

XI.—*On Borolanite—an Igneous Rock intrusive in the Cambrian Limestone of Assynt, Sutherlandshire, and the Torridon Sandstone of Ross-shire.* By J. HORNE, F.R.S.E., and J. J. H. TEALL, F.R.S., of the Geological Survey. (Communicated by permission of the Director-General of the Geological Survey.) (With a Plate.)

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The remarkable development of igneous rocks associated with the Torridon sandstone and Cambrian strata in Assynt, Sutherlandshire, forms one of the striking geological features of that region. In the various papers descriptive of the ancient sedimentary formations of the North-West Highlands by former observers, references are made to the lithological characters of these crystalline rocks and to their mode of occurrence.

I. *Previous References to the Igneous Rocks associated with the Torridon Sandstone and Cambrian Strata in Assynt.*

In 1856, Professor NICOL, in his paper "On the Red Sandstone and Conglomerate, and the Superposed Quartz-rocks, Limestones and Gneiss of the North-West Coast of Scotland," notes the occurrence of a bed of greenstone in the cliff of limestone to the south of the Inn at Inchnadamff.* He further states that in the area to the east of Ledmore, the relation of the quartzite to the gneiss bounding it on its eastern side was not visible on the line followed by him, as a mass of red felspar porphyry intervenes near Loch Borolan.

In 1858, Sir RODERICK MURCHISON, in his paper "On the Succession of the Older Rocks of the Northernmost Counties of Scotland, with some observations on the Orkney and Shetland Islands," refers to the band of red porphyry with large crystals of felspar, detected by Mr C. W. PEACH and traced by him round the flank of Canisp, which is there interposed between the gneiss and the Torridon sandstone.†

* *Q. J. G. Soc.*, vol. xiii. p. 25.

† *Q. J. G. Soc.*, vol. xv. p. 365.

Again, in 1859, MURCHISON called attention to a band of syenitic greenstone, intercalated in the grey limestones at the bend of the road about a mile west from Inchnadamff. He states that it is from 40 to 50 feet thick, and as regularly bedded as the limestone both above and below it, though on examination it is seen to be a true igneous rock, containing crystals of hornblende with felspar and quartz. The indications of contact alteration produced by this igneous mass had evidently attracted his attention, for he notes that the limestone above the igneous rock is more altered than that which lies beneath it, being in parts a crystalline marble.*

In his brief summary of the igneous rocks of Sutherland, in the same communication, MURCHISON refers to an igneous rock of felspathic character, with some varieties, which, though termed porphyries, are rather syenites, breaking through the quartz-rocks far above the limestone of Assynt. These rocks spread out into large masses in the tract to the east of Assynt, which is traversed by the road to Oykel Bridge.†

In 1860, Professor NICOL announced that, in the course of the previous year, he had observed that the Canisp porphyry not only breaks through the quartzite overlying the Torridon sandstone, but forms a mass more than a mile in diameter in the quartzite within a few hundred yards of the Inn at Inchnadamff. From these facts he inferred that the igneous intrusions must have been later than either the red sandstone (Torridon) or quartzite.‡

In 1882, Mr HUDDLESTON referred to some of these igneous rocks in the Cambrian strata of Assynt, describing them as “a kind of diorite.”

In his various papers published in the *Mineralogical Magazine* from 1881 to 1884, Professor HEDDLE gave the results of his detailed examination of these rocks. He indicates the distribution of the Canisp porphyry, and speaks of it as one of the most striking porphyries of Scotland. He describes it as a structureless paste of a buff or dull brown colour, studded with crystals of a bright brick-red colour, commingled with others of a pale yellow ochre tint and with minuter ones of a dark green. He notes the occurrence of porphyritic crystals of orthoclase with albite and augite in the rock.§ Regarding the igneous rocks in the quartzites and dolomite in the neighbourhood of Inchnadamff, he refers to their distribution, and points out some of the lithological varieties, from the Canisp porphyry to the more basic types found in the limestone, in which hornblende is more abundant.¶ Special reference is made to the remarkable “red porphyry” of Loch Borolan, and to the large area which it occupies from Ledbeg eastwards towards Kinlochailsh.** He takes exception to the name given to the rock of this hilly region, because no true porphyritic structure can be seen in it; it has two ingredients, felspar and quartz, the former showing traces of crystalline form while the latter is frequently altogether absent. He defines the rock as a mass of agglutinated granules of a more or less brilliant red felspar. While indicating the localities of the

* *Q. J. G. Soc.*, vol. xvi. p. 221.

† *Q. J. G. Soc.*, vol. xvi. p. 232.

‡ *Q. J. G. Soc.*, vol. xvii. p. 99.

§ *Min. Mag.*, vol. iv. p. 233 *et seq.*

¶ *Min. Mag.*, vol. v. pp. 136 to 144.

** *Min. Mag.*, vol. v. p. 144 and p. 295 *et seq.*

marbles, he noted the important fact that they were all more or less adjacent to the mass of red felspar rock on Cnoc-na-Sròine or its branches, and he further made the important deduction that the marble is merely a portion of the limestone series of Assynt.* But while giving weight to these observations, he was inclined to the opinion that the red rock of Cnoc-na-Sròine is a mere variety of the "Logan Rock."

Near the south-western limit of the Cnoc-na-Sròine mass Professor HEDDLE observed a rock on the east bank of the Ledbeg River, at the bridge on the road leading to Elphin, about which he makes the following statement. The rock "is highly characteristic, though its characteristic features are possibly due to a modification of pseudomorphic alteration. In structure it resembles the westerly dull-red bed of 'Logan,' but it has a brown colour blotched with dull greenish-grey. It has a waxy lustre, is translucent, and the greater part of it cuts easily with the knife. It consists of a muddy dull red felspar, in rude crystals, embedded in a substance which is identical in appearance with the pseudophite from Plaben Budweis." †

Again, to the east of Aultivullin and Loch Am Meallan, he was impressed with the peculiar features of the rocks forming the main mass of borolanite. He observes that they are "in appearance intermediate between that of Cnoc-na-Sròine and the 'Logan Rock,' with here and there a great resemblance to the rock seen at the Bridge of Ledbeg; at other points there is some slight resemblance to an igneous rock. The rock of the east end of the hill is again like 'Logan,' of a red hue, and a grey-brown labradorite-like bed is the last seen." ‡

In 1883, Dr CALLAWAY made brief allusion to some of the igneous rocks in the Assynt series, referring more particularly to the Loch Ailsh group, extending from Ledmore to the gap south of Loch Ailsh. While noting the granitoid texture which is characteristic of this mass, he called attention to an exceptional garnetiferous variety occurring to the east of Loch Borolan, on the slope north of the road.§ In the appendix to this paper, Professor BONNEY describes the microscopic characters of a few specimens of these igneous rocks, collected by Dr CALLAWAY.¶ Regarding the exceptional garnetiferous variety, he states that it is "a most perplexing rock. In the slide a fair quantity of black mica is at once recognised, and a number of subtranslucent sap brown garnets, the larger (being the less regularly formed), including flakes of mica, &c. . . . The ground of the slide appears to consist partly of a felspar, in patches of a most irregular form (with perhaps a little quartz), and a mineral which occurs in rather wavy bunches, like tufts of long thread or rootlets, or a kind of 'canal system.' It seems to have replaced the felspar, and may be one of the fibrolite group."

One of the dykes in the Traligill Burn near Inchnadamff is described by Professor BONNEY as a hornblende porphyrite.

In 1886, one of the authors of this paper published notes on some hornblende-bearing rocks from Inchnadamff, containing a description of the rocks and the characters of the

* *Min. Mag.*, vol. v. p. 274.

§ *Q. J. G. Soc.*, vol. xxxix. p. 409.

† *Mineralog. Mag.*, vol. v. p. 294.

¶ *Q. J. G. Soc.*, vol. xxxix. p. 420.

‡ *Mineralog. Mag.*, vol. v. p. 295.

rock-forming minerals.* He indicated some of the remarkable lithological varieties of these intrusive rocks, and gave analyses of three specimens, viz. :—1. Hornblende porphyrite, intrusive in quartzite ; 2. Porphyritic diorite ; 3. Plagioclase—pyroxene—hornblende rock near Inchnadamff, intrusive in limestone. The last, which is the most basic, differs from the others in containing a large amount of colourless pyroxene. The author suggested that “in all probability the pyroxene is a nearly pure lime-magnesia bisilicate, and one is tempted, therefore, to ask whether it may not be due to the absorption by the igneous magma of a certain amount of the dolomitic limestone into which the rock has been intruded.”

In 1888, in the report on the recent work of the Geological Survey in the North-West Highlands of Scotland, special reference was made to the intrusive igneous rocks associated with the Torridon sandstone and Cambrian strata in Assynt, brief descriptions being given of the geological features which they present in the field.†

II. *Physical Relations of the Igneous Rocks intrusive in the Torridon Sandstone and Cambrian Strata.*

1. Before proceeding to the description of the particular group of rocks that form the subject of this communication, it may be desirable to refer generally to the physical relations which the igneous materials, as a whole, present in the field. Perhaps their most characteristic feature is their occurrence in the form of intrusive sheets injected along the planes of bedding of the sedimentary strata. The remarkable parallelism of the igneous bands, varying in thickness as a rule from 10 to 50 feet, and the manner in which they cling to the same horizon for considerable distances, have led one or two observers to the conclusion that they are contemporaneous lava flows. But a careful examination of the physical relations of these igneous rocks reveals certain phenomena which are characteristic of intrusive sheets. First, when the igneous bands are traced along the line of outcrop, they pass transgressively from lower to higher members of the same group, and occasionally plunge downwards into a lower platform. A striking example of these phenomena is to be found on the western face of Canisp, where a mass of porphyritic felsite rises from the old platform of Archæan gneiss, passing upwards into the overlying Torridon sandstone and eventually spreading along the bedding planes. Second, where the sheets reach a considerable thickness, both the overlying and underlying strata are altered by contact metamorphism. The zone of marble surrounding the great igneous mass to the east of Ledbeg admirably illustrates this local metamorphism, and even in the case of the thinner sheets, the quartzites are hardened and welded to the igneous rock. Third, there is a marked absence of cellular structure in the various types of igneous materials. Fourth, they occasionally contain fragments of the sedimentary rocks which they traverse.

* Notes on some hornblende-bearing rocks from Inchnadamff. J. J. H. Teall, *Geol. Mag.*, 1886, p. 346.

† “Report on the Recent Work of the Geological Survey in the North-West Highlands of Scotland, based on the Field Notes and Maps of Messrs B. N. PEACH ; J. HORNE ; W. GUNN ; C. T. CLOUGH ; L. HINXMAN and H. M. CADELL,” *Q. J. G. Soc.*, xliv. p. 378.

2. The detailed mapping of the region has also shown that these igneous intercalations are more or less confined to certain definite horizons in the sedimentary strata. Several sheets are interleaved in the Torridon sandstone, which rests unconformably on the eroded platform of Archæan gneiss, while in the overlying Cambrian strata, two occur in the basal quartzites, two in the "Pipe-Rock," one in the "Furoid Beds," two in the lowest group of limestone, and one in the succeeding group of Eilean Dubh limestone. These intrusive masses are not always traceable, some of the bands being much more constant than others, but in the area surrounding Inchnadamff they are typically developed.

3. It is rather remarkable that this outbreak of volcanic activity in these ancient sedimentary systems is comparatively local, for though the Torridon sandstone and the overlying Cambrian strata can be traced continuously for a distance of 90 miles across the counties of Sutherland and Ross, the igneous rocks are confined to a limited portion of this belt. In the area lying to the west of the post-Cambrian terrestrial movements, they extend from Loch Assynt to near Elphin—a distance of about nine miles, but in the region affected by these movements they stretch from Glencoul to Ullapool—a distance of 24 miles. Originally they must have penetrated far to the east, for they are carried westwards with the associated sedimentary strata along the higher thrust-planes.

4. From the fact that the intrusive sheets are truncated by the numerous thrusts or lines of displacement traversing the region, it is obvious that the period of volcanic activity to which they belong is later than the Cambrian limestone of Durness and older than the post-Cambrian movements.

III. *Intrusive Mass of Cnoc-na-Sròine, Loch Borolan, and Ruighe Cnoc.*

1. In the southern portion of Assynt, there is a remarkable development of these intrusive igneous rocks, covering an extensive area from Ledbeg eastwards to a point near the road leading to Loch Ailsh—a distance of 5 miles. They can also be traced from the peat-clad moor south-east of Loch Borolan northwards to the slopes of Sgonnan Mòr. The particular group of rocks which are specially described in this paper are associated with this great intrusive mass.*

The relations of this extensive series of igneous rocks to the surrounding strata are of special interest and in the neighbourhood of Ledbeg and Ledmore are rather complicated. In the latter region there are various outliers of materials lying above the Ben More thrust-plane, originally continuous but now occurring in isolated patches, which cover alike portions of the igneous rocks and the adjacent marble. Notwithstanding these complications, there are several sections defining the limits of the intrusive rocks and their relations to the altered Cambrian limestone.

Between Ledbeg and the road leading to Loch Ailsh the eruptive rocks form a range of hilly ground rising to a height of 1305 feet in Cnoc-na-Sròine. From Loch Borolan to

* The description of the physical relations of this intrusive mass may be more readily followed by referring to Sheet 101 (one-inch) of the Geological Survey Map of Scotland.

Ledbeg they have been so denuded as to present a prominent escarpment skirting the road leading to Inchnadamff. But this conspicuous crag is by no means the western limit of the mass.

Ascending the Ledbeg River from the point where it joins the Ledmore River, $\frac{3}{4}$ of a mile east of Cama Loch, the coarse granitic rock is exposed at various points in the stream section. About 70 yards to the south of Ledbeg Cottage the marble is visible, and further up the stream, at the ford leading to the cottage, the basal bands of the Durness limestone are met with in a highly altered form. A few yards to the west of the river, and immediately to the north of the cottage, one of the bands of serpulite limestone at the base of the Grudaidd group is clearly recognisable, though considerably metamorphosed. Returning to the river, and following the section to a point about 200 yards above the footbridge, there are several excellent exposures of the granitic rock penetrating the marble on both banks of the stream. Indeed the site of the old quarry where the marble was formerly wrought is close by this locality, being situated a few yards to the east of the river and near the road to Inchnadamff. The evidence that the marble is merely an altered portion of the Durness limestone is still further strengthened by the occurrence of recognisable bands of the basal limestone in an altered form, in a tributary of the Ledbeg River, about 500 yards to the north of Ledbeg Cottage. Our colleague, Mr PEACH, who mapped this portion of the Ledbeg River, has traced the marble at intervals from Ledbeg westwards to a point high up on the slope of Cnoc-an-Leathaid-Beg, where it is associated with the pink granitic rock. At the latter locality the marble and the intrusive granitoid rock are alike buried underneath the basal quartzites and the "Pipe-Rock," resting unconformably on a slice of Lewisian gneiss. These materials form an outlier separated by denudation from the displaced masses lying above the Ben More thrust-plane.

On the south side of the Ledbeg River, due south of the shepherd's house at Loyne, there is another small outlier of shattered basal quartzite, separated by a powerful thrust-plane from the underlying materials. Measuring about 700 yards in length and about 400 yards in breadth, these displaced quartzites rest partly on thrust "Fucoid Beds," serpulite grit and basal limestone, and partly on the marble. Along the eastern limit of this outlier a line of swallow holes can be traced, and the marble is visible in a conspicuous grassy patch of ground adjoining the basal quartzites about 500 yards to the south of the river. Crossing the flat peat-covered ground to the south of this exposure, the marble is again seen in a small rocky knoll within 50 yards of the boundary line of the granitic mass of Cnoc-na-Sròine. From the latter point the boundary line of the igneous rocks sweeps eastwards along the southern slope of the valley to the base of Ruighe Cnoc, where there is a fine escarpment of the pink granitic rock. For most of this distance the junction of the intrusive mass with the thrust Cambrian strata is buried under peat and drift.

But on the north side of the valley, about 150 yards to the north-east of the Loyne shepherd's house, there is a detached mass of the pink orthoclase rock of Cnoc-na-Sròine in

immediate contact with the marble. An excellent section of the igneous rock is exposed in a small tributary of the Ledbeg River, showing the intrusive mass penetrating the marble. The altered limestone can be traced from the northern limit of this igneous rock for a distance of about 150 yards to the base of Ben Fuarain, where it is covered by crushed Torridon sandstone. Here again a gradual passage is observable from the white crystalline marble into the white limestone of the Eilean Dubh group. The crushed and shattered Torridon sandstone, overlying the marble and unaltered Durness limestone, rests unconformably on Lewisian gneiss, and both are covered in turn by the basal quartzites and a small portion of the "Pipe-Rock." All these materials, viz., the gneiss, the Torridon sandstone and Cambrian quartzites, are separated from the underlying limestone by a complete discordance. They form one of the most interesting of the numerous outliers of displaced materials resting above the Ben More thrust-plane.

Proceeding to the south-west slope of Sgonnan Mòr, several sections of special interest are met with, revealing the relations of the igneous mass to the surrounding strata. On this declivity four small streams unite to form an important tributary of the Ledbeg River at Luban Croma. In each of these burns the intrusive rock is visible, and in the two most northerly there are excellent sections showing peculiar types of the igneous mass penetrating the marble between the 1000 feet and 1250 feet contour lines. Not far above this level, both the marble and the intrusive rock are abruptly truncated by the Ben More thrust-plane bringing forward a slice of Archæan rocks covered unconformably by the Torridon sandstone and Cambrian strata. On the south-west slope of this mountain, the Torridon flags, shales and grits overlie in inverted order the igneous rock and the marble, for as we ascend the slope the strata have a persistent easterly dip till we reach the coarse conglomerate at the base of the Torridon sandstone, in contact with the overlying Lewisian gneiss and its basic dykes.

The ground between Sgonnan Mòr and Kinloch Ailsh has not been surveyed in detail, but from certain traverses across the area it seems apparent that the intrusive igneous rocks reappear at certain localities with the displaced materials overlying the Ben More thrust-plane.

In the neighbourhood of Strathsheaskich near Loch Ailsh the eastern limit of the intrusive mass can be approximately defined by means of rocky knolls projecting through the peat and drift. It is bounded by massive white marble, apparently resting on the igneous rock, and dipping towards the east at angles varying from 30° to 70° . This junction line can be traced through the gap, close by the Kinloch Ailsh road to the high road leading to Inchnadamff.

The southern limit of this great intrusive mass is to a large extent obscured by the extensive covering of peat stretching continuously from the Kinloch Ailsh road westwards to Loch Urigill and Ledmore. But occasional exposures of rock are to be found in the streams cutting through the peat and drift. It extends far to the south of the road between Loch Borolan and Aultivullin, for it is visible in small burn sections about three-quarters of a mile due south of Aultivullin. Here again it is overlapped by the Cambrian

quartzites and Lewisian gneiss lying above the Ben More thrust-plane. The marble is found along the north-east shore of Loch Urigill, about a mile to the south of Loch Borolan, and it is therefore probable that the igneous mass extends for some distance southwards from the latter loch.

Excellent sections are visible along the banks of the Ledmore River from Loch Borolan to the point where it is joined by the Ledbeg tributary. Immediately to the south of the junction of these two streams there are small exposures of those peculiar types of the igneous rocks, which are specially described in this paper, laid bare by the denudation of the adjacent quartzites and gneiss overlying the Ben More thrust-plane.

2. Summarising the foregoing evidence regarding the physical relations of the great Loch Borolan igneous mass, it is evident (1) that a zone of crystalline marble can be traced for long distances in immediate contact with or close to the eruptive rock, (2) that a gradual passage can be followed at certain localities from the marble into recognisable bands of the Durness limestone, (3) that on the slopes of Sgonnan Mòr and again at Cnoc-na-Glas-Choille the intrusive mass is truncated by the main outcrop of the Ben More thrust-plane, (4) that in the neighbourhood of Ledmore, Ledbeg and Loyne, outliers of the materials overlying the Ben More thrust-plane cover portions of the intrusive rock and the altered Cambrian strata, (5) that from the apparent superposition of the marble along the eastern limit of the igneous mass, it is not improbable that the latter may resemble the other intrusive sills in Assynt, and may have been originally injected as a great sheet along the bedding planes.

3. Throughout this extensive area, there are striking lithological differences in the character of the eruptive rocks. The prevalent type in the western portion of the mass along the ridge extending from Cnoc-na-Sròine eastwards to Lochan Sgeirach is a coarse granitic rock consisting mainly of orthoclase with a little quartz. Occasionally large porphyritic crystals of orthoclase are developed and mica is sometimes present.

4. But immediately to the east of Loch Borolan, and about three-quarters of a mile to the east of Aultnacallagach Inn, the rock assumes a different phase. Dark brown and black garnets are associated with the orthoclase and a peculiar blue mineral to be referred to presently. The rock is massive, of a greyish or pink tint, unfoliated, and effervesces freely with acid. This type is well developed on the rocky knolls to the north of the road on the slope named Am Meallan on the 6-inch Ordnance Map.

Not far to the east of this locality there is a small stream (Aultivullin) draining Loch-a-Mheallain and flowing southwards into the Allt Lon Dubh, situated about a mile and a half to the east of Aultnacallagach Inn. Another striking variety is exposed in this burn section above the waterfall. This type is distinctly foliated, with white knots and abundant black garnets set in a dark grey matrix. The dip of the foliation planes is towards the east at an angle of 15° . On the hill slope to the east of this stream and Loch-a-Mheallain this foliated variety of borolanite is conspicuously developed, but the foliation disappears as we pass eastwards towards the limit of the mass. Following the high road from Aultivullin for about half a mile to the east of that locality, the unfoliated

type of this rock is exposed in knolls by the side of a small stream. The rock is dark grey, with abundant white knots and black garnets, effervescing very freely with acid. The foliated and unfoliated varieties just referred to are traceable at intervals in the stream sections to the south of Aultivullin as far as the slope of Cnoc-na-Glas-Choille.

These exceptional varieties to which special attention is called in this paper have been traced across an area upwards of two miles in length from Loch-a-Mheallain to Cnoc-na-Glas-Choille, and about a mile in breadth from east to west.

But, in addition to these localities, abnormal types which will be referred to on a subsequent page occur not far to the south of the junction of the Ledmore and Ledbeg Rivers, and also at the base of the north-west slope of Cnoc-na-Sròine. At the latter locality it forms the margin of the igneous mass, and the marble occurs not far distant on the south bank of the Ledbeg River, about half a mile to the east of the Loyne shepherd's house.

But perhaps the most interesting sections showing the relation of this peculiar type of rock with the pink and white knots to the marble, occur in the small streams on the south-west slope of Sgonnan Mòr.

IV. *Petrological Description of Borolanite.*

1. The prevailing type is a medium-grained rock of a dark grey colour. It frequently contains whitish or pinkish patches, usually more or less spherical or ellipsoidal in form, but occasionally showing polyhedral boundaries. These patches vary considerably in size. The smallest are only just distinctly visible to the naked eye; the largest measure an inch or more across. They also vary considerably in relative abundance. Sometimes they are absent altogether, whereas at other times the main mass of the rock is composed of them. The general appearance of a polished surface is represented in fig. 1.

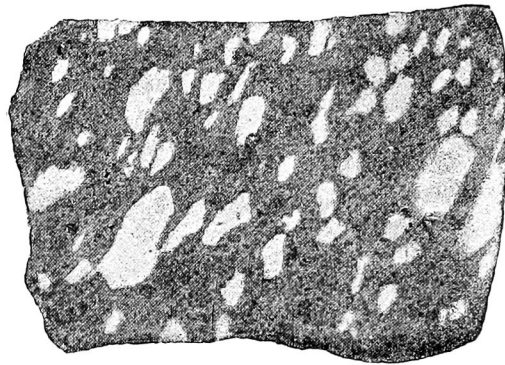


FIG. 1.—About Two-thirds Natural Size.

Where the rock has been subjected to deformation during or subsequent to consolidation, the white patches take the form of lenticles or streaks, as may be seen in fig. 2.

2. The principal interest of these rocks centres in their peculiar mineralogical composition. The dominant constituents are orthoclase, plagioclase, a substance which gelatinises with hydrochloric acid, melanite, pyroxene and biotite. The small black spots seen in fig. 1 are due to the garnet. Apatite, sphene and iron ores occur as accessory constituents. The secondary products include a peculiar blue substance which is probably an alteration product after a mineral of the sodalite group, white mica and possibly calcite. Many of the specimens effervesce freely with acid, but this is probably

due rather to the introduction of carbonates from the surrounding limestone than to their development by the decomposition of the rock.

Nepheline almost certainly occurred as an original constituent of some varieties, but is now only represented by decomposition products. Wollastonite is present as the principal constituent of certain inclusions occurring in a specimen from the south side of Sgonnan Mòr.

Orthoclase enters largely into the composition of all the rocks, and is found also in certain veins. Tested by SZABO's method, the felspar of the rock appears to be identical with that of the veins. The flame-reaction is that of an orthoclase fairly rich in soda.



FIG. 2.—About Half Natural Size.

The specific gravity is about 2.52. The felspar of the veins is of a purplish-brown colour, and the individuals often measure an inch across. The two cleavages are easily recognisable, but the basal cleavage is much the more perfect of the two. The reflections from the basal cleavages are bright, those from the clino-pinacoid dull. The individuals are tabular, with conspicuous development of the clino-pinacoid. Flakes parallel to $M \{010\}$ give extinction angles of 6° or 7° referred to the trace of the $P \{001\}$ cleavage. Those parallel to P sometimes give straight extinction and sometimes an indefinite extinction due to different portions extinguishing in slightly different positions. In the M -flakes the emergence of a positive bisectrix is seen in convergent light, and the position of the optic axial plane can be proved to be that of normal orthoclase. The twinning, when it occurs, is on the Carlsbad plan. In the massive varieties the orthoclase occurs, as a rule, in large, allotriomorphic grains, forming, as it were, the groundmass of the rock, the other minerals being present in it as inclusions. In the foliated varieties it forms granulitic aggregates. Orthoclase forms a large portion of the white spots, where it is often micro-pegmatitically intergrown with a substance which is probably an alteration product after nepheline.

Striated or plagioclase felspar is comparatively scarce and is entirely absent from many varieties. It occurs as small irregular grains between large individuals of orthoclase, as grains in association with similar grains of orthoclase; and also as a

constituent of microperthite. In one specimen fairly large individuals without any very definite crystallographic boundaries were observed in a fine-grained groundmass of biotite and orthoclase.

Next to orthoclase, melanite is the most important constituent of these singular rocks. It is black, and possesses, when broken, a somewhat resinous lustre. Good crystalline form is absent, as a rule, but perfect little crystals may occasionally be observed. The dominant form is the rhombic dodecahedron {110}. The edges of this form are sometimes truncated by those of the icosi-tetrahedron {211}, exactly as is the case in the well-known melanite from Frascati. The mineral fuses in the flame of the blow-pipe to a black glass which is slightly magnetic. In thin sections the colour of the melanite is seen to vary from a pale to a deep brown (see fig. 1, Pl. XXXVII.). The central parts of an individual are sometimes more deeply coloured than the marginal parts, and sometimes the reverse relation may be observed. The borders of the differently tinted portions may correspond to the crystallographic outline of the individual, thus producing true zonal structure, or they may be irregular.

The individuals vary in size from very small grains, only .05 mm. in diameter, to large crystals or irregular masses measuring 1 or 2 mm. across. Melanite is both idiomorphic and allotriomorphic with respect to feldspar. Iron-ores, sphene and biotite occur as inclusions.

The biotite appears black when viewed macroscopically. Cleavage flakes, examined with the microscope, appear a dull dark green by transmitted light, and are nearly uniaxial. Thin sections at right angles to the principal cleavage change from dark green to yellowish brown as the stage is rotated over the polariser. The individuals vary considerably in size and are generally irregular in form. The larger flakes are often corrugated. Pyroxene, iron-ores, garnet and occasionally feldspar, occur as inclusions.

The pyroxene is green both by reflected and transmitted light. It is quite subordinate in quantity, as a rule, to the orthoclase and melanite. In one specimen from the north-west slopes of Cnoc-na-Sròine and in another from the burn close to the marble at Ledbeg it occurs abundantly, and makes with feldspar the bulk of the rock. Melanite is absent from these specimens. As a rule, the mineral is without any very definite crystalline form, but sometimes the individuals are elongated in the direction of the vertical axis and more or less idiomorphic in the prismatic zone. The forms recognisable are {110}, {010} and {100}. The prismatic faces {110} are not uniformly developed in the different crystals; sometimes they appear only as slight truncations and sometimes they are developed almost to the exclusion of the clino-pinacoid. The ortho-pinacoid is always conspicuous when any trace of form is present. As already stated, the mineral appears green in thin sections, but the tint is not uniform—the marginal portions being often more deeply coloured than the central parts. There is also a faint pleochroism. The least axis of elasticity makes an angle of about 40° with the vertical axis of the crystal. All the above characters agree with those of pyroxenes known to occur in nepheline-bearing rocks. Magnetite and apatite are present as inclusions.

Sphene is by no means uniformly distributed in the different varieties. In the specimen from the north-west slopes of Cnoc-na-Sròine, to which reference has already been made, it occurs in large ophitic plates which are allotriomorphic with respect to felspar and pyroxene. In the melanite-bearing rocks sphene is frequently present in the form of minute ($\cdot 03 \times \cdot 07$ mm.) and often spindle-shaped granules. These granules are found only in the garnet. They sometimes occur so abundantly as to leave scarcely any of the isotropic garnet-substance between them in the thin sections. At other times they are entirely absent. That they are sphene is proved by the fact that they possess the refraction, double-refraction, colour, pleochroism and dispersion of this mineral.

Apatite is present in the form of stout hexagonal prisms. It is always perfectly fresh, and may occur as inclusions in any of the other constituents. In one exceptional specimen from the burn at Ledmore it is present in great abundance. This specimen is a black, coarsely crystalline rock composed of pyroxene, melanite and apatite, with a little biotite and pyrite.

Magnetite is sparingly present in many of the rocks. It occurs as grains which may be readily extracted from the powder of the rock by means of a weak magnet.

The felspar of these rocks is frequently associated with a turbid substance giving indefinite optical characters. In one or two instances this substance shows hexagonal (see fig. 5, Pl. XXXVII.) and rectangular sections. As a rule, it either forms micro-pegmatitic aggregates with felspar, or occurs in patches with no suggestion of crystalline form. On treating a slide or a cut surface of the rock with hydrochloric acid, little protuberances of gelatinous silica mark the distribution of this substance. The acid solution contains soda in abundance.*

It seems impossible, therefore, to avoid the conclusion that nepheline occurred as an original constituent of these rocks. This conclusion is strengthened by the fact that melanite and green pyroxenes are well-known associates of nepheline and leucite.

A peculiar blue substance occurs wedged in between the large individuals of orthoclase in certain veins, and is found also as a constituent of some of the white spots. It shows aggregate polarisation, and is decomposed by hydrochloric and sulphuric acids, with the separation of gelatinous silica and the evolution of bubbles.

After adding water to the hydrochloric acid solution and evaporating slowly, salt and gypsum crystals are developed—the former in great abundance. A partial analysis was made on about half a gramme of this substance, with the following result:—

Silica,	.	.	.	.	.	.	36·1
Alumina,	.	.	.	.	.	.	28·4
Lime,	.	.	.	.	.	.	3·2
Potash,	.	.	.	.	.	.	1·8
Soda,	.	.	.	.	.	.	16·2
Sulphuric anhydride,	.	.	.	.	.	.	5·9
<hr/>							
Sp. Gr.,	.	2·41	–	2·43.			91·6

* Proved by the uranium-acetate test.

Water and carbonic acid are present, but were not determined. The reaction of this substance with acid is suggestive of cancrinite, but the occurrence of sulphuric acid points to the conclusion that it is an alteration product after a mineral of the sodalite group.

Wollastonite was found only as a constituent of certain inclusions in a specimen collected on the south side of Sgonnan Mòr. These inclusions are of a greenish white colour. When examined with a lens they are seen to consist mainly of a colourless mineral having a pearly lustre and a fibrous structure. This mineral is decomposed by hot hydrochloric acid, and the solution, after the addition of dilute sulphuric acid, yields gypsum crystals in abundance. Its specific gravity is 2.895. By detaching a small fragment and crushing it upon a slide, numerous long flat laths are obtained. These invariably give straight extinction. When examined in convergent polarised light they fall into two groups:—(a) Those which show the emergence of an optic axis near one margin of the field of view and that of a bisectrix on the opposite margin; (b) those which show the emergence of an optic axis nearly in the centre of the field of view. Observations on flakes of the first group prove that the optic axial plane is at right angles to the length of the flakes, and that the minor axis of depolarisation is parallel to the length. We may, therefore, infer that the acute bisectrix is the least axis of elasticity and that the double-refraction is positive. All these facts point to the conclusion that the mineral is wollastonite. The flakes above referred to are determined by the two dominant cleavages. The straight extinction is a consequence of the fact that the edge formed by the meeting of the two principal cleavage planes is at right angles to the plane of symmetry of the monoclinic mineral, and coincident, therefore, with the mean axis of elasticity.*

The greenish tinge of the aggregates of wollastonite is due to the presence of a large number of extremely minute granules of green pyroxene. It is interesting to note that the aggregates of wollastonite from Willsburg, N.Y., U.S.A., also contain grains of a similar pyroxene.

3. One of the most striking features of these remarkable rocks is the pseudo-porphyrific aspect due to the white or more rarely pink patches. Under the microscope these patches are seen to be in all cases aggregates. Orthoclase in the form of allotriomorphic grains is the principal constituent, but there is generally more or less of the substance or substances which gelatinise with hydrochloric acid and possess other characters indicating the former presence of nepheline and sodalite. Micro-pegmatitic intergrowths of felspar and the indefinite substance are not uncommon. We are indebted to Professor DERBY of São Paulo for an interesting suggestion as to the nature of these patches. A specimen of the rock containing the white patches was given to him, and in writing to

* Particulars as to the means by which wollastonite was identified are given because they do not appear to be generally employed by petrologists. It is often much easier to identify a mineral by studying the form and optical characters of the small fragments obtained by crushing than by examining thin sections. A description of the ordinary rock-forming minerals from this point of view would be of great service, and anyone who will undertake the work will confer a benefit on petrologists.

one of us he says :—" In preparing a specimen of your melanite rock, I cut through some of the white aggregates and was struck by the tendency to polyhedral outlines, which is not apparent on a broken surface but is quite distinct on the plane saw-cut face. This to me is very suggestive of the pseudo-crystals of leucite in some of the related Brazilian rocks,* and suggests an interesting subject for investigation." In the same letter he says that he has found a micro-pegmatitic intergrowth of orthoclase and nepheline in some of the pseudo-leucites. We have re-examined the whole of the material at our disposal, but are not able to add anything to what has been stated above. In addition to the constituents already mentioned as occurring in the white patches, we find also melanite, calcite and white mica. The melanite, however, is rare. It is always much less abundant in the patches than in the main mass of the rock.

The matrix in which the white patches are embedded, and the entire rock-mass when these are absent, are composed of two or more of the constituents already enumerated. The type rock is essentially composed of orthoclase and melanite. A good idea of its microscopic character may be obtained from a glance at fig. 1, Plate XXXVII.

As frequently happens when any extensive mass of plutonic rock is examined there is considerable variation in the relative proportions of the different constituents, but this is not sufficient to take away from the orthoclase-melanite combination its dominant character. As illustrating the extremes of variation which have come under our notice, we may mention a rock from a point about one mile east of Aultnacallagach which is mainly composed of large individuals of orthoclase with a small quantity of the peculiar blue substance wedged in between the more or less idiomorphic crystals of the former mineral; and one from the burn near Ledmore which consists of pyroxene, melanite, biotite, apatite and pyrite. One of these varieties consists, therefore, entirely of aluminous-alkaline silicates; the other almost entirely of ferro-magnesian minerals. The former occurs as a pegmatitic vein in typical borolanite.

Another exceptional type was obtained on the north-west slopes of Cnoc-na-Sròine. It is essentially composed of orthoclase and pyroxene; with biotite, sphene, apatite and the doubtful substance which gelatinises with hydrochloric acid as subordinate or accessory constituents.

In the majority of cases the rocks are massive, but in some instances a well-marked foliation may be observed. In the foliated varieties the white patches have been orientated or even pulled out into lenticles and streaks. The movement probably took place during the final stages of consolidation.

We have, then, a group of rocks, especially characterised by the association of orthoclase and melanite. They are extensively developed in the neighbourhood of Loch Borolan, and as a new name appears to be required, we propose to call them borolanites. The typical rock is a crystalline granular aggregate of orthoclase and melanite. Biotite, pyroxene, alteration products after nepheline and sodalite, sphene and apatite, occur as subordinate and variable constituents.

* See "On Nepheline Rocks in Brazil," *Quart. Jour. Geol. Soc.*, vol. xlvii. (1891), p. 251.

4. The affinities of borolanite are unmistakable. It is a member of the foyaite (elæolite-syenite) family. The occurrence of melanite as an important accessory in certain rocks belonging to the nepheline-leucite group has long been recognised. In our rock we have melanite raised to the rank of an essential constituent. Borolanite, as we have already shown, is intrusive in the Cambrian rocks of Sutherlandshire. The nearest rocks in any way allied to it are the elæolite-syenites of the Christiania district, which are also intrusive in Lower Palæozoic strata.

APPENDIX.

So far as our own observations go, we have met with borolanite only in the neighbourhood of the granitic mass of Cnoc-na-Sràine. Our colleague, Mr HINXMAN, has observed a patch of borolanite intercalated in the thrust Eilean Dhu limestone at Elphin (Group II., Durness series, Cambrian). The rock is well exposed at the back of the Weaver's Cottage, south of the Elphin Schoolhouse; it is in places highly decomposed, grey, with white knots and abundant melanite. Our colleague, Mr GUNN, has found dykes of the same type of rock in the area he has surveyed in West Ross-shire. He has kindly furnished us with the following note:—"In the Coigach district of West Ross-shire, about five miles to the north-west of Achiltibuie, there are found at Camas Eilean Ghlais *two vertical dykes of borolanite intruded into the Torridon sandstone*. They run in a general W.N.W. and E.S.E. direction, and vary considerably in width—the widest one east of the house being nearly thirty feet across, but further west only about six feet. This, which is the most southerly of the two, is also the longest, and can be traced for a length of half a mile or so."

A hand specimen of the rock is medium-grained, brownish-grey and massive. Lath-shaped cleavage faces of felspar may be seen with the naked eye. Numerous minute black specks (melanite), uniformly scattered through the rock, are visible with a pocket lens.

Under the microscope the rock is seen to be composed of orthoclase, nepheline (partly fresh and partly altered to a substance giving aggregate polarisation), melanite, ægirine and biotite. The main mass is an aggregate of orthoclase and nepheline or its alteration product. Traces of idiomorphism may occasionally be seen in both constituents, but, as a rule, the outlines of the individuals are not crystallographic faces. Melanite is scattered through the orthoclase-nepheline aggregate in small crystals of the usual form. In thin sections the crystals are either pale yellow or very deep brown. Not unfrequently a pale external zone surrounds a deeply coloured nucleus.

Ægirine occurs in long prisms idiomorphic in the prismatic zone. The prisms are crowded together in certain portions of the slide, not uniformly scattered through it. This is the only rock in which we have detected typical ægirine. In the other rocks the corresponding mineral is a green pyroxene with high extinction angles. The biotite occurs in the form of six-sided tablets. It is nearly opaque in thin sections when

viewed by rays vibrating at right angles to the principal axis, and appears a fiery reddish-brown when viewed by rays vibrating parallel with this axis.

To remove all doubt as to the identification of nepheline, the following analyses were made :—

	I.	II.	III.
Silica,	47·8	47·9	69·3 [†]
Titanic acid,	·7	n.e.*	
Sulphuric acid,	·4	n.e.	
Alumina,	20·1	21·8	16·8
Ferric oxide,	6·7	7·6 [†] }	
Ferrous oxide,	·8	n.e.	
Manganic oxide,	·5	n.e.	
Baryta,	·8	n.e.	
Lime,	5·4	5·1	3·9
Magnesia,	1·1	1·0	·3
Soda,	5·5	5·6	4·6
Potash,	7·1	7·2	1·7
Loss on Ignition,	2·4	2·4	2·4
	99·3	98·6	99·0

I. Bulk analysis of the rock. For this analysis we are indebted to Mr J. HORT PLAYER.

II. Bulk analysis of another sample, by TEALL.

III. Analysis of the part soluble in hydrochloric acid from the same sample as No. II., by TEALL.

DESCRIPTION OF THE PLATE.

Fig. 1. Typical borolanite from the north-west slope of Cnoc-na-Sròine. Magnified 33 diameters. Ordinary light. The minerals represented are melanite, biotite (4) and orthoclase (6). The melanite is seen to be idiomorphic with respect to orthoclase and biotite. The felspar breaks up, under crossed nicols, into an aggregate of large irregular grains.

Fig. 2. A rock essentially composed of orthoclase, pyroxene (3) and biotite, from the base of Cnoc-na-Sròine. Magnified 28 diameters. Ordinary light. This figure illustrates the general character of the pyroxene which occurs in the borolanite. The other minerals represented are orthoclase and magnetite (1). Under crossed nicols the individuals of felspar give more or less lath-shaped sections, and are in almost all cases twinned on the Carlsbad plan.

Fig. 3. Another portion of the same rock, also magnified 28 diameters. Sphene (2), pyroxene, biotite and felspar are represented. The sphene forms a large ophitic plate, all parts of which belong to one crystalline individual.

Fig. 4. Portion of one of the white patches occurring in typical borolanite. One mile east of Aultnacallagach. This figure illustrates the peculiar micro-pegmatitic structure (8) referred to in the text.

Fig. 5. The rock is similar to the one represented in figs. 2 and 3. It does not contain melanite. A portion of a large crystal of sphene is represented at the top of the figure. The other minerals are green pyroxene, felspar and pseudomorphs after idiomorphic nepheline (7) ?

* Not estimated.

† Total iron reckoned as ferric oxide.

‡ Silica and insoluble residue.

KEY PLATE.

FIG. 2.

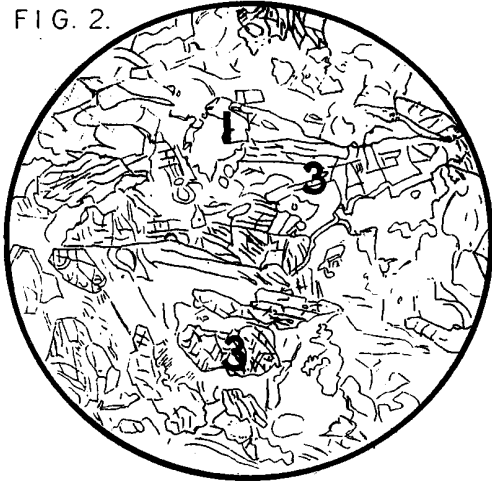


FIG. 3.

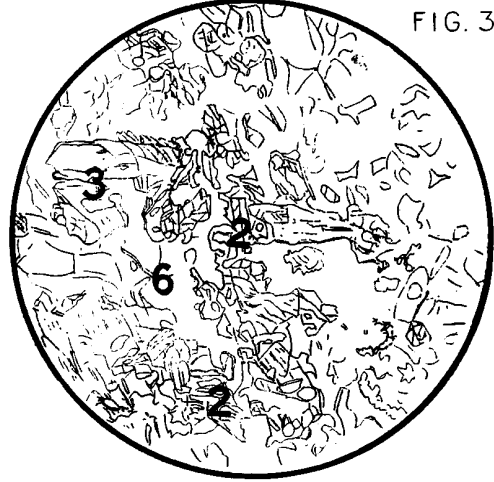


FIG. 1.

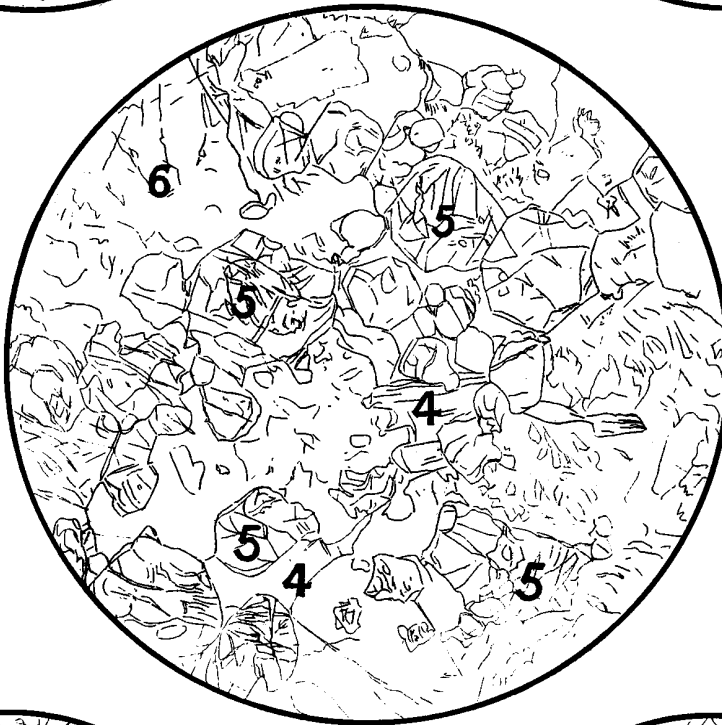


FIG. 4.

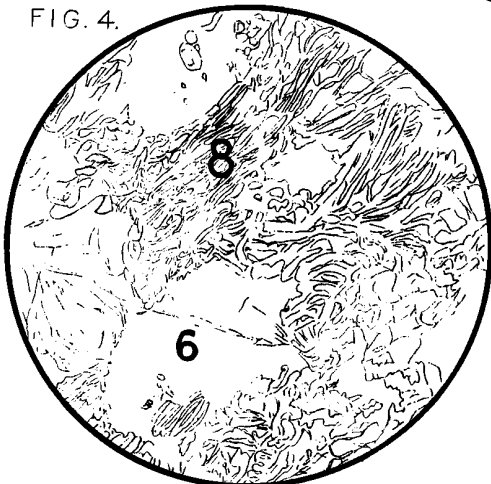


FIG. 5.

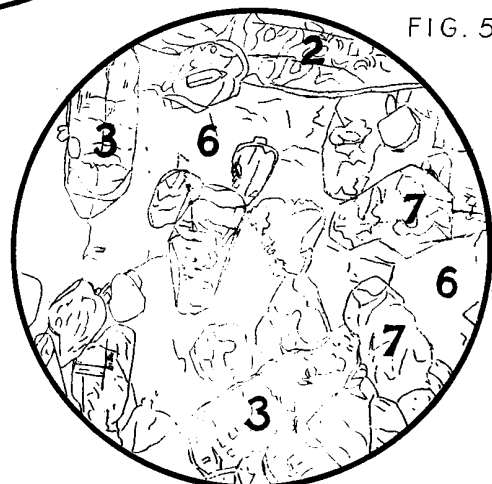


Fig 2.



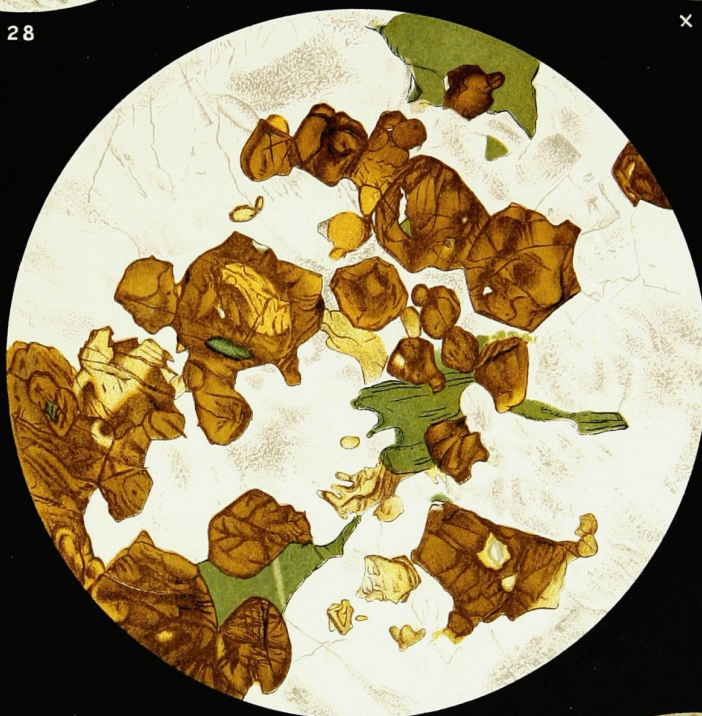
x 28

Fig. 3.



x 28

Fig. 1.



x 33

Fig. 4.



x 50

Fig. 5.



x 60