LI.—*On a Coarsely Spherulitic ("Variolitic") Basalt in Skye.*
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Communicated by permission of the Director-General of
the Geological Survey. (Plate XXIII.)

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LAST summer, during the examination of the southern extremity of the district of Sleat, in the island of Skye, a thin basic intrusive sheet was met with, which contained spherulites of an unusually large size. Some of them are considerably larger than any yet recorded in basic rocks either in Britain or elsewhere.

In Sleat spherulites are abundant in the trachytic or andesitic, pitchstone, and granophyre dykes, and they sometimes occur in basaltic intrusions, but, except for the occurrence now to be described, no spherulites larger than boy's marbles have been noticed. In some parts of the world, however, as is well known, the spherulites in acid rocks attain a very large size. Professor J. W. Judd¹ mentions some in the granophyre of the Cuillin Hills that are nearly two and a half inches in diameter. One of us² has recorded some in the rhyolites of Bala age at Careg-y-dafaid near Pwllheli, Carnarvonshire, which are as much as two feet in diameter. These, however, are small beside the examples noticed by Whitman Cross³ in the rhyolite of Silver Cliff, Colorado, which are sometimes ten feet in diameter.

A certain vagueness or mystery which has always attached to the petrographical treatment of the so-called "variolites" seems to arise partly from the usually minute dimensions of the special structures in question, partly, and mainly, from the much altered character of most of the examples studied. The fullest description we have is perhaps Löwinson-Lessing's account of the rock of Jalguba⁴ on Lake Onega. There the largest spherulites are only about a quarter of an inch in diameter. The largest recorded "varioles" in British examples range up to half an inch, in the rock of Roundwood, Co. Wicklow, as described by Sollas. In the case here described the diameter of the individual spherulitic growths is often as

¹ Q.J.G.S., vol. xlix. p. 187, 1893.

² "Bala Volc. Rocks of Caernarv." (1889), p. 35.

³ Proc. Colo. Sci. Soc., 1890, p. 275; 17th Ann. Rep. U.S. Geol. Sur., Part II., p. 298, Pl. xxviii., 1896.

⁴ Tscherm. Min. Petr. Mitth. (N.S.), vol. vi. pp. 281-300, Pl. iv., 1885.

much as two and a half or three inches. Further, the rock is practically in its pristine condition. For these reasons the description given below may be of interest for purposes of comparison.

Basaltic rocks exhibiting spherulitic or variolitic structures, perfect or imperfect, and of several distinct types, have already been described from different localities among the Tertiary rocks of the British Isles; viz., by Judd and Cole from the Beal¹ in Skye; by Cole from the Quiraing in Skye, from Ardtun in Mull,² and from Tollymore, Annalong,³ and Dunmore Head⁴ in County Down; by the late Professor Heddle from Loch Screden in Mull.⁵ From Palæozoic or presumably Palæozoic rocks examples have been studied by Blake⁶ and Cole⁷ from Careg Gwladys in Anglesey; by Groom from Carrock Fell⁸; by Miss Raisin from various localities in the Lleyd district of Caernarvonshire⁹; and by Sollas from Roundwood, Co. Wicklow¹⁰; some of these having many points in common with the rock now described from Camas Daraich. Andesites with variolitic structure have been noted from Beinn Shiant in Arduamurchan,¹¹ Aran Benllyn near Bala, Carrock Fell,¹² and the Fishguard district.¹³

The sheet to be described is exposed near high water mark near the centre of the bay of Camas Daraich, just on the E. side of the Point of Sleat (one inch sheet 61), and runs almost horizontally through a series of contorted granulitic grits or arkoses. The best exposures are a little W. of the centre of the bay, at a distance of about $\frac{1}{2}$ mile from the Point. In this locality the thickness is generally one or two feet only, and in one place the intrusion assumes a vertical dyke-like form, running almost at right angles to the ordinary outcrop, and is only from four to five inches thick. A similar sheet is seen, but more obscurely, in another locality $\frac{1}{4}$ mile N.E. of these exposures. There is an obscure area, partly of tidal sand, between the two localities, but it is probable that the sheets in both belong to the same intrusion.

¹ Q.J.G.S., vol. xxxix. p. 460, 1883.

² Q.J.G.S., vol. xlv. pp. 300-307, Pl. xi., 1888.

³ Sci. Proc. Roy. Dubl. Soc., vol. vii. pp. 511-519, Pl. xxi., 1892.

⁴ *Geol. Mag.*, 1894, pp. 220-222.

⁵ Trans. Geol. Soc. Glasg., vol. x. pp. 84, 85, Pl. iii., 1896.

⁶ Rep. Brit. Assoc. for 1888, pp. 410, 411, Pl. v., fig. 22.

⁷ Sci. Proc. Roy. Dubl. Soc., vol. vii. pp. 112-120, Pl. x., 1891.

⁸ Q.J.G.S., vol. xlv. pp. 298-304, Pl. xii., 1889.

⁹ Q.J.G.S., vol. xlix. pp. 145-159, Pl. i., 1893.

¹⁰ Sci. Proc. Roy. Dubl. Soc., vol. viii. pp. 94-106, 1893.

¹¹ Judd and Cole, *l.c.*

¹² Harker, *Geol. Mag.*, 1894, pp. 551-553; "Petrology for Students," fig. 41, 1895 and 1897.

¹³ Reed, Q.J.G.S., vol. li. pp. 183-187, Pl. vi., 1895.

In the best exposures the radiate spherulites are seen to occur in abundance throughout the entire thickness of the sheet, excepting for about an inch near the top and bottom surfaces. These thin external portions are so fine in grain that no constituents are separable by the naked eye. Just at the top surface a thin selvage, perhaps $\frac{1}{8}$ inch in thickness, of black glassy rock is seen, and this has partly weathered with a blue colour. The exact surface of contact with the country rock is not so distinctly seen near the bottom of the sheet. The spherulites are distinct in weathered rock faces, and in freshly broken hand specimens the radial feathery lines belonging to the shapes appear as bright silk-like threads, which at once attract the attention, even before their methodical arrangement is made out.

In the dyke-like portion of the intrusion the spherulites are less at the distance of one inch from the side than further in, and it is probable that the general rule¹ of decrease in size as the surface of the intrusion is approached obtains also in the rest of the intrusion. Yet, in one place, at a distance of only two inches below the top surface of the sheet, an oval spherulite, exposed on a rock face parallel to the surface, was observed, which had a longer diameter of three and a half inches. No spherulite appreciably larger than this was anywhere noticed, and it seemed as if the general size of the spherulites was as large at this distance from the surface as in the middle.

The forms of the spherulites are various. Many of them are bounded by plane surfaces on one or more sides, and so appear in sections as polygonal or partially polygonal figures. In the forms with rounded or curved surfaces, oval sections are more common than circular sections, but the differences between the longer and shorter diameters are usually not great. In a few cases, however, the sections are more elongate, and we get an approach to "axiolites." It has not been noticed that there is any general difference in shape between the sections exposed in rock faces parallel to the cooling surfaces and those in rock faces perpendicular to these surfaces.

Where the spherulites are edged by plane surfaces, we always find that these surfaces are in close contact with the sides of other spherulites. In the portion of the intrusion which shows distinct spherulites to the eye there are small areas here and there in which we can discern no radiate structure. These areas are more or less evenly mixed among the spherulites, and are perhaps equal to the spherulites in extent. When two

¹ This rule is shown excellently in the trachytic or andesitic dykes of Sleat, and also in those of the Cowal district of Argyllshire. See "Geology of Cowal," p. 169.

spherulites are close together without any such area between them, their surface of contact becomes a plane, and when a spherulite is in contact with other spherulites on all sides,—as is the case quite commonly,—all the sides of this spherulite are plane surfaces, and they have polygonal outlines. When a spherulite is bound on one side by an area which shows no radiate structure, its boundary on this side is a curved surface, even while the other sides which abut against other spherulites are planes. It seems probable, therefore, that we may regard the spherulites with plane surfaces as having been formed by the growth into close contact of forms which had originally rounded surfaces.

The sheet is crossed by joints parallel to the cooling surfaces and also by others which cut the rock into columns perpendicular to these surfaces. The spherulites are crossed by both these sets.

A specimen which was taken two inches below the top surface of the sheet, and itself showed spherulitic structure, was determined, by Walker's balance, to have a specific gravity of 2.92, and another specimen gave the same figure. This high density indicates a thoroughly basic composition for the rock.

Four specimens were selected for closer examination, and thin slices were prepared from them. Three of the specimens

FIG. 1.

[7845, 7947, 7948] are dense rocks of very dark grey or almost black colour on a fresh fracture, but with the peculiar sheen resulting from the presence of innumerable slender fibres. Further inspection shows that these fibres have a radiate disposition about certain centres, forming spherulitic growths with diameters ranging from $1\frac{1}{2}$ to 3 inches. The remaining specimen [7846], taken nearer to the surface of the intrusion,

is rather blacker and more compact, with a certain lustre suggestive of some amount of fresh glassy base. Here the spherulites are smaller, ranging from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter. In all cases the spherulites are closely crowded, for the most part impinging upon one another, though one specimen shows small interspaces without evident radiate structure. The polygonal outlines of the spherulites, resulting from the manner in which they are crowded together, are well shown on the smooth-cut faces or in the slices as held up to the light (fig. 1).

The first three slices are sufficiently alike to be described together. They are seen to consist to a large extent of slender divergent fibres which are clear and colourless, with low interference-tints, and are evidently of felspar. From some rather wide extinction-angles measured, it seems to be a rather basic labradorite, but the overlapping of the fibres renders any precise optical tests difficult of application, and most of the extinction-angles were quite low. This anomaly, arising from the way in which the thin nearly parallel fibres overlie one another in the thickness of the slice, is observed in other variolitic basalts. Thus in the Jalguba rock, already referred to, Löwinson-Lessing¹ found extinction-angles up to 5° only, although analyses of the rock prove that the felspar must be a labradorite. A like inference might be drawn in our own case from the specific gravity of the rock.

In addition to the felspar which forms the bulk of the rock, the slices show olivine, augite, magnetite, and some interstitial matter. Olivine is always abundant in numerous crystals which range from .002 to .005 inch or more, and, though minute, are of notably greater dimensions than the thickness of the felspar fibres. They interrupt the latter in such a fashion as to show that they are of earlier crystallization than the spherulites, but in no case have they been seen to serve as nuclei for the spherulitic growths. The olivine is clear and colourless except at the margin of each crystal, which is beginning to pass into a pale green serpentine. This change seems to be facilitated by a certain structure parallel to the brachypinacoid, often apparent as a faint striation parallel to the long axis of a crystal-section.

Augite has a faint yellow tinge in the slices. In those parts where the felspar is in thin parallel fibres the augite occurs in the interspaces between the fibres. Sometimes it is in granules no longer than broad, but more usually it is in pieces of considerable length, from three or four up to nine or ten times as long as the distance between adjoining fibres. We often see four or five adjoining interspaces occupied by augite pieces which are similarly oriented, as if they belonged to one individual. The augite seems, therefore, to be of later growth than the felspar fibres, and to be of the ophitic character so common in the intrusive Tertiary basalts of Scotland. The areas in which the augite pieces extinguish simultaneously vary considerably in size. On the average they are perhaps about the same size as the olivines, but are more variable in occurrence. Not uncommonly there are various augite areas with different orientation in close contact.

¹ *Loc. cit.* p. 292.

Magnetite is always well represented, but is in smaller crystals than the olivines or augites. It is partly in little octohedra, some of which lie across the felspar fibres, but in other places it lies between these fibres in pieces which have their longest sides in contact with them, as if the margins of the pieces had been to a large extent determined by pre-existing fibres. It also occurs as small inclusions in the augite.

The interstitial matter in these slices is not in large quantity. In the interspaces between the felspar we notice, besides the augite and the magnetite, various spaces which are crowded with minute doubly refracting particles or with fibres which seem to extinguish parallel with their length. Some of the spaces have their whole area taken up by these minute fibres arranged in fan-shaped aggregates, and perhaps they represent minute vacuoles of irregular shape which have been infilled with chlorite. In other spaces we notice only scattered points or strokes of light in rotating under crossed Nicols, and there is a certain amount of a colourless glassy base present. There are also a few small amygdules of chlorite, or of chlorite and calcite, of a rude spherical form and often about $\cdot 025$ inch in diameter. The felspar fibres near these show no indication of disturbance.

It is doubtful whether anything other than spherulites is shown in these three slices. The felspar does not always appear as fibres. There are parts where both it and the augite are in broader pieces without any clear order in their arrangement, and where the augite shows less numerous intersections by the felspar. These parts occur in thin stripes between the parts with the fibrous felspar, and have their greater lengths parallel to the average direction of the felspar fibres at their sides. Also, in part of slice 7947, in one of the spherulites which has been cut at a considerable angle to its radial lines, the felspar fibres appear much shorter than in the other spherulites of this and the other slices. Taking the appearances together, they are perhaps best explained on the supposition that the felspar is to some extent in the form of thin plates with their greatest lengths diverging from the centre to the edge of the spherulite, but with their broad sides often lying at considerable angles to one another. When the plates are cut nearly at right angles to their broad sides we get the thinnest fibres, but the lengths of the fibres vary according as the slice is cut parallel to the greater lengths of the plates or not. And in cases where the plates are cut nearly parallel to their broad sides the fibrous appearance of the felspar is lost.

The remaining sliced specimen (7846) was taken, as stated above, from a spot somewhat nearer the surface of the intrusion,

and it shows features in some respects differing from those of the other examples. Glass is here richly present and is of a brown colour in the slice. The felspar fibres embedded in the glassy base are not so broad as before and become gradually more slender as they approach the surface of cooling. The magnetite specks decrease in size *pari passu* with the felspar. Olivine is present as abundantly as in the other slices, and of dimensions not much inferior; but here the crystals are of skeleton form, often with forked extremities, or they enclose relatively large glass-inclusions with a regular disposition (fig. 2).

Augite is distinguishable in the part furthest away from this surface and occurs in the same way as in the other slices. Nearer to the surface the rock is very fine in grain and also more opaque, so that the different constituents, excepting the olivine and magnetite, cannot be satisfactorily separated. In this more opaque part there are, however, various clearer spaces, often from .01 to .003 inch diameter, which are occupied by growths of microlites in complicated arborescent forms. A few of these forms are seen within the spherulitic area and interrupt the fibres of it as if they were of earlier formation than them.

FIG. 2.

Another observation relates to the direction of elongation of the olivine crystallites. A large number, tested with a mica-plate, showed that the length of the section always coincides with the lesser axis of the ellipse of elasticity. Assuming then, what seems to be universally the case in olivine, that

$$a = \gamma, \quad b = \alpha, \quad c = \beta,$$

it is clear that these crystallites are elongated parallel to the a -axis. This has been noticed before in olivine-crystallites, *e.g.* by Rinne¹ in the lavas of Vesuvius. In the Hawaiian basalts, on the other hand, Dana² found the crystallites to be greatly elongated in the direction of the c -axis. In slags, according to Vogt,³ the common habit of olivine is tabular, the broad faces belonging to the pinacoid, b (010). In such minerals as the felspars and pyroxenes, as is well known, the general rule is that the crystallites are elongated parallel to the intersection of the principal cleavages: perhaps the greater variety

¹ Neu. Jahrb. für Min. 1891, vol. ii. pp. 272-280.

² Amer. Jour. Sci., vol. xxxvii. p. 447, 1889.

³ Studier over Slagger, p. 47, 1884.

of habit exhibited by olivine may be connected with the absence of any very strongly pronounced cleavages. In the first three slides of our rock, described above, the olivine seems to have the forms and habit represented in fig. 3, A, without any very marked direction of elongation. In the slide now under notice we have the same forms, but with elongation parallel to the *a*-axis (fig. 3, B), or more usually with such imperfect development as is roughly shown in fig. 3, C. In some of the little cross-sections, however, it is seen that the form *b* is represented by only one of the pair of faces. This

FIG. 3.

hemimorphism with respect to the *b*-axis has been remarked also by Rinne and others. The cross-shapes due to interpenetrating twins on (011) and (120), described by several writers, we have not observed in our rock.

Although no other rock has been found in Sleat showing structures comparable with those of the Camas Daraich occurrence on the same scale of magnitude, many of the trachytic or andesitic, and some of the basaltic, dykes of the district exhibit a variolitic tendency. The structure is usually on quite a small scale, and varies from mere fan-like and sheaf-like groupings of felspar fibres to complete radiate spherulites. It is often to be noticed, however, that the development of the structure as revealed in thin slices is much less perfect than might be inferred from the pronounced spherulitic appearance of exposed surfaces in the field.

FIGURES IN TEXT.

Fig. 1. Slice 7948, twice natural size (diagrammatic), showing portions of three spherulites with the polygonal boundaries due to their close packing. The lowest of the three is cut transversely to the direction of the fibres.

+ 300

Fig. 2. Skeleton-crystallites of olivine, $\times 100$ to 150 ; slice 7846.

Fig. 3. Crystallographic habit of olivine ; A, in the general body of the rock ; B, in the more glassy variety ; C, in the skeleton-crystallites of the latter.

EXPLANATION OF PLATE XXIII.

FIG. 1, [7845] $\times 25$, Natural Light. This illustrates the character of the general body of the rock. The figure includes only a small part of one of the large spherulites, its centre being well outside the field, so that the radiate arrangement of the slender felspar fibres which form so large an element in the rock is scarcely indicated. The olivine appears as small, clear crystals and crystal-grains, showing in places incipient conversion to serpentine at the margin of a crystal. The smaller opaque crystals are magnetite. The augite, which forms ophitic granules in the interstices of the felspar fibres, becomes conspicuous only when polarised light is used. A glassy residue is present here only in small amount, and is not apparent in the figure.