30. *On some NODULAR FELSITES in the BALA GROUP of NORTH WALES.*

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[PLATE X.]

THE great group of felsites associated contemporaneously with sedimentary deposits of Bala age has been admirably described by Sir A. Ramsay in the *Memoirs of the Geological Survey**, and its extent is indicated on their maps†. Some peculiar structures exhibited here and there in these ancient lava-flows have, I believe, remained hitherto undescribed, except by an incidental notice in that volume (pp. 93, 94), and in the *Catalogue of Rock-specimens in the Jermyn-Street Museum*. During the last two years I have devoted some time to the study of their microscopic structure, the results of which are perhaps of sufficient interest to be laid before the Society.

The lavas of this northern border of Wales, from the peak of Snowdon to the valley of the Conway, are, so far as I know them, generally compact, with a more or less conchoidal fracture, exhibiting sometimes a distinctly fluidal structure, and of a pale grey colour inclining to green‡. Small scattered felspar crystals are not uncommon, and even minute grains of quartz; but, as a rule, these lavas are by no means distinctly porphyritic. Their general character, together with the special structures which I propose to describe, is well exhibited in more than one locality in the neighbourhood of Bettws-y-Coed. The highroad from the latter place to Pentre Voelas, on approaching the deep glen in which the falls of the Conway are concealed, runs at a considerable distance above the river on the right bank of the valley. Close to a little public house called the Conway Falls Inn we find the following section. The rock on either side of the house is a compact felsite. This continues for some distance as we ascend the road, and then becomes pretty distinctly cleaved, showing here and there a rather flattened nodule or spheroid about $\frac{1}{2}$ inch in diameter, the interior of which is often hollow. To this succeeds a peculiar rock, which at the first glance might easily be taken for a true schist, cropping out so as to form a little crag or reef on the left hand-side of the road. It consists of wavy laminæ of a whitish material (apparently minute quartz and

* The *Geology of North Wales* (Memoirs, vol. iii.).

† They are a little below the horizon of the Bala limestone. For stratigraphical details I refer the reader to the excellent description in the memoir, ch. xiv.

‡ Several of the Snowdonian felsites with the associated ash-beds are carefully described by the late Mr. Ward in his paper "On the Microscopic Structure of Ancient and Modern Volcanic Rocks" (*Quart. Journ. Geol. Soc.* vol. xxxi. p. 401). I venture, however, to think that prolonged study would have enabled him to speak more confidently as to the distinction between the lava-flows and the finer ash-beds. Mr. Rutley also has recently described and figured some peculiar varieties from the Snowdon district (*Quart. Journ. Geol. Soc.* vol. xxxvii. p. 403).

felspathic constituents) and of films of a glistening pale green mineral, together with 'eyes' of quartz, and seemingly vesicles, about as big as a pea (but flattened), sometimes merely lined, sometimes nearly filled with a ferruginous mineral, which is often associated with quartz. This rock quickly passes into a less fissile and much more coarsely spheroidal rock, its nodules being often as large as a pigeon's or bantam's egg, ovoid in form and compressed-looking, round which the cleavage-planes are bent. A band about a couple of yards wide, almost free from "nodules," succeeds; and then comes another band like the former, the upper part of which is crowded with nodules (some attaining 5 inches in longest diameter). These weather out from the matrix so as to give the rock the aspect of a coarse conglomerate. For a short distance beyond this, the rock (so far as I followed it up the hill-side) is not exposed. Then succeed some rather compact dark-coloured rocks (cleaved) of ashy aspect and evidently sedimentary origin.

Before proceeding to describe the microscopic structure of the above rocks it may be well to notice briefly two or three other sections. By the wicket-gate leading down to the Conway Falls from the road to Pandy Mill a face of rock is exposed in which we find:—(1) rather cleaved felsite with many concretions, diameter about 1 inch; (2) felsite less cleaved, fewer and smaller concretions; (3) felsite irregularly jointed, somewhat cleaved; (4) felsite (?) much cleaved; (5) dark ashy rock, much cleaved. The bedding, if one can infer it from (4) and (5), appears to be nearly vertical. The next section occurs in the Lledr valley, on the left bank, about half a mile above the new viaduct. Here a mass of felsite occurs (not less and perhaps more than forty feet thick) between 'slabby' ashy slates of darker colours; nodules abound in the upper part of this rock, which forms a bold cliff with a talus of fallen blocks below. Part of the rock appears to be crowded with ovoid or almost shuttle-shaped nodules, defined in part by the bending of the cleavage-surfaces round them. Sometimes these are hollow, sometimes wholly filled by one or more of the following minerals—quartz, a brown iron oxide, and a compact dull-green flinty substance. I found, about four years since, on the slopes at the head of Llyn Idwal*, a fallen block of a similar rock which had evidently come from the crags of the Glydyr.

I proceed now to describe the above rocks more minutely, and take first a specimen of the normal felsite from a little pit close to the Conway Falls Inn. This is a compact, bluish-grey rock, weathering to a paler tint, with only a few small felspar crystals and specks of a dull green colour scattered throughout the ground-mass. Under the microscope the rock (Pl. X. fig. 1) exhibits traces of a fluidal structure. The bands, wavy or corrugated, are mainly indicated by microliths of a pale gold-green mineral, apparently of rather irregular outline. A mineral, presumably the same, occurs sparsely in small aggregated patches (the dull green specks visible to the naked eye) and resembles one of the chlorite group rather than a hornblende. The slide

* The Museum of Economic Geology, Jermyn Street, contains a specimen from the Glydyr Fawr, as well as specimens from Digoed, near Bettws-y-Coed.

contains one or two crystals of felspar, one showing plagioclastic twinning. The above microliths are present in these also, together with a speck or two of epidote and a little ferrite. The ground-mass exhibits the usual devitrified structure, which also gives some indication of a fluidal arrangement*.

Another specimen taken from about four yards lower down than the outcrop of the first nodular part differs only in its fluidal structure being more uniformly banded (fig. 6), and in giving, even macroscopically, indications of cleavage, the cracks, under the microscope, being seen to be coated with the green mineral already described. The schist-like rock is not easily cut for the microscope; but Mr. Cuttall has succeeded in preparing for me a fairly thin transverse section (fig. 3). It is more decomposed than the other specimen; but the character of the ground-mass is similar, indications of fluidal structure can still be seen, and the cleavage is marked by irregular wavy cracks, very roughly parallel with it. These are coated by a green mineral, resembling that already described, but more filmy. It is very difficult to isolate one of the folia of this sufficiently to determine its optical characters. So far as I can ascertain, it is not monoclinic or triclinic; it is doubtless a hydrous mineral, probably related to the mica group, or it is not unlike that which passes under the name of sericite. A mineral of this general character is frequent in schistose rocks. The slide includes two or three of the knots or 'eyes,' which give, as already mentioned, a marked character to the rock. These are clearly vesicles, now filled more or less completely with crystalline quartz and a dusty brown mineral (limonite, with perhaps a trace of manganese). As the cleavage-cracks bend round these, we may, I think, affirm without hesitation that we have here a vesicular rhyolitic lava which, after the cavities had been more or less filled with infiltrated chalcedonic quartz and ferrite, assumed under pressure a rude cleavage-structure, the cracks of which by further infiltration were coated with the micaceous mineral. The above-described schistose aspect of the rock, macroscopic as well as microscopic, shows that it would not be prudent to reject absolutely, without any qualification, the view which regards foliation† as a process subsequent to and influenced by cleavage; it suggests also that in some cases lavas and tuffs may have been the rocks from which certain schists have been produced.

In describing the more distinctly spheroidal masses which succeed

* The felsite from the Conway Falls, which in places exhibits a tolerably well-marked columnar structure, is a slightly greener rock, but does not materially differ from the above, except that the chloritic mineral is a little more abundant, and the rock apparently a little more decomposed. The general character of these rocks is so well rendered in fig. 2, plate xxi. vol. xxxvii. of the *Quarterly Journal*, illustrating Mr. F. Rutley's excellent paper on some rocks of about the same age nearer Snowdon, that I have thought it needless to give illustrations. The petrologist will readily understand the merely varietal differences from this as a type.

† See also Dr. Sorby's Presidential address, Q. J. G. S. vol. xxxvi. Some cases, however, of "cleavage foliation" I am myself disposed to regard as the result of pressure during the process of mineral change, *i. e.* as rather subsequent to it than anterior, inasmuch as the structure is produced when the crystals which occur in the foliated rock are being formed, and so in the last stage of the development.

(excepting that with the very large pebble-like concretions) it will save time to include the specimens from the Lledr valley which are similar in character. Of these two rocks I have had a series of slides prepared. The rock has now lost the schisty structure, or at any rate retains no more than gives it at the first glance an ashy aspect*. In these the ground-mass exhibits more or less clearly a fluidal structure and is devitrified. In it there have been vesicles: these (as described above) are more or less filled with chalcedonic quartz; this on the inner side of the layer frequently terminates in well-marked pyramids; the brown and the green minerals appear to have been deposited subsequently, the former being mainly an impure chalybite with some limonite †, the latter a felted mass of a chloritic mineral, which towards the margin exhibits beautiful vermicular concretions. Owing to the smallness of the individual scales the results of optical tests are not quite satisfactory to me; but I think it probably rhombohedral, and it agrees generally with the mineral which Prof. Heddle and Prof. A. Geikie ‡ recognize as delessite §. I have already noticed the peculiar ovoid or shuttle-like form assumed by these masses; this is due in part to the bending of the rude cleavage-surfaces round these harder amygdaloids (as round included fragments); but I doubt whether this is the only reason of the structure. One slide, cut transversely to the longer axis of a nodule, shows it to be bounded by a well-defined ring indicated by a dark line. Under the microscope we see that the form of the inner surface of the cavity is less regular. It is almost wholly filled with chalcedonic quartz. The dark line cuts through the matrix, the outer edge is sharp; it is defined by minute scales of the green mineral and of ferrite, as if infiltration had taken place along a crack inwards; and a vein of chalcedonic quartz cuts through it and communicates with that in the interior of the vesicle in a way which suggests that the crack defining the ring was anterior to the filling of the vesicle and to the cleavage of the rock || (see fig. 5).

*This peculiarity is noticed by the Officers of the Survey (Geology of North Wales, p. 93), who speak of it as "a very singular rock, having a felspathic base, sometimes hard and compact, and sometimes flaky; in the one case like a trap, in the other like an ash." To indicate the accuracy of this description, I may mention that until I saw it through the microscope, I thought the latter variety more probably a peculiar form of an ashy rock.

† Through the kindness of Prof. Williamson a qualitative analysis of this mineral has been made for me at the University College Laboratory by Mr. F. H. Hatch. He reports:—"Soluble in HCl.; insoluble in H₂O. Metals present: (1) Iron in proportion of ferrous to ferric = 3 : 1, (2) Manganese, (3) Calcium, (4) Magnesium. Acid: Carbonic acid only." It is therefore, as I anticipated from the microscopic examination, an impure chalybite.

‡ Heddle, "Chloritic Minerals," Trans. Roy. Soc. Ed. vol. xxix p. 55.

§ Little fragments of the material containing it (always, no doubt, associated with silica) are almost exactly like fragments of greenish flint. They are, however, easily scratched, having a hardness of about 3, and are slightly unctuous to the touch.

|| One of the varieties of felsite from the Lledr valley is rather slaggy-looking, and has small irregular cavities nearly or quite filled with a brown ferruginous mineral, showing a slight approach to the schisty rock of the Conway valley.

I pass next to the mass above the Conway Falls Inn, which contains the large pebbly "concretions." The "matrix" gives, as before, indications of cleavage; and the flattened aspect of the nodules is probably due to pressure. The chief difference between this rock and the former (apart from the greater size of the nodules) is that the spheroidal boundary is more definite, giving the rock the appearance of a conglomerate, and the "pebbles" are frequently solid to the core.

From one of these, nearly three inches in diameter, I have had a slice cut; I expected to find some traces of a radial structure, deeming it a kind of spherulite; of this there is not the slightest indication. The slide (fig. 4) exhibits a wavy fluidal structure, and does not materially differ from that of the felsite obtained near the inn, showing, like it, one or two crystals of felspar and aggregations of the green mineral. The fractured face of the nodule gives indications of cracks concentric with the exterior.

I turn now to a rather similar rock, obtained several years since from the neighbourhood of Beddgelert. This also has a most singular resemblance to a conglomerate with a compact matrix. The latter is rather darker in colour than the rock we have been describing; the "pebbles" show a similar compact homogeneous aspect. One of these under the microscope exhibits the usual structure of a devitrified rhyolitic lava, except that it is rather more stained with ferrite, opacite &c., with some scattered grains of iron-oxide. The matrix has its devitrification-structure more minute; and its fluidal structure is mainly indicated by viridite*. Several parts of the slide present distinct though rude indications of a perlitic structure†.

In the lower part of the yellowish felsite, which forms the mass of Conway Mountain‡, and a short distance to the west of that town, is a thick band of spheroids which seems to run rather evenly for a considerable distance. Another band, not less than twenty feet thick (the rock here, I was informed, had been quarried for china-clay), occurs near the crest of the mountain. The spheroids are sometimes a couple of inches in diameter; they are often hollow at the core; and the more compact rock below exhibits occasional small cavities with irregular flinty-looking patches, sometimes dark, sometimes pinkish in colour: like the above-described green patches, they are rather unctuous and easily scratched with a knife.

This great mass of felsite is overlain by a grit evidently composed of materials derived from it, and sometimes by no means easy to distinguish with the unaided eye.

A similar felsite (part of the same mass displaced by a fault) forms the Diganwy Hills. The upper surface of the flow was well exposed

* The term is used advisedly; most of the mineral is not doubly refracting, and so differs from that described above. From its relation to cracks &c. it is clearly, in its present form, a mineral of secondary origin.

† See fig. 4, pl. xxi. vol. xxxvii. (illustrations to Mr. F. Rutley's paper). I have no doubt this is the second rock mentioned in Mr. G. G. Butler's note, p. 403.

‡ See Memoir, p. 107, considered, like those last described, to form a part of the great group of lava-flows so finely exhibited in Snowdon.

in 1878, opposite to the gate of the Diganwy Hotel. A little below this the felsite is also very spheroidal, the ovoid balls being often almost in contact, from 1 to 1·5 inch in diameter, and sometimes even double the latter size. Where not decomposed, they have within a cherty aspect. The structure occurs most conspicuously in a band several feet thick. Here also the surface of the mass is overlain by a grit derived from the felsite, in which pebbles of that rock occur; and then comes, apparently in immediate succession, a black slaty rock. Specimens of the spheroidal rock from the upper part of Conway Mountain, and of a spheroid from Diganwy, have been examined microscopically. Both are considerably decomposed. The outer part of the spheroid (like a kind of envelope, more regular on the outer than on the inner side) exhibits a very well-marked fluidal structure, which shows a general parallelism to the bounding surfaces, bending up into wave-like crests in the interior. This, in the former specimen, is hollow, with more or less of a lining of minutely crystallized quartz. The matrix of the rock, among the spheroids, shows also a fluidal structure; but this is more irregular and more decomposed than in the Diganwy specimen. The "husk" of this exhibits a very fine fluidal structure, rather more corrugated than in the other case; the interior is occupied by a pale brown, more homogeneous material, with occasional lacunæ. This, with crossed Nicols, exhibits many minute bright specks, with others that are colourless. It would seem as if a little of a glassy base still remained. As in places the boundary between this and the "husk" is very sharp, I have doubted whether it may not be formed by subsequent infiltration; but since in other places the one seems to pass into the other, and the structure more resembles that of a glassy rock with minute devitrification-structure, I incline to the opinion that it is merely a more compact and homogeneous form of the parent rock. These rocks, then, present us with structures resembling in some respects those already described from the felsites of the Bettws-y-Coed district*.

A specimen of the ordinary cream-coloured felsite of the Conway Mountain has also been examined. The rock is often very platy, so that it might almost be mistaken for a bedded mudstone; occasionally (as notably in a quarry near a foot-bridge which crosses the railway a little west of Conway) it is a pale greenish-grey colour, showing that the yellowish tint is the result of decomposition. Under the microscope it exhibits innumerable minute semitransparent dusty granules, and, with crossing Nicols, a patchy, very minute devitrified structure, giving indications of banding, the patches apparently composed of ill-defined microliths so arranged that each patch is approximately of one tint†.

* I have not entered into other details of the more minute mineral structures, the results of devitrification, infiltration, &c., deeming them of no very special interest.

† I have also examined the dark felsite further west, on the other side of the fault crossing the western end of Conway Mountain. It differs from those described above in having its base (I incline to the opinion that there is still a

A well-preserved flinty pale-grey felsite with nodular inclusions of quartz, in places dark green, with admixture of a chloritic mineral, may be seen in loose blocks by the road-side between Penmaenmawr and Conway. Under the microscope it shows a wavy fluidal structure, like many of the above, with a few small felspar crystals, most being orthoclase. The inclusions are vesicular cavities filled with quartz, and vermicular chlorite, like that described above, with a few tufted groups on the edge of the cavities of what appears to be a colourless mica, which also is occasionally seen in the above-described specimens. I do not know the locality where this particular variety of felsite occurs *in situ*; but doubtless it is one of those belonging to the Bala group.

From the above descriptions we are, I think, justified in the following conclusions:—

(1) That these Bala felsites are a group of ancient rhyolitic lavas, exhibiting vesicular, slaggy, fluidal, and other characteristic structures, and in no way (except as regards the effects of their great age) different from those of modern date.

(2) That the nodular or spheroidal structure has been produced in two ways:—

(a) By simple contraction and roughly concentric cracking of the mass in cooling, being thus intermediate between the perlitic structure common in glassy acid lavas, and the spheroidal structure common in basalt, which, so far as I know, is rather rarer in the former.

(b) By similar contraction in cooling, which is determined by the presence of a cavity, and produced as follows:—When the cavity is first formed, we may regard the whole viscid mass in the neighbourhood as in a state of equilibrium between the various forces acting on the cooling lava (contraction &c.) and the pressure of the gaseous contents of the cavity. As cooling proceeds (uniformly suppose) the volume of the latter diminishes rapidly, and its pressure against the walls of the cavity decreases. The various forces are no longer in equilibrium, and the contractile strain will be relieved by the formation of a crack, roughly concentric with the cavity, which, as we might expect, is more regular than it in form*.

glassy residuum) crowded with microliths, many of elongated form, which, from their very small extinction-angles with the longer edge, I should infer to be oligoclase; but there is some orthoclase. Some longer felspar crystals are more or less replaced by a filmy transparent mineral, giving brilliant colours with polarized light, neither monoclinic nor triclinic. There is a grain or two of ilmenite (fig. 2). This rock passes into the compact greenish-grey felsite of Penmaenbach, which exhibits a somewhat similar but less definite structure, and is more decomposed. It is marked on the Survey map as intrusive. I had not time to work out its stratigraphical relations; but petrologically it has rather the characters of a flow.

* I do not remember to have noticed an instance of the presence of cavities in the spheroids of a basic rock; but Prof. A. H. Green has mentioned to me an instance observed by him on the coast of Newfoundland, where cavities partly filled with calcite, quartz, and epidote, occur in the middle of large rude spheroids in a dark trap, probably a diabase.

(3) That the cavities are then filled, wholly or partially, by infiltrated minerals in the usual way.

(4) That the nodules thus rendered more solid (and in other cases from the effect of their form, aided perhaps by extremely minute differences in texture due to the disturbance of equilibrium in cooling) produce the usual distortion of the cleavage-planes when the whole mass is compressed.

(5) That, in some cases, further infiltration takes place along the cleavage-planes, giving rise to the schisty aspect.

At what period the devitrified structure was produced it is difficult to say. I should not wish to preclude myself from supposing that in some cases it may have been set up during the cooling of the lava. It may be well in conclusion to call attention to the occurrence of two great outbursts of rhyolitic lava in approximately the same area of North Wales, separated by so vast an interval of time as that which divides the Bala from the later Pre-Cambrian period.

EXPLANATION OF PLATE X.

- Fig. 1. Felsite from close to the Conway Falls Inn, illustrating the normal condition of the rock (p. 290), $\times 20$.
2. The dark-coloured felsite from the western end of Conway Mountain (p. 295, note), $\times 20$.
 3. The schistose felsite from the road-side above the Conway Falls Inn (p. 291), $\times 20$.
 4. Slide cut from the interior of one of the large pebble-like nodules, nearly 3 inches in diameter, in the felsite rather beyond the schistose rock of last figure (p. 293), $\times 50$.
 5. Part of a nodule, showing portion of a cavity, a boundary crack defined by a dull green mineral and the subsequent chalcedonic infiltration, a few yards below the schistose felsite above Conway Falls Inn (p. 292), $\times 20$.
 6. Felsite, about four yards lower down the road than the outcrop of the first nodular felsite (fig. 5), from the road-side above the Conway Falls Inn (p. 291), $\times 20$.

DISCUSSION.

Prof. BLAKE asked why, if the cracks were formed in the felsites in the way described, similar cracks are not found in other amygdaloidal rocks.

Rev. E. HILL asked if there were any criteria by which these altered felsites could be distinguished from true schists and gneisses.

The AUTHOR stated in reply to Mr. Blake that the conditions of rock-formation were so various that it was impossible to explain

A.S. Foord. del. et lith.

Mintern Bros. imp.

BALA NODULAR FELSITES.

why all apparently similar rocks did not present the same characters. In accounting for the presence of a structure, he could not undertake to explain its absence. In reply to Mr. Hill he said that the mimicry of foliation could only deceive the unassisted eye, and disappeared when the microscope was applied to the study of the rocks.