15. *The LOCH AWE SYNCLINE (ARGYLLSHIRE).* By EDWARD BATTERSBY BAILEY, B.A., F.G.S. (Read February 26th, 1913.)

[PLATES XXXI & XXXII.]

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I. INTRODUCTION.

THE district described in the present paper forms portion of the low coastal region of Argyllshire, and presents few physical difficulties to the investigator. There are, however, other difficulties, resulting from the fact that igneous and sedimentary schists occur together here in about equal proportions, and have been alike subjected to a system of small-scale isoclinal folding; moreover, though lavas are well represented, fully half the igneous schists are sills, and so are of little use for stratigraphical purposes.

Under the circumstances, it is not surprising that progress has been slow. Macculloch, writing in 1819 [1, p. 292],¹ did himself less than justice, for he seems to have decided against the igneous origin of any of the schists of the region, erecting his Chloritic Formation to include the whole assemblage. In regard to structural matters he was more fortunate, for he gave a clear account of the lie of the rocks in the southern part of the district, where he located

'a line of vertical beds . . . towards which the strata converge on each side, both from the south-eastern and north-western boundaries'

[1, pp. 288-89]. In nature, of course, the line is rather vague, being more correctly designated as a narrow belt, where both bedding and cleavage are often extremely steep or vertical. This belt runs from the eastern shores of Loch Sween, north-north-eastwards through the southern end of Loch Awe. For some miles to the south-east of its course the prevalent dip of both bedding and cleavage is towards the north-west, and *vice versa*. There is also a tendency for the angles of inclination to be higher near the central belt than at a distance; but this does not preclude the existence of many open anticlines and synclines, affecting bedding, not cleavage, quite close up to the central line.

¹ The numerals in brackets refer to the Bibliography, § VI, p. 298.

There followed a long interval during which very little was done; but at last, in a paper read in 1860, the late Mr. Jamieson [2] demonstrated the truly igneous nature of many of the schists. As a matter of fact, their porphyritic and other igneous structures are frequently preserved in great perfection; in other instances, however, careful comparison and examination are necessary before a confident opinion as to their nature can be entertained. Mr. Jamieson called all these igneous rocks 'greenstones'; but the term 'epidiorite' has been so commonly applied to them since, that it will be used in the sequel. He gave an excellent account of the various sedimentary schists which accompany the epidiorites. He also advanced the view that the structure of the district is synclinal; but, when we look into the matter, we find that he had nothing to go upon save the inward inclination of the strata, and this, considering that isoclinal folding is prevalent, is not in itself a sufficient criterion.

In 1885 Mr. J. B. Hill began mapping the district for the Geological Survey, and by degrees brought order out of chaos. Half of the area included in the appended map (Pl. XXXII) has been surveyed by him, and the results obtained have been fully set forth in the maps and memoirs of the Survey and in papers communicated to this Society. We may notice especially a paper [7] published in 1899, which incidentally presents his position in regard to both structure and succession. His two main achievements are, I think, the recognition of the Loch Awe Syncline and the separation of the sedimentary complex of the district into two divisions:—the Loch Awe Group and the Ardrishaig Phyllites. It is true that he never vouchsafes a clear statement as to how the existence of the Loch Awe Syncline can be demonstrated; but, for the following two reasons, it seems mere justice to accord to him the credit of the discovery:—

1. It was Mr. Hill who first correlated the Craignish Phyllites, on the north-west side of the Loch Awe outcrop, with the Ardrishaig Phyllites on the south-east.

2. It was he, again, who mapped the Ardrishaig Phyllites across the general strike of the Loch Awe Group, at the northern end of the loch: where, once the mapping has been accomplished, the superposition of the Loch Awe Group upon the Ardrishaig Phyllites may be quite well described as self-evident.

Although Mr. Hill did the lion's share of the work, he had many collaborators as time went on. In the nineties Mr. C. T. Clough mapped the greater portion of the Ardrishaig Phyllite outcrop in Cowal, on the south-east side of Loch Fyne. About the same time the late Mr. R. G. Symes entered the district from the north-west, and became responsible for a limited area in the neighbourhood of Loch Avich. In 1895 Mr. H. Kynaston joined the ranks of the investigators, and surveyed a considerable portion of the district near the northern end of Loch Awe, especially that part which lies on the western side of the loch. His work was brought to a close when he went to the Transvaal in the spring of 1903. Meanwhile Mr. Hill's active co-operation had well-nigh ceased:

for he had been transferred to the English staff in 1897, and most of his time was thenceforward occupied in Cornwall. In 1901 Dr. B. N. Peach came into the district, and, with the late Mr. J. S. Grant Wilson and Mr. H. B. Maufe, carried the survey down the two sides of Loch Craignish; the Craignish peninsula itself fell mainly to Mr. Maufe. Later all three mapped small disconnected areas in the more southern part of the district; Dr. Peach undertook the examination of the Tayvallich peninsula himself, there making a most important discovery to which I shall return presently. In 1904 Dr. Peach left the West Highlands for Ross-shire, and Mr. Clough returned once more to Argyllshire. Mr. Wilson died in 1908, and Mr. Maufe left for Rhodesia in 1910. By this time mapping in the district had already been brought to a close (1906), but the southernmost of the 1-inch maps (Sheet 28), with its explanatory memoir, did not appear till 1911. My own connexion with the district dates from 1902, when I started work south of Loch Crinan. The conditions were very advantageous, as Dr. Peach was making geological history rapidly in those days, and always kept me in touch with his latest results. For a couple of seasons Mr. G. W. Grabham was working on the two sides of Loch Caolisport, along with Mr. Clough; but Africa claimed him too, and in 1906 he went to the Sudan. In the same year Mr. W. B. Wright also undertook the mapping of a small area east of Loch Caolisport, thus helping to complete the survey.

Naturally, as a result of so much co-operation, a great advance in our knowledge of the district was achieved. It is the purpose of the present paper to develop two somewhat important points, concerning which it seems to me that conclusions previously arrived at and published by Mr. Hill call for modification:—

1. Dr. Peach has shown that the epidiorites of the region include many volcanic rocks, whereas Mr. Hill regards them all, in the district which he has mapped, as intrusive.
2. I have myself introduced a considerable alteration in the reading of the stratigraphy of the Loch Awe Group.

These two points have a close connexion, for, as a matter of fact, Dr. Peach's discovery of a recognizable volcanic zone afforded a valuable additional clue in the disentanglement of the stratigraphical problem. It is convenient, however, to consider them apart, indicating very briefly the progress of research in each case.

II. THE VOLCANIC ROCKS.

In 1903 Dr. Peach discovered unmistakable pillow-lavas (Pl. XXXI) exposed on the coast south of Tayvallich, in association with black slates, limestones, and fragmental rocks like tuffs and agglomerates [13, p. 59]. The discovery came rather late in the day, for by this time all the district north of Tayvallich had already been mapped. Still, there were several records

which at once suggested that Dr. Peach's discovery would have a wide application in the northern part of the region. Extracts from such passages as bear upon this point are given below.

In 1897 Mr. Kynaston noticed that certain 'epidiorite sills,' not very far from the northern end of Loch Awe, showed peculiar structures which he attributed to mechanical deformation [6, p. 62]. In these sills there are, he says,

'numerous elongated and oval masses of the rock, around which the rest of the mass appears to sweep with a kind of flow-structure on a large scale. The whole section gives the appearance of gigantic "augen-structure." This is well seen in the burn at Ardbrecknish,¹ and again south-west of Kilchrenan.'

Dr. Peach, whose attention was drawn to some of these 'augen' by Mr. Kynaston, has told me that he regards them as deformed pillow-structures, an interpretation supported by photographs which may be consulted in the Survey collection (numbered C 772-774).²

Three years later Mr. Kynaston, in dealing with the same district, actually divided the epidiorites into two classes, grouping the more vesicular rocks among them as 'lavaform,' although he still regarded them as intrusive [9, p. 34]. Among his lavaform epidiorites are some, the description of which again suggests the existence of pillow-lavas; for we read that a

'rock, seen to the south-west of Kilchrenan, forms hard, roughly spheroidal cores, packed closely together in a dull fine-grained green schist.'

In summing up, he says:—

'We thus have varieties of the so-called "epidiorites," which in hand-specimens and in thin slices under the microscope have every appearance of true lava.'

It must be remembered that Mr. Kynaston left for South Africa in the spring of 1903, the year in which Dr. Peach later on obtained conclusive evidence of volcanic rocks south of Tayvallich. Accordingly, Mr. Kynaston's description in the Geological Survey memoir on the northern part of the district, published in 1908, was written with the idea that, despite appearances, all the epidiorites were really sills. We may note, however, that he supplies us with an additional locality for what one may reasonably interpret as a pillow-lava [16, p. 43]. After referring to a porphyritic vesicular epidiorite 2 miles south-south-east of Portsonachan, that is, on the eastern side of Loch Awe, about 3 miles south of Kilchrenan, he goes on to say,

'Not far from this locality there is a zone of rock, forming part of the same mass, which consists of numerous lenticular patches of a highly amygdaloidal rock embedded in a fine-grained greenish schistose matrix. . . . The rock has strongly the appearance of a highly vesicular basic lava.'

Farther south, about a quarter of a mile north-east of Loch a' Ghille, which lies a mile and a half south-east of Loch Avich,

¹ East of Loch Awe, 2½ miles east-south-east of Kilchrenan.

² There is a very fine series of photographs, taken by Mr. R. Lunn, in the Geological Survey collection, illustrating the geology of the Loch Awe district, especially the Tayvallich peninsula.

Mr. Symes had a similar experience [8, p. 62], for he met with an epidiorite outcrop, which he described as follows:—

‘The first few feet of this sill lying next to the dark slates present a highly vesicular and amygdaloidal texture. . . . Where the kernels have weathered out the rock is so cellular as closely to resemble a lava, which the rock may possibly have been.’

This observation was made in 1899, and its record constitutes the first published expression of opinion that volcanic rocks may exist in the district. I believe that it is fair to assign no small share of the credit of this observation to Dr. Peach.

It was presently found that this vesicular epidiorite was not an anomaly: for two years later Dr. Peach, the late Mr. Grant Wilson, and Mr. Maufe found it convenient to group the epidiorites of the large district lying between Loch Avich and Crinan Loch into two types—both types, as was the custom of the time, regarded as intrusive [12, p. 129]. One type is

‘a fine-grained rock, slaggy and highly vesicular at its margin, sometimes showing an arrangement of phacoids with vesicular outer layer and a non-vesicular interior suggestive of the “pillow-structure” visible in certain lava-flows. Sills of this rock are usually associated with phyllites and limestones, and apparently produce little or no metamorphic action upon the neighbouring sedimentary rocks.’

This absence of special metamorphism due to contact-alteration in the sediments accompanying the ‘lavaform epidiorites’ is a significant fact; for the regional metamorphism of the district is of so low a grade that contact-alteration accompanying the coarse-grained epidiorites is often very conspicuous. It was, of course, because many of the epidiorites of the region are obvious intrusions that there was such reluctance to admit that any of them might be lavas.

Although Dr. Peach and his collaborators did not re-examine the ground, it is not surprising to find them, in the memoir which appeared in 1909 [17, pp. 43, 45], expressing the opinion that, in the light of the Tayvallich evidence, some of the epidiorites should be regarded as true lavas. In support of this, Mr. Maufe published a very convincing sketch from his notebook of one of the vesicular sheets, showing well-defined pillow-structure [17, fig. 5, p. 45].

Turning eastwards, we encounter similar evidence, for in 1900 Mr. Hill met with highly vesicular epidiorites in the neighbourhood of Loch Awe. After describing a typical development of these rocks near Inverliver, he adds:—

‘Mr. Teall has pointed out the resemblance of these unaltered rocks to the volcanic accompaniments of the Lower Silurian radiolarian cherts in the South of Scotland and elsewhere.’ [8, p. 42.]

Dr. Flett has of late greatly added to the significance of this comparison of Dr. Teall’s, for he has extended it to include the lava-types of the western region already mentioned [17, pp. 50–56], and also of the Tayvallich country itself [18, pp. 84–96; see also 19]. Dr. Flett has furthermore expressed the opinion that the coarsely-crystalline intrusive epidiorites must be regarded as

genetically connected with the lavaform varieties. This conclusion is likely to meet with fairly general acceptance in regard to the

Fig. 1.—*Pillow-lava, Rudha Barain, western shore of Loch Awe, 1 mile east of Inverliver.*

{The 'pillow' showing concentrically-arranged vesicles measures 1 foot in length by 9 inches in breadth. The interspaces between the 'pillows' are occupied by sandy slate.}

majority of the intrusions, but it will be readily understood that petrological comparison of metamorphic igneous rocks *inter se* is a

peculiarly difficult field of research, and that the results obtained are often merely tentative.

I may complete this notice, of the accounts so far published of what I take to be the Tayvallich volcanic zone, with a reference to another

‘porphyritic epidiorite, which resembles a deformed pillow lava in which the interspaces between the pillows have been infilled with sediment.’

This last I found in 1905 on the shores of Loch nam Ban, east of Loch Sween [15, p. 92]. Farther north, along the same line of strike, vesicular epidiorites had previously been met with by Mr. Hill and Dr. Peach, and their distribution is such that the Loch-nam-Ban occurrence is linked on with those of the Loch Awe and Loch Avich region.

Fig. 2.—*Deformed pillow-lava, Rudha Cuillin, eastern shore of Loch Awe, a mile and a half east of Inverliver.*

[The ‘pillows’ are from 2 to 5 feet long.]

It is clear, then, that by 1905 a large body of evidence had accumulated, which was susceptible of the interpretation that Dr. Peach’s ‘Tayvallich volcanic zone’ was widely developed in the precincts of Loch Awe. It was, of course, highly desirable critically to re-examine this old evidence in the light of the new interpretation. An opportunity came with the publication of Sheet 37 and its accompanying memoir [14], an event which rendered the geology of the district accessible to the private worker in an altogether new sense. This occurred in 1905, and in the spring of 1906 I set out in my holiday-time to look into the matter for myself. On the ground, the evidence seems conclusive. The stream-section at Inverliver furnishes a very clear exposure of what, I think, must be regarded as a succession of vesicular lavas; while the shores of Loch Awe, not far away, exhibit the two highly-typical examples of pillow-structure illustrated in figs. 1 & 2 (pp. 285–86), which are exact copies of sketches made on the spot.

On such evidence as this—and it is repeated elsewhere in the neighbourhood—it appears justifiable to recognize the ‘lavaform’ epidiorites of Loch Awe and its vicinity as true lavas. This opinion is greatly strengthened by another circumstance which became apparent during my visit. There are numerous more or less conglomeratic beds associated with the lavaform epidiorites of the Loch Awe district, and in several cases they contain fragments of epidiorite of lavaform type. As this is a very important point, I shall illustrate it by citing in the following section a few examples of which I have taken definite record. Reference to similar occurrences, already recognized by Dr. Peach in the neighbourhood of Tayvallich, will be found in the Stratigraphical Appendix, § VII, p. 304.

III. EPIDIORITE-FRAGMENTS IN CONGLOMERATES NEAR LOCH AWE.

Mr. Hill has mapped a conglomerate or conglomeratic series¹ in the district between Glen Aray and Loch Awe. I examined very carefully the wide exposure that occurs half way across between the valley and the loch. The conglomeratic beds have a dark matrix, which may be either siliceous or slaty, and sometimes gritty with quartz- and felspar-grains. The most conspicuous pebbles, ranging up to a foot or more across, consist of pebbly quartzite or grit, and present a water-rounded form with little deformation. They had evidently hardened before they were made into pebbles. With these are associated a great number of small flattened fragments of epidiorite. It takes a good deal of searching to find large lumps, in the light of which the smaller pieces can be interpreted with confidence; but such do occur here and there—some of them very slaggy, and recalling at once in their appearance the pillow-lava series. The epidiorite-pebbles are much more deformed than those made of quartzite.

On the north-western shore of Loch Awe, opposite Innis Stuire (the island through which the line of section AB, Pl. XXXII, passes), the evidence is less certain. A conspicuous outcrop of pure banded black limestone is followed towards the lake by thin gritty limestone, containing big pebbles of quartz and pure limestone. Next comes a thin bed of breccia, exactly like the gritty limestone, save for the addition of very numerous fragments of a pale rock which is apparently epidiorite. This breccia is succeeded by a strong outcrop of gritty limestone, containing fragments of pure limestone, on the extreme shore-line. Finally, there is pebbly quartzite.

Recrossing Loch Awe, one meets with the following section at a lime-kiln, a quarter of a mile due south of Fincharn Castle, which stands on the shore opposite Inverliver. The rocks are

¹ This is the only one of the conglomerates, now dealt with, that it has been found practicable to show in the map, Pl. XXXII.

steeply inclined and often vertical, and their cleavage dips north-westwards at angles ranging from 45° to 30° . The section is given from north-west to south-east, without any suggestion as to the order of original superposition :—

	<i>Feet.</i>
Epidiorite	20
Quartzose slates.....	15
Epidiorite	4
Slates	3
Gritty limestone with large epidiorite-blocks	5
Pure dark-grey limestone.....	20
Similar limestone, except that it carries pebbles consisting mainly of quartz: these pebbles are few and scattered, and are at first small; but, farther on, they measure as much as half an inch across	42
Non-porphyritic epidiorite	40
Gap with pure limestone outcrops.....	30
Pure limestone, dark grey, bedding well preserved.....	3
Breccia containing very numerous fragments of fine-grained non-porphyritic epidiorite in a limestone matrix, which weathers in honeycomb fashion owing to an abundance of big crystals of black calcite; the matrix also contains numerous large grains of quartz	3
Strongly pebbled dark-grey limestone	150

Fig. 3.—*Breccia containing epidiorite-fragments interbedded between fine-grained limestone and gritty limestone. Limekiln, a quarter of a mile due south of Fincharn Castle, eastern side of Loch Awe, opposite Inverliver.*

[The bedding is steep, the cleavage gently inclined north-westwards.
Length of exposure figured = approximately 20 feet.]

The mode of occurrence of the breccia intercalated between pure and gritty limestones is illustrated in the above sketch, fig. 3.

On the two sides of Stronesker, which lies a mile and a half due south of the southern end of the loch, there are important

outcrops of limestone; both outcrops are pebbly and occasionally conglomeratic, with large grains of quartz and felspar and fragments of dark-grey pure limestone. A conglomeratic band east of the stream, east of Stronesker, contains abundant fragments of slaggy and compact epidiorite.

It may be asked how the presence of epidiorite-fragments in the conglomeratic beds of the district had not been recognized long ago. The answer is that they had been missed at first, when there was so much that was new to grapple with; but, in 1900, just at the close of his work, Mr. Hill did begin to realize their existence in certain cases. By this time, however, he had come to regard the intrusive nature of the epidiorites of the district as certain, and consequently interpreted any conglomeratic bed in which he recognized an epidiorite-fragment as a 'crush-conglomerate.' His views are expressed in a paper published in 1901 by this Society [10]. During my traverse in 1906, I did not visit any of the localities which Mr. Hill had described; but, in 1908, I had the opportunity of carefully examining the main example at Creag nam Fitheach, a mile south of the head of Loch Craignish. The breccia in this case consists of irregular blocks of the vesicular type of epidiorite, set in a scanty matrix of gritty limestone [17, pl. vi]. On so controversial a subject it must be admitted that there is room for two opinions. and Mr. Hill's interpretation is supported by the fact that it was adopted and applied to similar examples in the neighbourhood by Dr. Peach, Mr. Grant Wilson, and Mr. Maufe. At the same time, it seemed well-nigh incredible to me, when I saw the Creag-nam-Fitheach exposure, that such a breccia, in which individual elastic grains of quartz and felspar frequently interpose themselves between adjacent blocks of epidiorite, could have originated as a crush-conglomerate. Moreover, before my visit, Dr. Peach had repeatedly told me in conversation that, especially since his recognition of the Tayvallich volcanic group, he had grave doubts concerning the 'crush-conglomerates' of the northern part of the district, although he had for a time admitted their existence.

IV. THE STRATIGRAPHY.

In his 1899 paper, published by this Society, and in his subsequent writings for the Geological Survey, Mr. Hill put forward the following interpretation of the Loch Awe sequence:—

Grits and quartzites,
Black slate (locally green),
Limestone.

This he regarded as a descending sequence, modified by local passage of one type of sediment into another. His meaning is best expressed in his own words:—

'Although occupying a general position between the Ardrishaig slates on the one hand and the black slates on the other, the limestone does not rigidly adhere to that horizon, but may occur both within and above the black slate,

and it appears probable that it may sometimes occur within the Ardriahaig slates. Further, the black slates associated with the limestone are often feebly developed and may die out altogether, so that we get the limestone and grits in juxtaposition. Speaking generally, it may be stated that when the limestone departs from the normal type it partakes of the character of the sediment with which it is immediately associated' [14, p. 41].

Again, the black slates

'may occur above, or below, or in the limestone, and sometimes, by gradually becoming more calcareous, pass into the limestone, so that no line can be drawn where the limestone ends and the slates begin' [7, p. 474].

And, lastly,

'the green slates occur on the same stratigraphical horizon as the darker beds with which they are often associated, but their distribution is more local' [14, p. 43].

From the foregoing quotations it is clear that Mr. Hill's classification is somewhat vague. One circumstance which he emphasizes in all his descriptions is the essential unity of the Loch Awe Group. At the same time, he recognized that the deposition of the group was interrupted to some extent by contemporaneous erosion, resulting in the local production of a

'boulder-bed that occurs promiscuously throughout the series, and includes fragments of each lithological type' [14, p. 45].

He regarded it as likely that the 'boulder-bed' belonged to the same general phase of deposition as the coarse grits.

Dr. Peach for several years accepted Mr. Hill's main conclusions, save that he laid considerably more stress on the evidences of local erosion, and referred them all to the period during which the quartzite accumulated [14, p. 56; 17, p. 23]. In applying this view consistently, he was forced to assign many more outcrops of limestone to the quartzite division than had previously been done: for quite commonly the limestones of the Loch-Awe region carry large quartz and felspar-pebbles, exactly like those characteristic of the quartzite, and in many cases rock-fragments too. Here he came into conflict with Mr. Hill's observations: for the latter, in writing of the limestone, steadily maintained that the

'extreme divergences in type may all be met with in the same seam'
[14, p. 41].

Another, though minor, point of difference may also be noted: Dr. Peach thought that the grey and green slates and phyllites of the Loch Awe district represented a reappearance of the Ardriahaig Group, whereas Mr. Hill placed them in his Loch Awe Group, regarding them as a local facies of the black slates.

Dr. Peach's position in regard to the relation of the quartzite to the other sedimentary schists was based to a considerable extent upon analogies drawn from other parts of the Highlands, and, although never accepted by Mr. Hill, was adopted by the rest of us who were working at the time in the district. We were, however, not in a favourable position to form a judgment, since, although much of the region had been surveyed, no adequate geological map

had as yet been published. This want was rectified when, as already mentioned, Sheet 37 and its accompanying Memoir appeared in 1905 [14]. My visit to the district in the following spring led me to replace the previous classification of the Loch Awe Group by the following :—

Loch Avich Green Slates and Grits (volcanic rocks in the lower part),
Tayvallich Black Slates and Limestones (volcanic rocks throughout),
Crinan Quartzites and Grits,
Shira Limestone.

Of these zones, the Shira Limestone may be regarded as in part belonging to the underlying Ardrishaig Phyllite Group.

In the 1906 traverse, I found that this new classification held good in the central and eastern parts of the Loch Awe district and also in the Tayvallich peninsula, where I was fortunate enough to obtain clear evidence that the Tayvallich Slates and Limestones structurally overlie the main mass of quartzite. At the same time, I was still ready to believe that Dr. Peach's interpretation would hold without serious modification in the district south and west of Loch Avich, where he had originally developed it in conjunction with Mr. Maufe and Mr. Grant Wilson. I thought it likely, therefore, that the Craignish Phyllites would prove to belong to the Loch Avich division of the Loch Awe Group, and not to the Ardrishaig Group as heretofore supposed. However, this view has been perforce abandoned in the light of further research. On the publication of Sheet 45 with its explanatory memoir, in 1908, I immediately visited the northern part of the district, and in the same year I had the great advantage of a joint traverse with Mr. Maufe, in official time, through the country on both sides of Loch Craignish. The result of this more recent work was to vindicate Mr. Hill's correlation of the Craignish and Ardrishaig Phyllites—a correlation all along accepted by Dr. Peach; and, at the same time, to convince me that the north-western portion of the Loch Awe outcrop was susceptible of reinterpretation in such manner as to bring it into line with the rest of the district. About this time Dr. Peach realized the cumulative force of the evidence acquired, and so the two of us were able to co-operate in the description of the Tayvallich peninsula given in the memoir dealing with Sheet 28, which appeared in 1911. Since then I have not revisited the ground, except for a few days in 1912, when I returned to Loch Awe, and, among other things, examined the northern termination of the outcrop of the Loch Avich Slates and Grits.

Before giving the evidence for the new interpretation, I think it better to state quite clearly that it has not gained acceptance from Mr. Hill. We paid an official visit together to the Tayvallich peninsula in the spring of 1909, but Mr. Hill did not find the evidence presented to him sufficiently convincing to shake his old-established faith. His views upon the matter are set forth in the Survey Memoir [18, p. 61], where he indicates that his interpretation of the Loch Awe sequence has been influenced by the fact

that, in the neighbourhood of Dalmally, there is undoubtedly an extensive development of black slate or schist, and subordinate limestone interposed between the Ardrishaig Phyllites and a pebbly quartzite, of which last he speaks as the Loch Awe Grit. I have purposely excluded these northern rocks from the scope of the present paper, since I consider their relation to the Loch Awe Group a very much more difficult question to decide than is the sequence of the rocks actually included within the Loch Awe Syncline.

And now for the evidence upon which the present subdivision of the Loch Awe Group is based. It may be summarized under various headings :—

(1) Mr. Hill's contention that the Loch Avich Slates and Grits form part of the Loch Awe Group is justified by the nature of the grit or quartzite intercalations which accompany the slates: many of these agree precisely in character with the rocks of the main Crinan Quartzite.

(2) At the same time, the Loch Avich Slates and Grits furnish a definite stratigraphical horizon, as maintained by Dr. Peach. This much is apparent from the fact that their outcrop occupies a symmetrical position in the centre of the Loch Awe Syncline, and is, in its own central part, characterized by a complete absence of epidiorite.

(3) There is fairly conclusive direct evidence that the Loch Avich Slates and Grits structurally overlie all the other rocks of the Loch Awe Syncline. At the northern end of their outcrop, on the east side of Loch Awe, there is a very definite boundary between the slates and grits which form the central exposures and the surrounding epidiorites. In a north-easterly direction the sedimentary outcrop narrows and disappears, in a manner that almost certainly indicates the existence of a fold. It was obviously important to ascertain whether the disappearance of the sediments is the accompaniment of a north-easterly or of a south-westerly pitch: whether in fact the fold, if such there be, is anticlinal or synclinal. On visiting the exposure, it was found that grits are prominent where the sedimentary outcrop is wide, that is, towards the loch. They consist of strong pebbly quartzo-felspathic rocks with obscure bedding, so that their structure is not clear. Appearances suggest, however, that they occupy a syncline having a triplex termination. After the grit ceases, a considerable thickness of green cleaved mudstone with widely-spaced, faintly-marked bedding occupies the whole breadth of the narrowing sedimentary outcrop, and persistently shows south-easterly pitches, in accordance with the view that the outcrop is of synclinal nature.

(4) The Tayvallich Black Slate and Limestone division has an assemblage of characters which distinguishes it from the Shira Limestone. Among these characters the importance of black slate

in the Tayvallich Division, together with the frequent occurrence of pebbly and conglomeratic beds, may be noticed at once. Although Mr. Hill did not attach stratigraphical importance to these differences, he did not fail to record them [14, pp. 50–51]. Thus, in describing the district lying between Loch Fyne and Loch Awe, he says that the limestone, where it crops out at the margin of the Loch Awe Group—that is, according to the new interpretation, in the Shira position,—

‘although usually sandy, rarely exhibits the coarse gritty character seen further to the north-west. There is either an entire absence of black slate, or it occurs in very limited amount. Further, the boulder-bed has not been observed at that margin, so that, speaking broadly, the occurrence of the boulder-bed, the gritty limestone, and black slate in appreciable quantity appear to hang together. Moreover, the marginal limestone, where not associated with black slate, is seldom of the dark graphitic hue which it assumes when in association with well-developed black slate.’

To these differences it may be added that the Tayvallich Volcanic Zone, with its accompaniment of breccias containing epidiorite-fragments, is very strongly developed in the Tayvallich Slates and Limestones, and in the adjacent portion of the Loch Avich Division, but is completely unrepresented in connexion with the Shira Limestone.

(5) The associations of the Tayvallich Slates and Limestones distinguish this division from the Shira Limestone. The Tayvallich Division in the neighbourhood of Loch Awe is interposed between the Loch Avich Slates and Grits, in the centre of the syncline, and the surrounding Crinan Quartzite. The Shira Limestone, on the other hand, is admittedly interbedded between the Crinan Quartzite and the Ardrishaig Phyllites beyond. It is claimed that the differences, cited in this and the preceding section, are a proof of the stratigraphical distinctness of the two divisions.

(6) Structurally, the Tayvallich Slates and Limestones lie above the Crinan Quartzite, while the Shira Limestone lies below it. This structural proposition is, of course, quite distinct from the stratigraphical proposition argued above. It is based upon three main sections:—

(6 a) The relation of the Tayvallich Slates and Limestones to the Crinan Quartzite is exposed to perfection in the Tayvallich peninsula, and has been described by Dr. Peach and myself in the Survey Memoir [18, pp. 65–68]. The reader is referred to this description for details, which are illustrated by a text-map on the scale of 3 inches to the mile. The following are the main conclusions:—There is no sharp line of separation between the Tayvallich Division and the Crinan Division of the Loch Awe Group: the two are united by an intermediate zone in which there is conspicuous interbedding of the various rock-types—slate, limestone, and quartzite, any of which may assume a conglomeratic facies. But, despite the transition-zone, the two divisions have a well-marked individuality, and the Limestone-Slate Division, with its

associated lavas, clearly overlies the Quartzite Division, with its intrusive sills:—

‘The rocks of the area are sharply folded, in the manner usual in the region, about axes trending north-north-east and south-south-west, so that the order of superposition of the beds is only made apparent owing to a marked pitch of the axes of the folds towards the south-south-west in the northern part of the area. The Quartzite Group is thus carried to the southward underneath the overlying slates, limestones, and volcanic rocks, which cross the peninsula from the Sound of Jura inwards to the Linnhe Mhuirich¹ in the form of an escarpment facing the north, complicated by minor folding.’ [18, pp. 65–66.]

(6*b*) The Crinan Quartzite is less strongly developed in the north-western portion of the Loch Awe Syncline than elsewhere, and some of the mapping north of Kilchrenan may be open to criticism, especially as the ground is locally obscured by Glacial deposits. Still, I have satisfied myself as to the essential accuracy of Mr. Kynaston’s mapping in this locality, and have found independent evidence for a descending structural sequence from the Tayvallich Division right down to the Ardrishaig Phyllites. Mr. Kynaston has traced a conglomerate—which may be confidently correlated with the Glen Aray Conglomerate already described—in a curved outcrop past Kilchrenan, across the general strike of the folding, down to the shores of the loch. The exposures are discontinuous, it is true, but there can be no doubt that they all belong to a single horizon. On the south is an expanse of epidiorite, from beneath which the conglomerate emerges, owing to an obvious, though gentle, south-westerly pitch.² On the north and west is a tract of black slate and limestone, sometimes pebbly. All these sedimentary rocks, including the conglomerate, evidently belong to the Tayvallich Division, although the stratigraphical simplicity is marred to some extent by the local presence of a strong intercalation of pebbly quartzite occupying part of the interval between the conglomerate and the first important limestone. Beyond, again, is a belt of scattered quartzite-exposures, representing, I take it, the Crinan horizon. This belt is in turn limited by a limestone outcrop, or series of outcrops, which certainly must be referred to the Shira position, and as certainly overlies the Ardrishaig Phyllites of the slopes overlooking the loch.

(6*c*) In the previous paragraph it has been noticed that the Shira Limestone and other members of the Loch Awe Group clearly overlie the Ardrishaig Phyllites on the north-west side of Loch Awe. This feature is extremely well shown again in the country on the opposite side of the loch. It has already been stated that the recognition of this important structural relation, the superposition of the Crinan Grits and Shira Limestone upon the Ardrishaig Phyllites for miles across the general strike of the folds, is probably responsible for Mr. Hill’s belief in the existence of the Loch Awe Syncline.

¹ The western arm of Loch Sween.

² The agreement of this evidence with that already adduced in regard to the structural position of the Loch Avich Slates and Grits is complete.

The examples given above to illustrate the structural relations of the various members of the Loch Awe Group one to the other, and to the Ardrishaig Phyllites below, might doubtless be supplemented, with very little trouble, by further investigation. At the same time, they are regarded as sufficient in themselves. The reader must be warned, however, that he will find in the previous literature many references to 'folds' pitching in this direction or in that, to 'anticlines' and 'synclines,' to 'inliers' and 'outliers,' the existence of which, if established, would be fatal to the present interpretation. As a matter of fact, many of these folds, despite their definite designation, are essentially subjective, having been based upon the current reading of the stratigraphical succession. The geological literature of the Highlands has suffered greatly in the past from this subjective presentation of tectonics, for there are very numerous descriptions in which observation and inference have not been at all clearly differentiated. There can be little doubt that this indirect method of approaching tectonics owes much of its fascination to the success with which Prof. Charles Lapworth employed graptolitic zones in the elucidation of the structure of the Southern Uplands. Another point must be borne in mind in dealing with the Loch Awe sequence. The various rock-types, although sufficiently separated to allow of the subdivision of the group, are quite certainly interstratified to a very considerable extent. Thus it happens that in some sections we find folds exposed wherein black slate and limestone clearly underlie quartzite, and in others precisely the reverse. Such sections, revealing partial sequences, may prove of great service in working out the structure of the locality in which they occur; but, taken by themselves, they throw no light whatever upon the structural relationships of the major subdivisions of the Loch Awe Group.

(7) In the Scottish Highlands one should never assume that the order of structural superposition now obtaining is the same as the original order of stratigraphical superposition. In the Loch Awe Syncline, however, there is good reason to believe that the two are in agreement. This evidence is afforded at two localities.

(7*a*) At Kilmory Bay Mr. Grant Wilson found that the Ardrishaig Phyllites dipped steeply beneath a conglomeratic grit marking the base of the Loch Awe Group [18, p. 64]. The grit is, for the greater part, a pebbly quartzite with bands of fine conglomerate dispersed at intervals throughout. A feature of the conglomerate-bands, which impressed me very strongly, was that each of them has a well-defined base and an ill-defined top; the pebbles start suddenly in full force at the bottom, and then gradually decrease in number upwards, allowing the conglomerate-bands to merge, in this direction, with the containing quartzite. The tops and bottoms of the conglomerate-seams are thus strongly contrasted, and the contrast is of the type with which one meets, not uncommonly, in unfolded conglomerates. In fact, it is exceedingly difficult to escape the inference that these conglomeratic seams are 'right way up.'

If so, it follows that the Loch Awe Group is a later formation than the underlying Ardrishaig Phyllites, unless it has been thrust into its present position, which is a most unlikely alternative.

(7*b*) Evidence pointing in the same direction had previously been obtained by Dr. Peach. It has already been noticed that the Tayvallich lavas cross the peninsula with an escarpment facing north. At the foot of the escarpment are limestones and slates belonging to the Tayvallich Division, and from beneath these emerges a passage-zone, followed eventually by the main mass of the Crinan Quartzite. If it can be definitely determined whether the lavas in the escarpment are 'right way up' or no, then the original order of superposition of the various divisions of the Loch Awe Group follows as a corollary. This is exactly what Dr. Peach has succeeded in doing, with very fair certainty. Fig. 4, taken from Dr. Peach's description, shows the nature of the escarpment where it reaches the sea. The important point for our present purpose is the marked difference which exists between the tops and bottoms of the two lowest lavas.

Fig. 4.—*Volcanic section south of Port an Sgadain, western coast of Tayvallich Peninsula; after B. N. Peach.*

[Reproduced, by permission of the Controller of H.M. Stationery Office, from Mem. Geol. Surv. Scot. 1911: 'Geology of Knapdale, &c.' p. 69.]

Of these, the lowest of all (*a*, fig. 4) is about 20 feet thick, with an irregularly-jointed lower portion, containing few gas-cavities, and a remarkably rugged portion, 8 feet thick, consisting entirely of vesicular pillow-shaped masses. The second lava (*c*, fig. 4) is a highly vesicular rock, 15 to 20 feet thick, with numerous 'pipe-amygdales' in its lower portion set approximately at right angles to the base, and a porous upper surface. I agree with Dr. Peach in his opinion that this volcanic section has entirely the appearance of being 'right way up'; and from this it follows that the structural sequence in the Loch Awe Syncline, in all probability, agrees with the original order of superposition.

V. THE STRUCTURE AND THE METAMORPHISM.

I have already alluded to Macculloch's early recognition of the fan-structure which roughly marks the central line of the Loch Awe Syncline. This structure seems to become vague in the northern part of the Loch Awe district; but Mr. P. Macnair is probably justified in regarding it as the equivalent of the Ben-Lawers fan farther north-east in the Central Highlands [11, p. 207

and map facing p. 224]. It has long been claimed that Ben Lawers is, in the main, synclinal in structure, and—without entering further upon a subject which needs very careful consideration—it may be admitted, as a working hypothesis, that the Loch Awe Syncline is in part continued through Meall nan Tighearn towards the north-east along the Ben Lawers line. At the same time, it is fairly certain that the Loch Awe Syncline is also continued north-north-eastwards, where it would seem to reappear as the Glen Creran Syncline on the other side of the granitic complex of Etive. According to this view the Loch Awe Syncline bifurcates, giving rise to the Ben Lawers and Glen Creran branches, which are separated by the Glen Orchy Anticline recently described by Mr. M. Macgregor and myself [20].

It is a familiar fact that the Loch Awe Syncline includes schists of an unusually low grade of metamorphism. This point has been very clearly brought out in Mr. Hill's 1899 paper, so often referred to already. At the time he contented himself with a description of the phenomenon, without venturing upon any explanation of it. Later, however, he has offered two distinct suggestions of a possible connexion between the metamorphism and the structure of the district. In the Memoir on Sheet 37 [14, pp. 74, 75], he connected the low metamorphism of the rocks along the central belt with their variable inclination, which latter he regarded as an indication of a less compressed folding in this position than on either side, where steady inward dips predominate. Subsequently, in the Memoir on Sheet 28 [18, pp. 83, 84], he replaced this explanation by one which seems much more likely to be fruitful. Regional metamorphism, he suggests, is connected both with dynamic action and with depth-temperature; and accordingly the degree of metamorphism is likely to correspond, in a broad way, with the depth at which the deformation was achieved.

There is, of course, nothing new in Mr. Hill's suggestion that depth may have had a determining influence in metamorphism, for this is one of the oldest ideas in Geology. But the theory is none the worse for being old, and its application in a concrete case is exceedingly welcome. Its probability is considerably enhanced by the following consideration. On the south-east, the Loch Awe Syncline is flanked by the Cowal Anticline, which Mr. Clough has given good reason to believe is an anticlinal structure affecting schists already bent into great recumbent folds. Just as the axial belt of the Loch Awe Syncline is characterized by low-grade metamorphism, so that of the Cowal Anticline is characterized by high-grade metamorphism. In discussing this phenomenon Mr. Clough, in 1897 [5, p. 91], pointed out that the rocks at present exposed in the centre of the anticline

'must, before the ridging up, and subsequent denudation, have been lying under a much greater thickness of rock, and therefore presumably exposed to higher temperatures, derived from the earth's internal heat, than those now occurring far away on the flanks.'

In this opinion Mr. Clough was, to some extent, anticipated by

Nicol in a paper read before this Society in 1862: for, as Gunn has pointed out, Nicol seems to attribute the high metamorphism of the rocks exposed along the axis of the Cowal Anticline to their having been

'taken down into those interior regions of the earth's crust where the chief laboratories of metamorphic action are situated' [3, p. 199].

But to Mr. Clough belongs the particular credit of a new conception in Highland geology. For, according to his reading of the structure, the depth of the cover, under which the highly metamorphic rocks of Cowal crystallized, was not directly determined by the position of these rocks in an original stratigraphical sequence, but by the degree to which they had been buried beneath superincumbent folds. This conception is likely to prove of wide application, and I may conclude by suggesting that it may render more intelligible the progressive metamorphism noted by Mr. Hill north-east of Loch Awe. It has already been mentioned that near Dalnally there are black schists, limestones, and pebbly quartzites which Mr. Hill refers to the Loch Awe Group. They are, as the same author correctly points out, much more metamorphic than their supposed equivalents round about Loch Awe. Now, it so happens that a consideration of the relation of these rocks to the Glen Orchy Anticline and the Loch Awe Syncline renders it quite certain that, whatever their stratigraphical position, they structurally underlie the Ardrishaig Phyllites: that is, they are on a definitely lower rung of the tectonic ladder than the Loch Awe Group at Loch Awe.

It is to be hoped, however, that the 'depth principle' will not be pushed too far. There are already difficulties foreshadowed in its application, even in the West Highlands: for the metamorphism continues of low grade on the north-west side of the Loch Awe Syncline, as, for instance, in Islay, across the Sound of Jura. There are probably many factors at work, and one must always remember that great earth-movements may be accompanied by little metamorphism, when the tendency is, as in the North-West Highlands, to superpose metamorphic rocks upon non-metamorphic. The evidence which Mr. G. Barrow has adduced to connect the regional metamorphism of the Highland schists with certain widespread granitic intrusions must also be borne in mind [4 & 21].

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VII. APPENDIX ON THE STRATIGRAPHY.

It is not the purpose of this paper to replace the detailed account of the district already given in the Geological Survey Memoirs. At the same time, the following epitome of the stratigraphy is offered for the convenience of workers in other parts of the Highlands. This epitome is a compilation made in the light of personal knowledge. The whole district has been examined, except the part situated in Cowal and, northwards, from Glen Shira to Meall nan Tighearn. The Shira Limestone is dealt with more fully than the other divisions, as it is impossible to extract an altogether satisfactory account of it from the descriptions heretofore published; the differences, however, are all concerned with matters of detail.

The Ardrishaig Phyllites and Erins Quartzite.

The Ardrishaig Phyllites of the Loch Fyne and Craginish districts consist of soft greenish-grey phyllites and phyllitic mica-schists, in many parts containing calcareous lenticles half an inch or less thick. Intermixed with these lenticles are occasional thicker outcrops of pale-yellow, buff-coloured, and white limestone; and also bands of compact fine-grained quartzite, often slightly calcareous.

Small grains of blue quartz can at times be recognized in the siliceous bands, while conglomeratic seams have been described from the Loch Caolisport district by Mr. Clough and Mr. Grabham [18, pp. 53, 54], and from an island in Loch Craginish by Mr. Maufe [17, p. 13]; but such occurrences are quite exceptional.

In Cowal Mr. Clough has found a convenient lower limit to the Ardrishaig Group in an outcrop of graphitic mica-schists, with thin impure graphitic limestones and calcareous quartzites. This assemblage is sometimes spoken of as the St. Catherine's Graphite-Schist. Beyond comes the Garnetiferous Mica-Schist

Group, a non-calcareous mica-schist series, with many gritty intercalations in which pebbles can often be recognized. The most conspicuous feature of the Garnetiferous Mica-Schist of the Loch Fyne tract is the abundance of garnets, but this character fails towards the south-west. The garnets, where present, are frequently accompanied by actinolite.

Towards the north-east, in the Loch Fyne district, the St. Catherine's Graphite-Schist has not been mapped outside of Cowal; but its presence has been recorded by Mr. Hill at one or two points between Loch Fyne and Meall nan Tighearn. It is probable, indeed, that the division-line laid down on the map to separate the Ardrishaig Phyllites and the Garnetiferous Mica-Schist, in this part of the area, follows an approximately constant horizon.

Towards the south-east it is doubtful whether the St. Catherine's Schist persists or no. A remarkable change of stratigraphy is encountered in this direction: for a thick fine-grained quartzite makes its appearance, situated in a general way between the Ardrishaig Phyllites and the Garnetiferous Mica-Schist. It is quite certain that this quartzite, the Erins Quartzite as it is called, belongs in part to the Ardrishaig Group, since its development has been followed, more or less, stage by stage. What is uncertain is, whether any considerable proportion of it is equivalent to the Garnetiferous Mica-Schist farther north. A thin grey phyllitic division, the Stronchullin Phyllites, divides the Erins Quartzite into two roughly equal portions; and in it occurs a band of graphitic phyllite, which Mr. Clough suggests may be correlated with the St. Catherine's Graphite-Schist [18, p. 9]: this would relegate the lower half of the Erins Quartzite to the Garnetiferous Mica-Schist position. Mr. Hill, on the other hand, considers that virtually all the Erins Quartzite belongs to the Ardrishaig Group. The two portions of the Erins Quartzite are much alike; pebbly beds are rare, until the south-eastern border of the division is approached.

The quartzite is very slightly calcareous, where tested, and one or two bands of cream-coloured and grey limestone, several feet thick, are found near its north-western limit; even more important beds of grey limestone occur near its south-eastern margin.

The Shira Limestone.

This limestone is a comparatively thin and inconstant division. On the east side of the Loch Awe Syncline it is not appreciably developed south of the Crinan Canal, connecting Crinan Loch with Ardrishaig. North of the canal, however, the limestone is probably continuous, although, not unnaturally, it is shown on the map as having a broken outcrop.

A very good section is afforded by the River Add, which crosses the course of the Shira Limestone 5 miles north-north-east of Ardrishaig. The limestone occurs here in massive, cream-coloured, banded sandy beds, which effervesce with acid; some of the layers merge into calcareous quartzite. On the east it is separated by a

band of epidiorite from typical grey and green phyllites; on the west it is followed almost directly by massive beds of fine-grained grit with, at first, intercalations of grey-green phyllites of Ardrishaig type. When the phyllitic beds cease the fine-grained grits are so massive that their bedding is not easily discerned. There is no doubt at all that these grits, or fine-grained pebbly quartzites, belong to the Crinan Division.

I have seen very little of the junction-line between the Ardrishaig and Loch Awe Groups, from this point north-eastwards to the wide outcrop of limestone shown on the map (Pl. XXXII) 15 miles north-east of Ardrishaig. Here a visit made it obvious that an important limestone separates the Ardrishaig Phyllites from the Crinan Quartzite. It has the same characters as in Glen Shira—the type-locality with which I shall deal in detail presently.

Again, until Glen Aray is reached, I have no personal knowledge of the Shira Limestone. In Glen Aray that rock is involved in a porphyry intrusion, but its original characters are not destroyed. It consists of a thick mass of limestone weathering to a cream colour, with pale-grey fracture, and is much split up by partings of pale-grey phyllite. North-west of the porphyry is alluvium; but the first rock seen in the valley-bottom is massive somewhat pebbly quartzite, associated with a thin band of cream-coloured limestone.

Capital exposures are afforded by the tributary burns draining from the west into Glen Shira. The second burn south of Drimlee, 5 miles north-east of Inveraray, may be cited as typical. The greater part of this magnificent section, as one ascends from the Shira, is occupied by greenish-grey silvery phyllites. At first, a homogeneous mass of these phyllites is encountered, scarcely interrupted except by igneous rocks: fully three-quarters of the section is of this type. A change is ushered in by the appearance of several well-marked, fine-grained quartzite-bands. Above this, beds, ribbons, and lenticles of cream-weathering sandy limestone, grey and cream-coloured on the fractured face, are continually appearing intercalated in the phyllites. Where numerous, they give added power of resistance to the whole, and the stream rushes across their outcrop in a series of picturesque cascades. The proportion of limestone to phyllite is, as a rule, not very high; but, looking down upon the exposed dip-slopes above these waterfalls, the cream-coloured backs of the limestone-beds make a very conspicuous feature. This type of sedimentation prevails right up to the base of the Crinan Quartzite, save that strong beds of grey sandy limestone, intercalated with grey phyllite, occur in contact with the quartzite. In these dark limestones one has a foretaste of the carbonaceous character so prevalent in the Loch Awe Group. In the sections which remain to be described, the Shira Limestone exhibits this character much more strongly; and it is on this account that the division is regarded as transitional between the Ardrishaig and the Loch Awe Groups.

I have not followed the Shira Limestone continuously in its

curving outcrop leading from Glen Shira to Loch Awe, but a visit to the exposures 2 miles east of the loch showed that cream-coloured and blue-grey limestones are both well developed. Nearer the loch, in a stream crossed by the main road, a section is met with consisting largely of blue, compact, thinly-bedded limestone, with bands of grey slate and more siliceous material. The limestones here are very like many in the Tayvallich position, but the associated slates are never black. The interposition of this exposure between the Ardrishaig Phyllites and the Crinan Quartzite is fortunately quite clear, although the latter division is not very strongly developed.

The grey facies of the Shira Limestone continues west of Loch Awe. The part of the outcrop which approaches the escarpment of the unconformable lavas of Old Red Sandstone Age needs re-examination: it is possible—as the Crinan Quartzite is not in strong force—that I have locally confused Shira and Tayvallich Limestones, for black slate occurs with the limestone not far east of the lava escarpment. The matter is a subsidiary detail, so far as the present paper is concerned, but is of importance to anyone who attacks the problem of the black schists and pebbly quartzites of the Dalmally neighbourhood.

The next exposures to be noticed are on the west side of the Loch Awe syncline, a mile east of the head of Loch Melfort. Here the Shira Limestone is in two beds, separated by a thick epidiorite sill and some green phyllite. The lower band, as exposed near a lime-kiln west of a loch known as Loch Pearsan, on the borders of Sheets 36 and 37 of the Geological Survey 1-inch map, is a well-bedded grey limestone, 12 feet thick. It graduates upwards into calcareous quartzite, with small but recognizable pebbles. In this is a layer of fine-grained pebbly limestone containing limestone-fragments. The upper band, as seen on the northern and southern shores of Loch Pearsan, is a grey-banded limestone with some thin seams of black slate. Here, then, is the Shira Limestone exhibiting—in a very feeble manner, it is true—the pebbly nature and the association with black slate which are so emphatically characteristic of the Tayvallich Division.

Southwards for some distance the Shira Limestone has been recognized in places as a belt of calc-silicate-hornfels, resulting from the metamorphism induced by a small granite-boss. Its outcrop is not shown on the geological maps until, south of this granite, at the head of the alluvium deposited by the river leading into Loch Craignish, its position is marked in the field by three prominent bands of dark-grey limestone separated by grey phyllites; the zone extends here for about a quarter of a mile west from the margin of the Crinan Quartzite.

Beyond this, towards the head of the loch, one observes occasional exposures of dark-grey limestone; but the division is mostly obscured by alluvium, and no attempt has been made to continue its outcrop on the map. I searched such exposures as occur for black slate, but quite in vain.

The late Mr. Grant Wilson has pointed out [17, p. 24] that 'dark crystalline limestone, accompanied by dark phyllites, occur along the eastern shores of Eilean Rìgh and Eilean Macaskin in Loch Craignish.' These island-exposures belong, according to their geographical position, to the Shira Division, but I have had no opportunity of visiting them.

The Crinan Quartzites and Grits.

This division consists for the most part of pebbly grits, many of them sufficiently quartzose to deserve the name 'quartzite.' The texture varies from bed to bed, and from place to place. Often the rocks are very coarse, with large grains of blue or white quartz and fresh felspar. Dr. Flett, in summarizing what is known of the felspar-pebbles of the Loch Awe Group, says that microcline, orthoclase (often perthitic), and oligoclase are found in decreasing order of abundance [18, p. 58]. The coarser grits are sometimes definitely conglomeratic, carrying fragments of slate, limestone, and grit. Such rocks are less frequently found in the basal portion of the division, next to the Shira Limestone, than higher up. Mention has already been made, however, of the conglomeratic base of the quartzite at Kilmory Bay. Grant Wilson states [18, p. 65] that inland the conglomerate

'maintains its characters for a distance of about 4 miles along the strike.'

Another instance of a similar nature was encountered by Mr. Kynaston in a stream known as Allt Fearnà, 3 miles south-west of Dalmally. The base of the Crinan Quartzite, resting here upon grey silvery phyllites with limestone-bands, in the Shira position, is coarse and pebbly, and contains numerous fragments identical in type with the underlying limestone [16, p. 28].

While the dominant rock in the Crinan Division is pebbly quartzite or grit, there are numerous intercalations of slate and limestone of varying character. As an example, one may cite excellent exposures of grey slate and repeatedly interbedded fine-grained quartzite and grey sandy limestone at Ardnoe Point, and for 3 miles southwards along the shores of the Sound of Jura. Similar beds occur along the eastern coast of Loch Craignish, and have been recognized inland at many places; but they are not sufficiently differentiated to be mapped out separately as a sub-division of the Crinan Quartzite.

The Tayvallich Slates and Limestones.

This division is connected with the Crinan Grits and Quartzites by a transition-zone, in which there is marked interbedding of black limestone, black slate (with subordinate grey slate), and pebbly quartzite. Even in the heart of the division beds of pebbly quartzite are of not infrequent occurrence, and on occasion give rise to massive outcrops. The predominant rocks of the division are black slate and limestone, very intimately associated—so much so that it has been impossible, in many cases, to show them both on the map.

The limestones are generally black or dark blue, and are often of very considerable thickness. In crystalline texture they vary from fine to coarse, some occurrences being made up for the greater part of crystals of black calcite a quarter of an inch across. Many beds are strongly pebbled, with large grains of quartz and felspar, identical with those that occur in the Crinan Quartzite. In such cases pebbles of fine-grained limestone, slate, and epidiorite are not infrequently found. The slates of the group and the quartzite intercalations also not infrequently assume a conglomeratic facies.

Two conglomerates, the Glen Aray and the Loch-na-Cille Conglomerates, are particularly conspicuous, and have been indicated on the appended map (Pl. XXXII). One, the Glen Aray Conglomerate, has already been described in some detail in its outcrop between Glen Aray and Loch Awe (p. 287). West of Loch Awe, in the neighbourhood of Kilchrenan, it retains the same characters as in Glen Aray, except that (so far as I could see) it no longer carries epidiorite-fragments. The most abundant boulders are pebbly quartzite, but Mr. Kynaston has made the very interesting discovery of granophyre- and felsite-pebbles in it [16, p. 31].

The Loch-na-Cille Conglomerate, much farther south, was detected by Dr. Peach [18, p. 71]. It is extremely full of fragments of slaggy epidiorite, and also contains numerous pebbles of felsite, or porphyry, and quartz-syenite. Dr. Flett [18, p. 75] has investigated the petrology of the pebbles, and has found that the syenites are of the same type as those that occur in the conglomerates of Schiehallion, Islay, and the Isles of the Sea (Garvellach Isles), long ago described and compared by Macculloch [1, pp. 159, 249]. It is an interesting circumstance that the source of these quartz-syenite boulders is quite unknown.

Further careful search might quite likely reveal the presence of similar felsite, and perhaps even quartz-syenite, pebbles in several other conglomeratic beds of the Loch Awe district. At present, there are only two other instances of the kind known: Mr. Kynaston has recorded felsite-pebbles from a conglomeratic limestone, shown on the map (Pl. XXXII) as an isolated outcrop east of Loch Awe and 3 miles south of Kilchrenan [16, p. 31]; while Mr. Maufe has also found felsite in a conglomerate near Ormaig, about a mile south of the head of Loch Craignish and half a mile in from the coast [17, p. 37].

In the district dealt with in the foregoing pages these foreign pebbles are all found in conglomerates within the Tayvallich Division of the Loch Awe Group. It would be rash, however, to assume that this statement holds true throughout the Highlands and Islands of Scotland.

The Loch Avich Slates and Grits.

In this division there are considerable masses of well-bedded, green, cleaved mudstones; these alternate with fine-grained quartzose beds, sometimes containing sandy calcareous nodules.

and layers, and also with thoroughly pebbly quartzites or grits like those of the Crinan Division. It is difficult to form an opinion as to the relative abundance of slates and siliceous rocks in the group as a whole, but I think that the former are in excess. The grits are not infrequently conglomeratic.

The Tayvallich Volcanic Zone.

Dr. Peach's 'Tayvallich Volcanic Zone' is situated within the Tayvallich Slates and Limestones and the lower part of the Loch Avich Slates and Grits. The lavas are distinguished by their vesicular character, fine-grained texture, and not infrequent pillow-structure, together with their failure to induce contact-alteration. Characteristic tuffs and agglomerates are more or less absent, but conglomeratic beds containing fragments of vesicular epidiorite are common. Certain felspathic beds in the Tayvallich Peninsula have been interpreted as crystal-tuffs.

As already stated, Dr. Flett [18, p. 84] has made a careful petrographical examination of the lavas. He has referred them to the spilite group, and shown that their feldspar is always albite; their ferromagnesian constituent is chlorite, not hornblende.

The Epidiorite Intrusions.

The epidiorite sills are of doleritic texture, where not much sheared, and often show coarse ophitic structure in their central portions. In not a few cases they obviously transgress the bedding of the associated sedimentary schists, and also very frequently produce remarkable contact-alteration.

Under the microscope they are seen to consist essentially of hornblende and plagioclase, which Dr. Flett has found to be albite. The presence of chlorite, with much carbonate, in the lavas, and of hornblende, with comparatively little carbonate, in the intrusions, has led Dr. Flett to the view that the lavas were already much decomposed before they were folded, while the intrusions were fresh [18, p. 88].

Occasional leucocratic varieties are met with among the intrusive epidiorites. Their petrology has been described by Mr. Kynaston [16, p. 44] and Dr. Flett [17, p. 53, & 18, p. 91]. In one case micropegmatite was found to occur locally; in other instances the intrusions proved to have bostonitic affinities. It must be realized that these leucocratic rocks are extremely scarce.

EXPLANATION OF PLATES XXXI & XXXII.

PLATE XXXI.

Pillow-lava, An Aird, western coast of Tayvallich Peninsula. Reproduced by permission of the Controller of H.M. Stationery Office, from Dr. B. N. Peach's account of the Tayvallich volcanic rocks [18, pl. iii, facing p. 59]. (See p. 282.)

PLATE XXXII.

Generalized geological map of the Loch Awe District, based upon Sheets 28, 29, 36, 37, & 45 of the 1-inch map of Scotland issued by H.M. Geological Survey; revised and reduced by the author. Scale: 4 miles=1 inch, or 1: 253,440.

DISCUSSION.

The SECRETARY read the following remarks, received from Mr. J. B. HILL:—

‘In a paper communicated to the Geological Society in 1899 I described the Loch Awe Group, the members of which consist of limestone, black slate, and quartzite, the latter forming the top of the sequence. Black slate and limestone are not, however, confined to those horizons, slate often occurring higher up in the series among the quartzite, and limestone likewise appearing at other horizons. These occurrences beyond the main bands I nevertheless regarded as local and of limited continuity.

‘In the Tayvallich peninsula the Author has described a limestone band above the quartzite; and the question arises whether that band is local in character, or whether it represents a persistent band marking a definite horizon in its passage across the Highlands. The latter interpretation would imply that not only was there a definite horizon of black slate and limestone below the quartzite, but a corresponding succession above the quartzite. In the Loch Awe area, reduplication by folding is so pronounced a characteristic that the hypothesis of a double sequence must be viewed with suspicion, and needs strong evidence to support it.

‘If, however, the pillow-lavas of the Tayvallich peninsula were represented in the Loch Awe basin in association with the limestones of that area, there would be some grounds for placing that limestone above the quartzite, as such lavas have not been detected below the latter at the margin of the Loch Awe Group in the south-east where that group succeeds the Ardrishaig Series.

‘In the Loch Awe basin there is an immense epidiorite-sill of composite type, part of which is vesicular and corresponds petrologically to the pillow-lavas. I was for some time under the impression that the vesicular rock represents a contemporaneous lava; but the mapping of the area did not support this opinion, and pointed to its intrusive origin.

‘Later, Mr. Kynaston mapped these rocks in the neighbourhood of Port Sonachan, and, after starting with a similar opinion, was forced to abandon it and considered that they represented an intrusion at a shallow depth beneath the surface.

‘At a still later period Dr. Peach mapped similar rocks in the Loch Avich district, on the north-west side of Loch Awe, and, although inclined to regard them as lava-flows, could find no evidence in that direction, noting that no pyroclastic rocks had been found associated with them, and that their thickness and wide extension points rather to their intrusive nature.

‘Rocks of this character have not been observed below the quartzite to the south-east, between the Loch Awe and the Ardrishaig Groups, but their intrusive nature may satisfactorily account for such absence.

‘Not only is there an absence of pyroclastic rocks in the Loch Awe basin, but the peculiar acid rocks associated with the pillow-lavas of Tayvallich are also unrepresented, and it is probable that the Tayvallich rocks occupy a higher horizon than those of the Loch Awe basin.’

Mr. BARROW congratulated the Author on the able manner in which he had dealt with the additional evidence afforded by the volcanic zone on the question of the succession in the Highland Rocks. He wished that the Author had gone more fully into the history of the question as a whole. The quartzite was believed by the speaker to be the Highland Quartzite, which crossed Scotland from Port Soy to Islay, and, as Harkness had shown,

R. Lunn photo.

PILLOW-LAVA, AN AIRD, Western Coast of Tayvallich Peninsula.

[Reproduced, by permission of the Controller of H.M. Stationery Office, from Mem. Geol. Surv. Sect. 1911 :
‘Geology of Knapdale, &c.’ pl. iii, facing p. 59.]

reappeared in Ireland. The relative positions of the rocks of the groups had been proved by the speaker more than twenty years ago, and the conclusions reached were published in Sir Archibald Geikie's first Presidential address to the Geological Society (1891). The Blair Atholl Limestone (believed by the speaker to be the Tayvallich Limestone) was shown to be on one side of the Quartzite, and the Caenlochan Schist (Ardrihaig Phyllite) on the other. At the extreme north-eastern end of this outcrop, the quartzite was very thin, and passed down insensibly into the underlying dark schist, which there intervened between it and the Caenlochan Schist. Proceeding south-westwards, one noticed first the occurrence of small grains of the dark material at the base of the quartzite, later on small pellets, and finally in the area in question the original dark mud was at times completely eroded away; but now pellets of it, of larger size, occur in the quartzite. The real evidence adduced by the speaker, on which the succession turned, had never been published.

The AUTHOR, in reply, pointed out that Mr. Hill treated the mass of epidiorite in the vicinity of Loch Awe as a unit—either an immense sill or an immense lava. On this hypothesis Mr. Hill had, of necessity, set aside any interpretation involving the occurrence of lava, since parts of the mass showed definitely intrusive relations. The Author's observations led him to regard the mass as a complex series of lavas and associated sills.

Replying to Mr. Barrow, the Author drew attention to a paragraph written conjointly by Dr. Peach and himself in the Geological Survey Memoir on Sheet 28 (Scotland). The paragraph followed upon a description of the succession in the Tayvallich peninsula, and ran as follows [18, p. 61]:—

'It would be unnecessary to go beyond this, were it not that the relations of the Loch Awe Group in Argyllshire have been used in support of the theory of the "unconformable quartzite" in Perthshire and elsewhere. The writers are now of opinion that the change of front in the Tayvallich district strengthens, by analogy, the alternative interpretation of the Perthshire sections, which has for years been identified with the name of Mr. Barrow.'

Since the above was written the Author had tried to reach greater certainty in the matter, but without success. The district lying between Loch Awe and that part of Perthshire in which Mr. Barrow had worked was very difficult indeed to interpret. Quite apart, however, from the doubtful analogy between Loch Awe and Eastern Perthshire, the Author, speaking without any special knowledge, believed that Mr. Barrow was right in regarding the Perthshire quartzite as an interstratified member of the Perthshire sequence, and not an unconformable later group for ever making its appearance in isoclinal synclines.

Mr. Barrow had also referred to Islay. Here the Author was on familiar ground; and, while admitting certain general resemblances between the Islay-Jura sequence and that of Loch Awe, he found the differences of detail so considerable that he preferred to maintain an agnostic attitude in regard to matters of correlation.