26. *The* Origin *and* Associations *of the* Jaspers *of* South-eastern Anglesey.

By Edward Greenly, Esq., F.G.S. (Read April 30th, 1902.)

[Plates XV & XVI.]

Contents.

I. Introduction.

One of the most singular and striking rocks in that region of Anglesey which lies to the south-east of the principal mass of Carboniferous rocks, is a bright red jasper. Though never in masses of large size, it is widely distributed, occurring in three distinct areas, which may be called the Newborough, the Pentraeth, and the Beaumaris areas. The character, mode of occurrence, and associations of this jasper throw much light on its origin; they are so remarkable, and present such singular analogies with those of groups of rocks which have lately been described in different parts of the world, as to be, I think, matter of general interest, as well as important to workers among the older rocks of Britain. The object, therefore, of this paper is to describe the rocks and their relations in the districts where they have escaped the effects of the movements that have modified most of the region.

Their geological age, and, in particular, their relations to the crystalline schists of the region, cannot, in my opinion, be regarded as settled, some of the evidence being conflicting. But as questions of the greatest interest regarding metamorphism are involved, I propose, in the fourth part of this paper, to set forth this evidence as briefly as is consistent with clearness. I am the less unwilling to do so, because the problem is so closely allied in its nature to those that are still under discussion at the margins of several other metamorphic areas, as to be in itself, I think, interesting to geologists who are investigating questions of metamorphism.

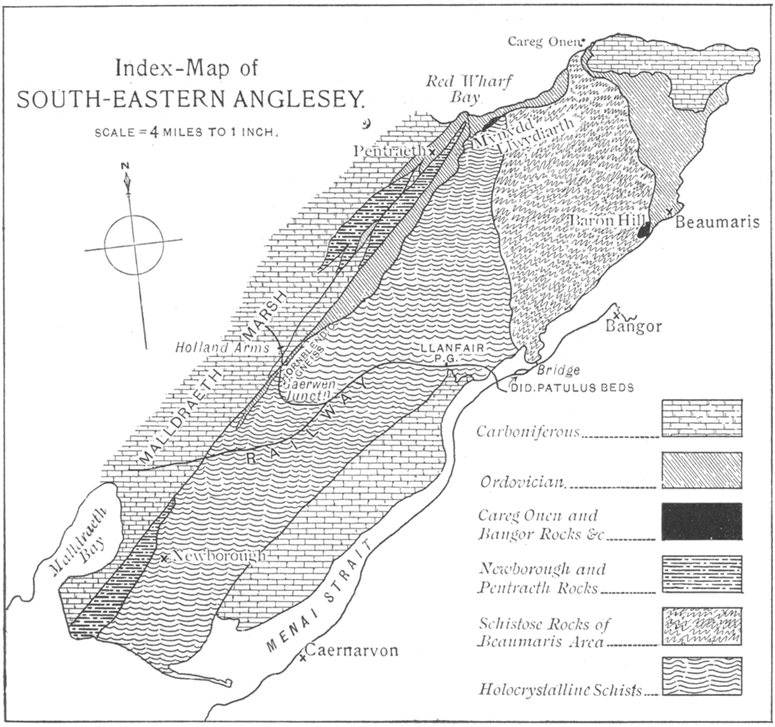
II. Description of the Rocks.

The principal associates of the jaspers are certain basic igneous rocks, limestones, and grits, the most important being the igneous rocks. Some fine shaly material, called elsewhere jaspery phyllite, will be described along with the jaspers.

Besides these, there are large quantities of a breccia which appears to be cataclastic, and also of various schistose rocks, the masses which retain original characters occupying comparatively small parts of the areas described, except in the Newborough district.

(i). The typical jasper is a very hard, brittle, bright blood-red rock, compact, and with irregular fracture, and often traversed by a large number of small quartz-veins. It possesses often a mottled texture, which gives, under the hand-lens, an appearance strongly suggestive of the presence of organic remains. But nothing certainly organic has yet been found in it. Some specimens have the

Fig. 1.



[The outcrop of Careg Onen Rocks at Careg Onen itself and the outcrops of the jaspers occupy areas of too limited an extent to permit of their being shown in the above map.]

aspect of red breccias, cemented by clear quartz. Many are definitely spherulitic. A thin slice shows a mosaic of quartz-grains which at first appear to have rather evenly rounded outlines, but on careful scrutiny between crossed nicols they show re-entering curves along which the grains interlock with each other. The mottling visible with the hand-lens is seen to be due to aggregations of hæmatite-dust, round about which the quartz is clear and nearly free from inclusions. Each of the aggregates is situated in the middle of a quartz-grain,

and is thus confined to the limits of what is a crystalline or optical unit. The mottled texture is therefore, now, a mineral and not an organic structure; but it is of course quite possible that it may have been originally due to the presence of organic bodies the outlines of which have become obliterated. (See Pl. XV, fig 1.)

The spherulitic varieties, when best developed, are composed of red spherulites, 2 to 3 millimetres in diameter, in a darker matrix. The spherulites have colourless, granular cores, around which is the pale red body, with radial structure, giving a dark cross between crossed nicols. The intervening matter is very dark with iron-ores, often sufficiently well crystallized to show definite flakes of 'eisenglimmer,' and evidently much altered. No organic bodies have been found in the cores of the spherulites.

The texture of the ordinary jaspers varies considerably within the limits even of a microscopic slide, some parts being rather coarser, and some more free from hæmatite than others. Numerous veins of quartz traverse the rock in all directions. These are of much coarser texture than the fine mosaic of the main body, and are also generally much more free from inclusions. A slide from Fferam-gorniog, near Pentraeth, contains also some curious groups of small doubly-terminated crystals of quartz. Well-formed rhombs of calcite or dolomite are not uncommon in the fine mosaic, and to a less extent also in the quartz-veins.

The jaspery phyllites have the same general appearance as the jaspers, but have a parallel structure and a duller surface. In thin sections they appear, like the jaspers, to be composed chiefly of very fine granular quartz, and hæmatite, but there are also present numerous minute clastic grains of white mica, and also of quartz: and the general texture is that of a fine ferruginous shale or mud, and unmistakably sedimentary. (See Pl. XV, fig. 2.)

(ii). The igneous rocks are diabases and serpentines.

The serpentines are of small size, and have only been observed in one or two places in the Pentraeth area. Though the fact of their existence is of considerable interest, no petrological detail concerning them is necessary for the present subject.

The rest of the igneous rocks are more or less altered dolerites or basalts, generally fine-grained, and, from their lightish tint when weathered, evidently not very basic in composition. They are generally of a dull green, but when slightly deformed are often reddish, and their schistose parts can then be easily mistaken for the red phyllites associated with the jaspers. Thin slides show a fine meshwork of slender lath-felspars, with some iron-ores, and sometimes (in the Newborough district) cores of augite still remaining. Generally, however, the pyroxenes have been replaced by the usual green alteration-products. Sometimes a tendency to a sheaf-like or radial aggregation of the felspars is well marked. (See Pl. XVI, fig. 1.)

But the most remarkable characteristic of these rocks is their structure on the large scale. In the field they are seen to be

Fig. 2.—*Diabase with pillowy structure; south-west of Bryn Llwyd, Newborough sand-hills, looking east-north-eastward.*

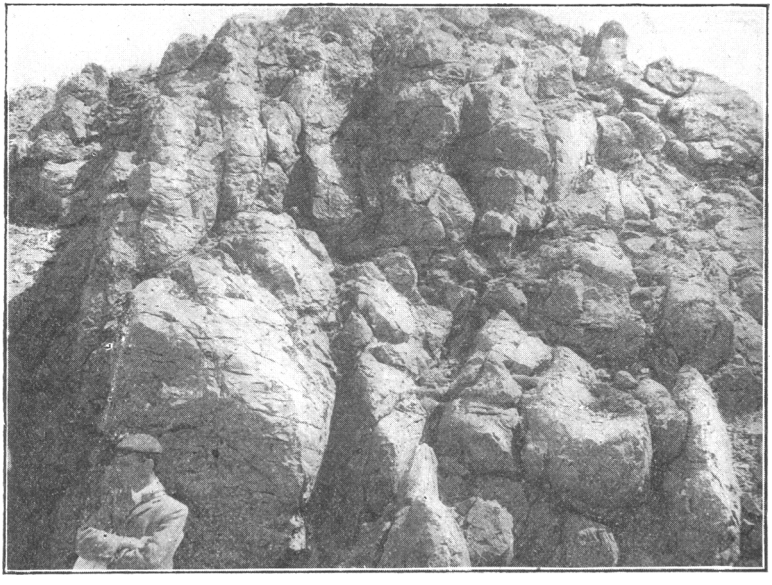
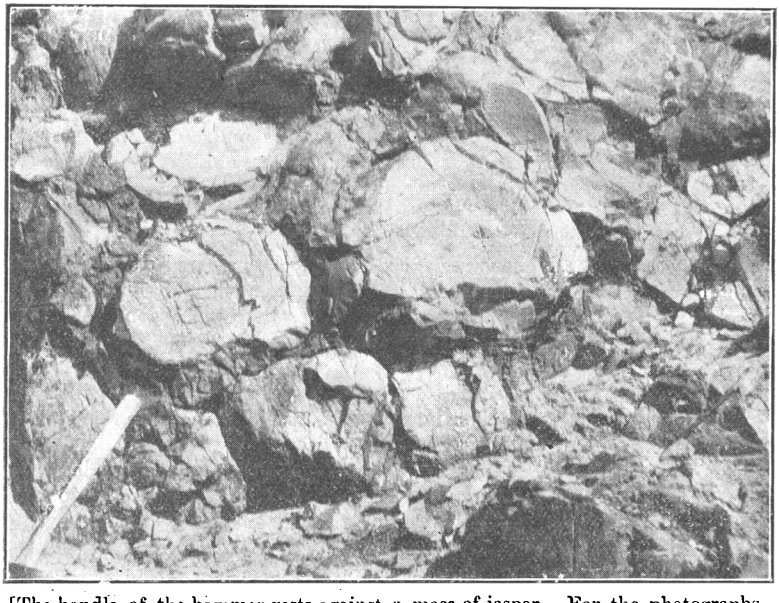


Fig. 3.—*Jasper filling interspaces of pillowy diabase; Cerig Mawr, Newborough sand-hills, looking northward.*



[The handle of the hammer rests against a mass of jasper. For the photographs from which the above figures are reproduced, I am indebted to Mr. J. Trevor-Owen, Headmaster of the Grammar School, Swansea.]

composed of ellipsoidal or spheroidal masses, piled and pressed upon one another, as if they had been rolled over and over in a semi-consolidated condition (figs. 2 & 3, p. 428). Sometimes between the masses are small interspaces; sometimes smaller ellipsoidal or pillowy masses fit into gentle re-entering curves in the sides of larger ones, suggesting very vividly, hard though they now are, the rolling and pressing against each other of pasty, yet individualized bodies.[1] A graphic description of their aspect will be found in the Rev. J. F. Blake's 'Monian System'.[2] This structure is here dwelt upon, on account of its close resemblance to, in fact identity with, the 'pillowy' structure of the basic lavas of the South of Scotland and other localities. Figs. 2 & 3 will at once recall the frontispiece in the Geological Survey Memoir on that district,[3] and also the rocks of Mullion Island at the Lizard, and Point Bonita in California.[4]

The pillowy masses are of two types—a larger and a smaller; and though they occur together, yet one or the other usually predominates in any one section. The larger (about 4 feet long) is ellipsoidal, the smaller being, as a rule, more nearly spherical. The middle axis of the ellipsoid is generally vertical, and the longest lies north-east and south-west: the ellipsoidal 'pillows' therefore stand 'on edge.' No marked difference of crystalline texture has been observed between the inner and outer parts of the 'pillows,' but a concentric shell-structure is common, which becomes sometimes almost a concentric fissility. Small spherical amygdules are not uncommon, but they are not a marked feature of the rocks. The general microscopic character agrees with that of the Scottish and other pillowy rocks. This pillowy structure is seen at Tan y Graig in the Pentraeth area; but it is much better displayed among the Newborough sand-hills, where the great bosses of volcanic-looking, dark-green rock, rising from beneath great drifts of sand, have a most singular, and somewhat forbidding aspect; and as they are, besides, kept bare of vegetation by the incessant sweep of the sand-blast, the whole aspect of the scenery has a desert-like look that one does not expect to see in Britain.

It is in these pillowy diabases that the variolite first observed by the Rev. J. F. Blake,[5] and afterwards described by Prof. Grenville Cole,[6] occurs. Prof. Cole has moreover been so kind as to write for me the following description of a variolite which occurs in the pillowy rock of Tan y Graig, Pentraeth:—

'No. 5, 1899.—The large spherulite from which this is cut clearly enveloped a previously banded and spherulitic mass, just as the large spherulites in acid

[1] Rocks of this kind have been referred to as 'spheroidal,' but the structure is evidently distinct from ordinary spheroidal jointing produced after consolidation: see Platania, 'Geology of Acireale' in Dr. Johnston-Lavis's 'South Italian Volcanoes' 1891, pp. 41–43.

[2] Quart. Journ. Geol. Soc. vol. xliv (1888) pp. 510–11.

[3] 'Silur. Rocks of Britain' vol. i (1899) pl. i.

[4] Trans. Roy. Geol. Soc. Cornwall. vol. xi (1893) p. 565; 'Eruptive Rocks of Pt. Bonita' Bull. Departm. Geol. Univ. Calif. vol. i (1893) pl. vii, p. 78.

[5] 'Older Rocks of Anglesey' Brit. Assoc. Rep. 1888 (Bath Meetg.) p. 416.

[6] Sci. Proc. Roy. Dublin Soc. n. s. vol. vii (1891) p. 112.

lavas often arise as local "knots" during the latest consolidation of the rock, and include the pre-existing structures. The brown tachylyte between the bands of small spherulites is in places distinctly perlitic, and its vitreous character is well preserved. The rock is generally more glassy than crystalline; but the more lithoidal bands show the tufted aggregates of microlites, and even the "pseudo-crystallites" that are so characteristic of true variolite.' (See Pl. XVI, fig. 2.)

'No. 4, 1899.—This rock also has retained its glassy characters far better than is the case in typical variolites. In this, it resembles the selvage of the variolite of Annalong (Co. Down). It has been brecciated during its viscid flow, like the obsidian of the Rocche Rosse at Lipari, and spherulitic matter has collected from the matrix in which the consolidated angular fragments of brown glass were carried onward. Banded structure, often very delicate, resulted from the movement of the mingled mass; and then the whole lava was again broken up, perhaps by earth-movement. The interstices between the fragments that were thus formed are now filled by chlorite, and what appear to be minute radial aggregates of chalcedony.

'The angular patches that look like pseudomorphs after olivine, occurring in the original glass and in the larger spherulitic aggregations, are of puzzling nature, since they seem identical with the minute spherulites that were developed at an early stage of the consolidation; every intermediate type, judging by outline, occurs between the tiny rounded spherulites and the angular little bodies that look like crystals. Even the latter are isotropic, and I fancy that they are spherulites actually passing into crystalline granules, but of what nature I cannot determine. Such an occurrence is a rare one, but is paralleled by the outlines assumed, before complete differentiation of the crystalline matter from the matrix, by the "spots" in some "spotted slates" produced by contact-metamorphism.

'This rock has, I take it, a complex history, the first brecciation occurring while it was still a viscid mass, and a certain blending thus occurring between the firmer glass-fragments and the new material that gathered from the matrix round them. The second brecciation affected both the old fragments and the matrix, which by this time had consolidated against them.'

In the Newborough sand-hills, the variolite is apt to occur in zones which are approximately parallel, and generally near to the margin of the 'pillows,' though in some of the smaller spheroidal bodies varioles are pretty evenly distributed throughout. This is the mode of occurrence of the famous variolite of Mont Genèvre,[1] where the diabase has pillowy structure of the same kind. Variolite has also been found in the Point-Bonita rock.[2]

(iii). The limestones have been described by Dr. Callaway, Prof. Bonney, the Rev. J. F. Blake, and others,[3] and no further petrological details are needed for the purpose of this paper.

(iv). The grits are of importance, chiefly in connection with the question of the age of the rocks; and a detailed description is not necessary here. They are moderate to very fine in grain, the finer beds passing gradually into shale. Bedding is seen in many places, and very clearly in the Newborough district, where it is rapidly

[1] Cole & Gregory, Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 295.

[2] Ransome, Bull. Departm. Geol. Univ. Calif. vol. i (1893) p. 99. The variolites of the Lleyn, described by Miss Raisin in Quart. Journ. Geol. Soc. vol. xlix (1893) p. 145, belong, no doubt, to the same series as those of Anglesey.

[3] Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 236; Brit. Assoc. Rep. 1888 (Bath Meetg.) p. 389.

contorted. Cleavage, though general in the finer beds, is never very strong. The rocks are generally red or green, and full of volcanic débris: broken felspars, fragments of andesites and diabases and pink felsite, and lapilli blackened with iron-ores, being often abundant. Indeed they bear a strong resemblance to the ashy grits of Bangor; a fact which must be of the highest importance in considering their age and that of the jaspers.

(v). Cataclastic and schistose rocks. It is no part of the purpose of this paper to describe these rocks, the history of which belongs to that of the earth-movements and metamorphism which have affected the district; but without some reference to them, no connected picture of the general field-relations of the jasper-bearing group as a whole could be presented.

The least altered are breccias, generally more or less schistose. The more altered are for the most part dull greenish and reddish schists, the two being intimately connected. The jaspers, limestones, and diabases are all found as fragments in the breccias, which are clearly cataclastic (' crush-conglomerate '). I have not, indeed, been able to satisfy myself of the pyroclastic origin of any rocks in the district, except two small bands among the pillowy diabases, and these appear to be true tuffs. The grits, too, can be seen in the act of breaking up into breccia. The rocks of the jasper-bearing group occur as lenticles in the dull green schists, of all sizes, from the smallest discernible with a lens to masses a mile or two in length. In the Newborough district, original, and in the Pentraeth district, schistose matter appears to predominate: the undeformed masses float, so far as can be ascertained, in a schistose matrix, the whole forming a kind of gigantic crush-conglomerate.

In the Beaumaris area the jaspers and limestones lie among schists; but as an important metamorphic question comes in here, this district will only be touched upon in the latter part of the paper.

III. Relations and Origin of the Jaspers.

We may now deal with those relations of the jaspers to the diabases and limestones, especially to the diabases, the consideration of which is the principal purpose of this paper.

The jaspers are found in the limestones and diabases in innumerable lumps and seams, generally small. One or two are some yards long, but these are exceptional, and they are seldom more than a foot or two in any dimension. Many have no regular shape, but there is one mode of occurrence that is evidently original. This is when the interspaces between the ellipsoids and spheroids of the pillowy diabase are filled in with jasper (see fig. 3, p. 428). Where the pillowy structure is strongly developed, this is the typical mode of occurrence of the jasper, and it is admirably exposed in many of the great bosses of the Newborough sand-hills.

Now, in a paper on 'Greenstones associated with Radiolarian Cherts,'[1] and also in the Geological Survey Memoir on the 'Silurian Rocks of Britain' vol. i (1899) pp. 85–87, Mr. Teall has pointed out that lavas exhibiting this peculiar pillowy structure have been found associated with radiolarian cherts in several parts of Britain, in Saxony, and in California, and at several horizons, those in California being as late as the Cretaceous.[2]

Further, it is known that, in the Southern Uplands of Scotland, the radiolarian cherts occasionally pass into the condition of jasper, and that this jasper is accordingly, like the chert, associated with the pillowy diabase.

Again, on the South-eastern border of the Scottish Highlands, jaspers and cherts are found[3] in association with highly-sheared rocks of basic igneous origin, though here original structures have been for the most part effaced. Radiolaria have been found in some of these rocks. I have examined specimens of jaspers from both these districts, and could not have distinguished them from those of Anglesey. Indeed, I ought to say that, whereas I had been disposed, for some time after going to Anglesey, to regard the jaspers as siliceous substitution-products [a view which I find was also taken by Prof. G. A. J. Cole[4]], the view taken in this paper was first suggested to me in 1898 by the fact that my friend, Mr. Barrow, at once recognized them as identical in character with those on the border of the Highlands.

If we now compare the photograph (fig. 3, p. 428) with pl. vi, p. 431, in the Geological Survey Memoir already quoted, we shall see that the jasper at Newborough is not merely associated with, but fills the interspaces of, a pillowy diabase in precisely the same way as does the radiolarian chert in the Girvan area. Further, Mr. Teall permits me to add that, without knowing anything at all of the associations of the rock, he wrote to me in 1898 concerning a slide which I sent him of a rock from the Pentraeth area: 'It reminds me of some of the diabasic lavas associated with radiolarian chert in the Southern Uplands.' This rock (Pl. XVI, fig. 1) showed the sheaf-like and radial grouping of felspar-laths like that figured by Dr. Ransome[5] in the Cretaceous diabase of Point Bonita, and in several other papers on variolite-bearing pillowy rocks. Finally, in the very fine 'jaspery phyllites' minute clastic micas can be made out, which could not be the case if they were siliceous substitution-products.

No radiolaria, indeed, have been actually found. But the rocks are so much jasperized, even in the most promising localities, that

[1] Trans. Roy. Geol. Soc. Cornwall, vol. xi (1893) p. 560.

[2] In the face of an association so world-wide, it seems difficult to avoid the conclusion (as suggested by Mr. Teall) that there is a causal connection.

[3] G. Barrow, Quart. Journ. Geol. Soc. vol. lvii (1901) p. 333.

[4] Sci. Proc. Roy. Dublin Soc. n. s. vol. vii (1891) p. 114. May not the silica which has penetrated the diabase have been derived from adjacent, and pre-existing, jasper?

[5] Bull. Departm. Geol. Univ. Calif. vol. i (1893) fig. 6, p. 85.

I fear there is not much hope that any organisms existing therein can have escaped effacement.

The indirect evidence here set forth, however, seems to me so strong as to leave little doubt that the jaspers of Anglesey are of organic origin, and that they are really altered radiolarian cherts.

That jaspers, whether associated with igneous rocks or not, should occur in connection with limestones, is only to be expected: and in the limestones, accordingly, we constantly find them, in all the three areas here described. As before remarked, they occur here generally in small irregular aggregates: but in a limestone north-east of Garth Ferry, on the Beaumaris road, there is a thin bed of jasper some yards long. Both these forms are, as is well known, characteristic of chert and flint in the Carboniferous Limestone and the Chalk. It is interesting to recall that, so long ago as 1888, the Rev. J. F. Blake wrote in his 'Monian System'[1] of limestones in the central region of the Island:—

'There are bands and isolated pieces of red jasper, which behave towards the limestones exactly as flint does to chalk, and a similar origin is at least suggested.'

I have not yet visited the spot referred to, but the rocks described are clearly the same as those of the south-east. In that remark, therefore, written 14 years ago, the Rev. J. F. Blake has anticipated the most important result arrived at in this paper.

To recapitulate: radiolarian cherts, sometimes altered to jasper, are intimately associated with, and fill interspaces in, pillowy diabase-lavas in the South of Scotland. The same association has been observed in several other parts of the world, and at horizons ranging from the Lower Ordovician to the Cretaceous.

The mode of occurrence of the Anglesey jaspers is similar, even in small details, to that of the cherts of the South of Scotland,[2] and it seems reasonable, therefore, to regard them as of similar origin.

Variolite, in the typical locality of Mont Genèvre, occurs in a diabase with the same pillowy structure as that possessed by the rocks so frequently associated with jaspers and cherts. It has actually been found in such at Point Bonita, but is there very rare. The Anglesey phenomena are therefore remarkably well developed; and the occurrence here of limestone also, completes, in a certain sense, the circle of associations.

IV. Age and External Relations.

This part of the subject falls under two heads:—(1) The relation of the group to the fossiliferous rocks; and (2) Its relation to the crystalline schists of the district.

[1] Quart. Journ. Geol. Soc. vol. xliv (1888) p. 489.

[2] The only direct evidence that the Anglesey diabases are true lavas is the occurrence of the thin tuffs. But the infillings of jasper could hardly find their way into an intrusive rock, until after considerable denudation.

On neither of these points is the evidence conclusive; but on the first, though imperfect, it is not contradictory, and I will therefore discuss this part of the subject before approaching the more complicated matter of the second.

(1) Relation to fossiliferous rocks.—The analogies with the rocks of the South of Scotland naturally suggest that the jasper-bearing group of Anglesey is, like the Scottish cherts, of Arenig age. And it is true that Ordovician rocks do occur in juxtaposition with the group in the Pentraeth area, although in the Beaumaris area the jaspers and limestones occur quite away from any fossiliferous rocks at all.

But at Pentraeth the known Ordovician rocks (probably Llandeilo-Caradoc) are of a different type, and also in a different condition. The Ordovician rocks are here, as all over the South-east of Anglesey (including the *Didymograptus-patulus* Beds at the Straits), a very uniform series of black shales and dark grits, and always unaltered, often not even cleaved. The jasper-bearing group, on the other hand, is extremely varied, cut up into lenticles by powerful earth-movements, and to a great extent schistose. The very scenery of the two groups is sharply contrasted. The same contrast has lately been remarked by Mr. Matley in the Lleyn Peninsula,[1] and there the fossiliferous rocks are of Lower Arenig age.

Further, it may be observed that in the mountainous areas of Snowdon and of the Harlech anticline, where the whole Ordovician Series is exposed from the Bala Beds downward, even into the Cambrian, in numerous sections, this jasper-bearing group has never been recorded.

It will thus be seen that there is no positive evidence to connect the jaspers of Anglesey with the Arenig Beds, and some negative evidence to disconnect them. Moreover, it must not be forgotten that the very association of jaspers and pillowy diabases, which furnishes the principal argument of this paper, is by no means confined to the Arenig Beds, but occurs at several different and widely separated horizons. We may therefore expect to find cases of this association in rocks of any period.

(2) Relation to the crystalline schists.—This is the most difficult part of the whole subject, for it is here that the conflict of evidence to which I have referred comes in.

The schists which are here meant are those of the region called by the Rev. J. F. Blake 'The Eastern Region' of the island, extending from the coast south of Newborough to the neighbourhood of Beaumaris and Llanddona. That part of this tract which lies to the east of a line running from the shore of the Straits a little west of the Menai Bridge to Coch y Mieri in Mynydd Llywdiarth, is composed of schists which are for the most part but minutely crystalline, and contain many lenticles of original clastic

[1] Geol. Mag. 1902, p. 122.

matter[1]; whereas the part to the west of this line consists of holocrystalline mica-schist in which no such original structures can be discerned. To discuss the origin of these rocks is no part of the purpose of this paper, and would open up large and far-reaching questions. I shall therefore describe their phenomena only so far as is necessary to a discussion of their relation to the jaspers.

There are two chains of evidence, and they had better be considered separately.

a.—The jasper-bearing group at Pentraeth and Newborough, either adjoins the crystalline schists of the western and most completely altered area, or is separated from them only by a narrow belt of Ordovician shales; and they are very different in condition. Nowhere in the jasper-bearing group in these areas, however highly sheared and altered they may be, are there any rocks the minerals of which indicate a very high temperature or very deep-seated conditions, except the micas in some of the schistose material, which do indeed appear to be authigenetic. The basic igneous rocks never pass beyond the stage of chloritic and epidotic schists: no hornblende has been observed in them; whereas the basic rocks of the adjacent complex are always true hornblende-schists, sometimes even hornblendic gneisses. Certainly it would seem extremely unlikely that there could be any connection between rocks at once so near together and so different in crystalline condition.

Moreover, a slide of one of the ashy grits of the Pentraeth area contains two fragments of a thoroughly crystalline mica-schist of the type most prevalent in the adjacent complex. The condition of the grit, and the mode of occurrence of the fragments, put a cataclastic origin out of the question. This grit must, therefore, be later than the crystallization of the mica-schists. It is associated with the jasper-bearing group, and if contemporaneous, that group must also be later than the crystallization of the schists in question.

b.—The second chain of evidence is as follows. The jaspers and limestones are found not only in the Pentraeth and Newborough areas, but also in the eastern part of the Eastern Schistose Region, that is, east of the line from the Menai Bridge to Mynydd Llwydiarth. They occur there as lenticles in the schists, and in such a way as to make it almost incredible that the structures of the enveloping rocks have not been developed since the jaspers and limestones became incorporated in them.[2] In Baron-Hill woods, lenticles of jasper, not more than 3 to 5 millimetres thick, are wrapped round by the folia of the fine schistose rocks exactly as any other phacoidal masses in them are. At Crymlyn, in the heart of the plateau, a jaspery limestone occurs in the schistose rocks, and a ravine some 30 feet deep has been cut through it and them. There is a very

[1] E. Greenly, Geol. Mag. 1896, p. 551.

[2] This would still be true, even if the rocks of this region were, as they very possibly may be, a complex of material of different ages.

strong resemblance between the prevalent types of this area and much of the material of the Pentraeth[1] and Newborough districts. Indeed, I can see no difference at all in some cases, either macro- or microscopically.

Now, along the line above mentioned, the schistose rocks of the eastern part of the Eastern Region appear to pass, by a perfectly gradual transition, into the holocrystalline schists of the portion to the west. Excellent sections are to be seen at a point in Mynydd Llwydiarth, 400 feet east-south-east of Hafod Leucu, and on the shore of the Straits below Cartrefle, the two ends of the line. The change of character affects not only the great body of acidic material, but the basic rocks contained in it. The rocks of the region, on both sides of the line, appear, therefore, to be a metamorphic unit; and there is nothing to show that on the east side we have structures of later date than on the west.

From this, consequently, it would follow that the crystallization of the whole region, including its most highly altered members, which are undoubted holocrystalline schists, is later than the jaspers, and than their incorporation in the schistose rocks of the eastern part of the area.

These two lines of argument lead thus to opposite conclusions; and the second is of such a nature as to call for great caution in its acceptance, because of the principles involved in it. For my own part, I do not think that there is a sufficient preponderance of evidence on either side to justify the pronouncement of a conclusion in this paper: and my aim is, rather to put each case, if it may be so spoken of, as strongly as possible.

The alternatives are, briefly, these:—

If the grits of Pentraeth can be shown to be contemporaneous with, or not later than, the jaspers, then the supposed unity of, and gradual transition in, the Eastern Region must be in some way deceptive. If the transition really exists, and the schistose complex of the region be a metamorphic unit, then the grits of Pentraeth must be of later date than the jasper-bearing group with which they are associated.

I hope that other parts of the island, the mapping of which I have not yet completed, may afford evidence that will finally decide which alternative must be adopted.

V. Summary.

It may conduce to lucidity to summarize briefly the principal conclusions and results contained in this paper.

A red jasper, with the fine shaly material called jaspery phyllite, is widely distributed in the southern and south-eastern parts of Anglesey, occurring in the districts of Newborough, Pentraeth, and Beaumaris.

Its associates are a varied group of rocks, comprising limestones, diabases, and serpentines, with grits and shales. They have been much modified by powerful earth-movements, which have produced

[1] J. F. Blake, Quart. Journ. Geol. Soc. vol. xliv (1888) p. 509.

brecciated and schistose structures through large parts of the areas, but original structures have survived in many places, and here the true relations of the rocks can often be seen.

The associations of the jaspers with the limestones, and especially with the diabases, are of the most intimate nature.

The diabases have the same characters, both in the field and under the microscope, as those basic lavas possessing the so-called 'pillowy' structure (often also variolitic), which have been found to be associated with radiolarian cherts and jaspers in several different parts of the world, and at several different geological horizons. Moreover, the relation of the jaspers to the igneous rocks here, is the same as that of the radiolarian chert in the South of Scotland to the accompanying igneous rocks.

On this ground, and also from the occurrence of jaspery phyllite with evident clastic texture, it is inferred that the jaspers of Anglesey are of organic origin, and must be regarded as altered radiolarian cherts.

The evidence for the age of the group is much less satisfactory. There is not sufficient to refer it to the Arenig Series, and it is possible that it belongs to a different period altogether.

Its relation to the crystalline schists of the region is obscured by conflicting evidence, which cannot yet be reconciled: one chain of evidence leading to the view that the group is older than, and has been involved in, the metamorphism of the adjacent schists, while another gives strong reason to suppose that it is altogether later.

EXPLANATION OF PLATES XV & XVI.

PLATE XV.

Fig. 1 [No. 6, 1899] Jasper, from 200 yards west of Bryn Hyfryd, Llansadwrn. The minerals shown are quartz, hæmatite, and a carbonate. Most of the hæmatite is in fine dust, but there are many flakes of definite eisenglimmer. The aggregates of hæmatite-dust which produce the mottled appearance are contained within single optical individuals of the quartz-mosaic. In the middle of the field is a rhombic section of a carbonate, with a zone of opaque hæmatite and a crystal of eisenglimmer. The light parts are quartz-veins. (× 36.)

2 [91 A] Jaspery phyllite, from Bryn Mawr, south-south-west of Pentraeth.—The rock consists of a remarkably transparent matrix full of hæmatite-dust. The small clastic grains seen are quartz and white mica. Thin quartz-veins cross the field. (× 36.)

PLATE XVI.

Fig. 1 [55 A] Diabase, from Fferam-gorniog, Pentraeth.—The only minerals shown are felspar and hæmatite-dust. The felspars have a sheaf-like or imperfectly radial arrangement. This rock contains small oval amygdules. (× 36.)

2 [No. 5, 1899] Variolite, from Taw y Graig, south-west of Pentraeth.—The only well-defined mineral is a felspar. The groundmass, though green with alteration-products, remains almost dark between crossed nicols. (× 36.)

[Fig. 1 in Pl. XV and fig. 2 in Pl. XVI are reproduced from slides kindly lent by Mr. George Barrow. He had them cut from specimens collected on the occasion of his visiting the ground with me, and they are now in his private collection. Fig. 2 in Pl. XV and fig. 1 in Pl. XVI are from slides in my own collection.]

Discussion.

Mr. G. Barrow said that he was interested in the group of rocks described by the Author, as they were the same group as the supposed Silurian rocks along the Border of the Southern Highlands. They here occurred in two different ways. First, along the least crystalline margin of the Anglesey schists; and again, faulted in some way against a highly crystalline portion of these schists. The second area showed that the condition of the jaspers, etc. remained the same in both areas, and it was not credible that the pillowy lavas and variolites could be of the same age as the hornblende-schists and hornblende-gneisses comparatively close by. Still more important, however, was the fact that small fragments of the well-crystallized schist occurred in the ashy grits associated with the lavas. It did not seem reasonable to suppose that these grits were of a totally different age from the lavas, and it seemed clear that the Anglesey schists were crystallized before the grits, lavas, and jaspers were formed.

The other (Beaumaris) area was of importance, as showing that on the outer edge of the aureole of crystallization in Anglesey these jaspers and green rocks again occur, in a manner suggesting their original association with the older rocks that pass into well-crystallized schists. But in all cases here, the junction of the jasper with the adjacent rock can be clearly seen to be due to movement, and not an original one. The evidence already given, however, shows unmistakably that the apparent identity in age has been produced by these movements, and, as in the Forfarshire area, it is a deception. The evidence from Anglesey certainly suggests that these jaspers and green rocks may be older than the speaker had supposed.

Prof. Bonney said that he agreed with the previous speaker in thinking that the apparent passage from the holocrystalline schists into the schistose rocks was more probably due to the crushing of a holocrystalline and a sedimentary group near their junction. Also, he did not see why a radiolarian chert should be associated over any wide area with a peculiar form of basic lava, having a structure which was likely to occur towards the outside of a mass of lava. Though doubtful about some details, he fully appreciated the value of the paper.

The Rev. J. F. Blake said that he was glad that the Author had visited the district near Newborough, which, though so inaccessible, was the most interesting in all Anglesey to a geologist. The present paper, however, dealt with only a few of the points of interest. Although the description of jaspers and pillowy lavas was taken from Malldraeth Marsh, the arguments for their age was taken from Pentraeth, where the ground was so broken that the relations of neighbouring rocks were by no means clear. He doubted whether the material filling the interstices of the pillowy lavas, or the folia in the crystalline schists which had been exhibited, had the same origin as true nodular jaspers, such as did

occur in Anglesey at Cerrig Ceinwen and elsewhere, and showed appearances which might be taken for the relics of obliterated organisms. In these cases they were not associated with igneous rocks, but with limestones and umber; and these associates occurred in every district among the Monian schists, which were overlain at no great distance by basal Cambro-Silurian conglomerates and shales in an unmetamorphosed condition, and without a sign of any such materials as limestone, umber, or jasper. There could be no doubt as to their age.

The 'jaspers' described by the Author seemed to be of more than one kind. There was not, so far as the speaker could learn, anything to connect them with radiolaria or with the Arenig rocks.

Prof. Sollas observed that cherts should not be accepted as radiolarian, unless they contained undoubted remains of radiolaria. He was far from inferring a necessary connection between radiolarian ooze and deep-sea deposits, but here we were asked to believe that such ooze occurred in the heart of igneous rocks. The necessary relationship between this occurrence and the pillowy structure of the diabase required to be proved. The slide which was said to represent radiolarian chert seemed to him very like ordinary spherulitic rhyolite. He congratulated the Author on the admirable, painstaking work which he had accomplished.

Mr. Coomáraswámy said that radiolarian remains did not necessarily imply a deep-sea origin for the formation in which they occurred. He had recently found radiolarian remains in the porcellanous plant-bearing shales of Upper Gondwána age, which occurred at Sripermatur, near Madras.

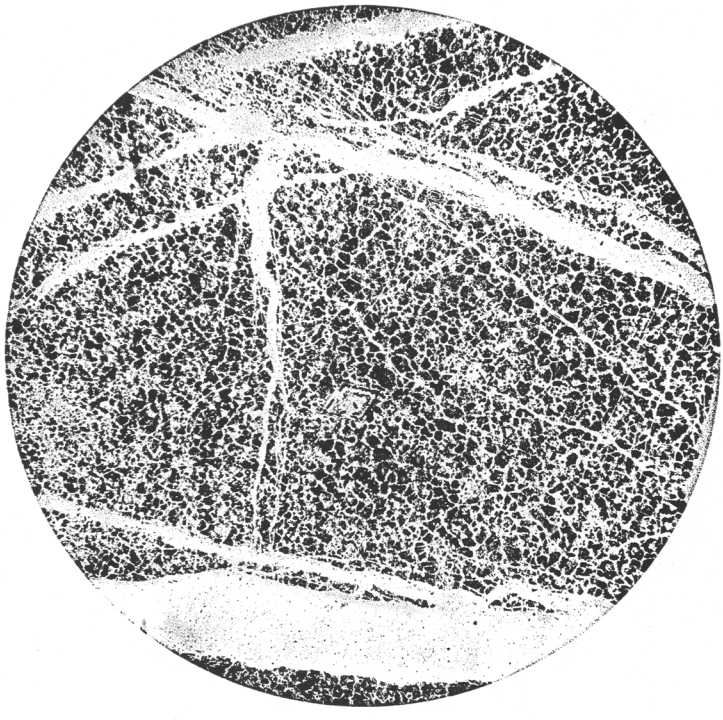
Dr. Flett stated that, in the supposed Arenig rocks on the southern border of the Scottish Highlands, many of the difficulties with which the Author had met in Anglesey were repeated. While in certain sections it was clear that there was a break between the supposed Arenigs and the Highland Schists to the north of them, in others there seemed to be no evidence of any interruption. At Aberfoyle some of the Highland rocks were as little metamorphosed as any of the supposed Arenigs.

The President agreed with the previous speakers in their appreciation of the value of the detailed geological work which the Author was doing in Anglesey, and welcomed this fresh instalment of the publication of his results. It was only by detailed work like this, that problems of such complexity as those presented by Anglesey would ever be solved. It was indeed most interesting to find here another example of that peculiar association of certain characteristic sediments and igneous rocks which had already been described from Southern Cornwall, Southern Scotland, and the Southern Highlands and elsewhere; and the same apparent geographical, lithological, and structural gradation from unaltered, through altered, into acknowledged metamorphic rocks. He had himself held the opinion that this peculiar association and gradation would ultimately be found to be due partly to the physical conditions of such an area at the time when its later recognizable sediments were

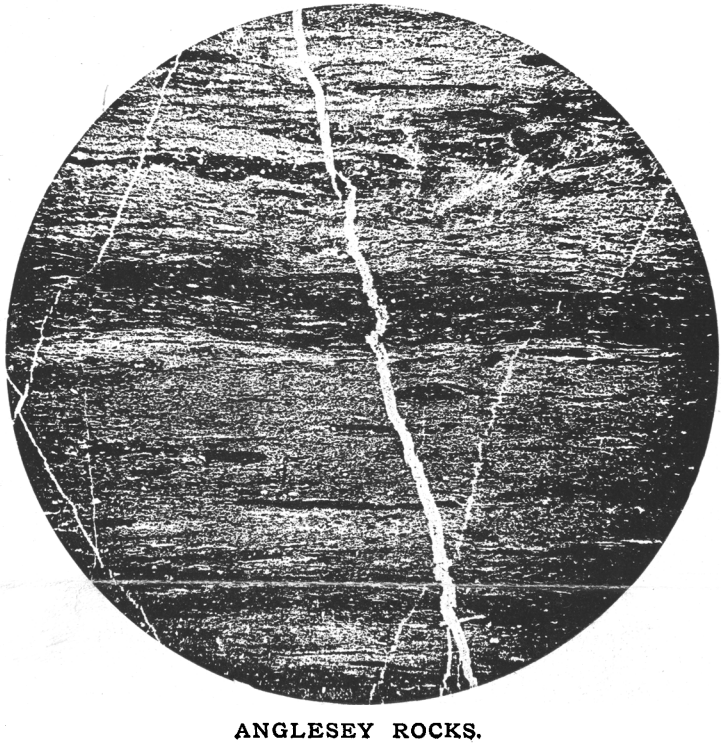
being deposited; and partly to the effects of the intense crust-creep to which the area itself had afterwards been subjected. Consider, for example, such an area as originally forming part of a slightly submerged continental shelf, or coastal platform, with volcanic and archipelagic conditions, and overlooking (say) to the south-eastward a broad and deeper sea. Suppose, further, the platform itself floored by rocks already metamorphosed, and that this platform remains covered by shallow waters for an extended period of geological time, while the sea-floor in front of it is continually deepening. Under these conditions, only such mechanical, volcanic, or organic material could become accumulated as rock-layers on the submerged platform, as by their original nature or rapid cementation were incapable of being swept off by the waves and currents of the shallow waters into the open and deepening sea beyond. Such rock-formations as would be accumulated on the platform would necessarily be thin, but would be lithologically varied and peculiar; while those laid down in the deepening sea outside would be of relatively enormous thickness, but would be lithologically monotonous. If, later on, the two regions became intensely folded, compacted, and overthrust by crust-creep, and the crests of some of the fold-ridges on the platform were worn down by denudation, so as to expose their cores formed of the original basement-floor of metamorphic rocks, most of the puzzling field-phenomena presented by Anglesey and North Wales, and the peculiar areas of similar character found elsewhere, might be expected to follow as a natural consequence.

The Author felt that, at that late hour, it was impossible to reply to the interesting points that had been raised in the discussion. He did not, of course, claim, in the absence of recognizable radiolaria, to have made a true demonstration of the organic origin of these jaspers; but he did submit that three converging lines of indirect evidence established a very strong probability. He laid especial stress upon the fine clastic nature of the jaspery phyllites. With regard to the relations of the jasper-bearing group to the crystalline schists, nothing that he could then add would better illustrate the peculiar perplexities of this problem than the remarks of Dr. Flett upon the rocks of the Highland Border. The interest that had been evinced by the Fellows of the Society would be a great encouragement in the work that still lay before him in the remaining parts of the island. He wished, in conclusion, to draw attention to the photographic reproductions by the process of contact, for which he was indebted to the kindness of Mr. J. H. Player, F.G.S.

1. *Jasper* ×36.

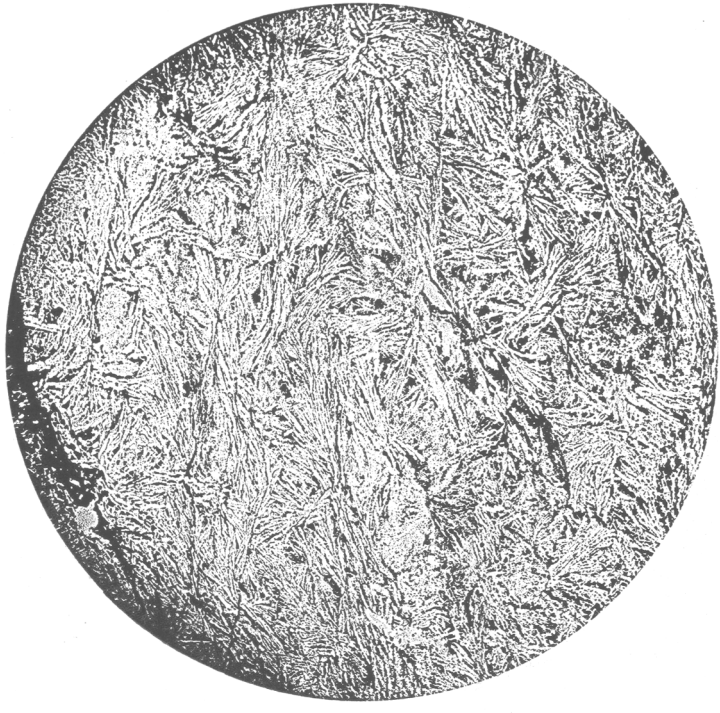


2. *Jaspery Phyllite* ×36.



ANGLESEY ROCKS.

1. *Diabase* ×36.



2. *Variolite* ×36.

ANGLESEY ROCKS.