by consequent rivers, more numerous than those surviving at the present day; but a prolonged period of old age followed, during which the consequent streams were reduced in number, and the hills were gradually degraded to mere elongated mounds. Having regard to our experience elsewhere as to the disappearance of drift materials, it seems to me impossible that any appreciable remnant of the earlier river-gravels could have survived such extensive denudation as this. When upheaval followed, and the second cycle began, no fresh transference of pebbles from the Lower Greensand to the Chalk could occur, except along the lines of the old consequent rivers. Prof. Davis lays it down as an essential difference between a cycle of denudation on an uplifted marine plain, and a second cycle following a subaërial plain, that the drainage of the former would for some time be solely by consequent streams, whereas that of the latter would from the first consist largely of revived subsequent rivers; and these subsequent rivers would evidently form an effectual barrier to such a direct transference of material as we are considering. Nor do I see how this distribution of chert could be accounted for by oscillations of existing consequent rivers on the peneplain: for, in the first place, the Southern Drift is often close to the escarpment, the straightness of which is attributed to planation; and secondly, rivers meandering in such wide curves could scarcely have the necessary transporting power.

It might perhaps be thought possible, without altogether abandoning Prof. Davis's hypothesis, to assume the marine origin of the drifts containing Lower Greensand pebbles, and treat them as belonging to a coastal plain continuous (after upheaval) with the subaërial peneplain: but, apart from objections which will be raised in connection with Prestwich's views, it must be remembered that Prof. Davis's conclusions rest, not on two separate lines of argument, but upon the c o m b i n a t i o n of a bevelled escarpment with the mature drainage-system. With the admission of marine action along the North Downs we destroy all evidence of subaërial bevelling, and thereby undermine the whole argument.

(C) Prestwich's Hypothesis.

Prestwich supposed that a Wealden island was formed at the close of the Cretaceous Period, over which the Chalk, though much thinned by marine denudation, extended during the Eocene Period (17, pp. 330–31); and consequently no Eocene beds were deposited in this area, parts of which have probably remained dry land ever since. In early Pliocene times a broad area separated England from Belgium, and the North Downs, at least as far as Dorking, were submerged (18, p. 167); but the extent of marine action is uncertain. In the early stages of the Red Crag a renewed upheaval united the Wealden peninsula to the Continent, and raised its central mountains to 2000 or 3000 feet above the sea (18, pp. 172–73): even then, however, the Chalk had been so little denuded that its thickness over the Crowborough district may have amounted to 100 feet (18, p. 169). The flanks of this mountain-chain were scored in pre-Glacial times by transverse streams, more numerous than at present; but these at first had a wide lateral spread, and only gradually became restricted to definite channels. The longitudinal valleys, and with them the escarpments, were formed by glacial action at a later stage.

This last view will receive but little support at the present day, nor will many be found to admit that rivers which arose at the end of the Cretaceous Period could have remained without definite channels, as Prestwich appears to believe, until after the deposition of the Southern Drift in Pliocene times. But I refrain from criticizing in detail these and other points which are not really essential to his theory, and pass on to more important matters.

The absence of Wealden pebbles from the Pliocene beds is supposed to prove (19, p. 157) that the Weald Clay and Hastings Sands were not much exposed at this period, and is therefore held to afford a weighty argument against extensive marine planation. Topley (26, p. 293) had previously pointed out that the Wealden sandstones have very little power of survival in running water, and soon wear down into sand, so that Prestwich's inference from their absence is hardly justified. Moreover, the Weald Clay yields an inappreciable number of such pebbles, while the exposure of any large surface of Hastings Beds is by no means essential to the hypothesis of a marine plain. The centre of such a plain can hardly be placed lower than the summit of the North Downs (882 feet O.D.), and, if I am not mistaken, the addition of 100 feet of strata to Crowborough Beacon (792 feet) would cover up the Hastings Beds altogether.

By a somewhat similar argument the rarity of chert in certain beds of Southern Drift is taken to indicate that, when these drifts were formed, the Lower Greensand was not widely uncovered (18, pp. 168–70). So far as the Farnham plateau is concerned this view is tenable, although there is something to be said against it; but, in applying the same reasoning to the Well Hill drift, Prestwich seems to have forgotten his own account of the supposed

Pliocene beds (17, p. 330), which according to him are largely composed of Lower Greensand material. Chert, too, as we have seen, is scattered all along the Downs in positions to which it can scarcely have been brought, except by the sea or by the earliest streams that traversed the coastal plain; therefore, whatever may be the explanation of the Well Hill gravel, there must have been an extensive exposure of the Lower Greensand in Diestian times, and *a fortiori* at the time of the Southern Drift.

No satisfactory explanation is offered by Prestwich of the wide distribution of chert along the Downs. While attributing some of it to existing rivers, with broader valleys than at present (18, p. 171), he recognizes that in other cases it is necessary to assume the existence of a large number of small streams, each taking its share in the transportation of drift (19, p. 136). It is, however, very difficult to believe that a drainage-system which originated in Eocene, or even Cretaceous times, and persisted through the Oligocene and Miocene, should have possessed a number of consequent elements in Pliocene times, and that practically the whole reduction in their number has been effected since that comparatively recent date.

One of the objections raised by Prestwich against the hypothesis of marine planation is founded on the relative thickness of the Chalk in the London Basin and on the Downs. Ramsay's diagrams show the planed-off Chalk extending for about 4 miles south of the present escarpment; he was probably depending a good deal on the general uniformity in level of the Downs and Lower Greensand escarpment as evidence of a plain, but Prestwich, who thinks that the diagram was only created to explain the distribution of flints, says (19, p. 158):—

'Taking the range of the Chalk from Crossness in the centre of the Thames Valley, where its thickness is known, to the edge of the Chalk escarpment at Otford, a distance of 14 miles, we find it diminished from 650 to 450 feet, a total reduction of 200 feet, or of $14\frac{1}{2}$ feet per mile. At this rate the Chalk should have extended 31 miles beyond the escarpment, or, taking only the Chalk-with-Flints, some miles (16 ?) less.'

I am at a loss to understand the bearing of these data upon the point at issue. It is universally admitted that some at least of this thinning of the Chalk is due to pre-Eocene causes, and most of the slope along which measurements are taken is actually covered by Eocene beds. Ramsay was not considering a pre-Eocene plain; and, although no definite period is fixed, he makes it abundantly clear that, if the Pliocene age of the Lenham and other beds could be established, he would be willing to accept that date for his plain of marine denudation (21, 5th ed. p. 345).

Prestwich's attitude is the more remarkable, because he himself has supplied evidence which points to a wholly different conclusion. His paper on the Darent deals largely with the 'Chalk Plateau,' which slopes away northwards from the escarpment, and he gives two important sections (19, pl. vi, figs. 1 & 2) showing its relation to the Eocene and Lower Cretaceous strata. If in these diagrams we take (*a*) the dotted line, showing the probable southward continuation of the Chalk Plateau, and (*b*) a line drawn through the junction of the Chalk and Upper Greensand, we shall find that they cut one another at no great distance from the present escarpment. The exact point of section will depend on the curve which we give to the second line; but it would be unreasonable, I think, to place it more than 5 miles south of the escarpment in fig. 1, while in fig. 2 this distance might even be reduced to $1\frac{1}{2}$ miles. There is strong reason, therefore, to believe that, when the plateau was formed, the southern limit of the Chalk occupied a position which agrees closely with Ramsay's diagrams.

What, then, is the nature of this plateau? I dismiss at once the idea, vaguely suggested by Prestwich, that it was the work of pre-Glacial rivers, because it does not seem possible that these rivers could effect such widespread and uniform planation. Prestwich's sections appear at first sight to show a great difference of angle between the plateau and the pre-Eocene Chalk surface; but the presence elsewhere of thin Eocene outliers upon the former indicates that this difference is to some extent due to a flexure which has affected both formations, especially along a line somewhat to the north of the plateau. Yet this plateau cannot be regarded as simply the old pre-Eocene surface laid bare by removal of the Eocene strata: first, because this would mean that the Lower Greensand was already exposed within a few miles of the present escarpment, and the Eocene deposits ought to contain chert pebbles; secondly, because the Tertiary outliers in the neighbourhood of Caterham and Reigate are themselves bevelled off so as actually to form a part of the plain. The simplest explanation, therefore, of the Chalk Plateau seems to be to regard it as the product of the Diestian sea, while admitting that in some cases it differs but slightly from the old pre-Eocene plain, and that in others it has been modified by early consequent rivers as well as (in all probability) by solution of the underlying Chalk.

(D) Warpings of the Plain.

Although the formation of a marine plain can hardly, from the evidence so far adduced, be regarded as definitely established, yet it will be convenient at this stage to assume its existence, and, deferring further proofs to the third section of this paper, to examine, so far as the limited data will allow, the warpings to which that plain was subjected during upheaval. In the eastern half of the North Downs (Botley Hill to Folkestone) the dotted line joining the summits (summit-line) in fig. 2 (p. 642) will probably be accepted, by all those who admit planation at all, as approximately representing the plain itself. It shows a remarkably uniform fall towards the east, and is reached by at least one hill in each interspace between the rivers. To the west of Botley Hill there is a similar fall towards the west as far as Farnham, and the apparently anomalous position of Holybourne Down can be accounted for by its being nearer to the central axis, and so being affected by the transverse warping which will be considered presently. There is also the same relation of the highest points to the river-valleys, including the Wandle (Merstham Gap) and Blackwater, except in the interval between the latter river and the Wey, where the general low level of the Hog's Back is due to causes which will be dealt with later. That the summit-line has again a definite relation to the original plain appears to me certain, but the suggestion of a fall towards the west is complicated by the changes in the dip. The latter increases steadily from Croydon to Guildford, remains extremely high between Guildford and Farnham, and then decreases again. If we assume that the retreat of the escarpment since the plain was uplifted has been uniform all along the line, it is obvious that its effect in lowering the summit of the Chalk must have been much greater where the dip is high than where it is low, and it is quite possible that some at least of the fall in the summit-line of fig. 1 (p. 642) is due to this cause. I think, however, that the assumption of a uniform retreat of the escarpment is most improbable. Where the dip was low, the Chalk on the plain would thin out gradually, and only a small part of its southward extension would consist of Chalk-with-Flints, which is usually harder than the Lower Chalk; it would, moreover, be entirely devoid of all Tertiary covering which would serve to protect it, except over a narrow belt, where the dip was high. Again, with a slight dip the escarpment would at first be very low, and its rise in height would be gradual as compared with the rate of its retreat northwards; whereas, with a high dip, the maximum height would be reached almost at once. So far, therefore, as I can judge, the rate of retreat of the escarpment might, in the early stages, be almost in inverse proportion to the steepness of the dip.

The lowness of the Hog's Back must certainly be attributed to the excessive inclination of the strata, and the removal of the Eocene beds which formerly covered the Chalk; but, all things considered, I see no reason for assuming that the plain to the west of Guildford ever attained a much greater elevation in the neighbourhood of the present escarpment than is indicated by the summit-line in fig. 1. It is clear from the form of the Wealden area, and the distribution of its component strata, that there is a general structural fall to east and west about a transverse axis running approximately through the Medway gap and Beachy Head; and the evidence embodied in figs. 1 & 2 (p. 642) seems to point to the plain having undergone a similar deformation, although the axis was apparently farther west, and the inclination much smaller, especially perhaps on the western side.

The South Downs are composed of at least two distinct lines of upfold, and are divided by several embayments into four portions, two of which project northwards into the Wealden area, while the other two are withdrawn farther south. Having regard, therefore, to the southward tilt which, as the rivers show, the plain must have had, it is not surprising that Chanctonbury Ring, which belongs to one of the southern lines of hills, fails to reach the summit-line (fig. 3, p. 642). The same influence may have been at work in lowering the hills to the east of the River Ouse, but in that region there may possibly have been, from the first, a decided tilt towards the east, corresponding to the tilt already traced in the North Downs. There is also a fall from Butser Hill to Ditchling Beacon, but it is by no means clear that this is a primary feature. The raised sea-beach of the south coast shows that movements, more recent than the plain, have lifted the western end of the Sussex coast fully 100 feet more than the eastern, and if we permit ourselves to make allowance for this along the Downs, we obtain an actual fall from Ditchling Beacon westwards in the uplifted plain.

Besides the broad warpings already noticed, there existed no doubt a certain number of minor irregularities in both the North and the South Downs. It is to this period that I attribute most of the transverse folds; but, as my belief rests on their relation to the rivers, the discussion of it must be left to the third section of this paper.

Along the escarpment of the Lower Greensand, and along the central axis of the Weald, we have, as already indicated, no evidence regarding the summit-line of the plain on which, if taken alone, reliance can be placed. But, in connection with what has gone before, the following points are worthy of consideration. Assuming that Leith Hill and Hindhead both approximately represent the plain, there is a fall in the Lower Greensand area towards the west. It is very slight (about 5 feet per mile), but, then, Hindhead is much nearer to the central ridge than Leith Hill and therefore higher up the slope of the plain; making allowance for this, the gradient probably differs but little from that shown in fig. 1 between Botley Hill and the Farnham Plateau—that is, about $7\frac{1}{2}$ feet per mile. Again, measuring from Blackdown (918 feet O.D.) to Wheatham Hill (813 feet) in the Western Downs (Alton Hills), we find a gradient of 9 feet per mile. It is true that Butser Hill (889 feet O.D.) is higher than Wheatham Hill, and that the latter may have had a capping of Eocene deposits; but, taken together, these gradients seem to point to the conclusion already arrived at, that the plain had a slight inclination towards the west.

We now turn to the warpings of the plain along transverse lines. Prestwich's sections enable us without difficulty to measure the gradient of the Chalk Plateau in the Darent region. A careful survey of it farther west, as far as the Mole, would be of considerable interest; but, in default of it, I think that the most satisfactory method is to take a few of the more important summits along the edge of the Downs, and measure the average gradients to points some 4 or 5 miles farther north, ignoring the minor valleys which sometimes intervene. We then have the following series, working from east to west:—

1. Terry's Lodge Hill (770 feet) to West Yoke (460 feet), about $3\frac{1}{4}$ miles distant. Average = 95 feet per mile. There seems, however, to be some additional disturbance near the escarpment; and, if we measure to

Swanscombe Hill (320 feet), 8½ miles from the summit, we have an average of only 55 feet per mile. The mean of the two calculations is 75 feet per mile.

2. Morant's Court Hill (704 feet) to 480 feet, at a distance of 3⅜ miles. Average gradient = 71 feet per mile.

3. Titsey Hill (878 feet) to 523 feet at 4¼ miles. Gradient = 83 feet per mile.

4. Botley Hill (882 feet) to 539 feet at 4 miles. Gradient = 86 feet per mile.

5. Gravelly Hill (778 feet) to 445 feet near Reedham Asylum (4⅝ miles). Gradient = 72 feet per mile.

6. Reigate Hill (763 feet) to 478 feet near Banstead, 4¾ miles away. Gradient = 60 feet per mile.

It may be objected that several of the localities selected are decidedly below the plain-level, as indicated by the dotted lines in figs. 1 & 2 (p. 642); but there are one or two points to be considered in this connection. In the first place, one of the summits used (Morant's Court Hill) is a mile to the north of the main escarpment-line, and allowance must be made for this. Secondly, the fact that there are large areas of evenly bevelled ground below the theoretical level of the plain seems to point, either to local warpings—which very probably occurred but are difficult to prove; or to lowering of these areas by various subaërial agencies. The extensive sheets of Clay-with-Flints which cover much of the Chalk in this region may point in this direction; while, when we have an opportunity of examining the surface of the Chalk below the superficial drifts, we always find it rising into a series of pinnacles, like the teeth of a gigantic saw; and this very strongly suggests that the process of solution, which must be constantly going on, may sometimes have caused a uniform lowering of the plain without much disturbance of the surface. Mr. Monckton (15, pp. 124–26) attributed to such action the lowness of the Tertiary beds at Tot Hill, and I incline to the belief that its effects are often very extensive.

In order, however, to prove that the conclusions reached in this paper do not depend on such debatable arguments as this, I will proceed to show how little the gradients are altered if we take the dotted lines in figs. 1 & 2 (p. 642) as our starting-point, instead of the actual summits.

1. Terry's Lodge Hill actually touches the dotted summit-line, so there is no correction to be made.

2. Morant's Court Hill is quite a mile to the north of the escarpment line, being in the re-entering angle cut by the Darent. Making allowance for this, and estimating the theoretical summit at 810 feet, we obtain a revised gradient of 80 feet per mile.

3 & 4. Botley Hill and Titsey Hill touch the summit-line; therefore no change is required.

5. Gravelly Hill. Theoretical summit, 840 feet; revised gradient = 85 feet per mile.

6. Reigate Hill. Theoretical summit, 810 feet; revised gradient = 70 feet per mile.

It will be seen, then, that the two methods of calculation lead to but slight differences in the results, although the second method tends to greater uniformity.

Passing to the west of the Mole, we find that the gradient from the summit of Hackhurst Down (733 feet O.D.) to the 600-foot contour farther north is about 106 feet per mile; but I think that there is a reasonable doubt as to whether the dip-slope here represents a pre-Eocene or a post-Eocene surface. In the face of such a question we naturally turn to the only Eocene outlier in this region, and we find near Hook Wood a patch of Woolwich and Reading Beds, surmounted by Southern Drift, reaching 678 feet O.D. within a mile of the escarpment. The theoretical summit here (see fig. 1, p. 642) is about 730 feet, which gives a gradient of 50 feet per mile. Not only is a measurement involving an Eocene surface more satisfactory than one derived from the Chalk alone (since the latter may be pre-Eocene), but we obtain from the Lower Greensand corroborative evidence that the smaller gradient more nearly represents the angle of the plain than the large one. Leith Hill reaches 965 feet O.D., and the distance between it and Hackhurst Down (733 feet) is 4 miles; consequently we have a gradient of about 57 feet per mile, according very closely with the one arrived at above.

Along the line of the Hog's Back no data are available, and indeed none can be expected, since that hill is so much below the level of the plain that it must have been entirely covered at the time of uplift by a thick layer of Tertiary strata. To the west of the Blackwater we find the Farnham Plateau (612 feet O.D), apparently at the level of the plain, and, measuring thence to Easthampstead Plain (423 feet O.D), we obtain a gradient of 21 feet per mile; but the line of measurement is not strictly at right angles to the strike. From Hindhead to the Farnham Plateau the average gradient is 30 feet per mile, but this also is taken along a somewhat oblique line. Lastly, measuring directly from Hindhead to Easthampstead Plain, and so leaving the Farnham Plateau to the west, the gradient is 27 feet per mile. Now chert, probably derived from Hindhead or somewhere near it, is found in the Drift on the Farnham Plateau, and more abundantly at Easthampstead; presumably, therefore, at the time when these drifts were formed (which I take to have been but little later than the upheaval of the plain) the Hythe Beds were already exposed at Hindhead. In that case this hill cannot have been much higher than at present, since only the upper layers of the Hythe Beds (less than 50 feet?) have even now been removed from its summit; and it follows that the gradients just quoted are approximately those of the original inclination of the plain, though it is not certain that the latter was uniform throughout.

Holybourne Down owes its elevation in large measure to its being higher up the slope of the plain (that is, nearer to the central axis); but there are no Eocene outliers on the north by which the gradients in that direction can be calculated. Taking Wheatham Hill (813 feet O.D.), however, as indicating the height of the plain along the central axis, and measuring northwards to Holybourne Down, we find a gradient of only $7\frac{1}{2}$ feet per mile. Of course, I cannot assert that Wheatham Hill retains its original elevation; but, even if we raise it as high as Butser Hill, the gradient is still small compared with those that we have just examined, and some evidence can be obtained elsewhere that the central region was very flat.

In the South Downs we seldom find such direct lines of observation as in the North Downs. The really high points along the escarpment-line are, as fig. 3 (p. 642) shows, few and far apart; and the same is true of a parallel ridge, about 3 or 4 miles farther south, with which comparison has to be made. Moreover, we have no evidence, so far as I know, of a distinction between a pre-Eocene and a post-Eocene planation of the Chalk, as we have in the North Downs, nor of the Eocene beds having undergone two periods of tilting; wherefore the gradients which we observe may possibly have but little connection with the Pliocene plain, a great part of which may, in this region, have been composed of Tertiary strata. I give the following observations, however, for what they are worth, premising that, except where otherwise stated, the hypothetical summit-line (fig. 3) has been used in calculating gradients:—

1. Butser Hill (889 feet; actual, not theoretical) to Windmill Hill (600 feet). Gradient = 105 feet per mile.
2. Linch Down (860 feet; 818 feet actual) to Bow Hill (624 feet). Gradient = 54 feet per mile.
3. Cocking Down (850 feet) to St. Roche's Hill (677 feet). Gradient = 48 feet per mile.
4. Chanctonbury Ring (779 feet; actual, not theoretical) to Cissbury Hill (603 feet) Gradient = 70 feet per mile.
5. Near Ditchling Beacon (810 feet) to Newmarket Hill (645 feet). Gradient = 47 feet per mile.

Although some of these gradients are not far removed from those of the North Downs, yet their paucity and irregularity, coupled with the doubts already expressed as to whether they are pre-Eocene or post-Eocene, must make us hesitate to accept them as evidence of marine action. The plain may, indeed, have existed; but, if a large portion of it was covered with Eocene beds, there is nothing surprising in the absence of evidence of it, for the South Downs, owing to their greater proximity to the sea, and perhaps to other causes (9, vol. iii, p. 404), have undergone more severe denudation than the North Downs. However this may be, we can safely assert that the marine plain, if it ever extended to this region, cannot have been continued in so steep an incline all the way to the central axis. Such a gradient as 50 feet per mile, continued from Duncton Down to Blackdown, would give an elevation of nearly 1300 feet; but there is reason to think that the Hythe Beds were already exposed in the central region, and in that case Blackdown cannot have been very much higher than at present (918 feet). It follows, therefore, that the existing gradient from Blackdown to Duncton Down (about 8 feet per mile) is not far removed from that of the original plain.

Although the data given above are very imperfect, and are by no means sufficient, taken by themselves, to establish planation, yet, if the existence of a marine plain be granted on other grounds, they present an intelligible picture of the warpings which it underwent during upheaval. The central region remained extremely flat, with a slope to north and south of (probably) less than 10 feet per mile. Possibly, too, there was, west of Botley Hill, a similarly gentle inclination towards the west. Along the line of the North Downs the gradients increased considerably. The figures tabulated above show a maximum of 80 to 90 feet per mile, in the region of Botley Hill, gradually diminishing to 30 feet per mile near Farnham, and taking therefore little or no notice of the increase in the dip of the strata towards the west. It must be remembered, however, that in the case of Farnham the gradient is calculated almost up to the central axis, whereas in only one other case (Leith Hill) is there any point of observation outside the Downs themselves; and the figures obtained elsewhere as to the flatness of the central region make it not impossible that there was a considerable increase in steepness immediately north of the Farnham anticline. Neither here nor elsewhere, however, is there any indication that the great North Down fold belongs, as a whole, to this period; on the contrary, Prestwich's diagrams of the Chalk Plateau seem to show that there were two distinct movements, and that the axis of the earlier (and stronger) one lay somewhat farther north than that of the second. The rivers, too, as will be pointed out later, negative the suggestion that the principal longitudinal anticlines and synclines are contemporaneous with the present drainage-system.

It may be noted in passing, although evidence is not yet available to prove this, that the flattening of the central region, and consequent low elevation of the Wealden dome, give a clue to that absence of glaciation which is now generally admitted.

III. Evidence of Rivers.

(A) Their Relation to the Rock-Folds.

Prof. W. M. Davis (3), in his masterly exposition of the general theory of river-evolution, naturally takes the simplest case—that of a plain sloping steadily down to the sea, at a slightly lower angle than the dip. In the Wealden area, however, this simplicity does not exist, for besides the main anticline, forming the central watershed, there are numerous other longitudinal anticlines and synclines parallel with this axial ridge, as well as a certain number of transverse folds at right angles to it; and it is, therefore, desirable to make some enquiry into the part played by those disturbances in river-development. If the longitudinal folds were contemporaneous with the initial stages of the present drainage-system, we should expect to find many of the synclines occupied by longitudinal consequent rivers; and these might help us to understand that combination of a bevelled escarpment with a mature river-system to which Prof. Davis calls attention. As a matter of fact, however, such rivers are rarely, if ever, found in that part of the Weald which is here examined. If, on the other hand, the folds were planed off by marine denudation before the present rivers arose, the relation of the latter to the synclines would not be so marked; both anticlines and synclines might indeed be occupied by rivers, as a result of secondary action, but none of these streams would deserve to be called consequent. At first sight, then, it appears as if we might obtain from this source some important evidence as to the course of denudation; but, unfortunately, the problem is complicated by other considerations.

The Wealden area seems to have been raised above the sea at the close of the Eocene Period, but the principal longitudinal folds are generally attributed to Oligocene or Miocene times. In that case, assuming that there has been no more recent marine action, the river-system was antecedent to the folds, and their effect upon it would depend on so many factors—for instance, the degree of maturity of the rivers, the intensity and rapidity of the movements, etc.—that it seems impossible to lay down any definite rules which will guide us in distinguishing between such an antecedent river-system and one developed upon a marine plain after the folds were formed. The transverse folds are perhaps more helpful, but unfortunately they are for the most part less forcibly developed, and therefore harder to trace. That transverse synclines arising during upheaval would attract consequent streams, while anticlines would repel them, is obvious enough; but the effects of the planation of such folds are worthy of closer study. Transverse synclines thus planed off would form salient angles in the line of Chalk upon the plain, while anticlines would form re-entering angles. If, then, the plain were tilted, in the manner already suggested, the edge of the Chalk would be higher along the synclines than along the anticlines, and this would give a decided advantage to those consequent streams which happened to coincide with the latter. For, although the initial rivers probably ran over a thin covering of marine deposits, yet the moment this was removed, one of the most important factors in determining the relative success of different consequent rivers in extending their territory through the 'hinterland' of soft beds would be the height at which they crossed the hard Chalk, or the rate at which they could cut it down. This principle may be illustrated by concrete examples. If we continue the dotted summit-line in fig. 2 (p. 642) to the point at which Topley supposes the Rother to have crossed the Chalk (26, pl. ii), we find that the latter only rose to 560 feet above present sea-level, and it is quite in keeping with this that the Rother should have captured, by means of subsequent streams, a large area of territory on both sides of the channel. It is tempting also, though probably not altogether safe, to attribute to the same causes the comparative failure of some of the more central rivers. The highest point in the North Downs is Botley Hill (882 feet O.D.), and it is certainly a curious feature that immediately to the east of it is the Darent—the only Wealden river which does not reach the Weald Clay; while on the west lies the Wandle, which, after obtaining a firm hold on the Weald, probably at more than one point, has now been completely severed from it. If I am correct in supposing that the warped plain fell away both east and west of Botley Hill, then the lower passage across the Chalk of the Medway and the Mole may have been one of the factors which led to the superiority of these rivers over their less fortunate neighbours, the Darent and the Wandle. The predominance of the Medway, however, extending as it does behind the Stour as well, cannot be wholly explained in this manner. Some of its advantage may be derived from the change of strike which (even if there be no true anticline) would reduce the level of the Chalk over which it flowed by forming in it a re-entering angle; and there is also the syncline in the Lower Greensand (26, p. 277) to be considered. The Medway, however, lies outside the scope of this paper, and I merely draw attention to these possible factors in its success, without attempting to determine their relative importance.

The effect of transverse folds on an antecedent drainage-system presents much the same difficulties as in the case of the longitudinal folds; but, if the folds were shallow (as they seem to be), and the rivers well established, I cannot see any probability that the main consequent lines of drainage would be much affected, except where fold and river happened to coincide: and this, unless the river-system was still very immature, would seldom happen.

There are several recognized instances (26, p. 277) of the coincidences of rivers with transverse synclines, and others (7, p. 406; 24, p. 10; 29, p. 431) in which the facts are more or less disputable; but I know of no such syncline unconnected with a river, so that contemporaneity of river and transverse fold is strongly indicated. Now, the transverse disturbances are considered by Dr. Barrois (1, p. 115) to be later than the longitudinal, and Mr. Young (29, p. 435) has given an instance in which this is certainly the case. If, then, we accept Dr. Barrois's opinion on this point, it follows that the longitudinal folds are antecedent to the rivers. This accords very well with the hypothesis of marine planation in Pliocene times, but is opposed to continuous subaërial denudation since the close of the Eocene.

There are said to be two rivers running along transverse anticlines, the Medway (27, p. 350) and the Cuckmere (1, p. 23). I am not in a position to affirm the accuracy of these inferences, but accepting them as correct, the hypothesis of prolonged subaërial denudation, whether the rivers were contemporaneous with or antecedent to the folds, affords no satisfactory explanation. If, on the other hand, we assume that marine planation followed the formation of these two transverse anticlines (and Dr. Barrois spreads them over a long period), the problem ceases to afford any further difficulty.

While, therefore, it would be very rash to draw conclusions from the relations of rivers to the folds without collateral evidence, yet it is legitimate to claim that they do, on the whole, support a belief in a period of marine planation which was subsequent to most of the longitudinal folding, and immediately antecedent to most, though perhaps not quite all, of the transverse disturbances.

(B) River Blackwater.

The present and past connections of the Blackwater with the Wealden area were discussed in a former paper (2), but some repetition here will tend to greater clearness. The pass between Hungry Hill and the Hog's Back (called in fig. 1, p. 642, the Aldershot gap) is divided into two valleys by a ridge ending in a mound of Chalk at Badshot Farm. The western valley was occupied until quite recently by the Farnham River; while the eastern is still traversed, when any water is there at all, by the Seale stream. I formerly assumed that these two valleys had, at an earlier stage, been united; but, since I wrote, Mr. G. W. Young (29, p. 432) has shown that there are two dip-faults, where only one is mapped by the Geological Survey, and that these two faults correspond in a striking degree with the two valleys. It is, therefore, quite possible that the latter have always been distinct, and that the faults actually determined from the first the courses of the two streams, a view which has been embodied in fig. 5 (p. 666); but I should like to have more definite evidence as to the courses of the faults before finally endorsing it. As is well known, the strike undergoes a change at this point, the Hog's Back running almost due east and west, while the hills on the north of the Farnham Valley run nearly east-north-east and west-south-west. The original head of the Blackwater, the course of which is now indicated by the Waverley Valley, ran at right angles to this western strike, and the two principal subsequent rivers enter from this side. One of these is the Farnham River, which, as far west as Bentley, formerly ran along an anticline, its gravels being still visible on the Alice Holt Plateau. The second, the Tilford River, appears to run in a syncline; it is not easy to trace the exact position of such a fold in the soft Folkestone Beds, but there is certainly a southerly dip in Alice Holt and Farnham Common immediately to the north, and a rise again farther south near Churt. There is strong evidence that this Tilford River was developed very late, as a westward continuation of the Godalming branch of the Wey; therefore it never really formed part of the Blackwater at all: for, in Pleistocene (late Palæolithic) times, transverse streams still carried chert from Hindhead directly into the Farnham River.

There is a third longitudinal stream, which, though of small dimensions, presents some points of interest—namely, the stream that rises near Haslemere, and flows in a deep valley between Blackdown and Hindhead to join the Headley River. In the first place it flows westwards, while the two subsequent rivers just mentioned flow eastwards. The latter course is the more intelligible, because, in consequence of the westerly dip, the exposure of the soft beds, to which the subsequent streams owe their origin, would usually begin in the east, and spread westwards: there would, however, be no difficulty in understanding the course of the Haslemere stream, if it could be regarded as of somewhat late origin, but that does not appear to be possible. The watershed dividing the northern from the southern rivers seems always to have run through or close to Blackdown, and the Lower Greensand ridge between Hindhead and Hascombe is notched by several valleys which formerly extended farther south. Hindhead itself, however, shows no trace of such notches, and the inference seems to be that the consequent streams which now run down its northern slope must have been cut off from Blackdown by the Haslemere Valley at quite an early stage. Martin (12, pp. 46 & 197) asserted that this valley marked the central anticline of the Wealden area, but, so far as I can ascertain, it coincides with a syncline; and the question arises whether its stream is to be regarded as a subsequent or as a longitudinal consequent. In the former case we may reason as follows: although the Hythe Beds were exposed by marine planation at Hindhead, yet owing to the dip of the strata, the soft Folkestone Beds must have appeared immediately to the west, and the syncline would cause a tongue of them to stretch eastwards between Hindhead and Blackdown. Owing to their softness, they would be lowered more rapidly than the Hythe Beds, and thus a subsequent valley would very quickly arise. If, on the other hand, we regard the stream as a longitudinal consequent, we must, on the hypothesis of marine planation, conclude that the syncline in which it runs was formed at the time of upheaval. There is nothing impossible in this; but, having regard to the rarity of any rivers which can be regarded as longitudinal consequents, I prefer, on the whole, the first hypothesis. The earliest drifts in the region attributed to the Blackwater are those of the Farnham Plateau, which have been fully described by Prestwich (18, p. 161), Monckton (13, p. 30), and others. Usually they do not exceed 10 or 12 feet in thickness, but it may be worth while to record that I have measured a depth of 27 feet on Beacon Hill, and also immediately south of the main road, half a mile west of Lawday House (the 'Wilderness' on the 6-inch map reprinted in 1904). If we may judge by the gradients already given, the gravels of Easthampstead Plain cannot be of much later date: due allowance must of course be made for the curve of the 'thalweg'; but the more distant gravels give evidence of so much transporting power that we must not make this curve too flat. There is, however, a marked difference in composition between the two drifts. On the Farnham Plateau Prestwich gives the percentage of Lower Greensand fragments at 6 per cent. Mr. Monckton reduces this to 5 per cent., but even that seems to me rather a high estimate; Hythe Bed fragments (chert), at any rate, are so scarce on most parts of the plateau that a prolonged search is necessary to find any at all, and even then the pebbles are extremely small, seldom exceeding 1 inch in diameter. In the Easthampstead gravels, on the other hand, although twice the distance from the nearest Hythe Beds (Hindhead), chert is exceedingly common, being estimated by Mr. Monckton at 4 per cent. of the large, and 9 per cent. of the smaller material. Prestwich accounts for the scarcity of chert on the Farnham Plateau by supposing that, at the time when the Drift was deposited, the Hythe Beds were hardly uncovered at Hindhead, and his lead has been followed by other writers; but this leaves the question of size untouched, while suggesting, perhaps, rather more difference of age between the two drifts than is quite compatible with the differences in level. Without denying, therefore, that Prestwich's explanation may be the true one, I am inclined to look about for other causes as well, and the following suggestion seems worth taking into consideration.

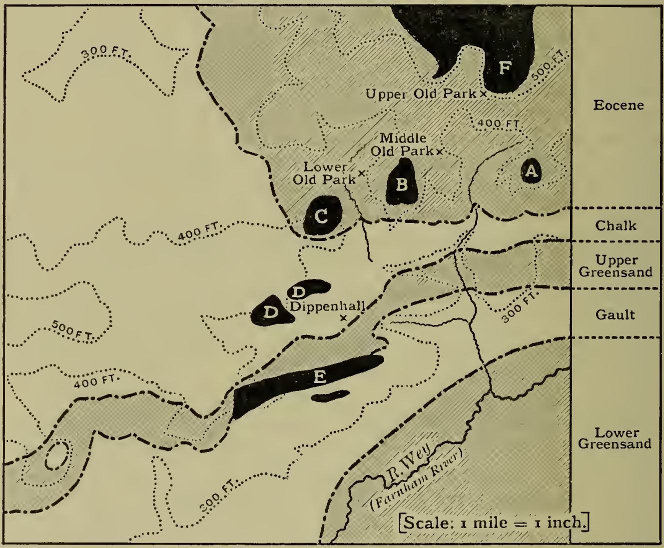
When the plain was first upheaved it was covered with a thin layer of Drift, containing a small quantity of chert; but as this material would be quickly worn away in a marine gravel, it is unlikely that its pebbles would be either large or numerous at any distance from their source. The earliest consequent streams caused a downward wash of this marine drift over almost the whole plain, but very soon a few of them obtained such a superiority over their neighbours that for the future they formed practically the whole of the consequent drainage-system. One of these successful rivers was the Blackwater, while another, as we shall presently see, flowed immediately to the west of the Farnham Plateau; and the scarcity of chert on the latter is due, not so much to the Hythe Beds being still covered up (except so far as they were concealed under the marine drift) as to the situation of the plateau between two successful consequent streams, instead of on a main line of drainage. Its chert in fact is, on this view, mainly, if not wholly, derived from a marine source. The great depth of the gravel may be due to some local warping of the plain; it lies immediately north of an important longitudinal anticline, and although the latter was probably formed, for the most part, at an earlier date, yet it is possible that during the upheaval of the plain a second slight movement occurred here, and that the Plateau Drift is a mass of 'aggraded' material at the foot of the slope so formed (see § II, p. 658).

A wide belt of gravel (fig. 4, F, p. 664), practically identical in composition with that of the plateau, and continuous with it, extends down the southern slope of the hill, reaching the 500-foot contour at Upper Old Park,[1] and descending almost to the 400-foot line at Upper Hale. It is no part of my present purpose to discuss the origin of this drift, and I am content to treat it (provisionally) as merely a part of the Plateau Gravel that has slipped down the hillside. There are, however, some outliers of similar gravel at a lower level which merit careful attention. The first of these is not marked on the Geological Survey map, but is described by Monckton & Mangles (14, p. 81) as lying half a mile west of Farnham Castle, and as being probably derived from the Plateau Drift. With the help of Mr. Monckton's notes, which he kindly sent me, I have entered this gravel in fig. 4 (A), in what appears to be its correct position, but I have no accurate information as to its extent. It lies just above the 400-foot level, about at the junction of the Chalk with the Eocene, and contains practically no chert. The

[1] The 'Upper Old Park' of the map used by the Geological Survey is really Middle Old Park.

second patch of gravel (fig. 4, B), lies between Middle and Lower Old Parks, and its relation to the underlying strata resembles the last, though it is slightly higher in level. I have seen no pit in it, and have only been able to study it on the surface of a ploughed field. Many large flints had been collected at the side of the field, and assuming (as is probable) that others had been used to mend the road, the gravel bears a general resemblance to that of the plateau, from which, however, it is now separated by a wide valley. I failed to find a single fragment of chert. Immediately to the west of Lower Old Park is a steep ravine, and beyond that

Fig. 4.—*Gravels in and near the Crondall Pass, with contour-lines and geological structure.*



[A & B, chert scarce; C, D, & E, chert abundant; F, Plateau Gravel.]

again, at 426 feet O.D., is another patch of gravel, lying on the Reading Beds (fig. 4, C); like the last, it is mapped by the Geological Survey as 'river-gravel,' but it differs entirely in composition. I am again dependent on a superficial examination, but even so the abundance of chert is obvious. A little farther south, near Dippenhall, are two adjoining sheets of gravel (fig. 4, D) lying on Chalk. The best exposure is in a pit rather below the 400-foot contour, but the Drift extends above that level, and from the large cavities which occur in this pit, and the way in which pinnacles of Chalk project up into the gravel, I conclude that the latter has, at this point, been lowered by the removal of the subjacent Chalk in solution. The percentage of chert in this gravel reaches quite 20 per cent.

in the smaller material (up to 2 inches in diameter); but large fragments are by no means uncommon, one which I measured being 14 by 5 by 4 inches. A quarter of a mile farther south again, but separated from the last by two valleys, a shallow and a deep one, is a ridge composed of Upper Greensand and Gault, and upon this rests a somewhat extensive bed of gravel (fig. 4, E), part of which spreads down the southern slope of the hill. The summit of the hill is above 400 feet O.D., and therefore about on a level with the Dippenhall gravels, while here, again, chert is abundant.

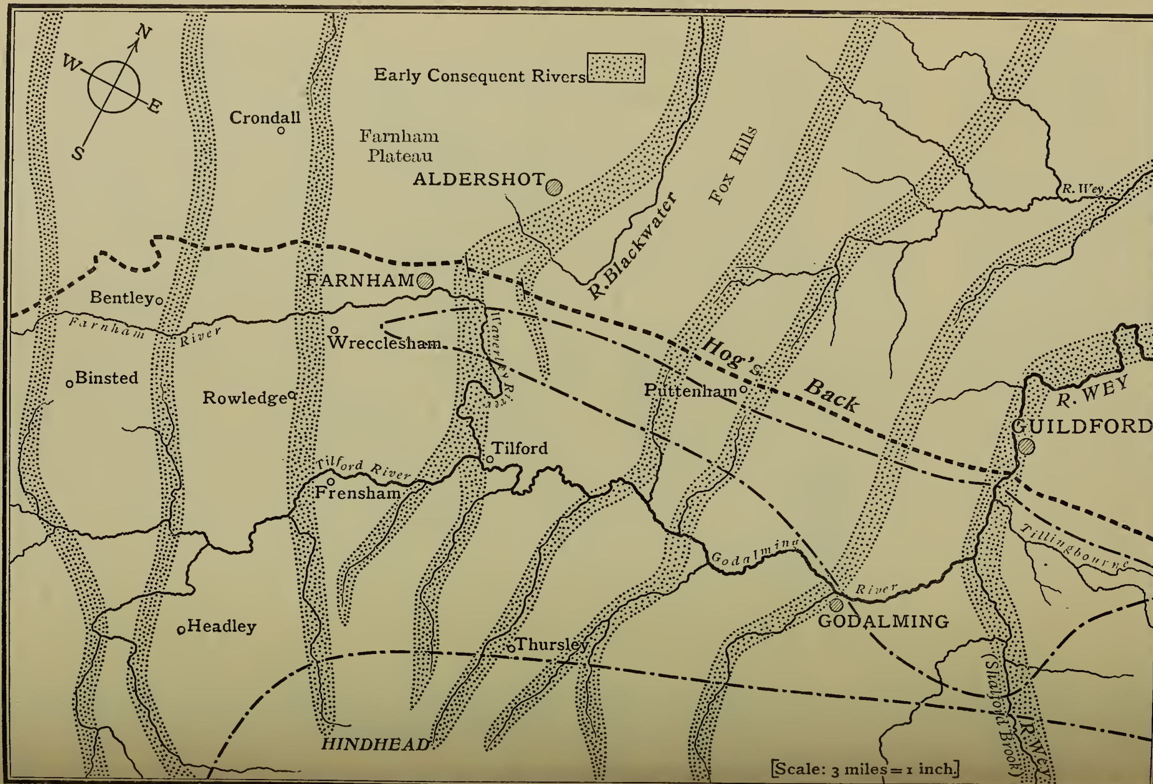
With regard to the origin of these remarkable gravels (C, D, & E) three hypotheses suggest themselves:—

(i) That they are the product of the Farnham River.
(ii) That they have been washed down from some higher and earlier drift.
(iii) That they are relics of a consequent river which flowed through, and gave rise to, the Crondall Pass.

(i) There are absolutely no drifts at a corresponding level higher up the Farnham Valley, and those nearer Farnham are, as we have seen, entirely different in character. We must therefore suppose that the latter (fig. 4, A & B) were washed down from the Plateau after the rest (C, D, & E) were deposited and that all other relics of this excursion of the river to the north have been destroyed. But the level at which they lie is not greatly higher than that of the Alice Holt Plateau, on the opposite side of the valley; and it is therefore certain that, when they were laid down, the Gault was already widely exposed about a mile farther south. Now, it is entirely contrary to experience that in a valley mainly consisting of Gault, a longitudinal river should spread laterally right across the Chalk (both Upper and Lower), and on to the Eocene strata beyond. That is a very serious objection; but, even if we overlook it, and assume that, on a frozen soil, all these formations were planed off to one level, we still should not obtain the observed phenomena. The gravels nearer the present river-bed are very poor in chert; only on the Alice Holt Plateau do we find anything like the same percentage, and even there the distribution is far from uniform. On the south side, which was reached directly by streams from Hindhead, chert is plentiful; but, along the northern ridge of the same plateau, which was mainly supplied by the longitudinal stream bringing flints from Alton, it is distinctly scarce. Therefore, assuming even that the river took the extraordinary course of crossing the Chalk, and that it has only left a record of that procedure at this one point, it still remains in the highest degree improbable that it could have brought so large a percentage of chert to the Crondall Pass as we there observe. Taken together, these objections appear to me to be absolutely fatal to the hypothesis under consideration.

(ii) We have an existing and obvious source for the gravels A & B in the Farnham Plateau, but nothing of the kind is to be found in the case of C, D, & E. The valleys separating the

Fig. 5.—*The western part of the River Wey, showing* (a) *the present limit of the Chalk,* (b) *its theoretical limit on the plain, and* (c) *the probable courses of some of the early consequent rivers.*



The heavy broken line indicates the present limit of the Chalk, and the dotted-and-broken line the limit of the Chalk two last run from west to east, and if the gravels themselves came from that direction, we ought to find an occasional chert pebble among the numerous flints which cover the fields a little farther west; yet so far I have utterly failed to do so. Again, the three beds, although lying on different formations, are all at very nearly the same level, as if the whole surface had been in some way planed off; but it is very difficult, on this hypothesis, to find any sufficient cause of planation: I am not, therefore, at all prepared to accept this view. But, even if I did so, it would be necessary to grant that the original drift was laid down by a consequent river running in this region after the Hythe Beds of Hindhead were exposed; and that admission would be sufficient for the purposes of the argument which I shall presently develop.

(iii) All these gravels (C, D, & E) are compactly grouped about a line drawn nearly due north and south through the Crondall Pass, and rest upon several strata of varying hardness which have all been planed off to approximately the same level. The great size, too, of some of the fragments of chert seems to indicate a more direct connection with the Hythe Beds than was possessed by most of the gravels of the Alice Holt Plateau. These features, together with the entire absence of similar gravels elsewhere, are far better explained by postulating a consequent river than in any other way. I am aware that this view has difficulties: I was myself for a long time averse to it, on the grounds that there was no similar drift to the north nearer than Hartford Bridge; that the Blackwater (in its early stages) was, on this hypothesis, deprived of several streams which I formerly connected with it; and that two such consequent streams, both carrying large quantities of chert, were unlikely to survive long in such close proximity. But none of these objections are really fatal, and the greater difficulties in the way of any other explanation have led me to disregard them (see 28, pp. 82 & 91).

To the west of Dippenhall scarcely any trace of high-level chert is to be found. On the summit of the Downs, north of Bentley, I obtained a few specimens not far from Glade Farm, and a single pebble, associated with some rolled fragments of sarsen, a short distance north-west of Penley Copse. In neither case, however, could I determine whether they originated with early consequent streams or with marine drift. On the marine theory, although consequent streams must have existed, it is uncertain whether in the meridian of Bentley they would find any chert in their courses before they were beheaded; farther west than Bentley they certainly would not be likely to do so (see fig. 5, p. 666).[1]

The existence of even one consequent river (Crondall River) crossing the Chalk to the west of the Blackwater necessitates some

[1] Mr. Osborne White (28, p. 91) is quite right in rejecting my former suggestion of a possible river-connection between the Hythe Beds of Hindhead and the Tisted Valley (Alton).

modification of the views expressed in my former paper (2) as to the origin of the Farnham River. The western part of it I still regard as having originated on Chalk, but some of its eastern end must have arisen in the softer Lower Cretaceous beds, and it is not easy to know what limits to assign to the two portions. It is perhaps significant that, although the Alice Holt gravels lie close to the crest of the anticline, the river to the west of Bentley departs altogether from that line, which is continued, with diminished intensity, through Upper Froyle, Holybourne Down, etc. (12, p. 48). In order to make clearer my own conception of the evolution of this river-system, I have ventured in fig. 5 to indicate the position of several early consequents, in relation to the existing streams; and at the same time I have tried to show the limits of the Chalk upon the marine plain, as compared with its present escarpment. When due allowance has been made for the wide margin of error inseparable from such an attempt, the development of the existing river-system from the marine plain presents no special difficulties. The extension of the Chalk is perhaps somewhat greater than might have been expected, but between the southern limit assigned to it and the crest of the Farnham anticline (say, roughly, the village of Wrecclesham) the strata are extremely level, so that planation would probably leave nothing but a thin layer of Lower Chalk; this would be cut into narrow strips by the numerous consequent rivers, and so, all things considered, its removal would be rapid. We are not obliged to determine the relative parts played by the sea and by rivers in producing the small amount of chert found on the Farnham Plateau and north of Bentley; but the Dippenhall drifts point to the survival of the Crondall consequent, until a valley had been excavated about 200 feet below the level of the plain.

If, on the other hand, we adopt the subaërial theory, without any assistance from the sea, we are obliged to attribute all the chert found north of the Farnham Valley to consequent rivers. It follows, then, that there was an early period of denudation, prior to the exposure of the Hythe Beds at Hindhead, which has left no distinct record behind it; and a second period to which all the remaining drifts belong, those of the Farnham Plateau (late Pliocene?) being the earliest. For convenience, I shall speak of these two periods as the first and the second cycle, without in any way implying a physical break between them.

We have no means of deciding at all closely the position of the Chalk escarpment at the end of the first cycle, but it is evident that the cycle must have been a long one, since the exposure of the Hythe Beds at Hindhead involves the removal of about 1000 feet of strata (26, p. 217) without counting the Eocene beds. On the other hand, in the second cycle Hindhead has apparently not been lowered more than 50 feet; and it is, therefore, somewhat surprising to find that at the beginning of this period (and even for some time later) the river-system was in a very immature state. The distribution of chert shows that the Farnham River did not exist, at any rate to the east of Bentley, and the Tilford River, as we know, is of much later date; hence it is evident that the whole system was still in the consequent stage. It may be urged that much of this district was covered with Chalk, and that subsequent streams do not readily arise on that formation; this I am ready to admit, and, indeed, I shall argue later that the difference between the Blackwater and the neighbouring river-systems is largely due to this cause: but the fact remains that, given time enough, subsequent rivers do arise, even on Chalk, as can be seen in Hampshire and in the Dean Valley (South Downs) at the present day. Moreover, why was there so much delay in founding a subsequent system in the Lower Greensand, to the south of the Chalk escarpment? The lowest point of the Chalk must have been in the syncline, approximately along the line of the Tilford River, and, taking the central axis as lying between Hindhead and Blackdown (see fig. 6, p. 670), the Chalk must have retreated by the slow process of subaërial weathering for a horizontal distance of about 7 miles before it reached the syncline. Seeing that soft beds were exposed at the foot of the escarpment during the whole of this time, the absence of a subsequent river seems to me surprising. I am aware that opinions may differ as to the readiness with which subsequent rivers can be developed—to that I shall return presently: but the fact cannot be denied that the second cycle successfully produced two such rivers in this region, while the first produced none; and if it is sought to explain this by supposing that the second cycle was longer than the first, we are confronted with the objection that, while the first cycle removed 1000 feet of strata from the central axis, the second cycle has effected but little reduction in the height of Hindhead, and none at all in the Farnham Plateau.

It appears to me, in fact, that those who uphold this hypothesis are on the horns of a dilemma. If, in order to account for the immaturity of the river-system, they push the Chalk escarpment far to the south at the beginning of the second cycle, they have to explain how this immense mass of Chalk was removed, while but little denudation occurred elsewhere; if, on the other hand, in order to avoid this difficulty, they bring the escarpment nearly into its present position, they increase the total distance over which it retreated during the first cycle, and thereby heighten our astonishment that the drainage-system should have remained so incomplete.

Prof. W. M. Davis, it is true, does not regard a well-established subsequent system of drainage as a normal product of one cycle of denudation; but, while attaching great weight to his opinion, I fail, having regard to the nature of the Wealden strata, to understand the grounds of his belief. All round the Wealden area the Chalk ends in an escarpment, and has presumably done so ever since it was first removed from the centre of the dome. But an escarpment implies the lowering of the beds at its foot, some of which (as, for instance, the Folkestone Beds) are extremely soft; and it appears to me incredible, unless all the consequent rivers were of exactly equal value, that the slow process of cutting back the escarpment could continue for many miles without the formation of extensive subsequent valleys. Moreover, in certain ways the conditions are peculiarly favourable for such formation: the Chalk is hard though pervious; but below it lies the impervious

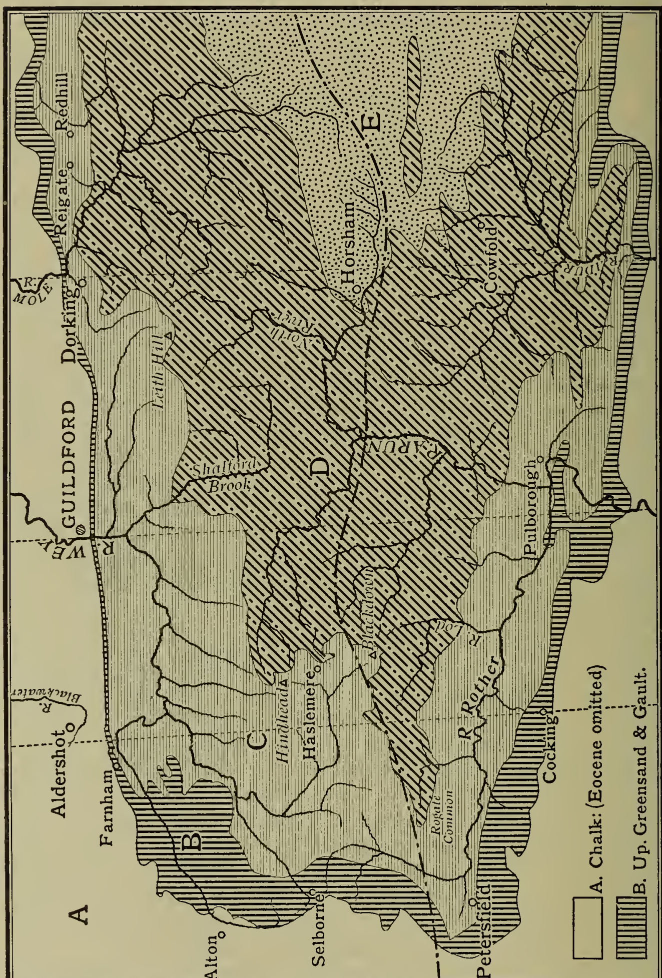


Fig. 6.—*General map of the Rivers Wey, Mole, Arun, and Adur, in relation to geological structure, on the scale of 8 miles to the inch.*

[The probable position of the central watershed in early times is shown as in fig. 8, p. 684; the fine lines joining the northern and southern rivers and passes are explained in the text, p. 690.]

Gault, and below that again the pervious Lower Greensand, and rain sinking into the latter would soon reach a saturation-point, determined by the level at which water could escape over the Gault. Any river, therefore, which passed over the latter at an exceptionally low point would drain the underground waters of the

Lower Greensand for a considerable distance on either side, and so rob neighbouring streams of their water-supply before their valleys were actually breached by the subsequent river. Although, of course, this principle is well understood, it is easily overlooked; and, in order to emphasize its importance, I may perhaps be permitted to call attention to an actual example of its action in this district. A little to the east of Farnham there were, till recently, two rivers flowing over the Gault and Chalk, at the same level, into the Blackwater; of these the Farnham River has been captured by the Wey, and now flows in a Lower Greensand valley 50 feet lower than its former companion—the Seale stream—and only a mile away from it. The consequence is that, at all ordinary times, the water which falls on the Seale basin is carried away underground into the Wey, and only when rain has been unusually heavy does any of it appear on the surface and flow northwards into the Blackwater. The Seale stream is therefore in an interesting transitional stage, in which it is robbed of most of its water-supply, although its valley has not yet been invaded.

But it is not only upon general considerations such as these that I found my opinion. Apart from arguments which might be derived from other districts (for instance, the Vales of Pewsey, Kingsclere, etc.), the drainage-area under consideration supplies direct proof of the rapidity with which rivers, both subsequent and obsequent, can be developed. The presence of chert all over the Alice Holt Plateau (including Farnham Common) affords strong grounds for the belief that, when the plateau was formed, the Tilford River was not yet in existence, at any rate between Headley Park and Tilford; and it is practically certain that the Waverley Valley was at that time occupied by the consequent head of the Blackwater. The present level of the river at Tilford is about 170 feet; that of the Alice Holt Plateau (the date of which is fixed by the palæoliths of late type in its gravels) 360 feet; and that of the Farnham Plateau, 610 feet. It is, therefore, clear that the formation of the Tilford River and the reversal of drainage in the Waverley Valley belong to the second half (and perhaps the smaller half) of the cycle of which the Farnham Plateau marks the initial stage. If that cycle has evolved the whole drainage-system from a marine plain, these facts are intelligible; but if, on the other hand, it is only part of a vastly longer cycle of subaërial denudation, the delay in the formation of a Lower Greensand subsequent appears to me very difficult to explain, in view of the rapidity with which it attained maturity when once it started.

So far I have only dealt with the hypothesis of complete marine planation on the one hand, and of prolonged subaërial denudation on the other; there remains Prestwich's alternative of a combination of the two. This is so elastic a theory that it is obviously impossible for me to meet, in this paper, all the various aspects which it may be made to present; but I think it will be found that, unless we practically identify it with the marine hypothesis, by assuming that the Chalk was planed off, across its whole outcrop, to a thin layer, all the objections derived from the immaturity of the river-system, which were urged against the subaërial theory, apply to this hypothesis as well.

(C) River Wey.

As in the case of the Blackwater, I shall first describe the phenomena in terms of the hypothesis of marine planation, afterwards pointing out the difficulties which lie in the way of the theory of continuous subaërial denudation.

If we exclude the area formerly drained by the Blackwater, the Wealden portion of the Wey may be said to consist of a main consequent trunk, and one subsequent tributary on each side. An important longitudinal fold runs along the whole front of the area thus drained, and reaches its greatest development at the very point at which it is crossed by the consequent river, thereby giving rise to the Peasemarsh inlier. No name was given to the consequent stream on the Ordnance Survey maps, but it is called by Martin (11, p. 72) the Shalford Brook, and as such it will be convenient to refer to it in this paper. It rises in the Weald Clay, receiving at its head a subsequent stream from the east; but its territory has been greatly encroached upon by the Arun, and it will be more convenient to defer consideration of this portion of it until the latter river has been described.

The western subsequent river (Godalming River) runs in the Lower Greensand, and for the most part in a shallow syncline, about 4 miles from the Chalk. The main part of the eastern subsequent (Tillingbourne) is much closer to the escarpment, and appears to coincide, in part at least of its course, with the anticline already mentioned, but there is a second longitudinal stream about a mile farther south, which runs for some distance nearly parallel with the Tillingbourne before joining it.

There are but few well-marked notches in the crest of the Chalk escarpment throughout this region, yet I think that, with a little study, the former passage across it of several consequent streams can be inferred with some confidence. Taking first, for the sake of clearness and convenience, the country to the east of Guildford, we find 6 miles from this town the well-known sands of Netley Heath, for which Mr. Stebbing's researches (25, pp. 524-26) strongly suggest a Pliocene date. It is, however, no part of my purpose to discuss the age of these beds, but merely to call attention to the gravel containing a good deal of chert which everywhere overlies them. Mr. Stebbing simply records its existence in each of the four sections detailed by him, without speculating on its origin; but I think that most observers, having regard to its relations and composition, and to the frequency with which it occupies channels ploughed in the sands, will agree in assigning it to fluviatile action, and therefore I may fairly claim it as the work of a consequent river. It lies for the most part just above the 600-foot contour, while on the east the Downs rise to 733 feet O.D. On the west there is no rise near the escarpment, yet a mile away to the north, near Woodcote Lodge (Hook Wood), gravel is found at 678 feet O.D., and this, if we allow a gradient of 50 feet per mile (see § II, p. 656), would be equivalent to about 730 feet on that part of the marine plain which overlay the present escarpment. Assuming that the Netley Sands, and perhaps the Eocene Beds seen at Hook Wood, were formerly thicker and more extensive than at present, but have been removed except where specially protected by gravel, there is no difficulty in understanding how the present configuration of the Downs has been evolved from the original plain. Much of the bevelling of the hill-crest is attributed to pre-Eocene causes, and the consequent river which gave rise to the gravels is regarded as having been cut off after it had excavated a valley about 120 feet deep. By that time the Lower Cretaceous strata must have been exposed a little to the south of the present escarpment, and the formation of a subsequent stream would normally follow.

About half way between Netley and Guildford is the gravel-bed of Newlands Corner, which also contains chert, and is indeed closely similar in composition to the Woodcote Lodge gravel (13, p. 33). It stands for the most part at very much the same level as that of Netley, and may also be ascribed to an early consequent river. According to my reckoning, the Chalk extended over this part of the plain for about 3 to 4 miles south of its present position, and most of the territory between it and the central watershed was occupied by Lower Greensand. Whether the Weald Clay was exposed is doubtful, but if not it would soon emerge, for its covering of Lower Greensand must have been planed off to a very thin layer.

To the west of Guildford the geological structure of the plain was more complex, and the evolution of the river-system is proportionately difficult to determine. There is no drift on the Hog's Back, and the only break in the even curve of its sky-line is a shallow depression, about 50 feet below the summit, immediately to the north of Puttenham; but this absence of drift and passes is not in the least surprising. The theoretical height of the plain at Puttenham is (see fig. 1, p. 642) about 660 feet, and, owing to the high inclination of the strata, this level would be reached at quite a short distance (less than a mile?) from the present summit; the latter, however, which hardly rises above 500 feet O.D., would be buried under at least 150 feet of Tertiary strata, so that a river might cut a valley as deep as that which we have already traced at Crondall (that is, 200 feet below the level of the plain) without leaving any lower pass across the Chalk ridge than we find above Puttenham at the present day. It is quite clear from this that the even bevelling of the crest of the escarpment along the Hog's Back cannot be connected with the plain which I am endeavouring to establish.

In the absence of drift the course of former consequent streams is more than ever a matter of conjecture; but it may be possible to trace, in the present consequent and obsequent streams, two former consequents: (*a*) from the Devil's Punch Bowl (Hindhead) past Elstead and Cutmill, and so over the Hog's Back near Shoelands (1 mile east of Seale); and (*b*) from Gibbet Hill (Hindhead) by way of Peperharrow and Puttenham to Wanborough, etc. (see map, fig. 5, p. 666).

I have endeavoured in fig. 5 to indicate the probable distribution of Chalk on the plain. Such an attempt is beset with so many sources of error that no accuracy of detail is to be hoped for; but, even if wrong, in many respects the diagram will serve to illustrate certain broad features which, if planation really occurred, must have had their effects on river-development.

If we take Section 73 of the Geological Survey and reconstruct a plain running from the summit of Hindhead to the hypothetical line shown in fig. 1 (that is, 660 feet at Puttenham), we find the Chalk stretching away in a continuous sheet as far south as Thursley. I do not think, however, that the details of this section can be altogether correct. In the first place, the thickness assigned to the Selbornian Beds (Gault and Upper Greensand) is probably far too small, and no allowance is made for the overthrusting and compression of the Chalk (29, p. 432). In the next place, Crooksbury Hill, a mile and a half to the west of this section, reaches 534 feet O.D., and consists wholly of Lower Greensand; and, assuming that it presents the top of the Folkestone Beds, we must still add about 250 feet for the Selbornian (9, vol. i, p. 92), bringing the base of the Chalk to 784 feet. The theoretical level of the plain, allowing a gradient of 30 feet per mile, is about 700 feet, so that there was probably an area from which the Chalk was absent; and, since there is a general dip towards the west, the Lower Cretaceous rocks must *a fortiori* have been exposed farther east. I am led, in fact, to believe that a belt of the latter rocks extended all the way along the crest of the anticline from Guildford to the Waverley Valley, and perhaps beyond, while a second belt of Chalk, planed off very thin, occupied the syncline to the south. The effect of this peculiar structure on the rivers can only be conjectured. The position which I have ascribed in fig. 5 to one of the early consequents suggests that it may possibly have been concerned with the production of some of the chert-bearing gravels farther north (Fox Hills, Chobham Ridges, etc.); but, although this would simplify the explanation of certain peculiar gravels about Windlesham (see 13, p. 36), there is no real evidence in favour of such a view. The Godalming River may have arisen in the Lower Greensand at an early stage, south of its present position, and followed the retreat of the Chalk northwards; and some of the early drifts around Thursley may be relics of this period. The streams traversing the northern belt of Lower Cretaceous rocks would then be diminished in volume, and soon diverted into subsequent courses, one running from Puttenham past Seale to the Aldershot gap (Seale stream) and the other eastwards from Compton to Shalford. The latter still survives, but the former, having a longer route to the sea, has been for the most part captured by an obsequent tributary of the Wey, which is still encroaching upon it at Seale. The entire absence of drift, or any rolled pebbles except a few scattered flints along the foot of the Hog's Back, is, so far as it goes, in favour of this hypothesis, since the Seale stream is never supposed to have traversed chert-bearing beds, and the Chalk on the south which it formerly drained had been planed off to below the flint-bearing level. As regards the part played by the two obsequent streams north of the Godalming River, I think any one who studies them will admit that, considering the softness of the strata, their adjustment to the surrounding country is still very immature, and thus a comparatively late origin (possibly after the removal of all the Chalk and Selbornian strata from the syncline) is rendered probable.

There are two points in this river-system, which, in my opinion, are more satisfactorily explained by the marine hypothesis: (*a*) the coincidence of the main transverse river with the point of greatest development of the longitudinal fold; and (*b*) the drifts on the Downs to the east of Guildford. With regard to the first point, if we assume fold and river to be contemporaneous, it is obvious that the position occupied by the latter presents a minimum of advantages. An antecedent river-system would be free from this objection, but the coincidence of the two features would be purely a matter of chance; and, unless the formation of the fold be assigned to a very early period, when consequent rivers were still extremely numerous, such a chance connection would be unlikely to occur. But, if the fold arose at such an early stage, it seems to me that the syncline, which forms part of it, should also have had its effect upon the drainage, and have been immediately occupied by a longitudinal stream. Now, we have no positive evidence as to the date of formation of the Godalming River, but we do know that the Tilford River, which occupies a continuation of the same syncline, was of very late origin; and this I regard as making it improbable that the former river arose as a direct consequence of a very early movement. So far as it goes, this is an objection to the subaërial theory. The marine hypothesis, on the other hand, by assuming that the summit of the anticline was planed off, thereby affording a large area of Lower Cretaceous beds in which this particular consequent river could develop, offers an ample reason for its success.

Let us consider next the drifts east of Guildford. The central region, round Horsham and St. Leonard's Forest, is composed of nearly horizontal strata, and immediately south of Leith Hill there is even a slight dip to the south; consequently, if the Hythe Beds (in accordance with the subaërial hypothesis) were first exposed in the centre, there must have been at one time a very great interval, between them and the Chalk, covered by Folkestone Beds and other soft strata. The conditions, therefore, were favourable for the early development of subsequent streams. If, however, we adopt the widely accepted chronology, by which the Southern Drift is assigned to the action of Pliocene rivers, it is evident that the time occupied in establishing a subsequent stream severing this part of the Chalk from the Hythe Beds was, compared with the total length of the supposed subaërial period, extremely short. This difficulty can be avoided, (1) by assigning a marine origin to the gravels in question, which, however, is opposed to Prestwich's conclusions as to the Southern Drift; (2) by assuming a much earlier origin (Miocene?) for this drift than is generally admitted; (3) by postulating wide oscillations of the River Wey on a nearly level plain of Chalk and Tertiary strata—a peneplain, in fact. I am not prepared to say that any one of these assumptions is wholly unreasonable, but am merely pointing out what appear to me to be obstacles to the acceptance of the subaërial theory, whether with or without a coastal plain. The marine hypothesis, on the other hand, offers a simple solution of the problem. The thin layer of planed-off Chalk was quickly removed until a definite escarpment began to be formed; whereupon a subsequent system arose, which cut off all the less successful consequent streams before they had had time to excavate any deep notches in the Downs.

On the view here adopted, the main differences in evolution between the Blackwater and the Wey are traceable to differences in the geological structure of the uplifted plain. The area belonging to the former was at first almost wholly covered with a layer of Chalk, which though thin, and perhaps easily removed, nevertheless caused some delay in the formation of subsequent streams; it was only after an excavation of 200 feet (measured along the present summit-line of the Downs) that the northern (anticlinal) subsequent was finally completed, and it was still longer before the Tilford (synclinal) River came into existence.

In the case of the Wey, on the other hand, a vast surface of Lower Greensand was already exposed; and in this the development of subsequent streams proceeded so rapidly that it is doubtful whether any of the captured consequents had time to cut a valley as deep as 150 feet before being beheaded.

Again, the excessive upheaval of the anticline near Guildford gave rise to a local dip towards both the east and the west, which enabled subsequent streams to work outwards in both directions from the Peasemarsh inlier; whereas in the case of the Blackwater the beds fall away towards the west, so that the development of subsequent tributaries was practically unilateral.

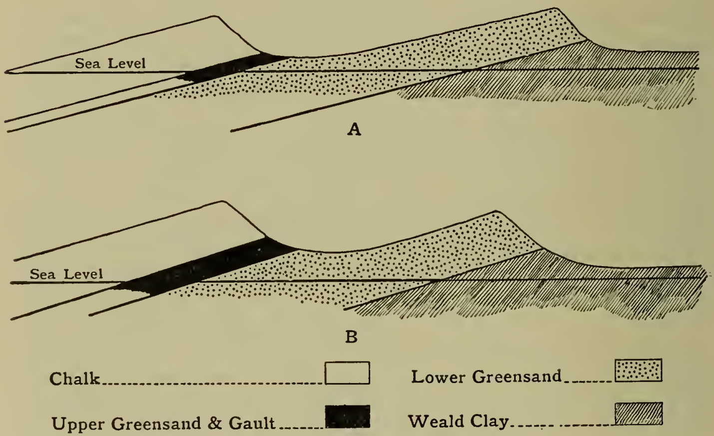
(D) River Mole.

Almost the whole main trunk of the Mole lies in the Weald Clay, and the most obvious peculiarity about it is the obliquity of its course to the general line of the Chalk escarpment. The latter, it is true, changes its direction at White Downs, some 3 miles west of Dorking, and takes a more northerly trend; but even to this line the Mole is somewhat oblique, just as the Shalford Brook is to the strike of the Chalk at Guildford. Across the Chalk itself the Mole runs nearly due north—again with no obvious relation to the strike—while on the Tertiary beds the north-westerly direction of the Wealden portion is for a time resumed. Further observation shows that, as regards the Weald Clay itself, there is a change of strike along part at least of the Mole's course, as may be seen if we follow, on the map of the Geological Survey, the belt of *Paludina* Limestone: this may account for the direction of the river across the Weald Clay, but leaves unexplained the change of course in crossing the Chalk.

The numerous tributaries which reach the Mole from the west follow approximately the direction of the strike, and are nearly at right angles to the consequent stream: only one of them lies in the Lower Greensand, the rest being all in the Weald Clay. On its east side the Mole receives but one important tributary, and since the strike on this side reverts to the normal east-and-west line, this stream, which follows it, differs markedly in direction from the longitudinal rivers on the west. On this eastern side there is no subsequent branch in the Lower Greensand, but we are introduced to streams of a type which is extremely common between Maidstone and Dorking, though unknown farther west—namely, obsequent streams traversing the Lower Greensand at right angles to the strike, and joining subsequent rivers in the Weald Clay. The most important of these in the region of the Mole is one which rises near Merstham, and cuts through the Lower Greensand escarpment at Redhill; but there are others on a smaller scale farther west, also belonging to the Mole, as well as several of importance farther east, belonging to the Medway.

Although the latter are outside the scope of this paper, they must be included in a general sketch of the origin of such streams, since they appear to me to have a possible bearing on the hypothesis of a marine plain. Whatever were the advantages possessed by the Medway and the Mole, they seem to have pushed out subsequent streams very rapidly in the soft Weald Clay (which *ex hypothesi* was from the first exposed), so that at a comparatively early stage they had wrested all the central area from their less fortunate neighbours. Meanwhile the latter had been cutting down the Chalk and spreading laterally in the Lower Greensand as fast as they were able, but after the decapitation which they had suffered in the Weald Clay, their progress was not very rapid. The Medway itself spread for some distance westwards in the Lower Greensand; but, owing to the narrower outcrop and (on the whole) less yielding material, its success was far less than in the Clay: while the only other river which extended laterally for more than a mile or two was the Darent. The Mole, for some reasons yet to be studied, made practically no advance eastwards in the Lower Greensand, though it established a small tributary on the west. The comparative success or failure to reduce the level at which they crossed the Chalk was of the utmost importance to the several streams which, though severed from the Weald Clay, survived for a time in the Greensand; for, unless they could cut down their valleys below the level at which the underground waters of the pervious Lower Greensand overflowed southwards on to the Weald Clay, they were certain sooner or later to be captured by obsequent streams advancing from this direction. Perhaps the two diagrams given in fig. 7 (below) will help to make this clear : in A the Lower Greensand river is at least as low as that in the Clay, and has a chance of surviving ; in B the Weald Clay river is lower than that in the Greensand, and the latter is doomed to failure. In a rough and diagrammatic way these two sections may be taken as representing the conditions obtaining, A at Leith Hill, and B at Redhill. In the former case the Weald Clay was little, if at all, exposed upon

Fig. 7.—*Diagrammatic sections illustrating the drainage of the Lower Greensand and the Weald Clay.*



[In A the Lower Greensand and the Weald Clay drainage are on about the same level, and the former has a good chance of surviving; in B the Weald Clay drainage is the lower, and is certain, sooner or later, to capture the Lower Greensand drainage.]

the plain, and the subsequent rivers in it and in the Greensand started on fairly even terms ; in the Redhill region, on the other hand, the area of Clay exposed was large from the beginning, and rivers developed in it with such rapidity that they first beheaded, and then completely captured the Greensand streams. In the whole region between the Mole and the Medway the only Lower Greensand river which has survived is the Darent: it does not seem to have long maintained its primary hold on the Weald Clay, since the Lower Greensand escarpment is almost everywhere above 600 feet ; but it must have had some initial advantages, of which the syncline described by Mr. Spurrell was perhaps the most important, whereby it succeeded in combining into two subsequent streams in the Greensand numerous small consequents which can now only be traced by the chert that they have left on the Downs. In this way it attained a volume which enabled it to keep pace, by cutting down the Chalk, with the excavation of the Weald Clay by the Medway. Next to the Darent the stream which survived longest was what I may call the Merstham River—a branch of the Wandle; assisted perhaps by a fault, as well as by a change of strike, it succeeded in excavating in the Lower Greensand a valley 4 miles long, and some of the chert which it carried down is perhaps still to be found in the gravels of Smitham Bottom. Dr. Hinde (6, p. 224) denies this, and regards the chert in question as having been washed down from the Clay-with-Flints and other drifts on the Chalk slopes bounding the valley; but, however this may be, the presence of chert in these drifts has still to be accounted for, and accords best with a belief in early consequent streams from the Wealden area: nor can I see any reason to doubt that the Wandle did in fact drain this portion of the Wealden area until a fairly recent period.

About the other consequent streams which the Mole succeeded in capturing there is not much to be said. Between Merstham and Dorking the summit of the Downs presents extensive surfaces of a plain gently sloping to the north, some of which correspond to Prestwich's 'Chalk Plateau,' but in other places the Chalk is covered by more recent deposits which seem to have been planed off by some denuding agency. The chert found on Headley Heath and Walton Heath may probably be attributed to early consequent rivers, one of which may be indicated by the obsequent valley of Pebble Coombe; but any such streams in this region must, owing to the obliquity of the Mole, have been either cut off altogether from the Wealden area, or reduced to infinitesimal dimensions, at a very early stage. It is important to notice that Betchworth Clump lies only a little to the south-west of Walton Heath, and that the present drainage of the latter is towards the east; it is, therefore, nearly impossible to ascribe the drift of this heath to an oscillation of the Mole.

It remains for me to try and discover some reason why the Mole, though possessing an undoubted advantage over the Wandle, only cut it off finally from the Wealden area by a flank movement in the Weald Clay instead of by direct attack in the Lower Greensand. If we could suppose that the latter had always had as narrow an outcrop as at present, no explanation would be needed; but this cannot be admitted. On the subaërial hypothesis the Greensand was first exposed near the central watershed, where the strata are but slightly inclined, and where therefore its outcrop must have been broad; and then the escarpment retreated slowly for a distance of 12 or 13 miles before arriving at its present position. Surely, during all the length of time that this implies, there must have been abundant opportunity for the growth of subsequent streams? The comparative thinness of the strata at this point, and local differences in composition, would certainly have their effect, but I very much doubt whether they afford a sufficient explanation. On the marine hypothesis it is most difficult to fix the limits of the various strata upon the plain; according to my calculations, the Chalk probably extended about 2 miles south of its present position, although over part of this distance it was bevelled off to a thin layer; but the position and width of outcrop of the Lower Greensand depend on so many uncertain factors that I cannot attempt to define them. It is evident, however, that planation would greatly reduce the horizontal distance through which these strata have retreated, and would therefore lessen the opportunities for the development in them of subsequent rivers; the dip, too, might conceivably be so great throughout their retreat as to keep the outcrop permanently narrow. Although, therefore, many details are obscure, yet I submit that the marine hypothesis offers a rather better solution than the subaërial of this particular feature of the Mole, as well as of the more general fact of the capture of Lower Greensand areas by obsequent streams from the Weald Clay. To sum up broadly, just as the Wey differed from the Blackwater owing to the plain in its district having consisted more of Lower Greensand than of Chalk, so the Mole differs from the Wey because so large an area of Weald Clay was already exposed during its initial stages.

Attention may be called here to the fact that a straight line drawn from White Downs to St. Leonard's Forest very nearly marks the watershed between the Mole on the one hand and the Wey and Arun on the other. This is unusually straight for a Wealden watershed, and is the more interesting because, as I shall argue later on, it probably in the first place separated the Mole from the Wey only, the Arun's intervention being secondary. Such a watershed suggests a structural cause, all the more because, in its obliquity to the main escarpment line, it agrees in general direction with the consequent trunks of the Wey and Mole; but, if such a cause exists, I must leave to others its elucidation. Martin (12, p. 195) asserts that there is an anticline in the Lower Greensand along this line; but I am unable to support his belief by personal observation, and the fact that no such fold is alluded to by more recent workers in this district (see especially 10) is strong negative evidence against its existence.

(E) River Arun.

The chief consequent river, in this case, runs approximately at right angles to the Chalk escarpment, and lies mainly in the Weald Clay. Except at its extreme northern end, where a large branch reaches it from the Horsham district, it is singularly deficient in tributaries on its eastern side; but three important streams join it from the west, two lying wholly in the Weald Clay, while the third and largest (the Rother [1]) runs mainly in the Lower Greensand.

[1] This must not be confused with the other river bearing the same name, mentioned on p. 659.

Beginning with the last-named river, we find that it rises at the foot of the Alton Hills, near Selborne, flows southwards as far as Petersfield, and then, turning to the east, pursues the remainder of its course along the foot of the South Downs. Some remarks on its extension to the north of Petersfield will be found in my former paper (2, p. 329), and only the part which lies between that town and Pulborough need be considered here. Although the strata in this region are thrown into numerous folds, the river seems only in places to coincide with the latter, and offers no reason for doubting that it is a true subsequent river, in the formation of which numerous consequent streams must have been captured. Unfortunately, though the summit of the Downs is furrowed by several passes, there is an entire lack of Drift, so that we cannot, as in the case of the North Downs, prove by the presence of chert the former connection of these passes with streams which once drained the Lower Greensand area. The Cocking gap, which sinks as low as 340 feet O.D., may plausibly be conjectured to have had such a connection, and there are several other passes well below the 500-foot contour; but it is not safe to assume in such cases that their present height at all closely represents the level at which their streams were beheaded, or even that they necessarily had a Wealden connection. For example, there is a very low pass between Petersfield and the Meon Valley; but the gravels of the latter contain no chert, and to suppose that any Wealden river ever flowed out in this direction would add greatly to the difficulty of accounting for the northern branch of the Rother, which stretches, past Liss and Greatham, far to the north of the original watershed.

From calculations based on Section 73 of the Geological Survey, I estimate that the Chalk originally extended over the plain as far as Henley Hill, some 5 miles to the north of the existing Downs; but there is evidence that the subsequent river, instead of waiting, as the Tilford River did, until most of this Chalk had disappeared, was formed in the Lower Greensand at an early period considerably to the north of its present position. As long ago as 1851 Murchison (16) described extensive sheets of gravel, containing an abundance of subangular flints, in this south-western corner of the Weald. More recently Dr. Elsden (4) has again called attention to them, and, associating them with others farther east, he comes to the conclusion that they are unconnected with existing rivers, and point to an ancient plateau between the Chalk and the central dome. So far as I have been able to examine one of the largest and highest of these sheets of gravel—namely, that on Rogate Common (about 500 feet O.D.)—it bears a general resemblance, in the subangular character of its flints, to some of the gravels of the Alice Holt plateau, near Farnham; and its distance from the Western Downs (Wheatham Hill, etc.) is very much the same as that of these latter drifts from the Chalk round Alton. It appears to me highly improbable that so wide an extent of flint gravel could have been deposited in its present position by consequent rivers; but I see no difficulty in believing that it was brought from the west by an early subsequent river, in some degree comparable to the Farnham River, which produced the similar gravel of Alice Holt. Whether that subsequent river was already connected with the Arun, or whether it joined one of the original consequent streams which the Arun has since captured, I am unable to say; but in either case it is to be regarded as an early portion of the Rother, which has steadily sunk down the hill-slope in its pursuit of the retreating Chalk escarpment. How soon it originated, there is nothing to show; but, from the amount of gravel which has slipped down into Harting Combe (see 16, fig. 3, p. 353), it seems certain that the river once extended farther north, and therefore presumably higher than the present summit of Rogate Common.

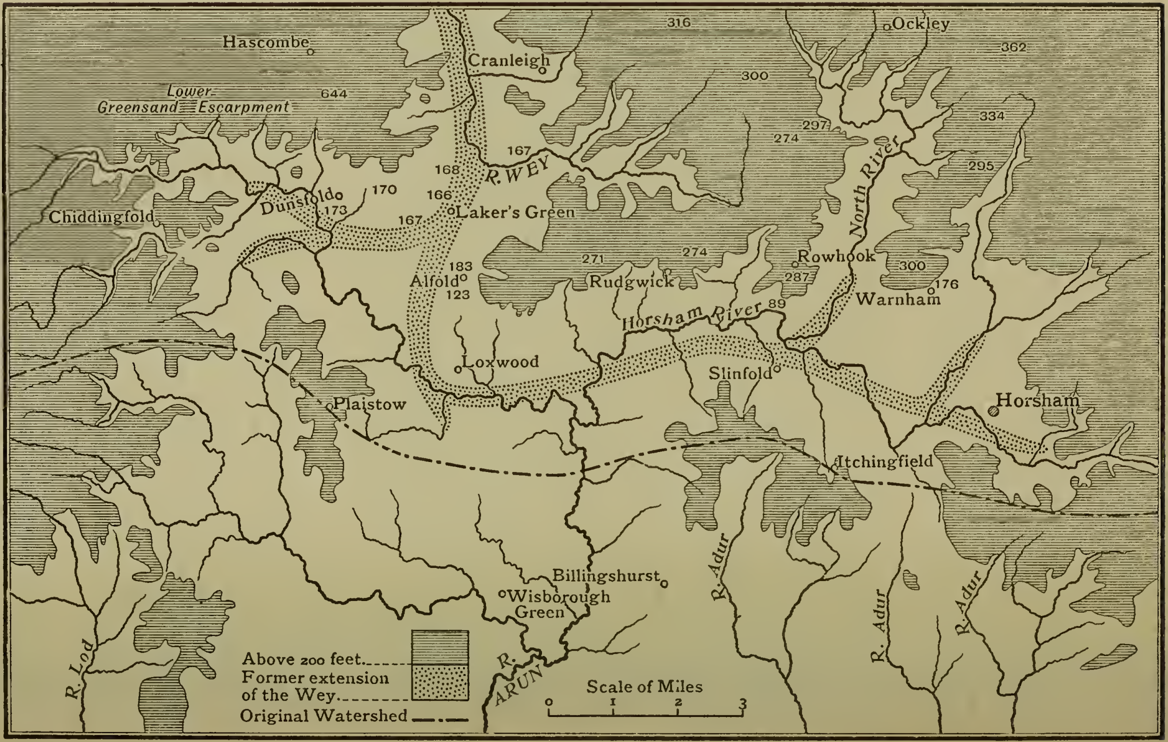
To the north of the Rother Valley is a large V-shaped area of Weald Clay hemmed in on the north, south, and west by two lines of Lower Greensand hills; and several tributaries of the Rother, of which the Lod is the largest, rise either in the northern ridge, or in the low-lying clay at its foot, and traverse the southern ridge in comparatively narrow gorges. That this structure is, in a general way, due to an anticline (or anticlines?) which has brought up the clay into the beds of the transverse rivers, is obvious enough; but I do not think that the details have been satisfactorily worked out. Topley (26, p. 225) regards this as part of the central line of elevation, continued westwards from Horsham; but the behaviour of the rivers, both here and in the Horsham district, appears to me to place the central watershed farther north (see fig. 6, p. 670). It is possible that we have to deal with a series of wave-like uplifts, arranged in échelon, and that each wave is traversed, at or near its highest point, by a consequent river; but I confess that I have no proof of this suggestion to offer. That the folds of this region are numerous was long ago shown by Martin (12), but they are very hard to follow, and little has been done since his day to elucidate them.

Passing now to the main consequent trunk of the Arun, and following it northwards, we find the next important tributary entering from the west near Wisborough Green, after having drained the eastern slopes of Blackdown: it runs in Weald Clay parallel to the line of Lower Greensand hills round Petworth, and in doing so passes across the north of the V-shaped area of clay already mentioned; the reason why it does not extend into this area is apparently because the anticline which gave rise to the latter dies away towards it eastern end (see 26, pl. ii). For the rest, this tributary appears to be an ordinary subsequent stream, and as such calls for no further observation.

Following the consequent river still farther northwards, we come to a point at which the stream splits into two branches, an eastern and a western, about 2 miles south-east of Loxwood (fig. 8, p. 684). Taking the western stream first, we find that it drains the whole eastern slope of Hindhead, as far south as Haslemere, and the southern face of the Lower Greensand escarpment between Hindhead and Hascombe: it thus extends far to the north of any probable position of the central watershed, and invades territory which we should naturally expect to find included in the basin of the Wey. I think it can be shown, not only that such an invasion has taken place, but that the transference of this region from the Wey to the Arun is of comparatively recent date. The head-waters of the Wey take a sharp bend at a point, about a mile to the north of Laker's Green, which may be taken as the junction of a subsequent with a consequent stream; and the ground all around this point is extremely flat, having evidently undergone a long and complete adjustment to the river-level. On the south there is a gradual rise to the high ground between Alfold and Rudgwick; and while on the east the valley of the subsequent stream soon narrows, on the west, although no stream joins the Wey from this side, the gently sloping plain can be followed beside the Wey & Arun Canal as far as Tickner's Heath, and thence past Dunsfold into the neighbourhood of Chiddingfold. South and west of Dunsfold the plain, gradually rising, can easily be traced for some distance, but it is intersected by numerous branches of the Arun, running in steep-sided valleys about 70 to 80 feet below the plain-level. It is impossible to represent all this on a map, but I think anyone who carefully studies the district will agree with me that the obvious adjustment of this plain to the head of the Wey, and the entire lack of adjustment, in spite of the soft soil, to the Arun, are proof that the latter has here effected a very recent capture—so recent, in fact, that the level of the Wey has since undergone no appreciable change. The accurate mapping of the plain would be a task of considerable interest for anyone living in the neighbourhood; but in a thickly wooded district this is no easy matter, and though I have followed it up in many directions, I have still much to learn concerning it. In the map (fig. 8, p. 684), therefore, in which I have endeavoured to indicate the former watershed and its relation to the rivers, I have not attempted any complete reconstruction of the old drainage-system.

We turn next to the easternmost of the two rivers forming the head of the Arun, which may for convenience be referred to as the Horsham River; and here the first question confronting us is whether it is a subsequent or a longitudinal consequent river; against the latter theory may be urged (*a*) that no other such river has been definitely proved to exist in this area, and (*b*) that there is no evidence of a synclinal fold which such a river requires. A longitudinal tributary of the Ouse practically continues the line of the Horsham River eastwards, and so long an alignment of river-valleys suggests a structural cause; yet, although there is a syncline near Slaugham, the Ouse does not run in it, but to the north of it, and the fold itself seems to die away before the Arun is reached. It must, of course, be admitted that, especially on an impervious soil, an amount of folding which would be practically imperceptible

Fig. 8.—*Map illustrating the present and past relations of the Wey and the Arun.*



to us now, might be sufficient to guide an early stream; but we have no right to assume such a fold except under very strong compulsion from collateral arguments.

On the other hand, this river is most difficult to account for as a subsequent outgrowth from the Arun. It passes close by the head of the Adur, which at Christ's Hospital is only separated from it by a narrow belt of flat ground; so that it must, on this hypothesis, have captured some territory from the latter river. This, however, is most improbable: the Arun and the Adur have equally good access to the sea, and there is nothing elsewhere to suggest that the former had any advantage; on the contrary, its failure to expand eastwards in the Weald Clay farther south indicates that there at any rate the Adur occupied the more favourable position. This objection, then, seems to me a serious one, so long as we attribute the subsequent river (if such it be) to the Arun, but it disappears if we suppose that the river was originally a branch of the Wey; and that proposition I shall now endeavour to prove.

From about Horsham westwards the river runs in Weald Clay (with occasional beds of Horsham Stone), and the hills bounding its valley on the north rise with an abruptness which is most unusual in these soft strata. On the well-known relief map of the Weald the ridge to the north of Rudgwick is absurdly exaggerated, and made to appear almost equally steep on both faces: in reality it slopes very gradually to the Wey on its northern side, and is only steep towards the south, where we find a rise near Rowhook of 200 feet in about a mile, and the hillside is scored with valleys of the narrow and abrupt type which we are accustomed to associate with obsequent streams.

In this region the sharp gradients of the valley may be attributed in part to the river having recently swung over towards its northern boundary; but farther east, near Warnham, there is again a steep hillside (gradient=120 feet in a mile), although the river does not run within 2 miles of the spot. Two important obsequent streams enter the Horsham River from the north, one being known as the North River, while the other may be referred to as the Warnham Brook, and we find on each side of these streams gradients almost as steep as those of the main valley.

Disregarding the North River for the moment, and fastening our attention on the ridges of higher ground bounding it, we observe that the Weald Clay, which covers all this district, stretches up the slopes of Leith Hill and its neighbours almost to the 700-foot contour; but, as we pass southwards, the ground falls away to 300 feet O.D. in little more than a mile, and then for upwards of 4 miles there is scarcely any variation in level until we plunge down, as already described, into the Horsham Valley. The North River and Warnham Brook cut through this upland plain of clay with gradients which are far more sudden than we should expect from the nature of the soil. In fact, if we compare these valleys with those of other parts of the Weald Clay area, we can hardly fail to be impressed, even after making due allowance for their obsequent nature, by their relative immaturity. So long as we persist in regarding this portion of the river-system as having originated with the Arun, this immaturity calls for, without receiving, an explanation. But, if we suppose that the original drainage-system belonged to the Wey, this difficulty vanishes; for the Arun, as we have seen, lies at a much lower level than the Wey, and while grading the bottom of the valleys stolen from the latter, has not yet had time to adjust the sides. We also, in this way, overcome the further difficulty of understanding how a southern river can have extended as far north as Leith Hill. The view, then, which I take of the early course of this river can be gathered from fig. 8 (p. 684). The original watershed ran (roughly speaking) through Itchingfield and Plaistow, and the Horsham River curved round into the Wey at or near Loxwood. When the Lower Greensand escarpment retreated, the longitudinal river did not follow it (perhaps because the dip is so slight), but kept up connection by means of obsequent streams which are now more than 6 miles long. Owing to the softness of the Weald Clay, and the greater proximity of the Arun to the sea, this river was able, at a comparatively late stage, and after a large area of the Clay had been adjusted to the Wey, to cross the original watershed and behead the Horsham branch of the latter river. This, of course, at once transferred to it all the tributaries lying above the point of capture; but the Dunsfold region continued to be drained by the Wey, and was only annexed by the slow process of obsequent growth. It is entirely in accordance with this view that the adjustment of the North River to its surroundings, though far from complete, is yet more advanced than that of the Dunsfold streams.

If we had been unable to trace the history of these northern extensions of the Arun—if its presence close to the Greensand escarpment on both sides of the Wey had appeared to be of long standing—we might have been tempted to assume that we were here in the presence of an earlier river-system, developed on the old Wealden island postulated by Prestwich. But we see now that no such assumption is necessary; on the contrary, we have strong reason for believing that these northward excursions are all of recent date, and have resulted largely from the softness of the Weald Clay, which can hardly have been exposed on such an island. The same is true of the other northward extension of the Arun, past Petersfield: this, too, is a secondary, not a primary feature, and has only been rendered possible by the exposure of soft beds in comparatively recent times.

(F) River Adur.

This river is so complex that it is not easy at first sight to determine which part of it should be regarded as the main consequent trunk: I believe, however, that the stream which runs past Cowfold, at right angles to the outcrop of the Hastings Beds, merits this description. It receives on its eastern side three subsequent tributaries, which need no special description. On its western side, what Martin (11) calls the 'Bines River' is also to be regarded as a subsequent stream, although different in direction from those on the east, since Martin's map shows that above West Grinstead it runs parallel, for some distance, with the outcrop of a sandy seam, and it is also parallel to the Wisborough Green branch of the Arun. It receives numerous consequent and obsequent tributaries which I cannot attempt to follow out in detail, a good deal of complication having been introduced by the great development in this region of the Greenhurst anticline, and the syncline to the south of it.

It will be found generally that rivers which occupy a large area of Weald Clay do not allow us to reconstruct the original consequent system as easily as we could in the case of the Blackwater; but there is no reason, on this account, to ascribe to them an earlier origin. The Weald Clay is soft, and, being impervious, every drop of water which falls on its surface runs off in superficial channels. The consequence is, not only that the rivers themselves are quickly base-levelled (none of the rocks in the Wealden area offer much resistance in this respect), but that the spaces intervening between the streams are speedily lowered, and wide marshy plains formed. On such plains the smaller streams are easily diverted even by trifling obstructions, and so in time are introduced a large number of divergences from the primitive rectilinear arrangement, more especially as the Clay is, on the whole, remarkably homogeneous, and free from alternations of hard and soft beds. I have already alluded to this influence of soil in discussing the development of the northern systems, but in the case of the southern rivers yet another factor is present—namely, the marked changes in relative level of land and sea which are known to have occurred along the south coast in recent times. Such oscillations cannot fail to have produced alternate excavation and aggradation of the river-beds, and these in turn would affect the river-junctions. In these various ways I believe that most of the irregularities of the Adur and its tributaries can be explained as due, either directly to structure (such as the change of strike), or to the influence of the Weald Clay; and since, on the marine hypothesis, the greater part of the exposure of the Weald Clay is subsequent to the plain, no argument against this hypothesis can be drawn from the river-system.

The Arun and Adur both pass through transverse synclines (26, p. 278), but the former has gained a further advantage by coinciding with the region in which the Greenhurst anticline attains its greatest development (12, pp. 134 & 196); and this coincidence I consider, as in the case of the Wey, to be connected with marine planation. Here, as there, the intensity of the disturbance has led to an easterly, as well as a westerly dip, thus enabling this river, like the Wey, to expand in both directions. The Arun, on the other hand, by the time the exposure of the Weald Clay spread westwards to it, found that formation already fully occupied by the Adur, and so has had to content itself, like the Blackwater, with a unilateral development.

(G) General Remarks.

The general tendency of the foregoing pages has been to re-establish, though on a very different foundation, Ramsay's hypothesis of marine planation. Perhaps only in the case of the Blackwater will the proofs be deemed sufficient; the other rivers, indeed, offer a good deal of evidence, derived mainly from their relation to the folds, and the distribution of chert, which appears to me to point in the same direction and to have a cumulative strength; but it may be thought wiser to reserve our final judgment on them until the whole river-system of the Wealden area has been critically examined.

There is a feature in the Chalk Plateau of the North Downs which demands further attention. In each interspace between rivers we notice one point which reaches the summit-line (figs. 1 & 2, p. 642), and from this the Downs generally slope away on either side, gradually at first, down to about 600 or 700 feet O.D., and then abruptly into the river-valley. It thus often happens that we find large areas of plateau, which appear to be parts of the plain, and yet are theoretically too low. Such curvature of the summit-line is normal where it is accompanied by horizontal curvature of the escarpment (3, p. 134); but in this region the latter is far too straight, and the inclination of the plateau too small, to produce the observed effect. Transverse synclines would be capable of giving rise to such curves, but so far their existence has not been satisfactorily demonstrated. In addition to this, a correspondence occurs in many cases, both in the North and in the South Downs, between the highest points on the summit-line and the watersheds of the subsequent rivers in the Lower Greensand. There is no need to give full details of this interesting fact, since it can easily be verified on any good map: it will be found especially conspicuous between the Wey and the Mole, on both sides of the Darent, at Lenham (between the Medway and the Stour); and in the South Downs at Ditchling Beacon (Adur and Ouse).

At first sight it appears as if, in the combination of these two features, we had evidence of the great age of existing consequent rivers, and of something approaching Prof. Davis's subaërial peneplain. We might suppose, if they stood alone, that, in the course of long ages, transverse watersheds were established in the Chalk area, on each side of which gentle slopes led down to the consequent rivers themselves; and that, on the retreat of the escarpment, the same watersheds had been preserved in the Lower Greensand. But further study reveals obstacles which appear to me fatal to this hypothesis. In the first place, it seems to require that the same watersheds should still extend over the Chalk itself, and it is seldom that any trace of such extension is found; whatever may be their ultimate connections over the Tertiary strata, nearly all the valleys which drain the Chalk-slopes start at right angles to the escarpment, and exhibit no relation whatever to the neighbouring consequent rivers. Secondly, there is the distribution of chert, so often insisted on in this paper, and the composition of the Southern Drift. It seems to me in the highest degree improbable that existing rivers could, on a Chalk soil, oscillate sufficiently to account for this distribution; or that, if they did so, they would have sufficient carrying power to transport the bulky material of which the Drift is often composed. I am aware that the Blackwater has carried chert several miles to the west of its passage across the Chalk; but the conditions are quite different: the river-curve in that case is on an Eocene soil, and by the time that the Loddon is reached the chert fragments are invariably small. Lastly, I may point out that the curve of the crest of the escarpment (though without, it is true, any present connection with the river-system) is very conspicuous on the Hog's Back, where the Chalk can hardly be supposed to have formed part of a post-Eocene plain, subaërial or marine. Some other cause, therefore, than the one just suggested, must be found for the peculiarities of the Downs and their relation to the subsequent rivers; whether, however, there are structural features which have hitherto escaped notice, or whether solution of the Chalk, acting more forcibly in the neighbourhood of the transverse rivers, could produce such large effects, I must leave others to determine.

The absence of any definite longitudinal consequent streams forbids us to assume that the rivers and longitudinal folds originated at the same time, and where connection exists between stream and syncline it has probably been arrived at, more often than not, as the result of a movement of the former down the dip-slope while the escarpment retreated before it. A similar movement has possibly more than once obscured early connections between longitudinal anticlines and subsequent rivers, as, for example, between Bentley and Farnham, where the high-level gravels still mark the former coincidence. On the other hand, there is strong reason to believe that the early success of the Wey and the Adur was in no small measure due to the exposure of soft beds along the planed-off crests of longitudinal anticlines. The evidence then, on the whole, points to the main longitudinal folds having preceded planation, though some further movement along the North Down line accompanied the upheaval of the plain; but the transverse movements, which in some cases at least are of later date than the longitudinal, often show a connection with the rivers which is best explained by the hypothesis of contemporaneity. Thus the Arun and the Adur, or perhaps the Wey, the Darent, and the Stour, pass through the Chalk in transverse synclines; a similar syncline coincides with the passage of the Medway through the Lower Greensand; and the old valleys of the Blackwater and the Merstham stream, as well as the Seale stream, are closely connected with transverse faults. Perhaps, too, we may associate with this cause the change of strike which accompanies the consequent trunks (past or present) of the Blackwater, the Mole, and the Adur, as well as the long straight watershed which separates the Mole from the Wey, including those streams which have been captured from the latter by the Arun.

Martin (11, p. 61) long ago called attention to the correspondence of the northern and southern river-gaps, which he thought indicated great transverse fissures; Topley (26, pp. 266–67) was also impressed by the same phenomena, though he rejected Martin's inference, and eliminated the 'wind-gaps' under the mistaken impression that they were unconnected with river-systems. More recently an elaborate comparison has been attempted by Mr. Spurrell (24, p. 9), and from his list I select the following pairs of valleys, without expressing any opinion as to the remainder: Aldershot (Runfold) gap and Cocking gap; the Wey and the Arun; the Mole and the Adur. If we join these pairs by straight lines (see fig. 6, p. 670) we obtain a degree of parallelism which is certainly very remarkable, and is not, I think, generally appreciated. But, before accepting the conclusion that these lines correspond with those of great transverse movements or dislocations, extending right across the Wealden area, we must consider certain other facts which previous writers on the subject appear to have overlooked. Of these six valleys four are still occupied by consequent rivers, while the former course of the fifth is known; and in each of these five cases the main consequent river-trunk, before it reaches the Chalk, lies to the east of the parallel line with which it is associated. It has already been argued that the gradients of the plain were slight in the region of the central watershed: the main fall was to north and south, but there was also some inclination towards the west; and it may be that the westerly trend of the consequent rivers is a resultant of the action of these two slopes. On the other hand, it is worth noting that the trunks of the Blackwater, Wey, and Mole are (or were) approximately parallel, not only one to the other, but to the watershed between the two last-named rivers; therefore, a deeper-seated structural cause for their obliquity is by no means improbable.

Up to the present I have treated the plain as a direct product of marine action alone; and, so far as the origin of the rivers is concerned, I see no reason no modify this view. If, however, the stratigraphical evidence (mainly negative) is to be trusted, there must have been two cycles of subaërial denudation—one very prolonged, extending through the Oligocene and Miocene Periods, and the other beginning in the Middle Pliocene and lasting to the present day. On the other hand, the cycle of marine denudation which separated these was very short, being confined to the Diestian stage of the Pliocene; and it may be questioned whether, in so brief a period, any great amount of planation was likely to be accomplished. The speculation, therefore, may be permitted that the removal of the Chalk was effected mainly during the first subaërial cycle, which ended in a more or less complete peneplain; and that the marine cycle (as Dr. Barrois supposed) had little effect on the rocks, being chiefly occupied in filling up the hollows of the peneplain. The absence of rolled shingle from the beds supposed to be Diestian would accord well with this view; and perhaps the supply of unrolled flints, which seems to have been so abundant at the beginning of the present cycle round the margin of the area, may be explained in the same way; for such flints would accumulate on a subaërial peneplain, and if quietly covered by the sea would be available for distribution by the new consequent rivers of the uplifted marine plain. Some may feel inclined to go a step farther, and assume that there was, on the plain, a partial revival of earlier rivers, whose valleys had been imperfectly filled by marine deposits. It may be that a few of the existing rivers have received assistance in this way; but in the area here examined I see no necessity for such an assumption even as regards the consequent rivers, while in the case of the subsequent streams there is strong evidence against it.

IV. Bibliography.

[The numerals in parentheses correspond with those quoted in the text of the paper.]

(1) C. Barrois. 'Recherches sur le Terrain Crétacé Supérieur de l'Angleterre & de l'Irlande' Mém. Soc. Géol. Nord, vol. i, 1876.

(2) H. Bury. 'Notes on the River Wey' Quart. Journ. Geol. Soc. vol. lxiv (1908) p. 318.

(3) W. M. Davis. 'The Development of Certain English Rivers' Geogr. Journ. vol. v (1895) p. 127.

(4) J. V. Elsden. 'On the Superficial Geology of the Southern Portion of the Wealden Area' Quart. Journ. Geol. Soc. vol. xliii (1887) p. 637.

(5) C. Le Neve Foster & W. Topley. 'On the Superficial Deposits of the Valley of the Medway, with Remarks on the Denudation of the Weald' Quart. Journ. Geol. Soc. vol. xxi (1865) p. 443.

(6) G. J. Hinde. 'Notes on the Gravels of Croydon & its Neighbourhood' Croydon Microscop. & Nat. Hist. Club, vol. iv (1897) p. 219.

(7) Rev. A. Irving. 'Note on the Elevation of the Weald' Geol. Mag. dec. iii, vol. vii (1890) p. 403.

(8) J. B. Jukes. 'On the Mode of Formation of some of the River-Valleys in the South of Ireland' Quart. Journ. Geol. Soc. vol. xviii (1862) p. 378.

(9) A. J. Jukes-Browne. 'The Cretaceous Rocks of Britain' Mem. Geol. Surv. vol. i (1900) 'The Gault & Upper Greensand of England'; & vol. iii (1904) 'The Upper Chalk of England.'

(10) T. Leighton. 'The Lower Greensand above the Atherfield Clay of East Surrey' Quart. Journ. Geol. Soc. vol. li (1895) p. 101.

(11) P. J. Martin. 'A Geological Memoir on a Part of Western Sussex: with some Observations upon Chalk-Basins, the Weald Denudation, & Outliers-by-Protrusion' London, 1828.

(12) P. J. Martin. 'On the Anticlinal Line of the London & Hampshire Basins' Phil. Mag. ser. 4, vol. ii (1851) pp. 41, 126, 189, 278, & 366.

(13) H. W. Monckton. 'On the Gravels South of the Thames from Guildford to Newbury' Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 29.

(14) H. W. Monckton & H. Mangles. 'Excursion to Farnham' Proc. Geol. Assoc. vol. xiii (1893–95) p. 74.

(15) H. W. Monckton & W. P. D. Stebbing. 'Excursion to Betchworth & Headley' Proc. Geol. Assoc. vol. xiv (1895–96) p. 124.

(16) Sir R. I. Murchison. 'On the Distribution of the Flint Drift of the South-East of England, on the Flanks of the Weald, & over the Surface of the South & North Downs' Quart. Journ. Geol. Soc. vol. vii (1851) p. 349.

(17) Sir J. Prestwich. 'On the Age of some Sands and Iron-Sandstones on the North Downs' Quart. Journ. Geol. Soc. vol. xiv (1858) p. 322.

(18) Sir J. Prestwich. 'On the Relation of the Westleton Shingle to other Pre-Glacial Drifts in the Thames Basin, & on a Southern Drift, with Observations on the Final Elevation & Initial Subaërial Denudation of the Weald; & on the Genesis of the Thames' Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 155.

(19) Sir J. Prestwich. 'On the Age, Formation, & Successive Drift-Stages of the Valley of the Darent: with Remarks on the Palæolithic Implements of the District, & on the Origin of its Chalk Escarpment' Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 126.
(20) Sir A. C. Ramsay. 'On the Origin of the Existing Physical Outline of a Portion of Cardiganshire' Rep. Brit. Assoc. (Oxford, 1847) Trans. Sects. p. 66.
(21) Sir A. C. Ramsay. 'Physical Geology & Geography of Great Britain' 1st ed. 1863, 5th ed. 1878.
(22) C. Reid. 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890.
(23) A. E. Salter. 'On the Superficial Deposits of Central & Parts of Southern England' Proc. Geol. Assoc. vol. xix (1905–6) p. 1.
(24) F. C. J. Spurrell. 'A Sketch of the History of the Rivers & Denudation of West Kent, &c.' (Greenwich, 1886).
(25) W. P. D. Stebbing. 'Excursion to Netley Heath & Newlands Corner' Proc. Geol Assoc. vol. xvi (1899–1900) p. 524.
(26) W. Topley. 'The Geology of the Weald' Mem. Geol. Surv. 1875.
(27) W. Whitaker. 'The Geology of the London Basin, pt. i' Mem. Geol. Surv. vol. iv (1872).
(28) H. J. Osborne White. 'The Geology of the Country round Basingstoke' Mem. Geol. Surv. 1909.
(29) G. W. Young. 'The Chalk Area of Western Surrey' Proc. Geol. Assoc. vol. xx (1908) p. 422.

Discussion.

Mr. G. W. Young congratulated the Author, and remarked that the seeming simplicity of structure displayed by the Weald vanished when the beds were studied in detail. Local lithological differences were complicated by earth-movements which were, particularly at the western end, more numerous and more extensive than was generally supposed.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXVI.

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

ADMISSION AND PRIVILEGES

OF

FELLOWS OF THE GEOLOGICAL SOCIETY OF LONDON.

Every Candidate for admission as a Fellow must be proposed by three or more Fellows, who must sign a Certificate in his favour. The Proposer whose name stands first upon the Certificate must have a personal knowledge of the Candidate.

Fellows on election pay an Admission Fee of Six Guineas. The Annual Contribution paid by Fellows is Two Guineas, due on the 1st of January in every year, and payable in advance; but Fellows elected in November or December pay no Contribution for the current year. The Annual Contribution may, at any time, be compounded for by a payment of Thirty-Five Pounds.

The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling-prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

CONTENTS.

PAPERS READ.

[No. 265 of the Quarterly Journal will be published next February.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library and Museum at the Apartments of the Society are open every Weekday from Ten o'clock until Five, except during the fortnight commencing on the first Monday in September, when the Library in closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1909–1910.

November 3rd, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read :—

1. 'Certain Jurassic (Lias–Oolite) Strata of South Dorset, and their Correlation.' By S. S. Buckman, F.G.S.

2. 'Certain Jurassic ("Inferior Oolite") Ammonites and Brachiopoda.' By S. S. Buckman, F.G.S.

3. 'The Granite-Ridges of Kharga Oasis: Intrusive or Tectonic?'[1] By William Fraser Hume, D.Sc., A.R.S.M., F.G.S., Director of the Geological Survey of Egypt.

4. 'The Cretaceous and Eocene Strata of Egypt.' By William Fraser Hume, D.Sc., A.R.S.M., F.G.S., Director of the Geological Survey of Egypt.

The following specimens and maps were exhibited :—

Ammonites, etc. from the 'Inferior Oolite,' exhibited by S. S. Buckman, F.G.S., in illustration of his papers.

Fossils, rock-specimens, and lantern-slides, exhibited by Dr. W. F. Hume, A.R.S.M., F.G.S., in illustration of his papers.

Carte géologique internationale de l'Europe, $\frac{1}{1,500,000}$: Livraison VI, Sheets E II, F II, F III, Berlin, 1909; presented by the Map Commission of the International Geological Congress.

[1] Withdrawn by permission of the Council.

November 17th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

James Alexander Haddon Armstrong, Dumisa, *via* Esperanza (Natal); Robert Alexander Farquharson, B.A., St. John's College, Oxford; George Arthur Green, Civil Engineer, P.W.D., Bombay (India); and John H. Wylie, 6 Watch Bell Street, Rye (Sussex), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Geology of Nyasaland.' By Arthur R. Andrew, F.G.S., and T. Esmond Geoffrey Bailey, B.A., F.G.S. With a Description of the Fossil Flora, by E. A. Newell Arber, M.A., F.G.S.; Notes on the Non-Marine Fossil Mollusca, by Richard Bullen Newton, F.G.S.; and a Description of the Fish-Scales of *Colobodus*, etc., by Ramsay Heatley Traquair, M.D., F.R.S., F.G.S.

2. 'The Faunal Succession of the Upper Bernician.'[1] By Stanley Smith, M.Sc., F.G.S.

3. 'Notes on the Dyke at Crookdene (Northumberland), and its Relations to the Collywell, Tynemouth, and Morpeth Dykes.' By Miss M. K. Heslop, M.Sc., and Dr. J. A. Smythe. (Communicated by Prof. G. A. Lebour, M.A., D.Sc., F.G.S.)

The following specimens, lantern-slides, etc. were exhibited:—

Fossils from Nyasaland and lantern-slides, exhibited by A. R. Andrew, F.G.S., and T. E. G. Bailey, B.A., F.G.S., in illustration of their paper and appendices.

Specimens from the Upper Bernician of Northumberland, exhibited by Stanley Smith, M.Sc., F.G.S., in illustration of his paper.

Specimens, rock-sections, and lantern-slides, exhibited by Prof. G. A. Lebour, M.A., D.Sc., F.G.S., in illustration of the paper on the Crookdene Dyke by Miss M. K. Heslop, M.Sc., and Dr. J. A. Smythe.

The type-scale of *Acrolepis (?) africana*, discovered by the late Prof. Henry Drummond, exhibited by Dr. R. H. Traquair, F.R.S., F.G.S.

A photographic transcript, made and exhibited by F. Edward Norris, F.G.S., of a record of an earthquake on November 10th, given by a newly erected seismograph at Guildford.

Crystals of gypsum formed in the sands of Karachungul Lake, Guriew District (Uralsk Prov.), near the north-eastern corner of the Caspian Sea, exhibited by W. H. Dalton, F.G.S., F.C.S.

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[1] Withdrawn by permission of the Council.

December 1st, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

Charles E. Ashcroft, Raniganj, Bengal (India); Sidney Bates, Prudhoe Grange, Prudhoe-on-Tyne; William Henry Booth, 20 Queen Anne's Gate, S.W.; Cyril Edward N. Bromehead, B.A., Museum, Jermyn Street, S.W.; Charles Barrington Brown, jun., B.A., Caius College, Cambridge; Reginald Cyril Herbert Cooke, F.C.S., London and Rhodesia; Edward Percy Currall, B.Sc., Hampton Road, Solihull, Birmingham; Charles J. Fauvel, 810 Salisbury House, London Wall, E.C.; Alexander Moncrieff Finlayson, M.Sc., Imperial College of Science & Technology, South Kensington, S.W.; Anu Ghose, Banganapalli, Madras Presidency (India); George John Selkirk Hollister, B.Sc., Iverleigh, Scalpcliffe Road, Burton-on-Trent; William A. Jenkin, 5 Bella Vista, Rio Tinto (Spain); William John, Sea View, Cefn Cribbwr, Bridgend (Glamorgan); Lieut.-Colonel John Lloyd Jones, I.M.S., United Service Club, Calcutta (India); Manoel Arrojado Lisboa, A.R.S.M., A.R.C.S., Villa Japurá, Petropolis, Rio de Janeiro; John Henry Lofthouse, Lyell House, Harrogate; Arthur Longbottom, B.A., 50 Braemar Avenue, Wimbledon Park, S.W.; Charles Nairne, Dishargarh P.O., Bengal (India), and Seafield Road, Dundee; John J. Nicholl, 52 Pulteney Road, Oxford Villas, South Woodford (Essex); Frank Oxley, Baxterby, near Atherstone (Warwickshire); R. Woodhouse Pocock, 28 Blomfield Road, Maida Vale, W.; Manmatha Kumar Ray, B.Sc., Purbasthali, Bengal (India); James Romanes, B.A., Christ's College, Cambridge; Eric William Seeman, A.R.S.M., St. Chad's, Ealing, W.; John Powers Smith, 1 Crawford Street, Dunedin (New Zealand); Francis Mackworth Trefusis, B.A., Exeter College, Oxford; Henry Titus Wakelane, M.Inst.C.E., Woodlawn, Teddington; and J. Penry Cyril Williams, Ph.D., P.O. Box 4, Calcutta (India), were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that Fellows were invited to send in to the Secretary, so as to reach him not later than January 10th, 1910, the names of any Fellow or Fellows whom they might desire to see placed on the Council. All names so sent in would be carefully considered by the Council, in making their recommendations to the Fellows at the Annual General Meeting.

The following communications were read:—

1. 'The Tremadoc Slates and Associated Rocks of South-East Carnarvonshire.' By William George Fearnsides, M.A., F.G.S., Fellow of, and Lecturer in Natural Sciences at, Sidney Sussex College, Cambridge.

2. 'On some Small Trilobites from the Cambrian Rocks of Comley (Shropshire).' By Edgar Sterling Cobbold, F.G.S.

3. 'The Rocks of Pulau Ubin and Pulau Nanas (Singapore).' By John Brooke Scrivenor, M.A., F.G.S.

4. 'The Tourmaline-Corundum Rocks of Kinta (Federated Malay States).' By John Brooke Scrivenor, M.A., F.G.S.

The following specimens and lantern-slides were exhibited :—

Rock-specimens and fossils from South-East Carnarvonshire, exhibited by W. G. Fearnsides, M.A., F.G.S., in illustration of his paper.

Specimens of Cambrian trilobites and lantern-slides, exhibited by E. S. Cobbold, F.G.S., in illustration of his paper.

Rock-specimens and microscope-sections, exhibited by J. B. Scrivenor, M.A., F.G.S., in illustration of his papers.

December 15th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President,
in the Chair.

David A. Louis, F.I.C., F.C.S., 123 Pall Mall, S.W.; Frederick William Moon, B.E., c/o Messrs. S. Pearson & Son, Ltd., Oilfields Dept., Coatzacoalcos, Vera Cruz (Mexico); and Edward Wilton Newton, Secretary of the Royal Cornwall Polytechnic Society, 4 Cross Street, Camborne (Cornwall), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Skiddaw Granite and its Metamorphism.' By Robert Heron Rastall, M.A., F.G.S.

2. 'The Metallogeny of the British Isles.' By Alexander Moncrieff Finlayson, M.Sc., F.G.S.

3. 'The Geological Structure of Southern Rhodesia.' By Frederic Philip Mennell, F.G.S.

The following specimens and lantern-slides were exhibited :—

Rock-specimens and lantern-slides, exhibited by R. H. Rastall, M.A., F.G.S., in illustration of his paper.

A specimen showing stones naturally embedded in woody tissue, from Syndale, near Faversham, exhibited by Cecil Carus-Wilson, F.R.S.E., F.G.S.

January 12th, 1910.

Prof. W. J. SOLLAS, LL.D., Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following Fellows of the Society, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—GEORGE WILLIAM YOUNG and JOHN HOPKINSON, F.L.S.

The following communications were read:—

1. 'On the Igneous and Associated Sedimentary Rocks of the Glensaul District (County Galway).' By Charles Irving Gardiner, M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S.; with a Palæontological Appendix by Frederick Richard Cowper Reed, M.A., F.G.S.

2. 'The Gneisses and Altered Dacites of the Dandenong District (Victoria), and their Relations to the Dacites and to the Grano-Diorites of the Area.' By Prof. Ernest Willington Skeats, D.Sc., F.G.S.

3. 'Recent Improvements in Rock-Section Cutting Apparatus.'[1] By H. J. Grayson. (Communicated by Prof. E. W. Skeats, D.Sc., F.G.S.)

The following specimens were exhibited:—

A series of rock-specimens, graptolites, trilobites, and other fossils, from the Glensaul district, exhibited by C. I. Gardiner, M.A., F.G.S., Prof. S. H. Reynolds, M.A., F.G.S., and F. R. C. Reed, M.A., F.G.S., in illustration of their paper.

Rock-specimens, microscope-sections, and photographs, exhibited by Prof. E. W. Skeats, D.Sc., F.G.S., in illustration of his paper.

Alkali and other rocks from the Macedon district (Victoria); and obsidianites from Victoria, South Australia, and Western Australia, exhibited by Prof. E. W. Skeats, D.Sc., F.G.S.

Photographs and lantern-slides illustrating the paper by H. J. Grayson, exhibited by Prof. E. W. Skeats, D.Sc., F.G.S.

Horizontal seismogram of January 1st, 1910, taken at Guildford, and exhibited by F. Edward Norris, F.G.S.

A stone-implement, from the collection of P. Anderson, Lerwick (Shetland), exhibited by James Cross, F.G.S.

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[1] Withdrawn by permission of the Council.

January 26th, 1910.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

Friedrich Noel Ashcroft Fleischmann, M.A., F.C.S., 37 Palace Court, Bayswater, W.; Robert William Church, B.Sc., Mining Engineer, Hazaribagh P.O., Chota Nagpur (India); Herbert Leader Hawkins, B.Sc., Lecturer on Geology in Reading University College, Durlstone, The Mount, Reading; Peter McIntyre, 18 Leinster Avenue, East Sheen, S.W.; Arthur John Maslen, F.L.S., Lecturer on Geology and Mineralogy at the South-Western Polytechnic, Chelsea, 23 Ellerby Street, Bishop's Park, S.W.; and Edmund Oswald Thiele, B.Sc., 12 Amity Grove, Raynes Park (Surrey), were elected Fellows; and Prof. François Alphonse Christian Forel, University of Lausanne (Switzerland); and Dr. A. E. Törnebohm, formerly Director of the Geological Survey of Sweden, Stockholm, were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On a Skull of *Megalosaurus* from the Great Oolite of Minchinhampton.' By Arthur Smith Woodward, LL.D., F.R.S., F.L.S., Sec.G.S.

2. 'Problems of Ore-Deposition in the Lead and Zinc Veins of Great Britain.' By Alexander Moncrieff Finlayson, M.Sc., F.G.S.

3. 'On the Vertebrate Fauna found in the Cave-Earth at Dog Holes, Warton Crag (Lancashire).'[1] By John Wilfrid Jackson, F.G.S., Assistant Keeper in the Manchester Museum.

The following specimens were exhibited:—

A skull of *Megalosaurus* from the Great Oolite of Minchinhampton, exhibited by F. Lewis Bradley, F.G.S., in illustration of the paper by Dr. A. Smith Woodward, F.R.S., F.L.S., Sec.G.S.; also lantern-slides exhibited by Dr. Smith Woodward in illustration of the same.

Lantern-slides, exhibited by A. M. Finlayson, M.Sc., F.G.S., in illustration of his paper.

Photographs and specimens from the cave-earth at Dog Holes, Warton Crag, exhibited by J. W. Jackson, F.G.S., in illustration of his paper.

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[1] Withdrawn by permission of the Council.

February 9th, 1910.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

The Rev. Joseph Fowler, M.A., Milton Vicarage, Portsmouth; James Bastian Hill, Geological Survey, 28 Jermyn Street, London, S.W.; Charles Edgcumbe Maddock, San José, Hill Street, Hastings (Sussex); and G. W. Tyrrell, Assoc.R.C.S., Assistant to the Professor of Geology in Glasgow University, 112 York Drive, Hyndland, Glasgow, were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. Douglas Mawson, B.E., Lecturer in Mineralogy in the University of Adelaide (South Australia), delivered a lecture entitled 'With Sir Ernest Shackleton in the Antarctic,' illustrated by lantern-slides.

The President proposed, and Sir Archibald Geikie seconded, a vote of thanks to the Lecturer, which was adopted with acclamation and suitably acknowledged.

Dr. Mawson exhibited and commented on certain specimens of rare minerals from the Broken Hill mining district (New South Wales).

ANNUAL GENERAL MEETING,

February 18th, 1910.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

Report of the Council for 1909.

It is gratifying to note that the increase in the Number of Fellows has been more than maintained during the past year. In 1909 the Fellows elected numbered 64 (as compared with 52 in 1908), and 40 of these paid their Admission Fees before the end of the year. Moreover, 15 Fellows who had been elected in the previous year paid their Admission Fees in 1909, making the total Accession of new Fellows during the twelve months under review amount to 55.

Setting against this number a Loss of 44 Fellows (30 by death, 12 by resignation, and 2 by removal from the List, under Bye-Laws, Sect. VI, Art. 5), it will be noted that there is a net increase in the Number of Fellows of 11 (as compared with an increase of 5 in 1908, and of 27 in 1907).

The total Number of Fellows is thus increased to 1294, made up as follows:—Compounders, 258 (4 less than in 1908); Contributing Fellows, 1011 (17 more than in 1908); and Non-Contributing Fellows, 25 (2 less than in 1908).

Turning to the Lists of Foreign Members and Foreign Correspondents, we have to deplore the loss of 1 Foreign Member (Dr. F. Schmidt), and of 1 Foreign Correspondent (M. Perceval de Loriol-Lefort). At the end of 1908 there were three vacancies in the List of Foreign Members; these, as well as the vacancy made by the decease of Dr. Schmidt, were filled by the election of Prof. B. Koto, Dr. F. Černyšev, Prof. J. H. L. Vogt, and Prof. R. Zeiller into that List. Three of the five vacancies arising in the List of Foreign Correspondents were filled by the election of Dr. D. de Cortázar, Prof. M. Lugeon, and Prof. R. S. Tarr, leaving two vacancies in the List of Foreign Correspondents at the end of 1909.

With regard to the Income and Expenditure of the Society during 1909, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £198 0*s*. 2*d*. brought forward from the previous year, and £2000, the amount of the Sorby and Hudleston Bequests) amounted to £3089 8*s.* 4*d.*, being £25 10*s.* 4*d.* more than the estimated Income. On the other hand, the total Expenditure during the same year amounted to £3125 19*s.* 4*d.*, being £15 8*s.* 8*d.* less than the estimated Expenditure for the year, and £36 11*s.* 0*d.* more than the actual Receipts, the year closing with a Balance in hand of £178 18*s.* 2*d.*

During the year a sum of £1000 was received from the executors of the late Dr. H. C. Sorby, being the amount of the legacy bequeathed by him to the Society. A similar sum was received from the executors of the late Mr. W. H. Hudleston, the amount of his legacy. The Council have invested the greater part of these two sums in the purchase of £2000 Canada $3\frac{1}{2}$ per cent. Stock, at a cost of £1982 11*s.* 0*d.*

Following on the informal polls of the Fellows referred to in the last Annual Report, a Special General Meeting of the Society was held on February 10th, 1909, the result of which was announced in the Proceedings for that date, vol. lxv, p. viii.

The Council have to announce the completion of Vol. LXV and the commencement of Vol. LXVI of the Society's Journal.

The seventh Award from the Daniel Pidgeon Trust Fund was made on April 7th, 1909, to Mr. Alexander Moncrieff Finlayson, M.Sc., who proposed to undertake researches on the Genesis of the Sulphide Ores.

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

The Wollaston Medal is awarded to Prof. William Berryman Scott, in recognition of his 'researches concerning the Mineral Structure of the Earth,' especially in relation to the Tertiary Mammalia and the Tertiary Stratigraphical Geology of North America and Patagonia.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Prof. Arthur Philemon Coleman, in appreciation of his contributions to the advancement of Geological Science, and especially of his work on the Sudbury Nickel-Ore Deposits and his investigations concerning the Glacial Geology of North America.

The Lyell Medal, together with a sum of Twenty-Five Pounds from the Lyell Geological Fund, is awarded to Dr. Arthur Vaughan, who, in the opinion of the Council, has deserved well of the science, especially in connexion with his researches into the Faunal Succession in the Lower Carboniferous Rocks of the British Isles.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. Edward Battersby Bailey, in recognition of his work on the Carboniferous Volcanic Rocks of Scotland and the Tectonic Structure of the Glen Coe Area, and to encourage him in further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. John Walker Stather, in acknowledgment of his work in fostering the advancement of Geological Science in the Hull district, especially in connexion with the Glacial Geology of East Yorkshire.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Frederick Richard Cowper Reed, in recognition of his researches on the Palæozoic Geology, and especially the Invertebrate Fossils, of Great Britain and Ireland and of the Indian Empire and other regions.

The other moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. Robert Broom, in recognition of his researches on the Reptiles of the Karroo Formation of South Africa.

Report of the Library and Museum Committee for 1909.

The Committee have pleasure in reporting that the Additions made to the Library during the year under review have maintained, both in number and in importance, the standard of previous years.

During the past twelve months the Library has received by Donation 229 Volumes of separately published Works, 316 Pamphlets, 33 Detached Parts of Works, 239 Volumes, and 35 Detached Parts of Serial Publications, and 25 Volumes of Newspapers.

The total number of accessions to the Library by Donation is thus found to amount to 493 Volumes, 316 Pamphlets, and 68 Detached Parts. Moreover, 153 Sheets of Geological Maps were presented to the Library, including 62 Sheets received from the Geological Survey of England and Wales, and 54 Sheets from that of Scotland; 9 Sheets from the Geological Survey of Canada; 3 Sheets from the Geological Commission of the Cape Colony; 4 Sheets from the Geological Survey of the Transvaal; 3 Sheets from the Geological Institute of Rumania; 3 Sheets from the Geological Survey of Japan; 2 Sheets presented by the Swiss Geological Commission; and 3 Sheets of the International Geological Map of Europe.

Among the Books and Pamphlets mentioned in the foregoing paragraph, especial attention may be directed to the following works:—the third edition of Prof. H. Rosenbusch's 'Elemente der Gesteinslehre'; Vol. I of the 3rd edition of Prof. E. Kayser's 'Lehrbuch der Geologie'; the Reports of the National Antarctic Expedition of 1901–1904, issued by the Royal Society; the Record of the Darwin-Wallace Celebration by the Linnean Society; the late Prof. A. Heilprin's work on the Eruption of Mont Pelé; Prof. A. Lacroix's exhaustive account of 'La Montagne Pelée après ses Éruptions'; Sir Archibald Geikie's memoir of 'Charles Darwin, as Geologist'; Prof. A. G. Nathorst's kindred theme, 'Carl von Linné als Geolog'; the Report on the San Francisco Earthquake issued by the Earthquake Investigation Committee (Carnegie Institution of Washington); the 2nd edition of the 'Geology of South Africa,' by Dr. F. H. Hatch & Dr. G. S. Corstorphine; the 2nd edition of the 'Geology of Cape Colony,' by Dr. A. W. Rogers & Mr. A. L. Du Toit; the two volumes and atlas recording the results of the Scientific Mission to Ethiopia, by the late Jean Duchesne-Fournet; Dr. J. M. Maclaren's exhaustive treatise on 'Gold'; the 5th edition of Dr. F. H. Hatch's 'Textbook of Petrology'; the finely printed first volume of the Memoirs issued by the new Geological Survey of the Netherlands; the Geological Survey Memoirs on the Neighbourhood of Newark and Nottingham, on the Country near Oban & Dalmally, on the Country around Londonderry, on the Water-Supply of Kent, Bedfordshire, and Northamptonshire; and the second edition of the Geological Survey Memoir on the Country around Newport (Mon.). Moreover, numerous publications were received from the Geological Survey Departments of Canada, the Cape Colony, the Transvaal, of the various States of the Australian Commonwealth, and of the Dominion of New Zealand; also from the Geological Survey departments of Hesse-Darmstadt, Würtemberg, Prussia, Norway, Sweden, Denmark, Russia, Rumania, Spain, and Portugal: from the United States Geological Survey and from the independent State Surveys of Iowa, Missouri, New Jersey, New York, and Ohio. The President of the Society presented to the Library the first five volumes of the Geologisches Centralblatt (Keilhack), bound in cloth.

The Books and Maps enumerated above were the gift of 144 Government Departments and other Public Bodies; of 179 Societies and Editors of Periodicals; and of 195 Personal Donors.

The Purchases, made on the recommendation of the standing Library Committee, included 39 Volumes and 4 Detached Parts of separately published Works; 55 Volumes and 11 Parts of Works published serially; and 15 Sheets of Geological Maps.

The Expenditure incurred in connexion with the Library during the Year 1909 was as follows:—

	£	*s.*	*d.*
Books, Periodicals, etc. purchased..........	78	12	9
Binding of Books and Mounting of Maps....	93	15	7
	£172	8	4

With regard to the Card Catalogue of the Library, Mr. C. D. Sherborn reports as follows:—

'The Card Catalogue progresses well, and the cards of "Geological Literature" for 1908 have now been checked, sorted, and put away in the cabinets. The literature from 1800 to 1894 has been begun; and, in order to proceed as rapidly as possible, two copies of the Royal Society's Catalogue of Scientific Papers were cut up into slips for mounting on cards. The twenty-four volumes were read and marked last year, and rearranged into one alphabet; and most of the cards for the letters A & B have been cross-referenced and arranged, and are now being put away in the cabinets. The literature from

1800 to 1908 therefore (with the exception of 1884–1894, not yet available), so far as A and B are concerned, will be at the service of the Fellows in the course of the next few months: some little time being required to sort into the cabinets the 40,000 cards resulting from last year's work. A feature in this new material is the marking of absent papers with the words NOT IN THIS LIBRARY; for every subject connected with geology, mineralogy, metallurgy, physical geography, and palæontology has been inserted. This remark can be crossed off, when the Librarian has been authorized to purchase the pamphlet. Further assistance is provided for the searcher, if he will trouble to refer from the NOT IN THIS LIBRARY card to that card which records the Transactions or other periodical in which the paper was originally published, for on it he will find recorded the Library in London where the publication can most conveniently be seen. As practically three years' work has been done in one, so as to give the new part a good start, the Fellows must not expect much advance to be made this year, for the work is laborious and exacting.'

Museum.

For the purpose of study and comparison, the Society's Collections were visited on 21 occasions during the year, the contents of 107 drawers being thus examined. The permission of the Council having been duly obtained, about 23 specimens were lent during 1909 to various investigators.

No expenditure has been incurred in connexion with the Museum during the past year.

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

I. Government Departments and other Public Bodies.

Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Argentina.—Ministerio de Agricultura. Buenos Aires.
Australia (S.), etc. *See* South Australia, *etc.*
Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.
Bavaria.—Königliches Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique, Brussels.
——. Musée Royal d'Histoire Naturelle. Brussels.
Bergens Museum. Bergen.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
Birmingham. University of.
Bohemia.—Naturwissenschaftliche Landesdurchforschung. Prague.
——. Royal Museum of Natural History. Prague.
Bristol.—Public Library.
British Columbia.—Department of Mines. Victoria (B.C.).
British Guiana.—Department of Mines. Georgetown.
British South Africa Company. London.
Buenos Aires.—Museo Nacional de Buenos Aires.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Camborne.—Mining School.
Cambridge (Mass.).—Museum of Comparative Zoology in Harvard College.

Canada.—Geological & Natural History Survey. Ottawa.
——, High Commissioner for. London.
Cape Colony.—Department of Agriculture (Geological Commission). Cape Town.
——. South African Museum. Cape Town.
Chicago.—'Field' Columbian Museum.
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Cracow.—Academy of Sciences.
Denmark.—Commission for Ledelsen af de Geologiske & Geographiske Undersögelser i Grönland. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works (Survey Department). Cairo.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Georgia.—Geological Survey. Atlanta (Ga.).
Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle an der Saale.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. India Office. London.
Holland.—Departement van Kolonien. The Hague.
——. Staatliche Bohrverwaltung in den Niederlanden. The Hague.
Hull.—Municipal Museum.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
Illinois State Museum of Natural History. Springfield (Ill.).
India.—Geological Survey. Calcutta.
——. Indian Museum. Calcutta.
——. Surveyor-General's Office. Calcutta.
Iowa Geological Survey. Des Moines (Iowa).
Ireland.—Department of Agriculture & Technical Instruction. Dublin.
Italy.—Reale Comitato Geologico. Rome.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Jassy, University of.
Kansas.—University Geological Survey. Lawrence (Kan.).
Kingston (Canada).—Queen's College.
Klausenburg (Koloszvár).—Provincial Museum & Library.
Leeds, University of.
London.—City of London College.
——. Imperial College of Science & Technology.
——. Imperial Institute.
——. Royal College of Surgeons.
——. University College.
Madrid.—Real Academía de Ciencias Exactes, Físicas & Naturales.
Magdeburg.—Museum für Natur- und Heimatkunde.
Melbourne (Victoria).—National Museum.
Mexico.—Instituto Geológico. Mexico City.
Michigan College of Mines. Houghton (Mich.).
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Missouri.—Bureau of Geology & Mines. Jefferson City (Mo.).
Montana University. Missoula (Mont.).
Munich.—Königliche Bayerische Akademie der Wissenschaften.
Mysore Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
Naples.—Accademia delle Scienze.
Natal.—Department of Mines. Pietermaritzburg.
——. Geological Survey. Pietermaritzburg.
——. Government Museum. Pietermaritzburg.
Newcastle-upon-Tyne.—Armstrong College.
New Jersey.—Geological Survey. Trentham (N.J.).
New South Wales, Agent-General for. London.
——. Department of Mines & Agriculture. Sydney.

New South Wales. Geological Survey. Sydney.
New York State Museum. Albany (N.Y.).
New Zealand.—Department of Mines. Wellington.
——. Geological Survey. Wellington.
Norway.—Geological Survey. Christiania.
Nova Scotia.—Department of Mines. Halifax.
Ohio Geological Survey. Columbus (Ohio).
Ontario.—Bureau of Mines. Toronto.
Padua.—Reale Accademia di Scienze, Lettere & Arti.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Peru.—Ministerio de Fomento. Lima.
Pisa, Royal University of.
Portugal.—Commissão dos Trabalhos Geologicos. Lisbon.
Prussia.—Ministerium für Handel & Gewerbe. Berlin.
——. Königliche Preussische Geologische Landesanstalt. Berlin.
Queensland, Agent-General for. London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Redruth.—School of Mines.
Rhodesia.—Chamber of Mines. Bulawayo.
Rhodesian Museum. Bulawayo.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Rumania.—Geological Survey. Bucarest.
Russia.—Comité Géologique. St. Petersburg.
——. Musée Géologique Pierre le Grand. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
São Paulo (Brazil).—Commissão geographica & geologica. São Paulo City.
——. Secretaria da Agricultura, Commercio & Obras Publicas. São Paulo City.
South Australia, Agent-General for. London.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tokio.—Imperial University.
——. College of Science.
Transvaal.—Geological Survey. Pretoria.
——. Mines Department. Pretoria.
Turin.—Reale Accademia delle Scienze.
United States.—Department of Agriculture. Washington (D.C.).
——. Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, University of.
Victoria (Austral.), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington (D.C.).—Smithsonian Institution.
——, State of (U.S.A.).—Geological Survey. Olympia (Wash.).
West Indies.—Imperial Agricultural Department. Bridgetown (Barbados)
Western Australia, Agent-General for. London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.
Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).

II. Societies and Editors.

Acireale.—Accademia di Scienze, Lettere & Arti.
Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-Naturalis Croatica.
Alnwick.—Berwickshire Naturalists' Club.
Basel.—Naturforschende Gesellschaft.
Bath.—Natural History & Antiquarian Field-Club.

Belgrade.—Servian Geological Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. 'Zeitschrift für Praktische Geologie.'
Berne.—Schweizerische Naturforschende Gesellschaft.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.) Society of Natural History.
——. American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brooklyn (N.Y.) Institute of Arts & Sciences.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie, de Paléontologie & d'Hydrologie.
——. Société Royale Zoologique & Malacologique de Belgique.
Budapest.—Földtani Közlöny.
Buenos Aires.—Sociedad Científica Argentina.
Bulawayo.—Rhodesian Scientific Association.
Caen.—Société Linnéenne de Normandie.
Calcutta.—'Indian Engineering.'
——. Asiatic Society of Bengal.
Cambridge Philosophical Society.
Cape Town.—South African Association for the Advancement of Science.
——. South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chambéry.—Société d'Histoire Naturelle de Savoie.
Chicago.—'Journal of Geology.'
Christiania.—Norsk Geologisk Forening.
——. 'Nyt Magazin for Naturvidenskaberne.'
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—'Colorado College Studies.'
Croydon Natural History & Scientific Society.
Denver.—Colorado Scientific Society.
Dijon.—Académie des Sciences, Arts & Belles-Lettres.
Dorpat (Jurjew).—Naturforschende Gesellschaft.
Dresden.—Naturwissenschaftliche Gesellschaft.
——. Verein für Erdkunde.
Edinburgh.—Geological Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Falmouth.—Royal Cornwall Polytechnic Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Fribourg.—Société Fribourgeoise des Sciences Naturelles.
Geneva.—Société de Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.
Halifax (N.S.).—Nova Scotian Institute of Science.
Hamilton (Canada).—Hamilton Scientific Association.
Hanau.—Wetterauische Gesellschaft für Gesammte Naturkunde.
Havre.—Société Géologique de Normandie.
Helsingfors.—Société Géographique de Finlande.
Hereford.—Woolhope Naturalists' Field-Club.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaft.
Hertford.—Hertfordshire Natural History Society.
Hull Geological Society.
Indianapolis (Ind.).—Indiana Academy of Science.
Johannesburg.—Geological Society of South Africa.
Kiev.—Société des Naturalistes.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Vaudoise des Sciences Naturelles.
Lawrence (Kan.).—'Kansas University Bulletin.'
Leeds.—Geological Association.
——. Philosophical & Literary Society.

Leeds.—Yorkshire Geological Society.
Leicester Literary & Philosophical Society.
Leipzig.—'Zeitschrift für Krystallographie & Mineralogie.'
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences.
Lille.—Société Géologique du Nord.
Lima.—'Revista de Ciencias.'
Lisbon.—Sociedade de Geographia.
Liverpool Geological Society.
——. Literary & Philosophical Society.
London.—'The Athenæum.'
——. British Association for the Advancement of Science.
——. British Association of Waterworks Engineers.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Journal.'
——. 'Nature.'
——. Palæontographical Society.
——. 'The Quarry.'
——. Ray Society.
——. 'Records of the London & West-Country Chamber of Mines.'
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Biblical Archæology.
——. 'The South-Eastern Naturalist' (S.E. Union of Scientific Societies).
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester Geological & Mining Society.
——. Literary & Philosophical Society.
Manila.—Philippine Journal of Science.
Melbourne (Victoria).—Australasian Institute of Mining Engineers.
——. Royal Society of Victoria.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Moscow.—Société Impériale des Naturalistes.
New Haven (Conn.).—'The American Journal of Science.
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
——. University of Durham Philosophical Society.
Northampton.—Northamptonshire Natural History Society.
Nürnberg.—Naturhistorische Gesellschaft.
Oporto.—Academia Polytecnica. [Coimbra.]
Ottawa.—Royal Society of Canada.
Paris.—Commission Française des Glaciers.
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.

Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Academy of Science.
——. Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
——. Société Scientifique du Chili.
São Paulo (Brazil).—Sociedade Scientifica.
Scranton (Pa.).—'Mines & Minerals.'
St. John (N.B.).—Natural History Society of New Brunswick.
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—'Centralblatt für Mineralogie, Geologie & Paläontologie.'
——. 'Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.'
——. Oberrheinischer Geologischer Verein.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. 'Zeitschrift für Naturwissenschaften.'
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Vienna.—'Beiträge zur Paläontologie & Geologie Œsterreich-Ungarns & des Orients.'
——. 'Berg- & Hüttenmännisches Jahrbuch.'
——. Geologische Gesellschaft.
——. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Biological Society.
——. Philosophical Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
Worcester.—Worcestershire Naturalists' Club.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Adams, F. D.
Aguilar y Santillan, R.
Allen, E. T.
Ameghino, F.
Anderson, J. C.
Arctowski, A.
Arctowski, H.
Ashton, W.
Augustin, E.
Avebury, Lord.

Barrois, C.
Bassler, R. S.
Beattie, J. C.
Belowsky, M.
Bennett, F. J.
Biddlecombe, A.
Black, C. H.
Bœhm, G.
Bonney, T. G.
Bourdariat, A.
Branner, J. C.
Brown, H. Y. L.
Brückner, E.
Brun, A.
Brunhes, J.
Bullen, Rev. R. A.
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Burrard, S. G.

Carez, L.
Carruthers, R. G.
Carus-Wilson, C.
Chapman, F.
Choffat, P.
Cole, G. A. J.
Condit, D. D.
Conwentz, H.
Cooper, A.
Corstorphine, G. S.
Coste, E.
Courty, G.
Crook, T.
Cvijič, J.

Dall, W. H.
Dalton, L. V.
Desbuissons, L.
Dewey, H.
Doflein, F.
Dollfus, G. F.
Duchesne-Fournet, P.

Favre, J.
Feilden, H. W.
Fenneman, N. M.
Ffarington, Miss M. H.
Filliozat, M.
Forel, F. A.
Fritsch, A.

Gaillard, C.
Gebhard, H.
Geijer, P.
Geikie, Sir Archibald.
Gilbert, G. K.
Glangeaud, P.
Gregory, J. W.
Grober, P.
Groom, T. T.
Guppy, R. J. L.

Habenicht, H.
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Harker, A.
Harmer, F. W.
Harrison, J. B.
Hatch, F. H.
Hayden, H. H.
Heilprin, A.
Helgers, —.
Hœpli, U.
Högbom, A. G,
Hopkinson, J.
Hume, W. F.

Iddings, J. P.

Jackson, J. W.
Johnson, D. W.
Johnston-Lavis, H. J.
Joly, J.
Joukowsky, E.
Jousseaume, F.
Jukes-Browne, A. J.
Jutson, J.

Kayser, E.
Knowles, Sir Lees.
Kolderup, C. F.
Komorowicz, M. von.

Lacroix, A.
Lake, P.
Lambe, M.
Lamplugh, G. W.
Lantenois, H.
Lapparent, A. de.
Lapworth, H.
Latham, B.
Lemoine, P.
Lisboa, M. A. R.
Liversidge, A.
Lœwinson-Lessing, F.
Lowe, H. J.
Lugeon, M.
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Maclaren, J. M.
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Marr, J. E.
Martin, E. A.
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Maufe, H. B.
Meunier, S.
Moberg, J. C.
Molyneux, A. J. C.
Mourlon, M.
Muret, E.

Nares, Sir Georg
Nathorst, A. G.
Newton, E. T.
Newton, R. B.
Nölke, F.
Noth, J.

Oates, F. F.
Oswald, F.

Pack, R. W.
Palache, C.
Parkinson, J.
Pavlović, P. S.
Penhallow, D. P.
Perceval, S. G.
Pjetursson, H.
Portis, A.
Pringle, J.
Prosser, C. S.

Rabot, C.
Rastall, R. H.
Reed, F. R. C.
Renevier, E.
Ricciardi, L.
Richardson, L.
Robarts, N. F.
Romanes, J.
Rosenbusch, H.

Sacco, F.
Sauvage, H. E.
Sawyer, A. R.
Schardt, H.
Scharff, R. F.
Schottler, W.
Schwarz, E. H. L.
Scrivenor, J. B.
Serretta, F.
Sheppard, T.
Sieburg, —.
Smith, F.
Smith, J.
Smith, W. D.
Spencer, J. W.
Spethmann, H.
Springer, F.
Steinmann, G.
Stevenson, J. J.
Stott, C. H.

Tesch, P.
Thiele, E. O.
Tœrnquist, S. L.
Toula, F.
Twelvetrees, W. H.

Uhlig, V.

Vadász, M. E.
Van Hise, C. R.

Wallén, A.
Walther, J.
Ward, K.
Warren, C. H.
Warren, S. H.
Washington, H. S.
Weinschenk, E.
White, I. C.
White, W. P.
Whitaker, W.
Widman, R.
Wilckens, O.
Williston, S. W.
Wiman, C.
Winwood, Rev. H. H.
Wollemann, A.
Woolacott, D.
Wright, F. E.

Zeiller, R.
Ziegler, V. de.

Comparative Statement of the Number of the Society at the Close of the Years 1908 and 1909.

	Dec. 31st, 1908.	Dec. 31st, 1909.
Compounders	262	258
Contributing Fellows	994	1011
Non-Contributing Fellows	27	25
	1283	1294
Foreign Members	37	40
Foreign Correspondents	40	38
	1360	1372

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1908 and 1909.

Number of Compounders, Contributing and Non-Contributing Fellows, December 31st, 1908			1283
Add Fellows elected during the former year and paid in 1909			15
Add Fellows elected and paid in 1909			40
			1338
Deduct Compounders deceased		9	
Contributing Fellows deceased		19	
Non-Contributing Fellows deceased		2	
Contributing Fellows resigned		12	
Contributing Fellows removed		2	
		—	44
			1294
Number of Foreign Members and Foreign Correspondents, December 31st, 1908		77	
Deduct Foreign Member and Foreign Correspondent deceased	2		
	—	2	
		75	
Add Foreign Correspondents elected	3		
	—	3	
		—	78
			1372

Deceased Fellows.

Compounders (9).

Bauerman, H.
Blakey, J.
Graham, Dr. C.
Hudleston, W. H.
Kelly, E.
Pollard, J.
Ripon, Marquis of.
Saunders, J. E.
Seeley, Prof. H. G.

Resident and other Contributing Fellows (19).

Amherst of Hackney, Lord.
Atkinson, J. T.
Brookes, J.
Ekin, C.
Forbes, D.
Fortescue, Hon. W. F.
Fraser, Dr. J.
Gunn, R. M.
Hughes, J. E.
Lock, C. G. W.
Lomas, J.
Myers, J. W.
Parsons, J.
Price, F. G. H.
Reade, T. M.
Ridyard, J.
Shilston, T.
Stanley, W. F.
Wardle, Sir Thomas.

Non-Contributing Fellows (2).

Polwhele, T. R.
Whiteaves, Dr. J. F.

Deceased Foreign Member (1).

Schmidt, Dr. F.

Deceased Foreign Correspondent (1).

Loriol-Lefort, P. de.

Fellows Resigned (12).

Browne, R. J.
Crawley, W. J. C.
Fisher, Dr. H.
Gough, G. C.
Grundy, J.
Jaquet, J. B.
Norman, R. S.
Parker, Rev. Dr. J. D.
Pawson, A. H.
Potter, E.
Smith, L. L.
Wood, C. A.

FELLOWS REMOVED (2).

Gregson, W. | Quentrall, T.

The following Personages were elected Foreign Members during the year 1909:—

Dr. Feodor Černyšev, of St. Petersburg.
Prof. Bundjirô Kôtô, of Tokyo.
Prof. Johan H. L. Vogt, of Christiania.
Prof. René Zeiller, of Paris.

The following Personages were elected Foreign Correspondents during the year 1909:—

Dr. Daniel de Cortázar, of Madrid.
Prof. Maurice Lugeon, of Lausanne.
Prof. Ralph Tarr, of Ithaca, N.Y. (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.

That the thanks of the Society be given to Prof. W. J. Sollas, retiring from the office of President.

It was afterwards resolved:—

That the thanks of the Society be given to Mr. G. W. Lamplugh and Dr. J. J. H. Teall (also retiring from the Council), retiring from the office of Vice-President.

That the thanks of the Society be given to Prof. S. H. Cox, Mr. R. D. Oldham, and Mr. R. H. Tiddeman, retiring from the Council.

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

OFFICERS AND COUNCIL.—1910.

PRESIDENT.

Prof. William Whitehead Watts, Sc.D., M.Sc., F.R.S.

VICE-PRESIDENTS.

Charles William Andrews, B.A., D.Sc., F.R.S.
Alfred Harker, M.A., F.R.S.
Horace Woollaston Monckton, Treas.L.S.
Prof. William Johnson Sollas, LL.D., Sc.D., F.R.S.

SECRETARIES.

Prof. Edmund Johnston Garwood, M.A.
Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

FOREIGN SECRETARY.

Sir Archibald Geikie, K.C.B., D.C.L., LL.D., Sc.D., Pres.R.S.

TREASURER.

Aubrey Strahan, Sc.D., F.R.S.

COUNCIL.

Tempest Anderson, M.D., D.Sc.
Charles William Andrews, B.A., D.Sc., F.R.S.
George Barrow.
Prof. William S. Boulton, B.Sc.
James Vincent Elsden, B.Sc.
Prof. Edmund Johnston Garwood, M.A.
Sir Archibald Geikie, K.C.B., D.C.L., LL.D., Sc.D., Pres.R.S.
Alfred Harker, M.A., F.R.S.
Robert Stansfield Herries, M.A.
Finlay Lorimer Kitchin, M.A., Ph.D.
Bedford McNeill, Assoc.R.S.M.
John Edward Marr, Sc.D., F.R.S.
Horace Woollaston Monckton, Treas.L.S.
George Thurland Prior, M.A., D.Sc.
Prof. Sidney Hugh Reynolds, M.A.
Prof. William Johnson Sollas, LL.D., Sc.D., F.R.S.
Aubrey Strahan, Sc.D., F.R.S.
Herbert Henry Thomas, M.A., B.Sc.
Prof. William Whitehead Watts, Sc.D., M.Sc., F.R.S.
Henry Woods, M.A.
Arthur Smith Woodward, LL.D., F.R.S., F.L.S.
Horace Bolingbroke Woodward, F.R.S.
George William Young.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1909.

Date of Election.

1877. Prof. Eduard Suess, *Vienna.*
1880. Geheimrath Prof. Ferdinand Zirkel, *Leipzig.*
1884. Commendatore Prof. Giovanni Capellini, *Bologna.*
1885. Prof. Jules Gosselet, *Lille.*
1886. Prof. Gustav Tschermak, *Vienna.*
1890. Geheimrath Prof. Heinrich Rosenbusch, *Heidelberg.*
1891. Prof. Charles Barrois, *Lille.*
1893. Prof. Waldemar Christofer Brögger, *Christiania.*
1893. M. Auguste Michel-Lévy, *Paris.*
1893. Prof. Alfred Gabriel Nathorst, *Stockholm.*
1894. Prof. George J. Brush, *New Haven, Conn.* (*U.S.A.*).
1894. Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1895. Dr. Grove Karl Gilbert, *Washington, D.C.* (*U.S.A.*).
1896. Prof. Albert Heim, *Zürich.*
1897. M. Édouard Dupont, *Brussels.*
1897. Dr. Anton Fritsch, *Prague.*
1897. Dr. Hans Reusch, *Christiania.*
1898. Geheimrath Prof. Hermann Credner, *Leipzig.*
1898. Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899. Prof. Emanuel Kayser, *Marburg.*
1899. M. Ernest Van den Broeck, *Brussels.*
1899. Dr. Charles Abiathar White, *Washington, D.C.* (*U.S.A.*).
1900. M. Gustave F. Dollfus, *Paris.*
1900. Prof. Paul von Groth, *Munich.*
1900. Dr. Sven Leonhard Törnquist, *Lund.*
1901. M. Alexander Petrovich Karpinsky, *St. Petersburg.*
1901. Prof. Alfred Lacroix, *Paris.*
1903. Prof. Albrecht Penck, *Berlin.*
1903. Prof. Anton Koch, *Budapest.*
1904. Prof. Joseph Paxson Iddings, *Chicago* (*U.S.A.*).
1904. Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905. Prof. Louis Dollo, *Brussels.*
1905. Prof. August Rothpletz, *Munich.*
1906. Prof. Count Hermann zu Solms-Laubach, *Strasburg.*
1907. Hofrath Dr. Emil Ernst August Tietze, *Vienna.*
1907. Commendatore Prof. Arturo Issel, *Genoa.*
1908. Prof. Bundjirô Kôtô, *Tokyo.*
1908. Dr. Feodor Černyšev, *St. Petersburg.*
1909. Prof. Johan H. L. Vogt, *Christiania.*
1909. Prof. René Zeiller, *Paris.*

LIST OF THE FOREIGN CORRESPONDENTS OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1909.

Date of Election.

1874. Prof. Igino Cocchi, *Florence.*
1879. Dr. H. Émile Sauvage, *Boulogne-sur-Mer.*
1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1890. Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Kiel.*
1893. Prof. Aléxis P. Pavlow, *Moscow.*
1893. M. Ed. Rigaux, *Boulogne-sur-Mer.*
1894. Dr. Francisco P. Moreno, *La Plata.*
1895. Prof. Constantin de Kroustchoff, *St. Petersburg.*
1896. Prof. Johannes Walther, *Halle an der Saale.*
1897. M. Emmanuel de Margerie, *Paris.*
1898. Dr. Marcellin Boule, *Paris.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Göttingen.*
1899. Prof. Franz Lœwinson-Lessing, *St. Petersburg.*
1899. M. Michel F. Mourlon, *Brussels.*
1899. Prof. Gregorio Stefanescu, *Bucarest.*
1900. Prof. Ernst Koken, *Tübingen.*
1900. Prof. Federico Sacco, *Turin.*
1901. Prof. Friedrich Johann Becke, *Vienna.*
1902. Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1902. Prof. Samuel Wendell Williston, *Chicago, Ill.* (*U.S.A.*).
1904. Dr. William Bullock Clark, *Baltimore* (*U.S.A.*).
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *Burlington, Iowa* (*U.S.A.*).
1904. Dr. Henry S. Washington, *Locust, N.J.* (*U.S.A.*).
1906. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1906. Dr. Jakob Johannes Sederholm, *Helsingfors.*
1907. Prof. Baron Gerard Jakob de Geer, *Stockholm.*
1907. Prof. Armin Baltzer, *Berne.*
1908. Prof. Hans Schardt, *Veytaux, near Montreux.*
1909. Dr. Daniel de Cortázar, *Madrid.*
1909. Prof. Maurice Lugeon, *Lausanne.*
1909. Prof. Ralph S. Tarr, *Ithaca, N.Y.* (*U.S.A.*).

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1831. Mr. William Smith.
1835. Dr. Gideon A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. Hugh Falconer.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron Leopold von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy.
1844. The Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. The Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. The Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Prof. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. Henry C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. Thomas H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Studer.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. William Thomas Blanford.
1884. Prof. Albert Jean Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Des Cloizeaux.
1887. Mr. John Whitaker Hulke.
1888. Mr. Henry B. Medlicott.
1889. Prof. Thomas George Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John Wesley Judd.
1892. Baron F. von Richthofen.
1893. Prof. Nevil Story Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie.
1896. Prof. Eduard Suess.
1897. Mr. Wilfrid H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Dr. Grove Karl Gilbert.
1901. Prof. Charles Barrois.
1902. Dr. Friedrich Schmidt.
1903. Prof. Heinrich Rosenbusch.
1904. Prof. Albert Heim.
1905. Dr. J. J. Harris Teall.
1906. Dr. Henry Woodward.
1907. Prof. William J. Sollas.
1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. William Berryman Scott.

AWARDS

OF THE

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

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. Gideon A. Mantell.
1836. Prof. G. P. Deshayes.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Prof. Edward Forbes.
1842. Prof. John Morris.
1843. Prof. John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape of Good Hope Fossils. M. Alcide d'Orbigny. }
1849. Mr. William Lonsdale.
1850. Prof. John Morris.
1851. M. Joachim Barrande.
1852. Prof. John Morris.
1853. Prof. L. G. de Koninck.
1854. Dr. Samuel P. Woodward.
1855. { Dr. G. Sandberger. Dr. F. Sandberger. }
1856. Prof. G. P. Deshayes.
1857. Dr. Samuel P. Woodward.
1858. Prof. James Hall.
1859. Mr. Charles Peach.
1860. { Prof. T. Rupert Jones. Mr. W. K. Parker. }
1861. Prof. Auguste Daubrée.
1862. Prof. Oswald Heer.
1863. Prof. Ferdinand Senft.
1864. Prof. G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Dr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. John Wesley Judd.
1874. Dr. Henri Nyst.
1875. Prof. Louis C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. Robert Etheridge, jun.
1878. Prof. William J. Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay H. Traquair.
1882. Dr. George Jennings Hinde.
1883. Prof. John Milne.
1884. Mr. Edwin Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Dr. Benjamin Neeve Peach.
1888. Dr. John Horne.
1889. Dr. Arthur S. Woodward.
1890. Mr. William A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville Adelbert Derby.
1893. Mr. John George Goodchild.
1894. Dr. Aubrey Strahan.
1895. Prof. William W. Watts.
1896. Mr. Alfred Harker.
1897. Dr. Francis Arthur Bather.
1898. Prof. Edmund J. Garwood.
1899. Prof. John B. Harrison.
1900. Dr. George Thurland Prior.
1901. Mr. Arthur Walton Rowe.
1902. Mr. Leonard James Spencer.
1903. Mr. L. L. Belinfante.
1904. Miss Ethel M. R. Wood.
1905. Dr. H. H. Arnold-Bemrose.
1906. Dr. Finlay Lorimer Kitchin.
1907. Dr. Arthur Vaughan.
1908. Mr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward Battersby Bailey.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

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

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

1873. Mr. William Davies.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. The Rev. W. B. Clarke.
1878. Prof. Hanns Bruno Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. The Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. Waldemar C. Brögger.
1892. Prof. A. H. Green.
1893. The Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustaf Lindström.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. { Dr. Benjamin Neeve Peach. / Dr. John Horne.
1900. Baron A. E. Nordenskiöld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.
1903. Dr. Charles Callaway.
1904. Prof. George A. Lebour.
1905. Mr. Edward John Dunn.
1906. Mr. Charles T. Clough.
1907. Mr. Alfred Harker.
1908. Prof. Albert C. Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur Philemon Coleman.

AWARDS

OF THE

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

1873. Prof. Oswald Heer.
1874. { Mr. Alfred Bell. / Prof. Ralph Tate.
1875. Prof. H. Govier Seeley.
1876. Dr. James Croll.
1877. The Rev. John F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James Walker Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. Thomas Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Dr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward B. Wethered.
1891. The Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. Griffith John Williams.
1894. Mr. George Barrow.
1895. Prof. Albert C. Seward.
1896. Mr. Philip Lake.
1897. Mr. Sydney S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Sir Thomas H. Holland.
1903. Mrs. Elizabeth Gray.
1904. Dr. Arthur Hutchinson.
1905. Mr. Herbert Lister Bowman.
1906. Dr. Herbert Lapworth.
1907. Dr. Felix Oswald.
1908. Miss Ethel Gertrude Skeat.
1909. Mr. James Vincent Elsden.
1910. Mr. John Walker Stather.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. Govier Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. Henry A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. Thomas Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. Edwin Tulley Newton.
1894. Prof. John Milne.
1895. The Rev. John F. Blake.
1896. Dr. Arthur S. Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Dr. John Edward Marr.
1901. Dr. Ramsay H. Traquair.
1902. { Prof. Anton Fritsch.
Mr. Richard Lydekker.
1903. Mr. Frederick W. Rudler.
1904. Prof. Alfred G. Nathorst.
1905. Dr. Hans Reusch.
1906. Prof. Frank Dawson Adams.
1907. Dr. Joseph F. Whiteaves.
1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.

AWARDS

OF THE

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

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. Henry A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. The Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. Alfred J. Jukes-Browne.
1886. Mr. David Mackintosh.
1887. The Rev. Osmond Fisher.
1888. Dr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. Dr. Louis Dollo.
1890. Mr. Charles D. Sherborn.
1891. Dr. C. I. Forsyth Major.
1891. Mr. George W. Lamplugh.
1892. Prof. John Walter Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Prof. Percy Fry Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William F. Hume.
1896. Dr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.
1901. Dr. John William Evans.
1901. Mr. Alexander McHenry.
1902. Dr. Wheelton Hind.
1903. Mr. Sydney S. Buckman.
1903. Mr. George Edward Dibley.
1904. Dr. Charles Alfred Matley.
1904. Prof. Sidney Hugh Reynolds.
1905. Mr. E. A. Newell Arber.
1905. Mr. Walcot Gibson.
1906. Mr. William G. Fearnsides.
1906. Mr. Richard H. Solly.
1907. Mr. T. Crosbee Cantrill.
1907. Mr. Thomas Sheppard.
1908. Dr. Thomas Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Mr. F. R. Cowper Reed.
1910. Dr. Robert Broom.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

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

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

1877. Prof. Othniel Charles Marsh.
1879. Prof. Edward Drinker Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Dr. J. J. Harris Teall.
1891. Dr. George Mercer Dawson.
1893. Prof. William J. Sollas.
1895. Dr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. Edgeworth David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.
1905. Prof. John Walter Gregory.
1907. Dr. Arthur W. Rogers.
1909. Dr. John Smith Flett.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

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

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1903. John Lubbock, Baron Avebury.
1906. Mr. William Whitaker.
1909. Lady Evans.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

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

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

1879. Purchase of Microscope.
1881. Purchase of Microscope-Lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Dr. Theodore T. Groom.
1902. Mr. William M. Hutchings.
1904. Mr. Hugh J. Ll. Beadnell.
1906. Mr. Henry C. Beasley.
1908. Contribution to the Fund for securing the Preservation of the Sarsen-Stones on Marlborough Downs, known as 'The Grey Wethers.'

AWARDS OF THE PROCEEDS

OF THE

'DANIEL PIDGEON FUND,'

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

DANIEL PIDGEON, F.G.S.

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

1903. Prof. Ernest Willington Skeats.
1904. Mr. Linsdall Richardson.
1905. Mr. Thomas Vipond Barker.
1906. Miss Helen Drew.
1907. Miss Ida L. Slater.
1908. Mr. James A. Douglas.
1909. Mr. Alexander Moncrieff Finlayson.
1910. Mr. Robert Boyle.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				140	0	0
Due for Arrears of Admission-Fees	151	4	0			
Admission-Fees, 1910	200	12	0			
				351	16	0
Arrears of Annual Contributions	130	0	0			
Annual Contributions, 1910, from Resident and Non-Resident Fellows	1860	0	0			
Annual Contributions in advance	65	0	0			
				2055	0	0
Sale of the Quarterly Journal, including Longmans' Account				160	0	0
Sale of the 'History of the Geological Society,' Centenary Record, General Index to the Quarterly Journal, Museum Catalogue, Hutton's 'Theory of the Earth' vol. iii, Hochstetter's 'New Zealand,' and List of Fellows				10	0	0
Miscellaneous Receipts......................				10	0	0
Interest on Deposit-Account				10	0	0
Dividends on £2500 India 3 per cent. Stock ..	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock.	8	0	0			
Dividends on £2000 Canada $3\frac{1}{2}$ per cent. Stock.	70	0	0			
				421	16	0
				£3158	12	0

the Year 1910.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House-Expenditure:						
Taxes		15	0			
Fire-Insurance and other Insurance	16	0	0			
Electric Lighting and Maintenance	50	0	0			
Gas	25	0	0			
Fuel	40	0	0			
Furniture and Repairs	50	0	0			
House-Repairs and Maintenance	40	0	0			
Annual Cleaning	20	0	0			
Tea at Meetings	16	0	0			
Washing and Sundry Expenses	35	0	0			
				292	15	0
Salaries and Wages, etc.:						
Assistant-Secretary	375	0	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	150	0	0			
Assistant-Clerk	150	0	0			
Junior Assistant	39	0	0			
House-Porter and Upper Housemaid	95	0	0			
Under Housemaid	48	18	0			
Charwoman and Occasional Assistance	10	0	0			
Accountants' Fee	10	10	0			
				889	3	0
Office-Expenditure:						
Stationery	35	0	0			
Miscellaneous Printing, etc.	60	0	0			
Postages and Sundry Expenses	80	0	0			
				175	0	0
Library (Books and Binding)				250	0	0
Library Catalogue:						
Cards	20	0	0			
Compilation	50	0	0			
				70	0	0
Publications:						
Quarterly Journal, including Commission on Sale	1000	0	0			
Postage on Journal, Addressing, etc.	100	0	0			
Record of Geological Literature	150	0	0			
List of Fellows	40	0	0			
Abstracts, including Postage	120	0	0			
				1410	0	0
				3086	18	0
Estimated excess of Income over Expenditure				71	14	0
				£3158	12	0

AUBREY STRAHAN, *Treasurer.*

January 31st, 1910.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1909	180	8	0			
,, Balance in the hands of the Clerk at January 1st, 1909	17	12	2			
				198	0	2
,, Compositions				175	0	0
,, Admission-Fees:						
Arrears	94	10	0			
Current	252	0	0			
				346	10	0
,, Arrears of Annual Contributions	124	2	0			
,, Annual Contributions for 1909 :—						
Resident Fellows	1841	12	0			
Non-Resident Fellows	4	14	6			
,, Annual Contributions in advance	67	4	0			
				2037	12	6
,, Publications :						
Sale of Quarterly Journal *:						
,, Vols. i to lxiv (less Commission £9 19*s*. 8*d*.)	99	9	11			
,, Vol. lxv (less Commission £2 18*s*. 9*d*.)	42	15	9			
				142	5	8
,, 'History of the Geological Society'.	....			7	0	8
,, Abstracts			6			
,, Record of Geological Literature ...	3	12	0			
,, List of Fellows		15	3			
,, Hutton's 'Theory of the Earth,' vol. iii		2	0			
,, Hochstetter's 'New Zealand'		6	4			
,, Museum Catalogue		2	6			
,, Centenary Record	1	6	2			
				6	4	9
,, Miscellaneous Receipts				10	16	6
,, Repayment of Income-Tax (1 year)				17	11	11
,, Interest on Deposit-Account				13	0	0
,, Bequests :						
Sorby	1000	0	0			
Hudleston	1000	0	0			
				2000	0	0
,, Dividends (less Income-Tax) :—						
£2500 India 3 per cent. Stock	70	18	8			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	14	4	5			
£2250 London & North-Western Railway 4 per cent. Preference Stock	85	6	3			
£2800 London & South-Western Railway 4 per cent. Preference Stock	106	3	4			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	49	2	0			
£267 6*s*. 7*d*. Natal 3 per cent. Stock	7	11	8			
				333	6	4
				£5287	8	6

* A further sum is due from Messrs. Longmans & Co. for Journal-Sales £63 5 7

Year ended December 31st, 1909.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire-Insurance and other Insurance	16	3	5			
Electric Lighting and Maintenance	52	15	1			
Gas	26	8	9			
Fuel	42	6	3			
Furniture and Repairs	79	12	2			
House-Repairs and Maintenance	147	11	6			
Annual Cleaning	26	11	6			
Tea at Meetings	17	10	4			
Washing and Sundry Expenses	34	5	0			
				443	19	0
,, Salaries and Wages:						
Assistant-Secretary	362	10	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	150	0	0			
Assistant-Clerk	150	0	0			
Junior Assistant	29	11	0			
House-Porter and Upper Housemaid	94	3	5			
Under Housemaid	48	10	8			
Charwoman and Occasional Assistance	15	7	1			
Accountants' Fee	10	10	0			
				871	7	2
,, Office-Expenditure:						
Stationery	33	12	11			
Miscellaneous Printing	57	19	11			
Postages and Sundry Expenses	73	13	11			
				165	6	9
,, Library (Books and Binding)				172	8	4
,, Library-Catalogue:						
Cards	13	1	0			
Compilation	50	0	0			
Cases	90	0	0			
Other Charges	13	15	2			
				166	16	2
,, Publications:						
Quarterly Journal, Vol. lxv, Paper, Printing, and Illustrations	875	8	9			
Postage on Journal, Addressing, etc.	117	16	9			
Record of Geological Literature	151	12	3			
Abstracts, including Postage	107	15	8			
Centenary Record	53	8	6			
				1306	1	11
,, Purchase of £2000 Canada 3½ per cent. Stock				1982	11	0
,, Balance in the hands of the Bankers at December 31st, 1909	167	16	2			
,, Balance in the hands of the Clerk at December 31st, 1909	11	2	0			
				178	18	2
				£5287	8	6

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

JOHN HOPKINSON, } *Auditors.*
GEORGE W. YOUNG, }

AUBREY STRAHAN, *Treasurer.*

January 31st, 1910.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	32	3	10	By Cost of Medal	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	8	10	,, Award from the Balance of the Fund	21	13	10
,, Repayment of Income-Tax (1 year)	1	12	4	,, Balance at the Bankers' at December 31st, 1909	32	1	2
	£64	5	0		£64	5	0

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	21	6	2	By Award to the Medallist	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	37	18	8	,, Award from the Balance of the Fund	29	10	4
,, Repayment of Income-Tax (1 year)	2	0	0	,, Balance at the Bankers' at December 31st, 1909	20	18	6
	£60	18	10		£60	18	10

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	53	12	10	By Award to the Medallist	25	0	0
,, Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	66	10	10	,, First Award from the Balance of the Fund	22	13	6
,, Repayment of Income-Tax (1 year)	3	10	4	,, Second Award from the Balance of the Fund	22	13	6
				,, Balance at the Bankers' at December 31st, 1909	53	7	0
	£123	14	0		£123	14	0

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	27	6	9	By Balance at the Bankers' at December 31st, 1909	41	7	0
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture-Stock	13	6	3				

	£	s.	d.		£	s.	d.
£210 Cardiff 3 per cent. Stock	5	19	2	"			
Repayment of Income-Tax (1 year)		6	4				
	£15	17	8		£15	17	8

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	31	4	5	By Grants	2	2	0
" Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	3	19	0	" Balance at the Bankers' at December 31st, 1909	33	5	7
" Repayment of Income-Tax (1 year)		4	2				
	£35	7	7		£35	7	7

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	43	9	6	By Cost of Medal	20	0	0
" Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock	19	17	4	" Balance at the Bankers' at December 31st, 1909	44	7	7
" Repayment of Income-Tax (1 year)	1	0	9				
	£64	7	7		£64	7	7

'Daniel Pidgeon Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	16	0	11	By Award	30	11	4
" Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	28	18	4	" Balance at the Bankers' at December 31st, 1909	15	18	5
" Repayment of Income-Tax (1 year)	1	10	6				
	£46	9	9		£46	9	9

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

AUBREY STRAHAN, *Treasurer*.

January 31st, 1910.

JOHN HOPKINSON,
GEORGE W. YOUNG. } *Auditors.*

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	32	3	10	By Cost of Medal	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	8	10	,, Award from the Balance of the Fund	21	13	10
,, Repayment of Income-Tax (1 year)	1	12	4	,, Balance at the Bankers' at December 31st, 1909	32	1	2
	£64	5	0		£64	5	0

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	21	0	2	By Award to the Medallist	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	37	18	8	,, Award from the Balance of the Fund	29	10	4
,, Repayment of Income-Tax (1 year)	2	0	0	,, Balance at the Bankers' at December 31st, 1909	20	18	6
	£60	18	10		£60	18	10

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	53	12	10	By Award to the Medallist	25	0	0
,, Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	66	10	10	,, First Award from the Balance of the Fund	22	13	6
,, Repayment of Income-Tax (1 year)	3	10	4	,, Second Award from the Balance of the Fund	22	13	6
				,, Balance at the Bankers' at December 31st, 1909	53	7	0
	£123	14	0		£123	14	0

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	27	6	9	By Balance at the Bankers' at December 31st, 1909	41	7	0
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture-Stock	13	6	3				
,, Repayment of Income-Tax (1 year)		14	0				
	£41	7	0		£41	7	0

Receipts.	£	s.	d.	Payments.	£	s.	d.
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	5	19	2	,, Balance at the Bankers' at December 31st, 1909	3	5	8
Repayment of Income-Tax (1 year)		6	4				
	£15	17	8		£15	17	8

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	31	4	5	By Grants	2	2	0
,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock..............	3	19	0	,, Balance at the Bankers' at December 31st, 1909	33	5	7
,, Repayment of Income-Tax (1 year)		4	2				
	£35	7	7		£35	7	7

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	43	9	6	By Cost of Medal	20	0	0
,, Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock	19	17	4	,, Balance at the Bankers' at December 31st, 1909	44	7	7
,, Repayment of Income-Tax (1 year)	1	0	9				
	£64	7	7		£64	7	7

'Daniel Pidgeon Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1909	16	0	11	By Award	30	11	4
,, Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock .	28	18	4	,, Balance at the Bankers' at December 31st, 1909	15	18	5
,, Repayment of Income-Tax (1 year)	1	10	6				
	£46	9	9		£46	9	9

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

AUBREY STRAHAN, *Treasurer.*

January 31st, 1910.

JOHN HOPKINSON, } *Auditors.*
GEORGE W. YOUNG. }

Statement relating to the Society's Property :

December 31st, 1909.

	£	s.	d.	£	s.	d.
Balance in the Bankers' hands, December 31st, 1909 :						
On Current Account	167	16	2			
Balance in the Clerk's hands, December 31st, 1909	11	2	0			
				178	18	2
Due from Messrs. Longmans & Co., on account of Quarterly Journal, Vol. LXV, etc.	63	5	7			
Arrears of Admission-Fees	151	4	0			
Arrears of Annual Contributions	254	4	0			
				405	8	0
				£647	11	9
Funded Property, at cost price :—						
£2500 India 3 per cent. Stock	2623	19	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502	15	3			
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898	10	6			
£2800 London & South-Western Railway 4 per cent. Preference Stock	3607	7	6			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	1850	19	6			
£267 6*s.* 7*d.* Natal 3 per cent. Stock........	250	0	0			
£2000 Canada 3½ per cent. Stock	1982	11	0			
				13,716	2	9

[*N.B.—The above amount does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications. The value of the Funded Property of the Society at the prices ruling at the close of business on December 31st, 1909, amounted to £11,703 16s. 9d.*]

AUBREY STRAHAN, *Treasurer.*

January 31st, 1910.

The Reports having been received, the PRESIDENT requested the permission of the Fellows to send a telegram of congratulation to Emeritus Professor E. SUESS, F.M.G.S.; and, this permission having been granted with acclamation, the following telegram was immediately despatched to Vienna:

'Professor E. SUESS, Afrikanergasse, 9
Wien, II.

'The Geological Society, assembled at its Annual Meeting, sends greeting, and offers its congratulations to the veteran author of "Das Antlitz der Erde" on the completion of his great work. SOLLAS, President.'

AWARD OF THE WOLLASTON MEDAL.

The PRESIDENT then handed the Wollaston Medal, awarded to Prof. WILLIAM BERRYMAN SCOTT, F.G.S., to the AMERICAN AMBASSADOR for transmission to the recipient, addressing the Ambassador as follows:—

Mr. WHITELAW REID,—

The Council of the Geological Society has awarded the Wollaston Medal, the highest honour which it can confer, to Prof. William B. Scott, in recognition of his distinguished services to Geology, especially by his brilliant researches into the Mammalia of the Tertiary Era.

It is now many years since Prof. Scott learnt from our famous masters, Huxley and Gegenbaur, all that the old world had to teach touching the comparative anatomy of the Vertebrata. Since then, by his admirable researches on the extinct mammals of both North and South America, he has helped to bring the New World into equal authority with the Old.

More than a quarter of a century ago he undertook, in company with his friend Prof. Osborn, those exploratory expeditions into the West of the United States which succeeded in exhuming from the Tertiary rocks the débris of successive mammalian faunas, and returned to the museums of the East laden with the spoils of the past. Illumined by his genius, this material has gradually taken form, and now reveals to an admiring world the ancestral history of diverse existing mammals, such as the Camel, the Rhinoceros, and the Dog.

More recently he organized an expedition into Patagonia, which, during three years of activity, proved equally fertile in results.

These are now being set forth in a series of exhaustive monographs, to which Prof. Scott has already contributed a masterly account of the genealogy of the Rodents and the Edentata.

In his comprehensive grasp of the manifold relations which unite the great complex of the animal world, and by his philosophic conception of the course of organic evolution, Prof. Scott ranks among the select few whom the future will number among the great palæontologists of the illustrious past.

In asking you to receive this Medal for him, I beg you to assure him of the deep interest with which the Society follows his investigations, and to express the hope that he may live long to enrich our Science with discoveries no less important than those which we now celebrate.

The Hon. WHITELAW REID replied in the following words:—

Mr. PRESIDENT,—

I have much pleasure in appearing before this learned body, on behalf of my distinguished countryman, Prof. Scott, to receive this Medal for him and in his name.

I may venture also to assure you of his warm thanks, and of the high appreciation with which the great honour that you have thus conferred—the greatest within your gift—will be regarded by Prof. Scott himself, and by the noted and very important institution with which he is connected—Princeton University, or 'Old Nassau,' as its *alumni* love to call it.

You have enhanced this honour by the cordial and gracious language in which you have been pleased to extend it. It is enhanced also by what I may perhaps call its family origin. We all know too well how family disputes are apt to be the worst and sometimes the most dangerous. Just so, no recognition of success is so sweet as that from the circle of kindred. A generous tribute like this, from the authoritative body of geologists in one branch of the great English-speaking family, for good work done by a leader in that important science in another branch of the same family, is peculiarly grateful to the recipient himself, and grateful also, as well as helpful and inspiring, to his University, to his friends, and in general to his countrymen.

Award of the Murchison Medal.

The President then handed the Murchison Medal, awarded to Prof. Arthur Philemon Coleman, to the Right Hon. Lord Strathcona and Mount Royal, G.C.M.G., High Commissioner for the Dominion of Canada, for transmission to the recipient, addressing him as follows:—

Lord Strathcona,—

The Murchison Medal is awarded to Prof. Coleman in recognition of his important contributions to geological science.

During his long and distinguished occupation of the chair of Geology in the University of Toronto, he has added largely to our knowledge of the history and formation both of the stratified systems and of the igneous rocks of Canada; nor has he restricted his attention to these, but has thrown much light on the origin of some of its most interesting scenery. He has travelled far and wide, and, bringing to bear the vast stores of information gathered in his journeys through North America, Europe, and Africa, he has increased the value of his researches by making use of the comparative method. The deposits of nickel-ore at Sudbury have yielded to his investigations conclusions of fundamental importance, which have been recognized and enforced by the veteran author of 'Das Antlitz der Erde.' No less important are the results of his researches on the Pleistocene Series in the vicinity of Toronto. His latest achievement—the discovery of glacial deposits in the Lower Huronian rocks of Canada—extends the evidence of uniformity into the remote past of the Protæon.

I had many opportunities of admiring the enthusiasm and energy of Prof. Coleman, when we were fellow-hammerers on the Dwyka Conglomerate, and it is with peculiar pleasure that I hand you this medal, which I beg you to be good enough to transmit to him.

Lord Strathcona said that he was greatly honoured and pleased to be the medium of transmitting the medal to Prof. Coleman, on whose behalf he ventured to express his warmest thanks. He added that this was not the first occasion on which he had acted as interpreter to the Canadian branch of the great English-speaking family, of the high esteem in which the old mother-land held the brilliant work accomplished by Canadian geologists.

Award of the Lyell Medal.

The President then presented the Lyell Medal to Dr. Arthur Vaughan, B.A., addressing him in the following words:—

Dr. Vaughan,—

The Lyell Medal is awarded to you in recognition of your distinguished services to Geology, especially in establishing the order of the Faunal Succession in the Lower Carboniferous rocks of Britain.

In your earlier studies of the Jurassic zones with their teeming fossils, you acquired a mastery over the investigation of the known which enabled you to venture with confidence into unexplored regions. Thanks to your researches, the Avon Gorge, once famous for its beauty, has now become no less famous as a scale of geological time.

From all sides—Wales, Ireland, France, Belgium, Germany, and remote parts of Britain—geologists, attracted by this long-desired means of correlation, have hastened on pilgrimage to Clifton, where, under your illuminating teaching, they have been made familiar in all its details with the new standard of reference.

How fortunate have been the results the pages of our Journal bear witness; our knowledge of the stratified crust has been enriched by a whole chapter, and the method of William Smith has once more achieved a triumph.

Of your power to instruct I speak with experience, for I was your pupil when last I visited the Avon section; this recollection adds to the pleasure with which, in the name of the Council, I hand you this award.

Dr. Vaughan replied as follows:—

Mr. President,—

Nothing could have given me greater delight, or have come at a more opportune moment, than the news of the award to me of the Lyell Medal.

With the zest for fresh labours partly dulled by a long illness, this eagerly desired prize came as a welcome spur, restoring self-confidence by assuring me of the sympathy of brother geologists. As yet, Sir, I can only hope that, some day, I may have done more to deserve this great honour and the kind words with which you have so generously accompanied its bestowal.

My thanks are rendered heartily and, in very truth, humbly to the Council of the Geological Society and to the many Fellows who have so kindly approved of their selection. I cannot allow this unique opportunity to slip of acknowledging how much my work owes to the inspiring advocacy of two staunch and long-time friends, Prof. S. H. Reynolds and Mr. E. E. L. Dixon.

Award of the Wollaston Donation Fund.

In presenting the Balance of the Proceeds of the Wollaston Donation Fund to Mr. Edward Battersby Bailey, B.A., the President addressed him in the following words:—

Mr. Bailey,—

The Balance of the Proceeds of the Wollaston Donation Fund has been awarded to you by the Council in recognition of the value of your investigations into the volcanic rocks of the Carboniferous System of Scotland and the structure of the Glen Coe area. After carrying out successful investigations on the geology of East Lothian, especially in relation to the Glacial phenomena, the volcanic rocks, and the Coal Measures of that district, you, in your paper written conjointly with Mr. C. T. Clough and Mr. H. B. Maufe on the Caldron Subsidence of Glen Coe, analysed with great skill a structure of remarkable complexity, and succeeded in tracing the successive stages of its formation, thus obtaining results which have an important bearing on some of the obscurer problems of volcanic and tectonic phenomena.

The Society hopes that your powers of exact observation and imaginative insight may be exercised with equal success upon the new and difficult problems which again confront you in the West of Scotland.

Award of the Murchison Geological Fund.

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

Mr. Stather,—

The Balance of the Proceeds of the Murchison Geological Fund has been awarded to you by the Council in recognition of the services that you have rendered to Geology, as well by fostering a love of research among your fellow-citizens in Hull as by your own investigations among the Glacial deposits of East Yorkshire.

For almost a quarter of a century you have furnished inspiration to an active band of fellow-workers, who have worthily maintained the traditions of East Yorkshire as a centre of geological study.

To your own investigations we owe a deeper insight into the intricacies of the latest Glacial deposits; we have learnt to discern in them successive horizons, each distinguished by characteristic boulders derived from different remote localities; we are able to trace their extension, beyond the limits once assigned to them, even on to the high Chalk Wolds; and we have gained an acquaintance in detail with the drifts of Kirmington and Beilsbeck, which possess so great an interest on account of their included fossils.

May you long continue to exercise that wisely directed energy which has enabled you, in the scanty leisure of a busy life, to achieve so much for our science.

Awards from the Lyell Geological Fund.

In presenting one moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Frederick Richard Cowper Reed, M.A., the President addressed him in the following words:—

Mr. Reed,—

A moiety of the Balance of the Proceeds of the Lyell Geological Fund has been awarded to you by the Council, in acknowledgement of the services that you have rendered to Geology and Palæontology, especially by your researches among the Invertebrate Fossils of Great Britain and Ireland, Africa, and India.

Since the publication of your first paper in 1892, memoirs and monographs have proceeded from your pen in an unremitting stream. Amidst work so various and voluminous, it is difficult, where all is good, to know what to select for special praise; but all will acknowledge, as enduring monuments of painstaking industry and exact research, your monographs on the Trilobites of Girvan, the Fauna of the Bokkeveld Beds, the Fossils of the Northern Shan States, and the Cambrian Fossils of Spiti.

To numerous colleagues in the field you have brought the indispensable aid of Palæontology. They will join in welcoming this award, and in expressing with me our best wishes for your continued success in the work of investigation.

The PRESIDENT then handed the other moiety of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Prof. ROBERT BROOM, M.D., to Dr. A. SMITH WOODWARD, Sec.G.S., for transmission to the recipient, addressing him as follows:—

Dr. SMITH WOODWARD,—

The Council of the Geological Society have awarded a moiety of the Balance of the Lyell Geological Fund to Prof. Robert Broom, in recognition of his work on the Fossil Reptiles of the Karoo.

While practising medicine in New South Wales, Prof. Broom found time to make researches into the anatomy of the Monotremes and Marsupials; these led him to reflexions on the origin of the Mammalia, and, in the hope of obtaining a solution of this question, he left Australia for Cape Colony, settling in a district where, while still engaged in the practice of his profession, he could collect and study the reptilian remains of the Karoo. He has since been able to devote himself almost entirely to this pursuit, and has published a long series of memoirs which add largely to our knowledge of the Fossil Reptilia.

We trust that the Karoo has still many discoveries in store for him, and that he may be destined to throw still further light on the predecessors of the Mammalia.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT.

Prof. William Johnson Sollas, LL.D., Sc.D., F.R.S.

During the past year we have had to mourn the loss of many distinguished Fellows of the Society: brief obituary notices of some of them follow.

Thomas Mellard Reade (1832–1909).—Mr. Reade was born on May 27th, 1832. He was the youngest son of William James Reade, the master of a small private school in Liverpool, and descended from a family of Staffordshire yeomen, some of whom—Sir Thomas Reade and the Rev. Joseph Bancroft Reade, F.R.S., for instance—rose to distinction.

His mother, whose maiden name was Mary Mellard, was a sister of Mrs. Craik, the author of 'John Halifax, Gentleman.'

At the age of 12, Reade left school, and entered the office of Messrs. Eyes and Son, a well-known firm of architects and surveyors; in 1853 he obtained an appointment in the engineer's office of the London and North-Western Railway at Warrington, and remained there until 1860, when he began practice in Liverpool on his own account as an architect and civil engineer, and ultimately met with very considerable success.

Mr. Reade did not take any serious interest in geology till he had almost reached middle age; his first contribution, a letter to 'Nature' on *Eozoon canadense*, was made in 1870, but from that time scarcely a year elapsed without one or more papers from his pen. His earlier work relates chiefly to Glacial and post-Glacial deposits, and the question of geological time; he was the first to arrive at an estimate of the rate at which rivers are conveying calcium carbonate to the ocean, and to calculate from the mass of limestone contained in the sedimentary series the age of the stratified crust; this he thought must amount to 600 millions of years. Later on, he devoted much attention to the origin of mountain-ranges, and arrived at the original and valuable conception of 'the level of no strain.' During the last ten years of his life he was engaged, in association with Mr. Philip Holland, in researches upon the lithology of the Ludlow and Old Red Sandstone rocks. He was the author of 'Chemical Denudation in relation to Geological Time' (1879), 'The Origin of Mountain Ranges, considered experimentally, structurally, dynamically, and in relation to Geological History' (1886), and 'The Evolution of Earth Structure, with a Theory of Geomorphic Changes' (1903).

Mr. Reade was elected a Fellow of the Society in 1872, and in 1896 he received the Murchison Medal in recognition of his work on the Origin of Mountain Ranges. He was several times President of the Liverpool Geological Society, namely, from 1875 to 1877, from 1884 to 1886, and from 1895 to 1897. In one of his earliest papers communicated to that Society he predicted that the tunnel then being constructed under the Mersey would encounter the Boulder Clay which filled the ancient river-channel, a prediction which was fulfilled, to the great inconvenience of the engineers.

Mr. Reade owed little to the gifts of fortune, beyond a powerful intellect and indomitable energy; these he strenuously excercised, to the great benefit of his fellow-townsmen and with no small advantage to our science. He enjoyed good health up to a few years before his death, which occurred on May 26th, 1909.

John Joseph Frederick Whiteaves, LL.D. (McGill), F.R.S. Canada (1835–1909).—Dr. Whiteaves was born at Oxford on December 26th, 1835; and resided in his native city until 1861. At the age of 21 he commenced his career as a systematic zoologist by making a collection of the land and freshwater shells of the surrounding district; from these he passed to the Jurassic fossils, of which he acquired a large collection, containing many new species. At about this time (1858 to 1860) fossil-collecting was more zealously pursued at Oxford that it has been since, and included among its votaries the present Master of Pembroke (Bishop Mitchinson), the Rev. H. H. Wood, and Mr. James Parker.

In 1863 Dr. Whiteaves was appointed Curator of the Museum and Recording Secretary of the Natural History Society of Montreal; he held this post until 1876, when he succeeded E. Billings as Palæontologist to the Geological Survey of Canada; later on he was made one of the Assistant Directors. In the New World he found a wide scope for his activity; he described the land and freshwater shells of the Province of Quebec, the Lower Silurian fossils of the Island of Montreal and its vicinity, and the marine Invertebrates of Eastern Canada; he added greatly to our knowledge of the palæontology of the whole of Canada, and conducted dredging expeditions in the Gulf of the St. Lawrence which revealed the existence in a still living state of the *Leda*-clay fauna, previously supposed to be extinct.

Dr. Whiteaves was one of the original Fellows of the Royal

Society of Canada. McGill University conferred upon him the honorary degree of LL.D. He was elected a Fellow of the Geological Society in 1859, and the Lyell Medal was awarded to him in 1907, in recognition of 'his prolonged and valuable contributions to the Geology and Palæontology of Canada.' An account of his life is given in the Geological Magazine for 1906.

Hilary Bauerman, Assoc.M.Inst.C.E. (1834–1909).—Mr. Bauerman was born in 1834, and at the age of 18 entered the newly established Government School of Mines and of Science applied to the Arts, which was subsequently transformed into the Royal School of Mines. The Government School was fortunate in possessing an exceptionally brilliant staff, which included teachers so diverse as Ramsay and Forbes on the one hand, whose wide knowledge of fact was devoted to the advancement of theory, and Warington Smyth and Percy on the other, whose equally wide knowledge of theory was made subservient to practical ends. It was with the latter that Bauerman was most closely allied by the natural disposition of his mind, and it was as a practical man applying Science to the Arts of Mining and Metallurgy that he spent the greater part of an unusually busy and useful life. In 1853 he proceeded to the Freiberg Mining Academy, and on leaving it in 1855 he was appointed an Assistant Geologist on the Geological Survey of Great Britain. In 1858 he was selected to act as Geologist to the North America Boundary Commission, and was engaged on the work of this Commission until 1863. From 1864 to 1888 he was constantly occupied in surveying and exploring mineral properties in various parts of the world, including the United States, Mexico, Brazil, Peru, Egypt, Arabia, India, Asia Minor, Norway, Sweden, and many other parts of Europe. His knowledge of European towns, both large and small, was remarkable, and frequently excited the astonishment of his friends; he seemed at home in most of them, and his memory was stored with details of their history. In 1883 he was appointed Lecturer on Metallurgy in Firth College, Sheffield; and in 1886 he succeeded Percy as Professor of Metallurgy in the Ordnance College, Woolwich, a post which he held until 1906, when he retired from the public service.

Bauerman was the author of a text-book on Descriptive and Systematic Mineralogy, and of the article on the Metallurgy of Iron in Phillips & Bauerman's 'Metallurgy'; he also contributed many valuable articles to the Journal of the Iron and Steel Institute.

He was elected a Fellow of this Society in 1863, and served on the

Council from 1874 to 1898; he was a Vice-President in 1886 and 1887. He contributed several papers to our Journal, treating of the geology of remote countries, such as Vancouver Island, Michigan, and Arabia Petræa; but he was best known to many Fellows of the Society as the Treasurer of the Geological Club, a post which he held for an unbroken period of many years.

He died of heart disease on December 5th, 1909.

Frederick George Hilton Price, F.S.A. (1842–1909).—Mr. Hilton Price was born on August 20th, 1842. His father was Mr. F. W. Price, a partner in the bank of Messrs. Child & Co. He was educated at Crawford College, Maidenhead, and at the age of 18 entered the bank of Messrs. Child & Co., of which he afterwards became the head acting partner.

He was elected a Fellow of this Society in 1872, and served on the Council in 1878 and 1879. He was a member of the Geologists' Association, and held the office of Treasurer from 1875 to 1881. He was also Director of the Society of Antiquaries, President of the Egypt Exploration Fund, a Vice-President of the Society of Biblical Archæology, and a Fellow of the Zoological and Numismatic Societies. He published several valuable works; among the best known are 'A Handbook of London Bankers,' 'Marygold,' 'The Signs of Lombard Street,' and 'Old Base Metal Spoons.'

Mr. Price's name will always be associated with the Gault; for eleven years he devoted most of his leisure to its investigation, working partly alone and partly in association with Mr. Starkie Gardner. He was greatly assisted by Griffiths, the fossil collector of Folkestone, whose services were kept in constant requisition. A compendious account of the final results of this investigation was given in a lecture delivered at Cambridge, and afterwards published as a pamphlet.

He married, in 1867, Christina, daughter of the late Mr. William Bailey, of Oakem (Staffordshire), by whom he had one son and one daughter. He died on March 14th, 1909, at Cannes, after an operation.

James Ebenezer Saunders, J.P., F.Z.S., F.R.A.S.—Mr. Saunders, at one time Alderman for the Ward of Coleman Street, Member of the Metropolitan Board of Works and of the London School Board, was elected a Fellow of the Society in 1855. He was one of the original members of the Geologists' Association.

Robert Marcus Gunn, M.A., M.B., F.R.C.S. (1851–1909).—Mr. Gunn was an eminent oculist who, while busily engaged in his profession, found time for much original investigation; he published many scientific papers on the comparative anatomy of the eye and on the physiology of vision, he also pointed out the importance of visible changes in the blood-vessels of the retina as indicating alterations of even graver significance in the general system. In his holidays he devoted himself enthusiastically to natural history and geology; he made a large collection of fossils from the Jurassic rocks of Sutherland—his native county—and from the Old Red Sandstone of Caithness. He was the discoverer of the famous *Palæospondylus gunni*. Up to the time of his death he was collaborating with Prof. Seward in a memoir on the Jurassic Flora of Brora, based mainly on his own collection, which has now been placed in the British Museum (Natural History). He was elected a Fellow of this Society in 1908.

He died at Hindhead on December 2nd, 1909.

Hindericus Martinus Klaassen (1828–1910).—Mr. Klaassen was born at Kritzum (Hanover) in 1828. In 1874, on retiring from business in London, he entered University College, London, as a student of Natural Science, paying particular attention to Geology. He became a member of the Geologists' Association in 1875, and in 1883 communicated a paper to it 'On a Section of the Lower London Tertiaries at Park-hill, Croydon' (Proc. Geol. Assoc. vol. viii, pp. 226–248). This is a valuable record of observations made during the excavation of a railway-cutting through the hill. This cutting also yielded to Mr. Klaassen the remains of some new species of fossils, the most interesting of which are *Coryphodon croydonensis* and *Gastrornis klaasseni*, both described by Mr. E. T. Newton, F.R.S.

Mr. Klaassen was elected a Fellow of the Society in 1877. He died on January 22nd, 1910.

William Ford Stanley, J.P. (1828–1909).—Mr. Stanley was born at Buntingford (Hertfordshire) in 1828. At an early age he was apprenticed to his father, a well-known mechanical engineer, and in 1854 he began business on his own account. As an inventor, designer, and manufacturer of scientific instruments he met with remarkable success. He was the author of several books, some speculative, such as 'The Nebular Theory in relation to Stellar, Solar, Planetary, Cometary, & Geological Phenomena,' and one—

'The Properties & Motion of Fluids'—recording the results of much original observation and reserach. He was elected a Fellow of the Geological Society in 1884. Mr. Stanley was a man of great generosity and public spirit; he presented to South Norwood a public hall and art gallery, and founded and endowed the Stanley Technical Trade Schools, in which a promising attempt is made to combine a general education with technical training. He died on August 14th, 1909.

James Parsons, B.Sc. (1876–1908).—James Parsons, the son of James St. John Gage Parsons, F.R.C.S., was born at Bristol on June 24th, 1876. He was taught science first at University College, Bristol, and afterwards at University College, London, where he acquired a knowledge of geology from Prof. Bonney. In 1903 he was appointed Assistant Director of the Mineralogical Survey of Ceylon, and in 1908 he succeeded the Director, Dr. A. K. Coomaraswamy, but with the title of Principal Mining Surveyor.

He was electeda Fellow of this Society in 1900; in the same year he contributed to the Geological Magazine a paper on 'The Development of Brown Mica from Augite'; a second paper on 'Quartz in Ceylon' was published in 'Spolia Zeylanica' in 1908.

At Christmas time in 1908 he left Colombo to spend his holidays at Nuwara Eliya, and on December 29th started out for a walk, leaving word that he should return for lunch; nothing more was heard of him, until, after 92 days' search, his remains were found by a native tracker in the surrounding jungle, only a mile from the house.

George Frederick Samuel Robinson, first Marquis of Ripon, second Earl of Ripon, K.G., D.C.L. Oxon, F.R.S. (1827–1909).—The Marquis of Ripon, though better known as a statesman than as a geologist, was an earnest student of science and took a keen interest in geology. He was elected a Fellow of the Society in 1867. He was also a member of the Yorkshire Geological Society and for many years its President.

Edmond Kelly, B.A. Cambridge, Chevalier de la Légion d'Honneur (1851–1909).—Edmond Kelly, a citizen of the United States of America, was born in 1851. After graduating in Columbia College, New York, he came to England and entered at St. John's College, Cambridge, where he studied natural science, and especially geology, under the tutorship of Prof. Bonney. After obtaining his

Bachelor's degree in 1874, he went to Paris and studied in the École de Droit as a preparation for the law, which he had by this time decided to adopt as his profession. He practised in New York and subsequently in Paris, where for a time he held the office of Counsellor to the American Embassy. He was elected a Fellow of our Society in 1875.

Kelly was a man of brilliant gifts, overflowing with original ideas, entertaining in conversation, an acute observer of men and manners, and possessed of a personal charm which endeared him to all his acquaintances. At Cambridge he was admired and loved by a large circle of fellow-students, among whom may be mentioned Teall, Strahan, Jukes-Browne, and Sollas. Although he did not contribute any original work to our science, he was keenly interested in it. At a very early stage of his career the doctrine of Evolution exercised its fascination over him, and he devoted much time and thought to investigating its application to human affairs; his conclusions were published in two notable works, 'Evolution & Effort' and 'Government or Human Evolution.'

When Darwin wrote the 'Origin of Species' he proposed to omit all reference to Man, because, as he said, the question was so beset with prejudice. But no great interval was allowed to elapse before Huxley, who was not afraid of prejudice, boldly attacked the problem, and endeavoured to show from anatomical evidence that Man's place in nature is with the anthropoid apes, and that he is more closely allied to these animals than they are to the monkeys next below them in the organic scale.

At that time the resuscitated hypothesis of evolution was a discredited heresy contending for recognition; it has now become an orthodox dogma, respectable beyond reproach. Our cousinship with the apes, more or less remote, is acknowledged without shame on our part, and let us hope without reason for shame on theirs.

Darwin's great work was published half a century ago, and at about the same time Prestwich and Evans returned from their visit to the scene of Boucher de Perthes's discoveries, and proclaimed their belief in the 'Antiquity of Man.' The question of the antiquity of our race, though involved in the doctrine of descent, was open to separate consideration, and was investigated not only by the biologists but by students of our own science. It offered an independent challenge to existing beliefs. The new views enjoyed a triumph in this case also, and we are now ready to accept with indifference whatever geological epoch may be assigned to the birth of our species, our sole concern being with the adequacy of the evidence.

Palæolithic man was the subject chosen by Sir John Evans for his Anniversary Address to our Society in 1875, and the next year saw the publication of Prof. Boyd Dawkins's ' Cave Hunting.' At this time research on prehistoric man in these islands reached its high-water mark, and the extraordinary advance which has attended subsequent investigation we owe to the industry and sagacity of our friends on the Continent, especially in France.

To those who have lived through the great intellectual revolution of the nineteenth century, nothing is more surprising, next to the complete ascendancy of the evolutional doctrine in every department of thought, than the change of scene which has followed on the change in the point of view. Our time has been spent in climbing the mountain-barrier, and our eyes are so accustomed to the bare rocks, peaks, and precipices that it is almost with surprise that we now find ourselves looking over a broad expanse of varied landscape, smiling and mysterious, where numerous bands of ardent explorers are already busy entering into possession. The precise nature of our newly discovered kinship, its degree of affinity, the successive steps in our pedigree, the changes of the environment, the final stages in the development of our species, the origin of existing races, and the ultimate mechanism by which the transformation of the species has been effected, these as well as a crowd of others are the questions which now press upon us for solution. The amount of laborious industry which has been devoted to their investigation is colossal and indeed appalling, the more especially as what has already been accomplished bears but a small proportion to that which remains to be done. The progress of discovery, instead of diminishing, increases the magnitude of our task. Thus, in the endeavour to reconstruct the genealogical tree of the Primates, recourse must be had in the first place to comparative anatomy, and especially to the results obtained by dissection, in any case a slow and laborious process, but now especially tedious—for, since we have become aware of the wide range of individual variation, it no longer suffices to dissect a single example of a species; in order to obtain an adequate knowledge of its structure a great number of examples are required, so that the frequency with which inconstant characters are present may be ascertained and expressed as far as possible by numerical values.

It is not only Comparative Anatomy which has thus enlarged the field of its labours, every branch of science finds itself compelled to undertake new enquiries and to extend its investigations into finer and finer details.

The memoirs to which these researches give rise are poured out in a continual stream; they are so numerous, so lengthy, so scattered through numberless Transactions, Proceedings, Journals, and other forms of publication, that it becomes increasingly difficult to contend with the literature alone, and Science seems in danger of being overwhelmed beneath the weight of her own acquisitions. Nor does there appear to be any prospect of alleviation by some process of natural selection. Our difficulties are not lessened by the fact that so much of this increasing literature is expressed in a variety of tongues, which include Russian and Hungarian, but not Greek nor Latin. Considering the number of languages which a scientific investigator must be able to read, with at least a certain amount of facility, it would be greatly to his advantage if some of them were more seriously taught at school; the dead languages are comparatively useless to him, and might be reserved for those who are likely to need them. As regards the literature of Rome and Greece, I must confess to have found greater delight in its masterpieces when presented in a scholarly translation than when spelling them out by my own unaided efforts. To me it seems nothing less than a scandal that so large a proportion of our youth are compelled to waste their best years at school over tasks of very doubtful utility, for which the majority have neither taste nor aptitude.

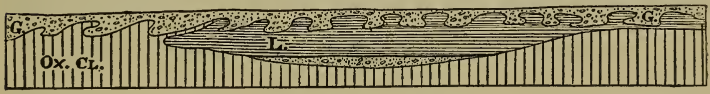
It is possible that we may soon find ourselves obliged to learn some Oriental languages: the Japanese have already entered with ardour into scientific research; they are beginning to share our anthropological studies, and the interest which we have shown in the anatomical peculiarities of their race they are returning by an investigation of ours. Comparatively recently a paper appeared by B. Adache & K. Fujisawa describing the occurrence of Mongoloid spots on a white baby of German parentage,[1] thus lending colour to Huxley's hypothesis of the origin of the Melanochroi by the crossing of the Xanthochroi with a dark race.

[1] 'Mongolen-Kinderflecken bei Europäern' Zeitschr. f. Morphologie & Anthropologie, vol. iv (1902) p. 463.

Palæolithic Man.—When Sir John Evans delivered his address on this subject he recognized only two stages in the palæolithic series, represented by cave man and river-drift man; as a result of investigations in France, we are now able to distinguish six, the Chellean, Acheulean, Mousterian, Aurignacian, Solutrian, and Magdalenian, some of these being capable of further division into two or more substages. They are enumerated above in the order of their age, the Chellean being the oldest.

All observers are agreed that the Chellean corresponds with an interglacial episode, the fauna associated with it, particularly *Elephas antiquus* and *Rhinoceros merkii*, pointing to a warm climate; but opinions differ as to which interglacial episode this may be: Prof. Boule pronounces for the last, Prof. Penck for the last but one. In our own country Acheulean implements are certainly younger than the Chalky Boulder Clay: the investigations made at Hoxne by Mr. Clement Reid, on behalf of a Committee appointed by the British Association, leave no room for doubt on this point; but it is not so certain that the Chalky Boulder Clay represents the last of the glacial episodes in our islands. In a paper read before this Society in 1904, Mr. Montgomery Bell[1] called attention to contorted gravels which occur at Wolvercote, a little north of Oxford, and 40 feet above the present level of the Thames, which runs close by. They are clearly exposed in a brick-pit, where they are seen to overlie the Oxford Clay in part, and in part some lacustrine beds of Pleistocene age (figs. 1 & 2). The gravels are folded into both of the underlying

Fig. 1.—*Diagrammatic section showing gravel* (G) *of the 40-foot terrace folded into the underlying Oxford Clay* (Ox. Cl.) *and lacustrine beds* (L.) *at Wolvercote brick-pit, Oxford.*

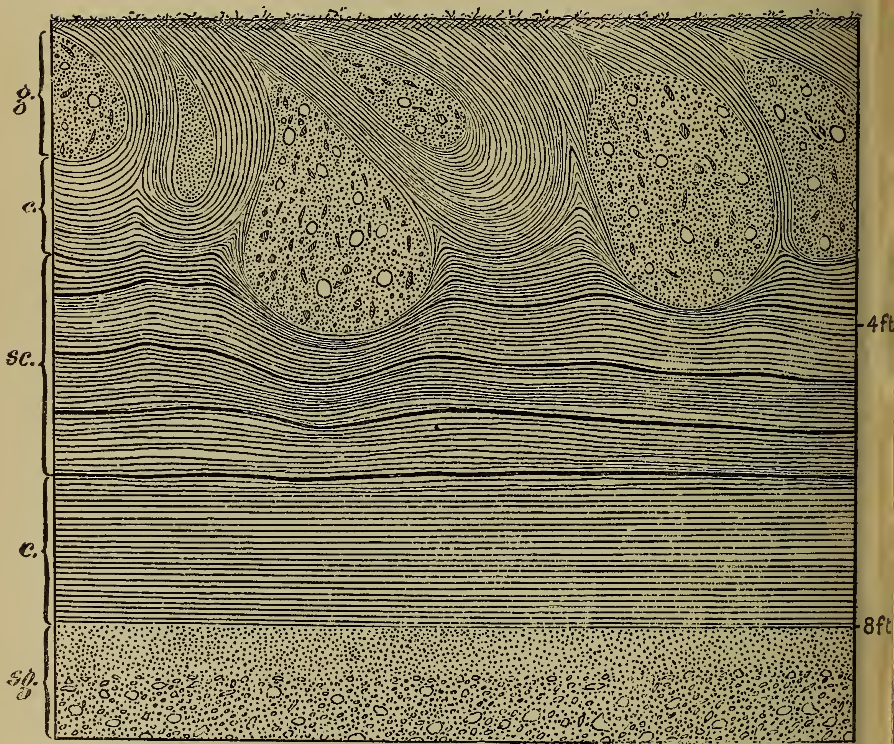


deposits; and at one spot both the Oxford Clay and the gravel are violently overthrust on to the lacustrine beds. Some very powerful superficial agent has evidently been at work, and we are led to suspect the action of land-ice. The gravel has yielded a scratched quartzite-pebble and a large subangular block of igneous rock

[1] 'Implementiferous Sections at Wolvercote (Oxfordshire)' Quart. Journ. Geol. Soc. vol. lx (1904) p. 120.

covered with characteristic glacial striæ. I had the pleasure of showing this block to Sir John Evans, who at once recognized it as a glacial boulder.

Fig. 2.—*Gravel* (g) *folded into lacustrine beds, consisting of thinly bedded clay* (c) *and sandy clay* (sc) *overlying sand and gravel* (sg), *Wolvercote, Oxford.*



[The folds in the drawing are more formal and better defined than they are in fact.]

Similar gravels, contorted and containing striated boulders, occur at Coombe, about 7 miles north-north-east of Oxford (137 feet above the Evenlode), and at Picket Heath's Farm on Cumnor Hill (356 feet above the Thames), where the gravel assumes the character of a true boulder-clay, and affords abundant glaciated boulders of igneous rocks which must have been transported from some remote locality not yet identified.

At one time, I was disposed to regard these gravels as fluvio-glacial, and to refer them to three different glacial episodes corresponding to the three several river-terraces with which they are associated; it now seems possible that they may be all of the same age, but the question can only be decided by further investigation. It is of subsidiary importance, the main point in connexion with our present enquiry being the supposed glacial origin of the Wolvercote deposits, for underlying these Mr. Bell has discovered a very fine series of beautifully worked flint-implements, which cannot be later, nor very much earlier, than Mousterian in age.

Some peat associated with the lacustrine beds has afforded plant-remains which point on the whole to a temperate climate.

Combining the information obtained by Mr. Clement Reid with that obtained by Mr. Bell and myself, we arrive at the following succession:—

Contorted gravel	Glacial episode IV.	
Wolvercote bouchers	Temperate climate.	Genial episode III.
	Cold climate?	
Acheulean of Hoxne	Temperate climate.	
Betula-nana beds of Hoxne .	Cold climate.	
Alder-beds of Hoxne	Temperate climate.	
Chalky Boulder Clay	Glacial episode III.	

The supposed existence of a fourth glacial episode in these islands is of considerable interest, especially as it is likely to give rise to controversy; but it is of very trivial importance, compared with the certainly ascertained fact that the Acheulean[1] stage is younger than the Chalky Boulder Clay and thus younger than the severest of the glacial episodes recognized in this country and in France. Thus this stage belongs to the later days of the great Ice-Age, and by far the greater part of the Pleistocene epoch is pre-Acheulean. This is a fact which must be constantly borne in mind when discussing the evolutional history of Man.

Skeletal remains of Palæolithic Man.—Human remains have long been known from the Magdalenian stage. They afford evidence of the contemporary existence of two very different races: one represented by the old man of Crô Magnon, on which much

[1] M. A. Rutot (Bull. Soc. Belge Géol. vol. xxiv, 1910, p. 89) lays great stress on the distinction between his Acheulean I and Acheulean II, and regards the former as older than the Chalky Boulder Clay. A critical examination of the palæolithic implements of the Thames valley, in the light of recent discoveries abroad, is greatly needed.

additional light has been thrown by the skeletons found in the caves of Mentone, and so admirably described by M. Verneau; the other by a single skeleton found under a rock-shelter in Chancelade, not far north of Périgueux. The latter, as clearly shown by Dr. L. Testut,[1] belonged to an adult man about 5 feet in height, who was beyond doubt an Eskimo. The Crô Magnon race, apparently extinct, were a tall people, 6 feet to 6 feet 3 inches in height; they combined a long skull with a short face,[2] and made a closer approach to the Mongolian type than to the Eskimo, in which both face and skull are long.

The capacity of the Chancelade skull is 1700 cubic centimetres, and thus surpasses the average cranial capacity of the existing Eskimo (1546 c.c.), which is itself unusually high. It would appear, therefore, either that the Chancelade skull is not an average example of its kind, or that the Magdalenian Eskimo possessed a higher cranial capacity than their existing descendants. Individuals with a capacity approaching the average are in every race by far the most numerous, and thus, judging from the doctrine of probabilities alone, the chances are in favour of the latter alternative.

The cranial capacity of the Crô Magnon race was also very great; it ranged from 1590 to 1715 cubic centimetres.

Thus, both the races which occupied the soil of Europe during Magdalenian times would appear to have been endowed with larger brains than the average of any existing civilized nation.

In the Solutrian age, to which we now pass, two races also coexisted. This at least is the conclusion to which Piette was led by a study of the famous statuettes belonging to this period. One of these races, according to Piette, was allied to the existing Bushmen or Hottentots, and the mural paintings found in many of the caves of Southern France and Northern Spain certainly find their closest parallel in the similar works of art executed by the Bushmen. Confirmation of this view is afforded by two skeletons (one of a woman, the other of a not fully adult man) found in the Grottes des Enfants, Mentone; they have been described by Verneau, who refers them to a 'negroid' race. The cranial capacity of the boy or young man is 1540 c.c., very much above the average of existing Bushmen (1330 c.c.) or indeed of any existing negro race.

[1] 'Recherches Anthropologiques sur le Squelette Quarternaire de Chancelade, Dordogne' Bull. Soc. Anthrop. Lyon, vol. viii (1889).

[2] Verneau, 'Les Grottes de Grimaldi' 1906.

The next older stage is the Mousterian. Apart from a lower jaw of doubtful age to be mentioned presently, it has afforded the oldest-known skeletal remains of Man. The Neanderthal calotte and other bones belong to it, the two skulls and fragmentary skeletons from Spy, the remains of about a dozen individuals from Krapina, the skull and other bones from La Chapelle-aux-Saintes, another fragmentary skeleton from the lower cave of Le Moustier, and in all probability the Gibraltar skull. The study of this rich material has afforded very consistent results, and we are now able to form a very definite picture of the bodily characteristics ot Mousterian man. He was short in stature, 5 feet 3 inches in height, but powerfully built and with a disproportionately large head. His face was strangely unlike that of any human race with which we are familiar. A retreating forehead rises out of a broad depression bounded below by the massive frontal torus, which bulges out in a continuous projection above the eyes and nose. The nose, which is broad and large, passes into the glabellar region with a gentle flexure, instead of encountering it abruptly: recalling in this respect the apes rather than the Australians. The sides of the nose are not so sharply defined from the cheeks as in ourselves, but lie almost in the same plane, thus producing a singular snout-like projection. The orbits are large and round. The upper lip is long, and this, together with the long nose, gives an unusual length to the whole face. The massive lower jaw is without a chin. Prognathism exists to a various extent; sometimes it is very marked, at others almost absent. A similar wide range of variation in this respect is to be observed among the native Australians.

The glabella-inion line on which such a mighty superstructure of measurements has been based proves now to be of only slight morphological value; in the case of the Neanderthal calotte it has led to a very erroneous estimate of the total height of the complete skull, and consequently of the cranial capacity. Prof. Boule finds by direct measurement of the skull from La Chapelle-aux-Saintes a capacity of 1600 c.c.[1]; and, since the Neanderthal calotte completely agrees in form and dimensions with the corresponding part of this skull, a similar capacity is to be inferred from it. Prof. Fraipont, as Dr. Boule informs me, has long been of opinion that the capacity of the skulls from Spy approaches 1700 c.c.

The Mousterian skulls are the oldest human skulls of which we have any knowledge; but, just as in the case of the Magdalenian

[1] C. R. Acad. Sci. Paris, vol. cxlviii (1909) p. 1354.

and Solutrian, they indicate that the primitive inhabitants of France were distinguished from the highest civilized races, not by a smaller, but by a larger cranial capacity; in other words, as we proceed backwards in time the human brain increases in volume.

This result is the more surprising, when we consider that the skull which at present makes the nearest approach to the Mousterian in its morphological characters is that of the Australian aborigines with a mean capacity of only 1250 c.c. In this respect, though certainly not in others, the Australian skull would seem to be far more primitive than that of Mousterian man.

It seems probable also that the Mousterians had reached a comparatively high stage in the evolution of religious ideas: the skeletons found at La Chapelle-aux-Saintes and Le Moustier had evidently been interred in a primitive kind of tomb; and not only had their weapons been buried along with the deceased, but in the case of La Chapelle-aux-Saintes the leg of a bison also, plainly intended to provide food for the departed spirit on its journey to the next world.

The races of Solutrian and Magdalenian times were endowed with no mean intellectual powers; the steady advance in the perfection of their weapons testifies to their inventiveness; their sculpture in bone and ivory, their line-engravings, and the mural paintings with which they adorned the caves that sheltered them are distinguished by truth, vigour, and refinement, and suggest comparison with the art of ancient Greece. Add to this that, according to Piette, they had bridled the horse, and in the case of the Magdalenians had adopted to some extent the custom of wearing clothes. We are thus far from recognizing in these primitive palæolithic hunters the brutal animal of dawning intelligence which we have been taught to expect, and the origin of our race must be pushed an indefinite distance farther back.

We have seen that four of the Mousterian skulls possess a capacity of 1600 c.c. or over, but the Gibraltar skull, which, though 'undated,' is also probably Mousterian, falls far short of this; according to my measurements, its capacity amounts to 1260 c.c., and I do not think that it can have exceeded this to any appreciable extent. But a range of capacity between 1260 and 1700 c.c. falls well within the limits observed in recent races, whether primitive, like the Australians, or civilized, like ourselves. It is possible also that the Gibraltar skull belonged to a woman.[1]

An instructive example of the distribution of cranial capacity in a modern race is afforded by the measurements made by F. Tappeiner[2] of 557 male skulls taken from a mediæval ossuary in Tyrol. Collecting these in groups, the frequency with which different capacities occur is represented by percentages in the following table:—

Cranial capacity in cubic centimetres.	*Individuals per cent.*	*Cranial capacity in cubic centimetres.*	*Individuals per cent.*
From 850 to 950	0·2	From 1450 to 1550	30·8
„ 950 „ 1050	0·0	„ 1550 „ 1650	19·5
„ 1050 „ 1150	0·4	„ 1650 „ 1750	11·2
„ 1150 „ 1250	2·0	„ 1750 „ 1850	3·2
„ 1250 „ 1350	7·5	„ 1850 „ 1950	0·6
„ 1350 „ 1450	24·1		

A doubt may arise, as to whether the Mousterian skulls are merely chance selections: they may have belonged to exceptional men, tribal chiefs perhaps, and the fact that in two instances they were found under circumstances which point to a ceremonial burial might tend to strengthen this suspicion. But, apart from the fact that exceptional men are not, as a rule, distinguished by exceptional heads, it is evident that the argument will not apply to the three skulls discovered in the Neanderthal and at Spy, for these were not found in a tomb.

The result of the numerous investigations carried out during the last quarter of a century is to show that no discoverable relation exists between the magnitude of the brain—or even its gross anatomy—and intellectual power. At first sight, the fact that the more advanced races of the present day are distinguished by a large average brain might seem to furnish evidence to the contrary; it must not, however, be overlooked that the largest existing average brain is to be met with, not among civilized races, but among the Eskimo.

The following list, which might be easily increased, is of great interest in this connexion:—

W. J. Sollas, Phil. Trans. Roy. Soc. ser. B, vol. cxcvii (1907) p. 322.
[2] Zeitschr. f. Ethnol. vol. xxxi (1899).

	Cranial capacity.	*Weight of brain.*	*Authority.*
Bismarck	1965 c.c.	1867 gms.	Waldeyer.
Kant....................	1715	......	Kupfer & Hagen.
Bobbe (a robber and murderer)............	......	1510	R. Wagner.
Mohl (a distinguished botanist)	1431	......	A. Froriep.
Do.	1500	......	Buschan-Stettin.
Gauss	......	1492	Rudmeyer.
Skobelew (General)...	......	1451	Sernoff.
Mommsen	......	1429	Hausemann.
Liebig	......	1353	
Menzel	......	1298	Hausemann.
Bunsen.................	......	1295	Do.
Leibniz................	1422	1257	His.
Gambetta..............	......	1247	Duval.
Do.	......	1160	Paul Bert.

It thus appears that there is no apparent reason why a great man should not possess a large brain (Bismarck); on the other hand, he may attain the highest flights of genius with a comparatively small one (Leibniz).

The dissection of the brains of criminals and of distinguished men fails to reveal any characteristic difference between them.

Since the motor-centre for speech is situated in Broca's area, we might have expected to find some connexion between great linguistic powers and the size or complication of the lower frontal lobe, but even this is not the case. Dr. L. Stieda[1] gives an interesting account of Dr. Georg Sauerwein, who was master of forty or fifty languages; after his death, at the age of 74, on December 16th, 1904, his brain was dissected by Stieda, but it revealed nothing which could be correlated with his exceptional gift.

The magnitude and visible complexity of the brain are possibly two of the factors which contribute towards the manifestation of intellect; but they cannot be the only ones: there must be others of equal or even greater importance, such as the ultimate structure of the grey matter, and the degree of perfection in the adjustment of parts. It is possible that the character of the circulation and the nature of the blood-supply may not be without influence, so that the intellect may actually be an affair not only of the head but the heart. There may be yet other factors of a more recondite character.

[1] 'Das Gehirn eines Sprachkundigen' Zeitschr. f. Morph. & Anthrop. vol. xi (1908) p. 81.

However this may be, the important fact remains that the Mousterian men, so far as we have any knowledge of them, seem to have been endowed with a larger brain than is common among existing races, whether savage or civilized. On the other hand, they were obviously more brutal than existing men in all the other ascertainable characters by which they differ from them; the great frontal torus, and the occipital torus as well, the retreating forehead, and the massive chinless lower jaw are some of the more striking of the numerous simian characters which they display.

Thus, as we proceed backwards in time Man departs farther from the ape in the size of his brain, but approaches nearer to the ape in the characters of his bodily framework. This must be regarded as a highly significant fact.

The Mousterian skeletons are not perhaps quite the earliest remains of Palæolithic Man; indeed the lower jaw discovered last year at Mauer, not far from Heidelberg, is unquestionably older. It has been well described by Dr. O. Schœtensack.[1] The dentition is thoroughly human. The incisors and canines have been worn down to a uniform level, so that the dentine is exposed within a ring of enamel. The premolars and molars, which rise to nearly the same level as the front teeth, display scarcely any signs of wear. In the apes the third molar is cut before the permanent canine, or at latest simultaneously with it: hence, as Dr. F. Siffe[2] points out, if the jaw had belonged to an ape the third molar should have been as much worn as the canine; the fact that it is not furnishes, therefore, additional evidence of the human character of the dentition.

The canine, so far as can be judged from its worn condition, does not appear to have projected to an appreciable extent beyond the general level. Far more simian characters are to be observed in the dentition of existing wild races than in that of this Heidelberg jaw.

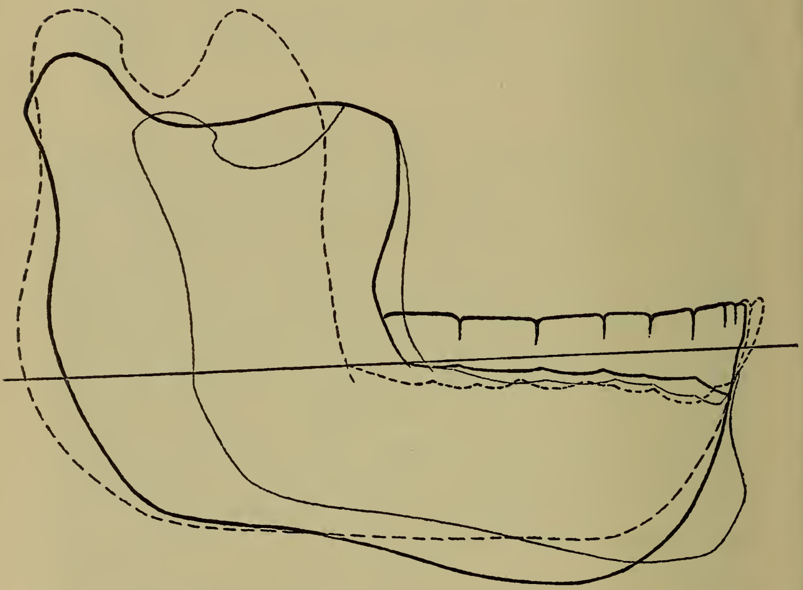
If the characters of the dentition are purely human, the same cannot be said of the jaw itself, which offers a startling contrast. Dr. Schœtensack scarcely exaggerates when he remarks that, if the jaw had been found without the teeth it might have been assigned, by some anatomists at least, to an ape. Its massive body and

[1] 'Der Unterkiefer des *Homo heidelbergensis* aus den Sanden von Mauer bei Heidelberg' Leipzig, 1908. Pp. iv & 67; 13 plates.

[2] Bull. Soc. Anthrop. 1909, p. 89.

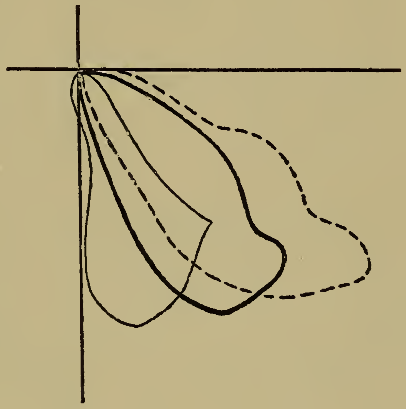
broad ascending branches at once distinguish it, even to the uninstructed eye, from that of existing men; but it is at the anterior extremity that its simian characters are most pronounced. The chin is entirely absent, and the profile is a simple, retreating, gentle curve, similar to that presented by the lower jaw of a chimpanzee or gorilla. In the illustration (fig. 3) the profiles of this region as it

Fig. 3.—*Projections of the Mauer jaw (thick continuous line), the jaw of an Australian aborigine (thin continuous line), and the jaw of a chimpanzee (broken line), superposed on the alveolar line.* ($\times \frac{4}{5}$.)



occurs in the Australian, the chimpanzee, and the Heidelberg jaw are superposed on a common base, provided by the alveolar plane, and it will be seen on inspection that the Heidelberg profile stands almost midway between the other two. The inner or posterior face of the anterior extremity is no less simian than the outer; the surface of the alveolar region slopes downwards more gently than in existing races, but more steeply than in the chimpanzee; the supramarginal sinus is more sharply expressed than in existing races, and forcibly recalls the corresponding region in the chimpanzee (fig. 4, p. lxvii). Just below it is the region where, in modern Man, we should expect to find the genio-glossal spines, but of these, as in the higher apes, there is no trace. It has been rashly inferred in other cases that the absence of these spines is connected with an imperfectly developed power of speech. How little foundation there is for this is shown by the

Fig. 4.—*Sagittal section through the symphyses of the lower jaw of Mauer (thick line), an Australian aborigine (thin line), and a Chimpanzee (broken line). Natural size.*



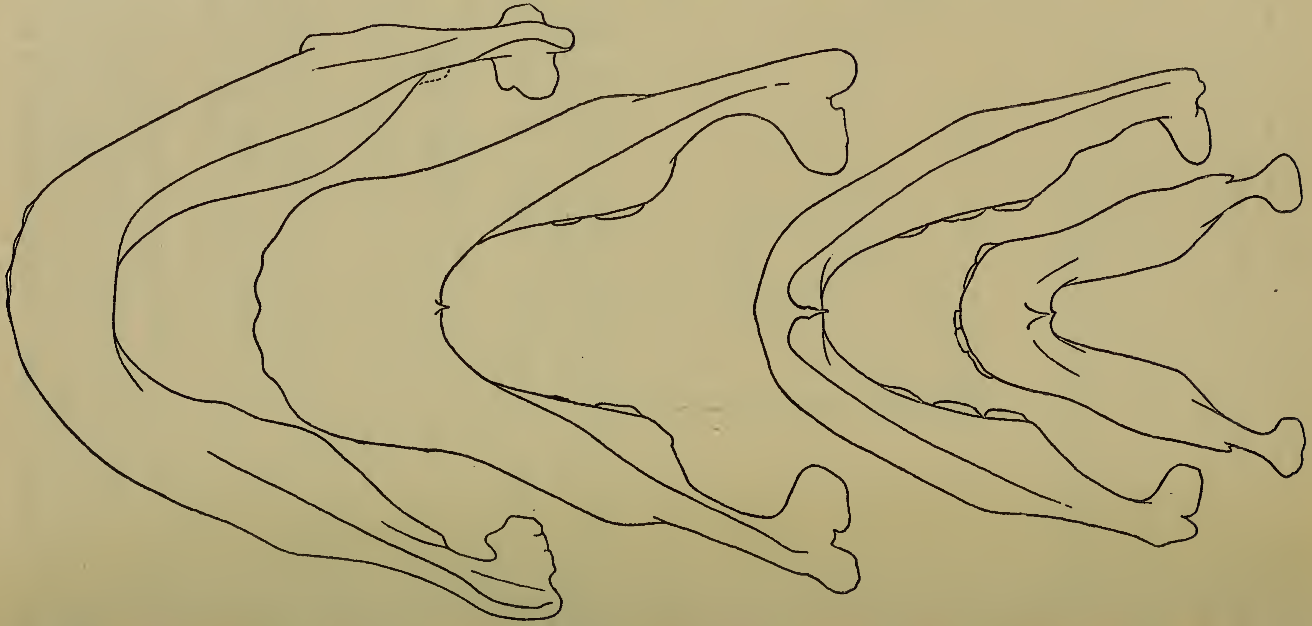
fact that they are not infrequently absent from the jaw of the Bushmen, a people no whit less talkative than the rest of mankind, and capable of conversing in English or other languages widely different from their own.

The Heidelberg jaw, in some respects peculiar (fig. 5, p. lxviii), in others simian, bears, as we have seen, a human dentition; this, like the fact that the Mousterian skull, though distinguished by many simian characters yet lodged a large human brain, is well worth bearing in mind.

No implements have been discovered in the bed of sand from which the Heidelberg jaw was obtained, but it has furnished an interesting fauna; one of the species (*Elephas antiquus*) suggests the Chellean horizon, another (*Rhinoceros etruscus*) has been found elsewhere in the Upper Pliocene.

Below the Pleistocene human remains are unknown. Fragments of flint with chipped edges, supposed by some to be human artefacts, are not uncommon, and are found as far back as the Oligocene. If a tool-making animal were already in existence at this early date, our attempts to frame a consistent hypothesis of the course

Fig. 5.—*The Mauer jaw, the jaw of an orang, of an Australian aborigine, and of a young gorilla (taken in order from left to right) seen from below, the alveolar plane being in all cases horizontal.* (× 0·62 *about.*)



[The differences between the Mauer jaw and the orang on the one hand, and the Australian on the other, are obvious on inspection.]

of human evolution would be greatly simplified, but for the existence of such a being far more cogent evidence is required than any which has so far been forthcoming.

In endeavouring to trace out the ancestry of Man, we must next proceed to the other members of the Primates, among which *Pithecanthropus* is by far the most human. Unfortunately, our knowledge of this creature rests on very fragmentary material, and is lamentably incomplete. We possess a cranial calotte, three teeth, and a femur; but that is all. The calotte is far from perfect, it has lost a great part of the glabellar region, and presents no trace of sutures. It is scaphocephalic, probably in consequence of premature synostosis, and is so far abnormal. Signs of a pathological condition are also presented by the femur, which has suffered from exostosis.

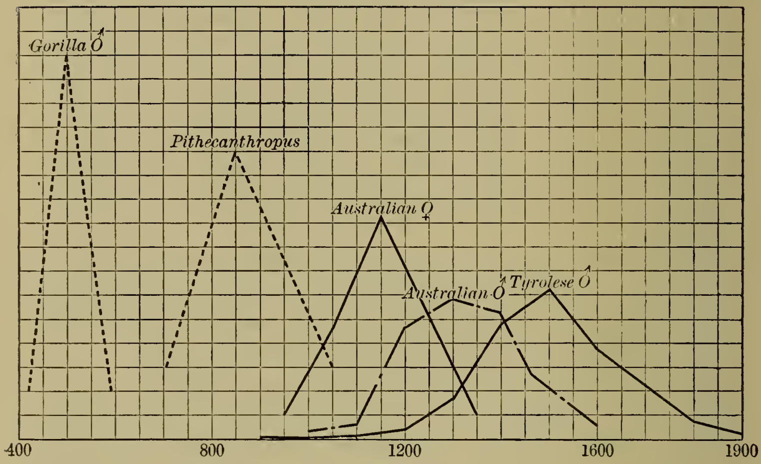
In the absence of sutures, and the consequent impossibility of determining the position of the bregma and lambda, it is dangerous to attempt any exact comparison of the characters presented by the cranial calotte: the elaborate measurements that have been based on the conjectural position of the bregma, and on the inion, which cannot be regarded as a trustworthy point of reference, are useless and misleading. Yet, despite its defects, the calotte has furnished a surprisingly large amount of valuable information. Dr. Dubois has obtained a cast of the interior which throws much light on the configuration of the brain; this presents simian as well as human characters, so far as can be judged from the description, which is not accompanied by figures.

The probable capacity of the original cranium has been estimated at 855 cubic centimetres; so many uncertainties, however, enter into the calculation that these figures cannot be regarded with much confidence. The actual capacity may have been slightly greater, but it is not likely to have been less.

If future discoveries should show that the estimated capacity is approximately correct and not far removed from the average for the species, then it would represent a true annectant stage between the cranial capacity of Man and that of the apes. This will be seen from the accompanying diagram (fig. 6, p. lxx). The first curve to the right represents the distribution of cranial capacity in a European race (Tyrolese men), the next in Australian aborigines (men), the third in Australian aborigines (women), the fourth is a purely hypothetical curve for *Pithecanthropus*, the fifth also hypothetical for the gorilla. The numbers representing the maximum, mean, and minimum capacity of the gorilla are based on measurements of thirteen adult male skulls.[1]

The femur, though it presents some characters which are also met with in the gibbon, is on the whole more human than simian, and belonged to an animal which walked erect.

Fig. 6.—*Curves of cranial capacity.*



The age of *Pithecanthropus* cannot be regarded as precisely determined; Dr. Dubois regards it as Pliocene, but the weight of opinion inclines to the Pleistocene.[2] The Kendeng Beds in which it was found are folded along with the underlying Tertiary, and are thus older than the existing river-terraces, which yet contain *Elephas* and *Hippopotamus*. J. Elbert,[3] the latest writer on the question, proposes the following classification of the Kendeng Beds:—

Upper Kendeng Beds	(Nos. 1– 4)	= Upper Pleistocene.
Middle Kendeng Beds	(Nos. 5–10)	= Middle Pleistocene.
Lower Kendeng Beds	(Nos. 15–21)	= Lower Pleistocene.
Transition	(Nos. 22–23)	
Upper Pliocene.		

[1] The mean may be too low. Keith obtained 530 cubic centimetres as the mean of nine skulls.

[2] W. Volz, 'Das geologische Alter der *Pithecanthropus*-Schichten bei Trinil, Ost-Java' Neues Jahrb. Festband (1907) p. 256; W. Branca, 'Vorläufiger Bericht, &c.' S.-B. d. k. Preuss. Akad. d. Wissensch. Berlin, 1908, p. 261.

[3] 'Dubois' Alterbestimmung der Kendengschichten, ein Wort der Entgegnung' Centralblatt für Min. Geol. & Pal. 1909, No. 17, p. 513.

Pithecanthropus was found in Beds 22–23, or on the supposed limit between the Pliocene and the Pleistocene.

From *Pithecanthropus* we pass next to the anthropoid apes which make their first appearance, simultaneously with the lower Catarrhine apes, in the Middle Miocene of Europe.[1] The Platyrrhine monkeys are represented by fossil forms in the Santa Cruz formation of South America, which Prof. W. B. Scott assigns to the Miocene. These monkeys are not known, fossil or living, outside of the South American continent.

The lowest suborder of the Primates, the Lemuroidea, are first met with in the Eocene of North America and Europe; in North America their remains are comparatively abundant, in France only two genera are known which are supposed to belong to this group.

Thus the stratigraphical succession in Holarctica is first Lemuroids, next Catarrhine apes including the Anthropoids, and finally Man.

So far we have been dealing with fossils, but we may now turn to the evidence afforded by recent investigations in comparative anatomy. We will consider first the brain, that organ of organs which before all else distinguishes the body of Man from the lower animals. The taxonomic importance of the brain has received general recognition from all those most competent to judge; Elliot Smith speaks of it as an organ of immense classificatory value, summing up, as it were, the whole animal, and displaying a marked tendency to the conservation of fundamental characters. It has been made the subject of the devoted labours of a crowd of brilliant anatomists, whose names I fear to mention, lest I should not complete the list; I will only refer, therefore, to my old friend Cunningham, whose recent death we so deeply deplore.

The brain of the gorilla has been very closely investigated by Prof. L. Bolk,[2] who concludes that although it recalls by many peculiarities the lower Primates, yet it already possesses in a more or less highly developed state all the principal furrows of the human brain, which it approaches in this respect more closely than any of the other Anthropoids. As regards the frontal region, in

[1] As these pages are passing through the press, the discovery is announced of several genera of apes in the Oligocene of the Fayûm: one is said to be a diminutive *Pliopithecus*. Max Schlosser, 'Zool. Anzeiger' March 1st, 1910, p. 500.

[2] 'Beiträge zur Affenanatomie, III. Das Gehirn vom Gorilla' Zeitschr. f. Morph. & Anthrop. vol. xii (1909) pp. 141–242, in particular pp. 238 & 242.

particular, he remarks that if a composite picture were obtained by superposing outline drawings of its topography taken from a number of examples, then this would show sharper furrows than in the chimpanzee and make a very close approach to the arrangement existing in Man. The brain of the chimpanzee presents the next closest alliance with that of Man, and that of the orang follows at no great interval. A gap then intervenes separating off the gibbon, which, as regards the anatomy of its brain, is more closely connected with the lower Catarrhine monkeys than with the man-like apes.

In thus speaking of the brain reference is intended to the cerebrum only; Prof. Bolk has also made a comparative study of the cerebellum as it occurs in the Primates, and finds evidence of an increasing resemblance to Man as its structure is traced upwards from the lower apes.[1] The cerebellum of the lemurs is said to present characters which distinguish it from the fundamental type of the Primates, and these are said to have been inherited from a prelemuroid ancestor. The general plan of the Primate cerebellum is first met with in the Arctopithecini (marmosets); from this we pass to the Platyrrhine and Catarrhine monkeys, which closely resemble each other in the characters of the cerebellum; from the Cercopithecidæ there is a transition to the gibbon, and from the gibbon to Man. The cerebellum of the chimpanzee makes a nearer approach to that of Man, and still nearer comes the cerebellum of the orang. No mention is made of the gorilla, which does not seem to have been investigated.

The relations of the brain of the lemurs to that of the other Primates has been made the subject of an exhaustive study by Elliot Smith.[2] These animals are now extremely specialized, and are more especially distinguished from the apes by the large size of their olfactory organs. In connexion with this specialization some of their cerebral characters, such as those that indicate a marked divergence from the Primate stem, for instance, may have arisen as comparatively late acquisitions. Elliot Smith remarks that the brain of the lemurs can only be explained by supposing that it had first made a fair advance along the main stream of the Primates, and then suffered a retrogressive development.

It is interesting to note that the fronto-orbital and paracalcarine sulci, which occur both in the lemurs and in some of the larger

[1] 'Das Cerebellum der Säugetiere' 1906.

[2] 'On the Morphology of the Brain in the Mammals' Trans. Linn. Soc. 1902, p. 312.

Cercopithecini, are absent in the New World apes. In other respects, however, the structure of the brain indicates a close connexion between the Cebidæ and the lemurs.

The general result of a comparative study of the brain of the Primates is to confirm the usually accepted view which recognizes the existence of a serial relationship between the ancestral lemurs, the lower Catarrhine monkeys, the man-like apes, and, finally, Man himself.

We may now pass from this most important of organs to characters of apparently the most trivial significance, and possibly for that very reason of all the greater value for taxonomic purposes. These are the patterns formed by the ridges which cover the palmar surface of the hand and the sole of the foot. Attention was long ago directed to them by Purkinje, and they have been made familiar to English readers by Sir Francis Galton's book on finger-prints. In the details of their form they are so special to the individual as to serve for his identification, yet they present signs of a common plan which can be traced as far back as the root of the Primates and even beyond it. Thus, stamped upon the palm of the hand and the sole of the foot, we all carry 'the mark of the beast.'

Fig. 7.—*Left hand of a baboon* (Cynocephalus babouin) *after Hepburn, Sci. Trans. Roy. Dublin Soc. vol. v (1905) pl. xlix.*

A remarkable memoir on these markings, which we owe to the skill of Miss Whipple, has been followed by another from the pen of Dr. O. Schlagenhaufen,[1] who makes especial

[1] 'Das Hautleistensystem der Primatenplanta, unter Mitberücksichtigung der Palma' Morph. Jahrb. vol. xxxiv (1905) pp. 1–125. This paper is accompanied by a full bibliography.

use of them as a means of comparison between man and the other Primates. Certain features in the patterns are shown to be distinctive of all the Catarrhine monkeys, including the Man-like apes and Man himself. The closest resemblance is found to exist in the case of the orang, chimpanzee, gorilla (fig. 8, p. lxxv), and Man (fig. 9). The great toe of Man presents a marked difference of pattern, which is explained as a recently acquired adaptation to the erect position. The degrees of resemblance between the patterns presented by the different members of the Primates have afforded material for the construction of the following genealogical tree :—

An elaborate study of the femoral arteries and their branches in the lower Catarrhine apes, lately undertaken by Dr. H. Blüntschli,[1] has revealed many points of resemblance between these apes and Man as regards the distribution of these vessels. *Semnopithecus*, in particular, presents many human characteristics, even in cases where the Cercopithecini are divergent. This genus, indeed, makes a remarkable approach to Man in several other respects : the discoidal placenta, for instance, is not infrequently single, the interorbital

[1] 'Die *Arteria femoralis* & ihre Äste bei den niederen Catarrhinen Affen Morph. Jahrb. vol. xxxvi (1907) pp. 276–461.

septum is broad, cheek-pouches are absent, and ischial tuberosities only slightly developed.

An examination of the fundus of the mammalian eye, by means of the ophthalmoscope, reveals a close general resemblance between all the members of the Primates, except the lemurs. Apart from these, the Primates, including the Platyrrhine apes, all possess a *macula lutea*. This character is probably connected with another equally distinctive, the power to converge the visual axes, which is also restricted to these apes. In the lemurs the *macula lutea* is

Fig. 8.—*Sole of the foot of* Gorilla gorilla, *Forbes*, ($\times \frac{2}{7}$), *after O. Schlagenhaufen, 'Das Hautleistensystem der Primatenplanta.'*

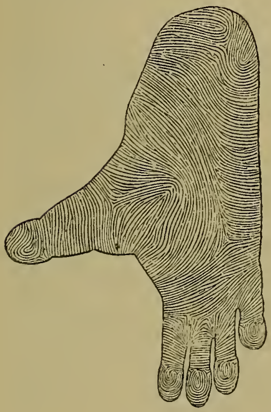


Fig. 9.—*Sole of the foot of a West African negro, showing primitive characters in the middle and proximal regions* ($\times \frac{1}{4}$), *after O. Schlagenhaufen.*

absent, as in the rest of the Mammalia. The lemurs are further distinguished from the other Primates by the oval form of the pupil.[1]

With these scanty citations from the results of recent work our reference to comparative anatomy may conclude; the numerous recent researches into embryology which confirm in a most striking manner the conclusions of anatomy must be passed over in silence; but I cannot refrain from alluding to the unexpected evidence

[1] G. L. Johnson, 'Contributions to the Comparative Anatomy of the Mammalian Eye, chiefly based on an Ophthalmoscopic Examination' Phil. Trans. Roy. Soc. ser. B, vol. cxciv (1901) pp. 1–82, pls.

f 2

pointing to a very close connexion between Man and the anthropoid apes, which has been afforded during the last decade by a novel method of investigation. The germ of this method is to be found in those famous discoveries by Behring, to which we owe the serum treatment for diphtheria. It was these that led Uhlenhuth to undertake the experiments on blood-relationship to which I will now refer. In his first experiments he made use of ordinary white of egg; a solution of this was injected into a living rabbit, and after some days the rabbit was bled. The serum of the blood so obtained was then found to give a precipitate when mixed with the white of a hen's egg, but not with that of a duck's egg or, indeed, any other kind of egg.[1] In his next experiments Uhlenhuth substituted the blood of a hen for the white of its egg. The serum of the rabbit's blood was then found to give a precipitate with hen's blood, but with no other kind of blood. The blood of other animals was similarly injected, and found to produce a serum which gave similar results.

Further experiments showed that the test was not perfectly diagnostic, since the blood of animals closely related to the one whose blood had been injected also gave a precipitate with the resulting serum, though not in so large an amount. Thus the injection of horse's blood produces a serum which gives a weak precipitate with ass's blood, sheep's blood with goat's blood, and so on.[2]

Thus the method provides not only a means of identifying a particular kind of blood, but of estimating the degree of relationship between the blood of different kinds of animals. It was applied by Uhlenhuth to the Primates. Human blood was injected into a rabbit, and a serum obtained which gave a precipitate not only with human blood, but with that of the man-like apes; on the other hand, it gave no precipitate with the blood of the lower apes.

The investigation was then greatly extended by Mr. G. H. Nuttall, who made a vast number of comparative experiments, and introduced more exact quantitative methods.[3] As one result, it was shown

[1] Uhlenhuth, Deutsch. Med. Wochenschr. 1900, No. 6; an excellent summary is given in the same author's 'Ein neuer biologischer Beweis f. d. Blutverwandschaft zwischen Menschen- & Affengeschlecht.' Corresp. Bl. Deutsch. Gesellsch. Anthrop. München, vol. xxxv (1904) p. 114.

[2] Injections of the juice of flesh had precisely similar effects upon the blood of the rabbit, the serum giving a precipitate with the juice of the same kind of flesh as that which had been employed for the injections; in this way a means was discovered for detecting horseflesh in sausages.

[3] 'Blood Immunity and Blood Relationship, &c.' Cambridge, 1904. pp. 444.

that Man is very closely related by blood to the anthropoid apes, less closely to the Cercopithecidæ, and only remotely to the apes of the New World. With the lemurs his blood shows no more affinity than with the rest of the Mammalia. The relationship may be expressed by figures, according to the amount of precipitate obtained in experimenting with the various animals in question; it is given as a percentage in the following table:—

Man	100
Orang	80
Cynocephalus mormon	50
Cercopithecus petaurista	50
Ateles vellerosus	25
Lemur	0

Thus, by a number of independent lines of enquiry, all converging towards the same result, we are led to conclude that Man finds his nearest congeners in the higher apes, especially the gorilla and chimpanzee. Next to these follow with increasing remoteness the gibbon, *Semnopithecus*, the other lower Catarrhine apes, and the extinct lemurs. The question then naturally arises whether this series may not represent more or less approximately the successive stages in his ancestral descent.

A number of famous anatomists have thought that it does, and such a conclusion might almost seem obvious. The obvious, however, is always open to suspicion, and E. D. Cope,[1] as early as 1893, suggested another line of descent, from which the Catarrhini were excluded, the Anthropomorpha (among which Cope included Man) being directly derived from the ancient primitive Lemuroids.

The origin of Man in particular was sought, not among the existing man-like apes, but in some member of that group now extinct. In this, of course, there was nothing new, for no one, so far as I am aware, has ever regarded any living species of ape as the immediate ancestor of Man. Indeed many anatomists, Huxley in particular, have repeatedly insisted on the singular manner in which human characters are distributed among the existing Anthropoids, some making a nearer approach to Man in one direction, some in another; a fact which seems to suggest community of origin.

But the other proposal to derive the Anthropomorpha direct from ancestral lemurs was unquestionably new, indeed revolutionary, and the chief claim it has to our serious consideration lies in the remarkable sagacity which underlies so many of the other bold speculations

[1] 'The Genealogy of Man' American Naturalist, vol. xxvii (1893) pp. 316–35.

advanced by Cope. Yet the arguments on which it is based are of the slenderest character: so far as I can make out, they are two in number: first, that the Anthropomorpha are distinguished by the absence of anapophyses to the vertebræ, although these processes are well developed in monkeys; but, as Cope mentions in the same breath, they are also well developed in lemurs, and thus, apart from the fact that they occasionally make their appearance as vestigial traces among the Anthropomorpha, this argument loses all its force.

The second argument is to the effect that large-brained Lemuroids existed in North America during the Lower Eocene period and that they were provided with an Anthropomorph dentition, the Anaptomorphidæ being especially cited in this connexion. But the same statement is true of the Cercopithecidæ, which possess an equally Anthropomorph dentition, and thus this argument affords as little reason as the first for excluding the Catarrhini from the ancestral series.

Max Schlosser,[1] one of our first authorities on the palæontology of the Primates, has adopted to some extent Cope's position. His latest classification of this order is as follows:—

PRIMATES.

I. Suborder **Mesodonta** (Cope): Primitive i, c, and m. $\frac{\text{i } 3-2, \text{ c } 1, \text{ pm } 4, \text{ m } 3}{}$.

Section 1. **Pseudolemuroidini** (Schlosser): pm $\frac{4}{4}$.

Family 1. Hypsodontidæ: i $\frac{3}{3}$, claws.

2. Notharctidæ: i $\frac{2}{2}$.

3. Adapidæ: i $\frac{2}{2}$.

Section 2. **Palæopithecini**: pm reduced in number.

Family 1. Anaptomorphidæ: i $\frac{2-1}{2-1}$.

2. Tarsiidæ: i $\frac{2}{1}$.

Section 3. **Mixodectini**: i originally normal, 3, sometimes specialized, and $\frac{1}{1}$.

Family 1. Oldobatidæ: i $\frac{3}{3}$, i enlarged.

2. Microsyopidæ: i $\frac{1}{1}$, i enlarged.

[1] 'Beitrag zur Osteologie & Systematische Stellung der Gattung *Necrolemur* sowie zur Stammgeschichte der Primaten überhaupt' Neues Jahrb. Festband 1907) pp. 197–226.

II. Suborder **Lemuroidea**: i and c specialized, m primitive.

Family 1. Lemuridæ: i $\frac{2-0}{2}$, c $\frac{0}{1}$, c resembles i, m primitive.

2. Nycticebidæ: i $\frac{2}{2}$, c $\frac{0}{1}$, c incisor-like, m primitive.

3. Chiromyidæ: i $\frac{1}{1}$, c $\frac{0}{0}$, m quadritubercular.

4. Archæolemuridæ: i $\frac{2}{2}$, c $\frac{1}{0}$, m quadritubercular (approach Anthropoidea).

III. Suborder **Anthropoidea**: i $\frac{2}{2}$ normal, c and m specialized.

Family 1. Arctopithecidæ: pm $\frac{3}{3}$ m $\frac{2}{2}$.

2. Cebidæ: pm $\frac{3}{3}$, m $\frac{3}{3}$.

3. Cercopithecidæ: pm $\frac{2}{2}$, m with opposed tubercles.

4. Simiidæ: pm $\frac{2}{2}$, m with alternating tubercles, hallux opposable.

5. Hominidæ: pm $\frac{2}{2}$, m with alternating tubercles, hallux not opposable.

Schlosser would exclude the Cercopithecidæ from the direct succession, on the ground that in Man and the man-like apes the tubercles of the upper molars bite between those of the lower molars, while in the Cercopithecidæ they meet in opposition. As Schwalbe points out, a slight difference in the relative length of the lower jaw would suffice to abolish this distinction.

Schlosser also lays great weight on the resemblance of the ancient Lemurs of Madagascar to the Anthropoids, but Elliot Smith,[1] who has paid special attention to this question, asserts in the most definite manner that he can discover no affinity between the apes and these fossils, and he places *Nesopithecus*, *Megaladapis*, and possibly *Chiromys* within the fringe of the Indrisinæ. He remarks that

'These lemuroids are the most diversely modified members of the most highly specialized family of the Prosimiadæ . . . they are the furthest removed from . . . the very early and remote ancestor from which both lemurs and apes could have sprung.'

M. Alsberg and H. Klaatsch[2] find in the primitive character of

[1] 'On the Relationship between Lemurs & Apes' Nature, May 2, 1907, p. 7.

[2] M. Alsberg, 'Die Abstammung des Menschen & die Bedingungen seiner Entwickelung' 1902 (I have not been able to consult this work); H. Klaatsch, 'Entstehung & Entwickelung des Menschengeschlechtes' Weltall & Menscheit, vol. ii, 1902.

the human hand an argument in favour of a remote origin. But there is no necessity to go back to the Prosimiadæ for an explanation of this. The general plan upon which the human hand is constructed is the same as that of the apes, and the details are so similar that Huxley used to cite the resemblance between the hand of Man and the man-like apes—a resemblance which is remarkably increased when the anomalous variations in the musculature are taken into account—as one of the clearest signs of close taxonomic affinity. The differences which distinguish the human hand, however primitive in appearance, are necessary adaptations connected with its perfection as a universal instrument.

There seems to be an increasing tendency on the part of many modern biologists to seek for the origin of any particular species, not in the vicinity of its closest existing relatives, but in some remote extinct ancestor; and as a consequence we may watch in process of growth a tree of life which for the greater part is a pure product of the imagination.

After admitting that Man may be traced to a primitive ancestor which is common to him and to all the man-like apes, we are next asked to believe that this ancestor was derived from another still more primitive, which was common to it and to the lower apes. Nor does the process stop there—a long procession of such ancestors, each embodying some human characteristic, stands behind. Thus Dr. W. Wiedersheim[1] in his latest work remarks:—

'The scientific results of the last few years have revealed the surprising fact that in tracing out this path (of human development) we must not confine ourselves to the line of the Primates. On the contrary, many definite characters of a very primitive nature clearly indicate that the human genealogy, that is the genealogy of the Primates in general, dates from a stupendously remote period, in fact that its roots must lie much deeper than is generally supposed (in the case of many mammals lower in the scale than Man). Although so far we have failed to discover conclusive evidence of the existence of pre-Pleistocene man, yet Tertiary man is a necessary postulate. Indeed, I am firmly convinced that, not only in the Tertiary, but in much earlier geological periods, possibly even in the Palæozoic Era, lower forms were in existence which had already taken the path of development peculiar to the Primates.'

Thus, as a mere article of faith, the ancestral series of the Primates is carried through the lower mammals into the Reptilian phylum; nor does there appear to be any reason why we should stop at this point; the same logical process consistently carried out will lead

[1] 'Der Bau des Menschen' Tübingen, 1908, p. 275.

us in the end to an ancestral Protist, and thus speculative biology provides us with a new form of the doctrine of predestination.

The crowd of primitive ancestors which are beginning to inhabit the world of thought are mere logical abstractions, which may never have enjoyed any real existence in the flesh. Unfortunately, they involve another series of equally abstract existences, known as parallel lines of descent; if these lines in any way resemble those which rest on clearer evidence, they must have been provided with secondary branches, and thus whole phyla are created, which have this peculiarity, that they must have flourished in the past without leaving any trace of their existence in the stratified rocks.

Primitive ancestors no doubt we must have: they are extremely useful hypotheses serving to fill the gaps, unfortunately too wide and numerous, which interrupt the continuity of our knowledge. But their invention ought not to be a facile task—it should be the concluding effort of a complete review of all the facts; then only can these hypothetical forms have any claim on our consideration and respect.

It seems possible that some of the more improbable hypotheses with respect to the descent of Man may have arisen from an imperfect appreciation of the phenomena of regression. These are acquiring increased importance with our increasing knowledge of extinct forms, and, owing to their abundance in the fossil state, of the marine invertebrates in particular; among these no group affords more valuable instruction than the Ammonites. As they ascend in time they give rise to species which, in some cases, not only return to the general form and special features of ornamentation that characterize their simpler extinct ancestors, but they even reassume the minute peculiarities of an earlier form of suture-line.

In several well-ascertained cases the regression is not merely a stopping short at an early stage of the ontogenetic development; this proceeds till it reaches a climax, and then continues in a backward direction. For those who regard development as a phenomenon of memory, it is as though the organism, after repeating its lesson in the usual way, had then proceeded to say it backwards.

Thus an organism or an organ may not only return to a more primitive morphological state, but it may do so by retracing its steps along the very same path as that by which it had previously made its advance. In this way we may arrive at a simpler explanation of the primitive characters of the human hand or the human teeth than by an immediate recourse to a remote lemurine ancestor. Even if we were not provided with a knowledge of the laws of regression, the vast body of weighty evidence which indicates very close relations between Man and the gorilla or chimpanzee should alone suggest the wisdom of caution before drawing far-reaching conclusions from the presence of a few imperfectly discussed primitive characters. So far as the evidence extends, there seems to be absolutely no reason for the invention of an independent phylum connecting the ancestor of Man with the extinct primitive lemurs or Prosimiadæ, nor does it seem to me necessary to place the point of departure of the generic *Homo* much below that of the existing higher apes, or indeed of the gorilla and chimpanzee; it is, indeed, not unlikely that the origin of the gibbon lies below that of Man, and the gibbon is more readily linked on to the lower Catarrhine monkeys than to the Prosimiadæ.

We now approach the most speculative and difficult part of all the enquiries which relate to the origin of Man—that is, the history of the process by which he has acquired his especially distinctive characters. This question is hardly ripe for discusion, yet it has been much discussed.

The character which before all distinguishes Man from the ape is manifestly his intellect, or its instrument the brain; next to this is the faculty of speech, then the powers of the hand, and the habitually erect attitude; last of all come the dentition and the comparatively hairless skin.

I may perhaps be permitted to state, merely as a confession of faith, my belief that the really fundamental change, underlying all the rest, was the increasing growth of the intellectual powers, and this I regard as an ultimate fact as difficult of explanation as any other ultimate fact, such as the origin of variations or even of life itself. But, having made this admission, I shall not introduce it into any of the following speculations, which will be more in accordance with the prevailing philosophy of the day.

The first change which started the ape on the path towards Man was probably the assumption of the erect attitude. The existing man-like apes seem to be almost on the verge of this[1]; that they do not quite attain it may be connected with the fact that their home is in the midst of the forest, where the advantages of an

[1] It is interesting to note that the gorilla stands up when fighting. 'He stands up on his hind legs . . . . advances with clumsy gait in this position and attacks his enemy . . . . he parries the blows directed against him with the skill of a practised fighter; . . . . grasps his opponent by the arm and crunches it, or else throws [him] down and rends him with his terrible canine teeth.' Quoted from Koppenfels by R. Hartmann, 'Anthropoid Apes' London, 1882, p. 234.

arboreal life are all in favour of a climbing habit, for which consequently their limbs have become better adapted than for walking.

It would be very strange, however, if some ancestral members of this intelligent group had not endeavoured to escape the pressure of the environment by invading the plains or open country. Such a change of habitat would almost inevitably necessitate either the assumption of an erect attitude or a return to a more perfectly quadrupedal state. In the case of the baboons, who have exchanged the shelter of the woods for rocky fastnesses, the latter alternative has been accepted. That it was otherwise in the case of Man must be owing to some special reason, most likely because he had already begun to make important use of his hands. The erect attitude emancipated the hands from the service of locomotion, and thus afforded them full opportunity for the exercise of higher functions. It was not, in all probability, that the erect attitude was first acquired as a necessary preliminary, but that an increasing appreciation of the powers of the hand led to a more frequent adoption of that attitude, and thus the transformation of both organs probably proceeded *pari passu.*

The accomplishment of these transformations must have been accompanied by correlative changes in the structure of the brain; the motor-centres for the hand in particular would be called upon to respond to the various and coordinated movements which this organ now learnt to perform.

It would seem probable that ancestral Man at a very early stage of his development was a social animal; the gibbons are semi-social, congregating towards evening upon the open ground in small troops; the gorilla, though less social, leads a family life and behaves like a gallant gentleman in protecting his harem and offspring; he is said to stand with his back against the tree in which they lodge, keeping guard the whole night through; and among the lower apes the baboons are famous for their rudely organized societies with patriarchal leaders and appointed sentinels.

The social instinct has, no doubt, played an immense part in human evolution; but that we must not overestimate it is suggested by comparison of the social dog with the individualistic cat, or the baboons with the less social apes. No yawning chasm separates the intellectual powers of these opposed examples. Its importance in the case of Man seems to lie in the fact that it provided favourable conditions for the evolution of speech. How this was acquired will probably always remain a matter of pure speculation; prophetic symptoms may be recognized here and there among the lower animals, but nothing more definite—of true speech, even in its rudiments, there is no sign. We cannot venture to assert anything as to the rate of its evolution; it is usually assumed to have been laboriously slow, yet the inspiration of a happy thought sometimes leads to unexpectedly rapid developments.

But, whether fast or slow, we may feel sure that the evolution of this faculty was accompanied by a corresponding evolution of the structure of the brain. The motor-centres which govern the musculature of the vocal organs were immediately concerned; but still more important in its effects was the opportunity afforded for the exchange of ideas, as well as for their registration, accumulation, and co-ordination. Under this stimulus, if any, the brain might escape from the limitation which restricts its size in the apes and acquire that more ample volume which the increasing operations of the mind entailed.

In connexion with all speculations concerning the origin of Man there exists a preliminary difficulty which deserves our serious consideration. Whatever views we may hold as to the true sequence of events there can be no doubt that the process of human evolution extended over a considerable interval of time, and during this period ancestral Man was exposed to all the dangers which accompany phylogenetic infancy. By what means, then, was his existence secured? A man without weapons plunged into the midst of the savage wild is of all animals the most helpless. The man-like apes, although they have already exchanged claws for very human-looking nails, still retain formidable canine teeth; in the gibbon these are provided with a posterior edge of razor-like keenness, and in the gorilla they are veritable tusks. Man alone among the Anthropoids is destitute of natural weapons.

Some distinguished writers, Schœtensack[1] and Klaatsch, for instance, suggest that during his transformation ancestral Man found an asylum in Australia; and there secure, as in an earlier imagined paradise, from large and fierce carnivora, he acquired a walking foot by climbing trees with the aid of a rope, and learnt to speak by listening to the songs of singing birds.[2]

[1] O. Schœtensack, 'Die Bedeutung Australiens für die Heranbildung des Menschen aus einer niederen Form' Zeitschr. f. Ethn. vol. xxxiii (1901) pp. 127–54.

[2] H. Klaatsch, 'Entstehung & Entwickelung des Menschengeschlechtes' Weltall & Menschheit, vol. ii (1902) pp. 204 & 206: 'Die Belauschung der Stimme der Vögel . . . . mag auf die Förderung der Sprachfertigkeit und damit auf die Hebung der geistigen Fähigkeiten von Bedeutung gewesen sein.'

While nothing is known, nothing is impossible, but it seems on the whole more likely that human evolution was accomplished under the pressure of severe competition. If we abandon the view that Man commenced his existence as a puny creature retaining the primitive characters of the lemurs, and ascribe his origin to a point on the ancestral tree not far below that from which the chimpanzee and gorilla branched off, we may then attribute to him at the beginning a strong bodily frame and a dentition well fitted for the purposes of offence and defence. The orang, as Selenka informs us, is more than a match for the dangerous carnivora with which he has to contend, and the gorilla is the monarch of the woods. Given a strong ape-like animal with social instincts wresting his sustenance from the wild beasts of the plains, and the evolutional path to Man lies open. The erect attitude, the dexterous hand, and the enhanced intelligence are not inconsistent with the possession of brute force and brutal characters; but, once acquired, they render possible another acquisition and this of tremendous import. A pointed stick and the notion of using it to thrust, and we have the primitive spear. Once armed with this the necessity for natural weapons vanishes. The massive jaws and fighting teeth can now be dispensed with, and may safely undergo a regressive development with adaptation to purely alimentary functions. The same fate attends the mighty brow-ridges, for it is extremely unlikely that these are intended, as Darwin supposed, to protect the eyes: Keith has pointed out that the temporal ridges in the male gorilla meet to form the sagittal crest at the time when the canines are cut, and thus stand in connexion with the powerful musculature of the jaw; the frontal ridge follows as a mechanical device to strengthen the skull transversely, thus enabling it to resist the stresses set up by the action of the muscles.

Thus, as Man ceases to be dependent on natural weapons and learns to subject the outside forces of the universe to his will, the marks of the brute gradually disappear, the ape fades away, and Man is increasingly revealed.

Such scanty information as we possess relating to the bodily structure of primitive Man is in complete harmony with this suggestion. As already pointed out, the dentition of the Heidelberg jaw—the oldest known—is completely human, while the jaw itself is semi-simian. Thus, even at this comparatively late stage, the brutal characters inherited from the ape, though waning, have not wholly disappeared. That this interpretation is correct, and that the case is not one of adaptation to the circumstances of the time, is suggested by the fact that many wild races of the present day, living under much the same conditions and provided with much the same appliances as the early Palæolithic men of Europe, are furnished with jaws which are as completely human as their dentition. That the characters of the human jaw are a comparatively recent acquisition is suggested by their notorious variability; Portal[1] remarked, as early as 1803, 'Il n'y a point d'os dans lequel on trouve de plus grandes différences que dans celui de la machoire inférieure,' and with this citation Virchow heads his paper on the Schipka jaw. Ascending in the scale of time we next encounter the remains of Neandertal man, representing the only race so far known to have inhabited Europe during Mousterian days. While essentially human it still presents numerous reminiscences of a simian ancestry. On the one hand, we have a brain of unusual magnitude, a human dentition, a human hand, and a human foot; on the other, a jaw not yet provided with a chin, great frontal ridges, and an elevated inion pointing to a brutal development of the muscles at the back of the neck.

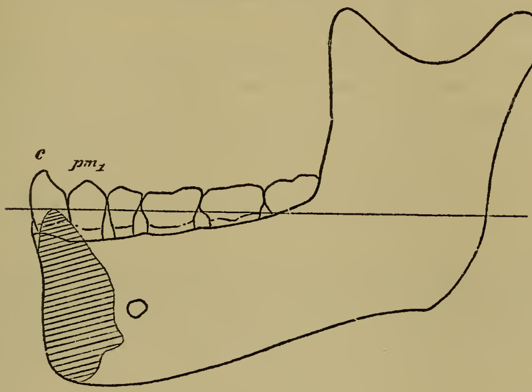
Even at the present day the useless frontal torus still survives, though in a more or less modified form; sporadic instances occur now and again among the civilized peoples of Europe, and it is a constant characteristic of the male Australian aborigine. In the search for simian vestiges these aborigines furnish indeed a most fertile field—even the teeth 'throw back' occasionally to an earlier stage, and projecting canines may sometimes be met with which recall the days when these were Man's fighting weapons. In the example shown in fig. 10 (p. lxxxvii) the left canine projects 4 or 5 millimetres above the apex of the adjacent premolar; and, though the incisors are missing, yet, judging from signs of wear, it must have projected a corresponding amount beyond these also.

How little we really know concerning the true course of human evolution is impressed upon us by the paucity of the evidence which we are able to adduce directly bearing on such speculations as we have considered. Nature no doubt is a strict adherent to logic, but she betrays a singular want of method in recording the steps of her argument. Our chief hope of additional knowledge rests on the chance of some fortunate discovery. The evolution of the elephant was involved in obscurity up to a few years ago, yet all the while its ancestral remains were lying exposed to view in the sands of the

[1] A. Portal, 'Cours d'Anatomie médicale' Paris, vol. i (1803) p. 190; R. Virchow, 'Die Kiefer aus der Schipka-Höhle, &c.' Zeitschr. f. Ethn. vol. xiv (1882) p. 277.

Fayûm awaiting the advent of Dr. Andrews, and the osteology of the Neandertal race was known only in piecemeal until Prof. Boule described the skeleton of La Chapelle aux Saintes from a district so

Fig. 10.—*Lower jaw of an Australian man, to show the projecting canine* (c). (× $\frac{2}{3}$.)



well worked over as the South of France. Many parts of the world, in Africa, Asia, and Australia, still await investigation, and at any moment the pick and shovel of advancing industry may unearth some link in the chain of evidence more precious than all the gold of the Rand.

It may be remarked, in conclusion, that, so far as the evidence extends, Man seems to have attained at a comparatively early stage the full powers of his intellect; his subsequent advance has been due less to its continued development than to its constant exercise, and especially to the perfection of speech, its great instrument. Many great thinkers have expressed themselves with just emphasis on this point, and a happy allusion to it is made by Huxley, who remarks that of all animals Man

'alone possesses the marvellous endowment of intelligible and rational speech, whereby, in the secular period of his existence, he has slowly accumulated and organized the experience which is almost wholly lost with the cessation of life in other animals; so that now he stands raised upon it as on a mountain-top, far above the level of his humble fellows, and transfigured from his grosser nature by reflecting here and there a ray from the infinite source of truth.'

The whole history of Man, so far as it is known to us, has been one long continuous advance, marked stage after stage by momentous discoveries; already on his first emergence from obscurity in

Mousterian times we find him in possession of the art of kindling fire; he knew how to fashion weapons and to wield them, and he had arrived at the belief that life is not ended with the grave.

Through the succeeding stages of the Palæolithic Epoch we witness a rapid improvement of implements and weapons, as well as the invention of new ones, and, most remarkable of all, the birth of art and its early efflorescence.

The close of the Palæolithic Epoch is marked by a considerable gap in our knowledge; but, as we enter the next succeeding or Neolithic Epoch, we discover evidence of another great forward step: the wild roaming life of the hunter has been exchanged for a pastoral existence in settled communities, Man has learnt to domesticate the animals of the chase and in so doing he has become domesticated himself.

No great interval separates the Neolithic Epoch from the early civilizations of Mesopotamia and Egypt, which are distinguished by an extraordinary advance in every direction, in art, science, and religion, and especially by the successful analysis of the spoken word into its elementary sounds and the application of this great achievement to the art of writing. Hence, at this stage, we approach the realm of history.

Thus we may conclude that, ever since its first appearance, the human race has given birth to great discoverers and great discoveries; even the Palæolithic Epoch may have nurtured its Watt, its Newton, or its Raphael. But it has remained for our own age to undertake consciously the systematic search for truth, and almost daily we are rewarded by an increasing insight into the nature of the outer world and a corresponding mastery over it.

This advance seems destined to continue, but it will probably be accompanied by unexpected developments; religion and philosophy have not spoken their last word, and the mysteries of the inner world disturb the age with premonitions of a new birth.

> . . . . ‘Prognostics told
> Man’s near approach: so in man’s self arise
> August anticipations, symbols, types
> Of a dim splendour ever on before
> In that eternal circle life pursues.’

February 23rd, 1910.

Prof. W. W. WATTS, Sc.D., M.Sc., F.R.S., President, in the Chair.

Leonard Miles Parsons, Hawkswell House, Keynsham, near Bristol, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communication was read :—

'Metamorphism around the Ross of Mull Granite.'[1] By Thomas Owen Bosworth, B.A., B.Sc., F.G.S.

The following specimens and maps were exhibited :—

Rock-specimens, microscope-sections, and lantern-slides, exhibited by T. O. Bosworth, B.A., B.Sc., F.G.S., in illustration of his paper.

Geological Survey of England & Wales: 1-inch Map, new series, Sheet 142, Melton Mowbray; and Sheet 347, Bodmin, 1909 (colour-printed), presented by the Director of H.M. Geological Survey.

March 9th, 1910.

Prof. W. W WATTS, Sc.D., M.Sc., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The PRESIDENT announced that the Council had awarded the Proceeds of the Daniel Pidgeon Fund for 1910 to Mr. ROBERT BOYLE, B.Sc., who proposes to make a series of researches on the Carboniferous Building-Stones of Scotland.

The following communication was read :—

'The Carboniferous Succession in Gower (Glamorganshire).' By Ernest Edward Leslie Dixon, B.Sc., F.G.S., and Dr. Arthur Vaughan, B.A., F.G.S.

The following specimens were exhibited :—

Rock-specimens, microscope-sections, and lantern-slides, exhibited by E. E. L. Dixon, B.Sc., F.G.S., in illustration of his and Dr. A. Vaughan's paper.

Specimens of riebeckite-granite from Northern Nigeria, exhibited by Dr. J. D. Falconer, F.G.S.

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

March 23rd, 1910.

Prof. W. W. WATTS, Sc.D., M.Sc., F.R.S., President,
in the Chair.

George Wood Cook, B.Sc., Principal of the Normal Practising School, Normal School Lodge, Bloemfontein (O. R. C.); Arthur Hubert Cox, M.Sc., Ph.D., Assistant-Lecturer and Demonstrator in Geology, in King's College, London, W.C.; David Davies, Ty Talwyn, Clydach Vale, Rhondda (South Wales); Frank Fowler, Commissioner of Lands & Mines, Georgetown (British Guiana); Harry Hannay, 10 Temple Fortune House, Hendon, N.W.; and George Bertram de Betham Kershaw, Engineer to the Royal Commission on Sewage Disposal, Ingleside, West Wickham (Kent), were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT referred in sympathetic terms to the recent decease, at the age of 98, of Prebendary WILLIAM HENRY EGERTON, who had been a Fellow of the Society since 1832.

The following communication was read :—

'On *Palæoxyris* and other Allied Fossils from the Derbyshire and Nottinghamshire Coalfield.' By Lewis Moysey, B.A., M.B., B.C., F.G.S.

Specimens of *Palæoxyris*, *Vetacapsula*, and *Fayolia*, as also lantern-slides, were exhibited by Dr. L. Moysey, B.A., F.G.S., in illustration of his paper.

April 13th, 1910.

Prof. W. W. WATTS, Sc.D., M.Sc., F.R.S., President,
in the Chair.

Herbert Basedow, M.D., Ph.D., M.A., B.Sc., Kent Town, Adelaide (South Australia); Robert George Carruthers, Geological Survey of Scotland, 33 George Square, Edinburgh; William Garrard Snowdon Gard, LL.B., 9 Rosslyn Hill, Hampstead, N.W.; Edward William Tunbridge, B.Sc., Rocklands, Woodbourne Road, Edgbaston, Birmingham; John Wells, Maison Coronel, Shareh Sheikh abu Sibaa, Cairo; and Arthur H. Williams, 385 Holloway Road, N., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Volcano of Matavanu in Savaii.' By Tempest Anderson, M.D., D.Sc., F.G.S.

2. 'Notes on the Geology of the District around Llansawel (Carmarthenshire).' By Miss Helen Drew, M.A., and Miss Ida L. Slater, B.A. (Communicated by Dr. J. E. Marr, F.R.S., F.G.S.)

The following specimens, lantern-slides, etc., were exhibited :—

Lantern-slides exhibited by Tempest Anderson, M.D., D.Sc., F.G.S., in illustration of his paper.

Specimens of rocks and fossils from the Llansawel District (Carmarthenshire), exhibited in illustration of the paper by Miss Helen Drew, M.A., and Miss Ida L. Slater, B.A.

Specimen with serial sections of *Caninia cylindrica* from Linney Down (South Pembrokeshire), exhibited by permission of the Director of H.M. Geological Survey; and photographs of serial sections from polished surfaces (a process involving the minimum of loss in cutting), taken by a new method by J. W. Tutcher, of Bristol, and exhibited by Dr. A. Vaughan, B.A., F.G.S.

Geological Map of Victoria; and Mineral Map of Victoria, showing the principal localities, both on the scale of 16 miles to the inch, 1909. Compiled and presented by E. J. Dunn, F.G.S., Director of the Geological Survey of Victoria (Australia).

April 27th, 1910.

Prof. W. W. Watts, Sc.D., M.Sc., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On the Evolution of *Zaphrentis delanouei* in Lower Carboniferous Times.' By Robert George Carruthers, F.G.S.

2. 'The Carboniferous Limestone South of the Craven Fault (Grassington-Hellifield District).' By Albert Wilmore, B.Sc., F.G.S.

The following specimens, etc., were exhibited :—

Specimens, microscope-sections, and lantern-slides of corals, exhibited by R. G. Carruthers, F.G.S., in illustration of his paper.

Fossils, microscope-sections, and lantern-slides, exhibited by A. Wilmore, B.Sc., F.G.S., in illustration of his paper.

Geologische Spezialkarte der Œsterreichisch-Ungarischen Monarchie, $\frac{1}{75,000}$—S.W. Gruppe: Sheets 78, 116, & 118; and N.W. Gruppe: Sheets 51 & 85, 1908–1910; presented by the Director of the K.-K. Geologische Reichsanstalt, Vienna.

May 25th, 1910.

Prof. W. W. Watts, Sc.D., M.Sc., F.R.S., President, in the Chair.

F. Frank Ogilvie, C.B., Secretary to the Board of Education, 15 Evelyn Gardens, South Kensington, S.W.; Raymond Edward Priestley, care of Prof. T. W. E. David, The University, Sydney (New South Wales); John Stansfield, B.A., Lecturer in Geology in McGill University, Montreal (Canada); Leonard Francis Wallis, B.Sc., 25 Derby Avenue, North Finchley, N.; and Arthur E. V. Zealley, Assoc.Roy.Coll.Sci., Rhodesia Museum, Bulawayo (Southern Rhodesia), were elected Fellows of the Society.

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

The List of Donations to the Library was read.

The Address which it was proposed to submit to His Majesty the King, on behalf of the President, Council, and Fellows, was read as follows, and the terms thereof were approved :—

'To the KING'S MOST EXCELLENT MAJESTY.

'May it please Your Majesty,

'We, Your Majesty's most dutiful and loyal subjects, the President, Council, and Fellows of the Geological Society of London, humbly beg leave to offer to Your Majesty our deepest and most heartfelt sympathy in the great and sudden sorrow which has fallen upon You, and most respectfully to express the grief that we, in common with all Your Majesty's subjects, feel at the great loss which has afflicted the Nation and the Empire in the tragic death of our late beloved and revered Sovereign King Edward VII, in the full vigour of his services for the welfare of humanity and the peace of the world.

'In the depth of our sorrow we find comfort in the assurance that the sceptre of our wise King passes into the hands of one who will keep ever before him the high destiny of the Nation, and we venture humbly to offer our fervent congratulations to Your Majesty on Your accession to the throne, which, under the sway of Your ancestors, has become the greatest in the world.

'We trust that the knowledge of the mineral structure of the earth, for a century the special care of this Society, may continue to grow and flourish under the rule of Your Majesty as it has done under that of Your illustrious predecessors.

'That Your Majesty's reign may be a long one and that it may overpass in ustre even those of the great Kings and Queens that have preceded You, s the earnest prayer of Your devoted subjects.'

The President then read the draft of a circular letter regarding the enhanced price of the Geological Survey Maps, which was to be sent to all institutions in the United Kingdom that are likely to be interested in the matter, bespeaking their support for a respectful representation to the Lords of H.M. Treasury. A draft of the terms in which this representation was to be made was also read.

The following communications were read:—

1. 'Dedolomitization in the Marble of Port Shepstone (Natal).' By F. H. Hatch, Ph.D., M.Inst.C.E., F.G.S., and R. H. Rastall, M.A., F.G.S.

2. 'Recumbent Folds in the Highland Schists.'[1] By Edward Battersby Bailey, B.A., F.G.S.

The following specimens, lantern-slides, and maps were exhibited:—

Rock-specimens, microscope-sections, and lantern-slides, exhibited by Dr. F. H. Hatch, M.Inst.C.E., F.G.S., and R. H. Rastall, M.A., F.G.S., in illustration of their paper.

Geological Survey of England & Wales:—1-inch Map, new series, Sheet 33—Stockton (drift), colour-printed, 1910; Sheet 229—Carmarthen (solid & drift), colour-printed, 1910; and Geological Index-Map (1 inch = 4 miles) Sheets 9 & 10, 11, 15, 17 & 18 (solid), colour-printed, 1910, presented by the Director of H.M. Geological Survey.

June 15th, 1910.

Prof. W. W. Watts, Sc.D., M.Sc., F.R.S., President, in the Chair.

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

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Natural Classification of Igneous Rocks.' By Dr. Whitman Cross, F.G.S.

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

2. 'The Denudation of the Western End of the Weald.' By Henry Bury, M.A., F.L.S., F.G.S.

3. 'An Earthquake Model.' By John William Evans, D.Sc., LL.B., F.G.S.

The President read the following communication received from Mr. S. S. Buckman, F.G.S.:

'May 29th, 1910.

'In my paper on "Certain Jurassic Species of Ammonites" (Quart. Journ. Geol. Soc. vol. lxvi, 1910, p. 90) I proposed for a new genus the name *Burtonia* (p. 97). With that kind helpfulness which is so distinctive of American scientific workers, Dr. W. H. Dall writes to say that this name is already in use—by Bonaparte for a bird and by Bouvignat for a naiad. I therefore desire to substitute the name *Bredyia* for *Burtonia* in my paper: *Bredyia* is from the River Bredy (pronounced Breedy, Briddy) which flows through Burton Bradstock, and its name presumably furnishes the syllable Brad. I wish to record my thanks to Dr. Dall for his kindness.

'The opportunity may be taken to rectify a misprint: in p. 68, line 7 from the top, *for* "striking" *read* "sticking."'

An earthquake model was exhibited by Dr. J. W. Evans, LL.B., F.G.S., and Mr. F. J. Bakewell, in illustration of Dr. Evans's paper.

The following maps were exhibited:—

Thirty-four sheets of the 6-inch Geological Survey Map of Scotland (solid and drift), presented by the Director of H.M. Geological Survey.

Sheet 5, Zeerust, and Sheet 6, Mafeking, on the scale of $2\frac{1}{2}$ miles to the inch, of the Geological Survey Map of the Transvaal, presented by the Director of that Survey.