Chapter 15 The Cainozoic igneous rocks (continued)

The minor acid intrusions

In this chapter are described the very numerous dykes, sills, and other intrusive masses of acid composition in Arran exclusive of the large granite masses previously described. There are two main groups: (1) the coarse quartz-porphyries; (2) the pitchstones and accompanying felsites. In both of these groups certain members are associated with rocks of tholeiitic type in composite intrusions. The riebeckite-orthophyre of Holy Island is also treated in this chapter. These rocks are of varying ages, but all appear to be later than the crinanite and quartz-dolerite sills. Some are certainly later than the northern granite, and may be contemporaneous with the rhyolite–felsite eruptions of the Central Ring Complex. Some of the felsites, however, are even later than this; other masses, such as the Holy Island intrusion, appear to be later than the dyke-swarm belonging to the final stages of the volcanic episode (*see* p. 223). Some of the rocks here described, as, for example, the pitchstones, and the altered felsites known as 'claystones', are amongst the most famous of Arran igneous types, and have been described frequently from the time of Jameson onwards. The phenomena of composite intrusions in this country were first described by Judd from Arran examples. <ref>On Composite Dykes in Arran, *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, pp. 536–565.</ref>

Quartz-porphyry, quartz-felspar-porphyry, and associated rocks

These are acid rocks with conspicuous phenocrysts of quartz, or quartz and felspars. They are often associated in various ways with hypersthene-basalt (or dolerite), and tholeiitic rocks, but occasionally occur alone. The largest masses are exposed on the southern and western coasts of Arran. One of the best known is that which extends from Bennan Head to Cnoc Clauchog, a distance of 31 miles, with an average width of outcrop of half a mile. About two square miles of country are thus occupied by this intrusion. Another widespread intrusion of the same character is that of Kilpatrick, which forms a range of cliffs at Brown Head, and extends from Corriecravie to Kilpatrick Point, a distance of 21 miles, with an average width of a mile. The area occupied is thus about 21 square miles.

The next quartz-porphyry along the west coast is that of Drumadoon, which forms the striking columnar cliff near Drumadoon Point (Plate 5), (Figure 2). This beautiful sill is closely associated with a broad dyke of the same petrographical character which, starting from the north side of Drumadoon Bay, runs north, flanks the Drumadoon sill on its eastern side, and enters the sea at Cleiteadh nan Sgarbh. What is probably the same dyke reappears on the shore three-quarters of a mile farther north at An Cumhann. The traceable length of this dyke is thus about 2 miles.

The only other large intrusion of quartz-porphyry is the great plug of Dun Dubh in the Corrygills district. This is probably associated with two dykes on the Corrygills shore. Finally, the ridge called Sgiath Bhan, which separates Glen Dubh from Glen Ormidale, is intersected by a number of thick quartz-porphyry dykes; and one or two dykes of the same nature are to be found in the Allt Dhepin, in Benlister Glen, and in Monamore Glen.

The Bennan Intrusion (Figure 24), (Figure 25)

This mass has been described by many of the earlier writers on Arran geology. The first modern description, however, was given in 1895 by Corstorphine,<ref>Ueber der Massengesteine der sudlichen Theiles der Insel Arran, *Tschermaks Min. u. Petr. Mitth.,* vol. xiv., 1895, pp. 443–470.</ref> who dealt fully with the field and petrographical characters of the intrusion, and recognized the xenocrystic nature of the quartz and felspar crystals enclosed in the associated diabase.' The Bennan intrusion is closely similar to the great composite sill of the south of Bute, which was described in the Memoir on North Arran, etc. (1903),<ref>pp. 98–99, 115–116.</ref> and was later more fully dealt with by Dr. W. R. Smellie.<ref>The Tertiary Composite Sill of South Bute, *Trans. Geol. Soc. Glasgow,* vol. xv., part ii., 1915, pp. 121–139.</ref> The Bennan intrusion has recently been re-examined by Mr. J. V. Harrison, mainly from a petrographical point of view.<ref>The Geology of a Composite Intrusion at Bennan, South Arran, *ibid.,* vol. xvii., part ii., 1925, pp. 173–180.</ref>

The Bennan mass is a composite intrusion consisting of quartz-felspar-porphyry and hypersthene-dolerite. It is best exposed at its south-eastern end, where its outcrop impinges on the coast at Bennan Head, and forms that striking headland. Not much is known of the northern part of the intrusion, which is largely covered by drift, although the Kilmory Water cuts a trench through it. A broad area of quartz-porphyry extends from Cnoc Clauchog, 3 miles N.N.E. of Lagg, south-south-eastwards to Bennan Head. In its northern part the outcrop reaches 1½ miles in width, but towards Bennan it narrows down to half a mile. At Bennan Head the outcrop makes a sharp, hook-shaped bend, and extends three-quarters of a mile to the north with a continually narrowing outcrop, until it just reaches the main road a third of a mile west of Levencorroch. The best sections are to be seen in the small quarries near the road, along the outcrop to Bennan Head, and in the Struey Water which dissects the intrusion along the median line of the above-mentioned sharp bend.

At its termination the Bennan mass stands out as a steep-sided, dyke-like ridge from 80 to 100 yards across. A wall-like junction against the sediments is clearly seen along the road leading to East Bennan farm. The intrusion consists of an interior mass of quartz-porphyry, flanked on east and west sides by basalt and dolerite. The quarry a third of a mile west of Levencorroch affords a partial section across the intrusion. Most of the exposure is in quartz-porphyry; but to the west side of the quarry there is a gradual though rapid passage to basalt by the enclosure of increasing numbers of basalt fragments, and the darkening of the quartz-porphyry by the absorption of basaltic material, until the acid rock is reduced to mere veins and strings in the predominant basaltic rock. In the smaller quarry nearer the road there is a similar transition to hybrid rocks, but this time in an easterly direction. Although the evidence is clear that the quartz-porphyry is the later member of the composite intrusion the basalt nevertheless contains a large number of quartz and alkali-felspar xenocrysts which it must have acquired before injection.

Both the flanking sheets of basalt can be traced south-westwards to the Struey Water. In the intervening area the intrusion forms a range of columnar cliffs fronting the sea. The adjacent Triassic marls and sandstones to the east are practically horizontal, and strike directly against the steeply-inclined lower edge of the intrusion (Figure 24). Several intercalations or floats of sedimentary rocks are to be seen in the lower basaltic sheet. Two of these floats are exposed in the Black Cave, on the shore just east of the Struey waterfall, where a cake of sediments ro feet by 3 feet in cross-section can be examined.

The exposures in the Struey Water are as shown in the section, (Figure 25). The lower part of the sill consists of coarse basalt or dolerite, forming the cliff over which the Struey Water falls on to the shore. The lower contact is not actually seen, although the occurrence of sedimentary intercalations and fine-grained basalt are indications of its proximity. To judge from observations by Gunn, as recorded on his field-map, the contact plunges steeply through the sediments. The dolerite, which is here coarse grained, is exposed for 150 yards upstream from the waterfall, when, at a sharp turn, the proximity of the central quartz-porphyry is shown by the occurrence of a thick mass consisting of dolerite fragments in a matrix of quartz-porphyry darkened by assimilation. This gives place to pure quartz-porphyry higher up. The upper sheet of basalt, with a fairly steep inclination, appears near the Cairn, a third of a mile from the mouth of the burn.

While there is an apparent thickening of the lower dolerite sheet in the Struey Water, it nevertheless fades out in the cliff a quarter of a mile to the west. Similarly the upper basalt sheet cannot be traced farther than about 200 yards west of the Struey Water. The quartz-porphyry, however, continues to the northwest, and as the inclination of the mass tends to flatten out into parallelism with the adjacent strata, the outcrop becomes wider.

The solid rocks in that part of the outcrop which is intersected by the Kilmory Water are much obscured by thick drift, but two masses of basaltic rock are involved with the quartz-porphyry near Aucheleffan (*see* One-inch Geological Map, Arran, 1910).

The general relation of the intrusion to the sediments in the Bennan area is that shown in the section, (Figure 24). The steepening on the eastern margin may possibly be due to faulting, the intrusion having ascended along a fault plane. This interpretation is suggested by Gunn on his field-map (Buteshire, Arran, Sheet 259 N.E.).

The field and petrographic resemblances between the Bennan intrusion and that described by Dr. W. R. Smellie from south Bute are striking, although the Bute intrusion is a quintuple composite sill, and the Bennan mass, so far as known, only triple. Just as at Bennan, there is indubitable evidence in Bute that the acid rock is the later injection; nevertheless the early basaltic member contains xenocrysts of quartz and felspar which could only have been derived from a magma identical with that of the quartz-porphyry. Dr. Smellie concluded on good evidence that the enclosure of xenocrysts, and the partial acidification of the dolerite, took place immediately before intrusion. It is difficult to imagine the mechanism by which the intrusion of these puzzling composite sills was effected, and the whole question needs much further investigation.

The Kilpatrick Intrusion

The name 'Kilpatrick intrusion' is applied to the wide stretch of quartz-porphyry which occupies the area between Corriecravie and Kilpatrick Point, and forms the cliffs of Brown Head at the south-western corner of Arran. The dimensions of this mass are given on p. 195. As mapped by Gunn (*see* One-inch Geological Map, Arran, 1910) a central band of felsite, running south-east from Kilpatrick to near Cnocan Doun, is injected into the mass; and the intrusion is flanked on its eastern margin by another mass of felsite, which forms The Torr (728 feet O.D.), and stretches away to the N.N.W. as a separate intrusion for 2 miles, terminating at North Feorline, Blackwaterfoot.

The Kilpatrick quartz-porphyry is well exposed at many places, particularly along the shore at Brown Head; but its contacts with the sediments are hardly seen at all, and it is therefore difficult to determine the real form of the mass. A re-entrant in the base of the quartz-porphyry in a gully near the 22nd milestone, half a mile northwest of Corriecravie, shows an exposure of coarse white sandstone with pebbly bands, which dips 70°–80° to the S.S.E. The section also shows fault-breccia dipping in the same direction. The base of the quartz-porphyry appears to cut across the edges of these upturned and dislocated strata, but the actual junction is not visible.

No junction is visible at the north end of the mass. The quartz-porphyry is exposed along the shore to Kilpatrick Point, and is there buried beneath sand and shingle. Here the intrusion must be some hundreds of feet thick, judging from the height to which it rises. In the raised-beach cliff near the caves (Preaching Cave — six-inch quarter-sheet, Bute 253 S.E.) the igneous rock shows well-marked bedding-joints dipping west at 20°, and an attempt at quarrying the massive blocks has been made at this spot.

There is no sign of any basalt or dolerite associated with the Kilpatrick quartz-porphyry.

The Drumadoon intrusions

A well-known mass of quartz-porphyry forms the striking columnar cliff at Drumadoon Point ((Plate 5), fig. 2). It is a composite sill, consisting of a central mass of quartz-porphyry approaching 100 feet in thickness, with a thin sheet of basalt at both top and bottom. The lower basalt sheet is best seen at the foot of the cliff, where it attains a maximum thickness of about 4 feet, but thins to 21 feet towards the south end of the cliff. The very thin upper sheet of basalt can be identified by fragments on the summit of The Doon, but it is best seen on the shore at Drumadoon Point. The basalt contains xenocrysts of quartz and felspar, and is identical with the similarly-occurring rock of Bennan Head. Near Drumadoon Point the sill seems to plunge eastward through the strata at angles varying from 40° to 20°. The mass at Drumadoon Point is either injected on a lower horizon than that which appears in the columnar cliff, or has been thrown down to the south along an east–west fault line. The two masses are displaced along an east–west line about a quarter of a mile N.N.E. of Drumadoon Point, and are at different levels. It is perhaps significant in this connection that many east–west dykes cut the quartz-porphyry in this locality.

About 300 yards east of Drumadoon Point a thick dyke of quartz-porphyry projects southward into the sea. This dyke can be traced to the north, and passes immediately to the eastward of the Drumadoon sill, of which it is possibly the feeder. It crosses The Doon, where it is obscurely involved with basalt. It is again seen half a mile north of The Doon at Cleiteadh nan Sgarbh, where it runs in a N.N.W. direction out to sea. At a point on the shore 150 yards south of Cleiteadh nan Sgarbh the section is that given in (Figure 26). The quartz-porphyry is 51 feet thick, and is flanked by at least 2 feet of basalt on its western edge, and also on its eastern edge. A thin dyke-like mass of basalt 6 to 9 inches in thickness is seen about 3 feet inwards from the eastern edge. Approaching the basalt on both sides the quartz-porphyry becomes much darker, and it is only possible to distinguish it from the xenocryst-bearing basalt by the greater abundance of its phenocrysts. This evidence is in favour of the priority of the basalt; and this view is confirmed by the presence on the shore of boulders of quartz-porphyry containing basaltic xenoliths. Flanking the composite dyke on its eastern side is a mass of yellow felsite at least 33 feet thick, but its eastern edge is not here seen. This mass is finely banded parallel to its western contact, and is therefore probably a later injection than the composite dyke. At Cleiteadh nan Sgarbh the felsite appears to be flanked by basalt on its eastern side.

What is almost certainly the same composite dyke reappears on the coast three-quarters of a mile farther north at An Cumhann on the Tormore shore; but it is here running in a N.N.E. direction. The late Prof. J. W. Judd fully described this dyke in his paper on the composite dykes of Arran,<ref>*Quart.Journ. Geol. Soc.*, vol. xlix., 1893, pp. 57–558, Fig. 5.</ref> and gave a cross-section showing a mass of quartz-porphyry, flanked by marginal basalts 3 to 4 feet thick, and with an approximately central ' dyke ' of basalt 4 feet wide. The whole mass is stated to be 90 feet wide, an estimate which agrees closely with the thickness of the dyke complex at Cleiteadh nan Sgarbh. Prof. Judd believed that the basalts were dykes intersecting the porphyry; and at least one of them shows chilled margins against the porphyry and is therefore later.

Dun Dubh

Dun Dubh is a prominent hill in the South Corrygills district, 1½ miles south-east of Brodick pier. It consists of a massive plug of quartz-porphyry extended in a W.N.W.–E.S.E. direction, and with a maximum width of 150 yards on Dun Dubh itself. To the E.S.E. it throws off a thinning tongue which crosses the Dun Fionn path, and is then lost. There is, however, a dyke of quartz-porphyry in the Corrygills cliff on the direct line of continuation of the Dun Dubh mass. Dun Dubh exhibits fine vertical columns on the north side, but these change to horizontal at the western end. No basalt has been found on Dun Dubh, but a separate exposure immediately to the north of the hill shows an obscure association of quartz-porphyry and basalt. Another dyke of quartz-porphyry II feet wide occurs on the Corrygills shore 200 yards south-east of the above-mentioned dyke, and due east of Dun Fionn.

Glen Ormidale and Sgiath Bhàn

On Sgiath Bhan, the ridge that separates Glen Ormidale from Glen Dubh, there outcrops a number of large quartz-porphyry dykes, which are associated, perhaps accidentally, with basaltic members. On the eastward slope of the hill, and trending E.N.E., there is a massive dyke of quartz-porphyry at least 20 feet wide. The southern contact is not seen; but towards the northern contact (Figure 27) the rock becomes fine grained and banded parallel to its vertical margin. At the actual junction with a strip of baked sandstone, it is practically a pitchstone. On the other side of the strip of baked sandstone there is a basalt dyke 12 feet thick. Traced upwards this dyke suddenly crosses the quartz-porphyry, and then resumes its former direction, but now on the southern margin of the acid dyke.

A second quartz-porphyry dyke is seen on the summit of the hill near its eastern end, running in a N.N.W. to S.S.E. direction. This dyke has a sharp, vertical contact with quartz-conglomerate on its western side. Near the 'B' of 'Bhan' (Buteshire, Arran, six-inch quarter-sheet 249 N.E.) it terminates, or passes under horizontal red sandstones, but reappears about 50 yards to the west, and continues across the hill to the cliffs fronting Glen Ormidale. One hundred and fifty yards west of the above dyke a third quartz-porphyry dyke appears on the southern slopes of Sgiath Bhan. This is 21 feet wide, and is flanked by a grey basalt dyke seen in partial exposures on its western side. This quartz-porphyry may be continuous with a dyke 15 to 20 feet wide, which cuts through a well-exposed fault in sediments and a felsite sill. The dykes of Sgiath Bhan thus seem to have been injected into a rectangular system of fissures orientated W.S.W.–E.N.E. and N.N.W.–S.S.E.

Two quartz-porphyry dykes are seen in the central headwater of Glen Ormidale Burn above 643 feet O.D. A number of other dykes which are probably to be classed here occur in Benlister Glen, Monamore Glen, and at the head of the Allt Dhepin.

Petrography of the quartz-porphyries and associated rocks

Dr. A. Harker's general description of the quartz-porphyries of Arran is as follows:

The commonest type is a *quartz-porphyry rich in porphyritic elements,* which are quartz and felspar, the former usually one-eigth to one-quarter of an inch in diameter, and the latter with a length of one-quarter- to one half an inch inch. These are often rather closely crowded in the grey groundmass, which is of fine texture, no other mineral being evident to the eye except in some examples an occasional flake of dark mica (Drumadoon, etc.). Thin slices show that the felspar is commonly sanidine, though often accompanied by some oligoclase in addition. Both quartz and felspar, but especially the former, contain abundant minute glass inclusions, and sometimes larger inclusions of the ground-mass, besides having often a rounded or irregular outline indicative of magmatic corrosion. The biotite is often considerably altered, and its presence is sometimes only to be inferred from brown ferruginous patches. In no case is it abundant. Rarely a little crystal-grain of augite is seen (S6396) [NR 90 25]. The groundmass is always microcrystalline, sometimes having the felspar in little crystals upon which the interstitial quartz is moulded, but more usually with a granular structure and with varying degrees of fineness of texture. There is in this common type little or no approach to spherulitic or other intergrowths, though exceptionally we may see a tendency to micropegmatite in a narrow fringe on the border of a felspar crystal (S6396) [NR 90 25]. The quartz-porphyry rich in phenocrysts, which appears to be the general type among the large sills, is also represented among the dykes. A specimen (S2455) [NR 883 309] from King's Cave is, in all respects, identical with those described above, having abundant corroded crystals of quartz, ■ inch in diameter, and of sanidine, often more than ¼ inch long. Another dyke-rock (S6381) [NS 010 250], from Allt Dhepin, a mile south of Loch na Leirg, is essentially similar, but with smaller porphyritic crystals.<ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol.* 1903, pp. 109–111.</ref>

The rocks answering to the above general description in the Survey collection, are: Bennan, (S6403) [NR 988 202], (S6365) [NR 999 213], and ((S24460) [NR 999 213] (this is the analysed rock, *see* p. 204); Kilpatrick, (S6396) [NR 90 25], (S25079) [NR 890 260] (the felspar in this rock is chequer-albite); Drumadoon, (S277) [NR 890 280] (very rich in dark red biotite and oligoclase, and distinctly more basic than the usual type), (S6393) [NR 882 288], (S6394) [NR 882 288], (S6395) [NR 882 288]; Drumadoon dyke, (S6369) [NR 890 280]; An Cumhann dyke, King's Cave, Tormore Shore, (S2455) [NR 883 309]; Dun Dubh, (S2456) [NS 038 342], (S3328) [NS 038 342] (rhyolitic flow structure in a cryptocrystalline groundmass); Allt Dhepin, one mile south of Loch na Leirg, (S6381) [NS 010 250]; Sgiath Bhan and Glen Ormidale, (S24364) [NR 983 342], (S25043) [NR 989 344], (S25044) [NR 989 344]. In the Sgiath Bhàn and Glen Ormidale dykes the phenocrysts are fewer and smaller than in the above-described rocks, and there is abundant chlorite in the groundmass which is arranged in ragged, moss-like aggregates, recalling a common mode of occurrence of aegirine and riebeckite.

An analysis of the oligoclase crystals of the entirely similar quartz-felspar-porphyry of South Bute, by Dr. A. Scott, has been recorded by Dr. W. R. Smellie.<ref>The Tertiary Composite Sill of South Bute, *Trans. Geol. Soc. Glasgow,* vol. xv., part ii., 1915, p. 138.</ref> The analysis, which is set forth below, gives a calculated composition Ab_5An_1.

SiO_2	62.67
$A1_2O_3$	22.48
Fe_2O_3	0.70
MgO	p.n.d
CaO	3.29
Na_2O	9.62
K_2O	0.41
H_2O	0.58
TiO_2	nt. fd.
BaO	trace
Li_2O	trace
	99.75
Or	2.2
Ab	81.22
An	16.40
Excess $A1_2O_3$	0.31
Fe_2O_3	0.70

H_2O	0.58
	101.43
SiO_2 deficit (calculated)	1.68
	99.75

This analysis is stated to have been made from a single crystal of the quartz-porphyry. The crystal contained inclusions of the groundmass which, no doubt, accounts for the slight discrepancies in the calculated mineral composition.

The quartz-felspar-porphyry of Bennan has been analysed by Mr. E. G. Radley, with the results set forth in Table 6, II. The poverty of this rock in Fe0 and Mg0 shows that pure, uncontaminated material was selected for analysis. In its silica percentage the rock compares closely with the granophyric granite of the Central Ring Complex (Table 5, 9), and with the biotite-granite of the northern boss (Table 3, 7). Nevertheless the norm calculation shows that the Bennan quartz-felspar-porphyry contains 42.4 per cent. of free quartz, as compared with 37.4 per cent. and 32.6 per cent. respectively in the other two rocks. The reason for this is found in the relative poverty of the Bennan rock in alkalies, especially soda, whereby less silica has been taken up in the formation of felspars, thus leaving a larger amount free. The Bennan rock, however, is richer in potash relatively to soda than either of the other comparable acid rocks of Arran. With the exception of its silica, the analysis closely resembles that of a hornblende-granophyre from Skye, which is tabulated for comparison (Table 6, 0).

(Table 6)

	11	O.	12.	P.	Q.	13.
SiO_2	75.22	71.98	54.83	53.97	54.11	55.79
$A1_2O_3$	12.22	13.13	14.10	14.65	11.65	15.97
Fe_2O_3	2.30	1.33	3.57	3.62	2.76	12.50
FeO	0.22	1.64	5.87	6.32	7.02	—
MgO	0.06	0.56	4.88	4.49	5.30	2.22
CaO	0.84	1.13	7.90	7.98	8.77	7.06
Na_2O	2.22	2.98	2.32	2.54	2.63	2.21
K_2O	4.94	4.93	173	1.52	1.75	1.86
H_2O>105°	0.52	1.38	1.23	0.94	0.81	Ign. 2.43
H_2O<105°	0.72	0.39	0.48	1.92	0.68	
TiO_2	0.28	0.37	0.74	1.24	3.37	
P_2O_5	0.18	0.19	0.24	0.27	0.58	
MnO	0.25	0.14	0.37	0.30	0.21	—
CO_2	0.03	—	1.90	0.51	0.05	—
FeS_2	nt. fd.	—	nt. fd.	0.09	0.22	-
(Ni, Co)O	nt. fd.	—	0.03	nt. fd.	—	—
BaO	nt. fd.	tr.	nt. fd.	0.04	0.03	
Li_2O	tr.	nt. fd.	tr.	tr.	nt. fd.	—
Cr_2O_3	—	—			0.03	—
Cl	—	0.01	—	—	—	-
S	—	—		—	—	0.45
	100.00	100.18	100.19	100.40	99.97	100.49

11. (S24400) [NM 4555 6779]. Lab. N. 829. Quartz-feldspar-porphyry, acid member of Bennan composite sill, Quarry, half a mile W.S.W. of Levencorroch, Arran. *Anal.* E. G. Radley.

O. (S7064) [NG 630 172]. Hornblende-granophyre, Beinn a' Chaim, 3.5 miles south by west of Broadford, Skye. *Anal.* W. Pollard. Quoted from A. Harker, The Tertiary Igneous Rocks of Skye, *Mem. Geol. Surv.,* 1904, P. 153.

12. (S24457) [NR 993 202]. Lab. No. 826. Hypersthene-dolerite, basic member of Bennan composite sill, shore at foot of Struey Falls, Bennan Head, Arran. *Anal.* E. G. Radley.

P. (S17170) [NM 5238 2024]. Lab. No. 432. Tholeiite, Talaidh type, basic margin of composite sill, Ruadh' a' Chromain, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir,* 1924, p. 17.

Q. (S23845) [NS 4054 5241]. Lab. No. 800. Andesitic tholeiite, 60-foot north-west dyke, a continuation of the Acklington—Hawick dyke. Lugton Water, 1000 yards south-west of Smithy, Lugton, Ayrshire. *Anal.* B. E. Dixon. Quoted from Summary of Progress for 1925, *Mem. Geol. Surv.,* 1926, p. 128.

13. Augite-andesite (=Tholeiite), the exterior member of Cir Mhòr composite dyke, Arran. *Anal.* J. A. Schofield. Quoted from J. W. Judd, On Composite Dykes in Arran, *Quart. Journ. Geol. Soc.,* vol. xlix, 1893, p. 543.

The basic rocks associated with the quartz-porphyries are of varying characters owing to their differing degrees of contamination with acid material; but the rocks which are comparatively free from admixture are, as the chemical analysis shows, of tholeiitic type. The rock, for example, that forms the basal contact of the Bennan sill, at the foot of the Struey waterfall (not represented in the Survey collection), is a typical tholeiite both in texture and mineral composition. The holocrystalline equivalent is a hypersthene dolerite which is prominent in a thickening of the lower basic member of the Bennan sill at the Struey Water. This rock has been analysed ((Table 6), 12). In thin section (S24457) [NR 993 202] it shows irregular grains of hypersthene, clinopyroxene, and magnetite, with well-shaped labradorite laths, in a mesostasis of alkali-felspar and quartz in micropegmatitic intergrowth. The texture is fine grained allotriomorphic. The hypersthene is pleochroic from pale green to pale brown-red; its alteration near a fissure filled with calcite produces a green bastitic material, and occasionally a small flake of biotite. The slice contains one or two large xenocrysts of oligoclase, and a few rounded spots of granular pyroxene which represent completely-absorbed quartz xenocrysts.

An analysis of this rock is recorded in ((Table 6), 12). The main feature of this analysis is its complete accordance with analyses of tholeiitic types from the Cainozoic igneous suites of the West of Scotland, those of the Talaidh (Mull) type, of the andesitic tholeiite of Lugton (Ayrshire), and the 'augite-andesite' (tholeiite) of the composite tholeiite-pitchstone dyke of Cir Mhòr, being recorded for comparison in (Table 6).

The similarities between these rocks may be further brought out by comparing their calculated mineral compositions, as in the table below:

	Q.	or.	ab.	an.	Ferric Minerals.
Hypersthene-dolerite, Bennan Head	13.8	10.0	10.4	23.1	33.7
Tholeiite, Cir Mhòr, Arran	14.6	11.1	18.4	28.4	27.5
Tholeiite (Talaidh type), Mull	10.3	8.9	21.4	23.9	35.5
Andesitic tholeiite, Lugton	10.0	10.0	22.9	15.1	42.4
Quartz-dolerite (Talaidh type), Mull	11.3	10.0	19.9	17.3	41.6
Craignurite (basic), Mull	11.9	11.7	21.5	14.2	40.8

The comparison also brings out the curious fact that while the two Arran rocks are richer in quartz and poorer in femic minerals than the other four, yet, on the other hand, they possess a more basic type of plagioclase felspar, as indicated by the ratios of total albite to anorthite.

Another slice from the Bennan mass (S6376) [NR 990 202], from the base of the cliff 300 yards west of the Struey Water, contains very little hypersthene, and shows very beautiful xenocrysts of quartz surrounded by broad coronas of pyroxene, as well as one or two felspar xenocrysts with their characteristic turbidity.<ref>A. Harker, in Geology of North Arran, etc., (Explanation of Sheet 21), Mem*. Geol. Surv,* 1993, p. 114.</ref>

Slices from the base of the Drumadoon sill (S25051) [NR 882 288], and from a basic member of the An Cumhann dyke (S25050) [NR 880 310], are tholeiitic basalts with well-shaped microlites of labradorite, grains of colourless augite (altered to a green chloritic substance in the Drumadoon rock) and iron-ore specks. The groundmass is a dark, cryptocrystalline to glassy, substance, with which are involved small irregular areas of quartz. Both rocks contain xenocrysts of quartz and alkali-felspar. G.W.T.

Pitchstones, felsites, and associated rocks

Dykes and sills of pitchstone, for which the Isle of Arran has long been celebrated, are pretty numerous in the island, and a good many of them occur in out of the way places in the interior which are not often visited. This glassy rock, which in some parts is called *bottle-rock* by the natives, is found of various shades of green from a light yellowish-green through various dark shades of the same colour to a black rock. Yellowish-brown and brown varieties occur, and occasionally the rock is reddish. In composition the rock varies from an almost perfectly clear glass to a coarse pitchstone porphyry, and there are spherulitic and banded varieties which remind us of similar structures in the felsites.

Both the dykes and sills of this rock are, as a rule, much more irregular or inconstant than those of the basic rocks, or of the felsites or quartz-porphyries, and we find sills changing into dykes, and *vice versa* without any apparent cause. None of the dykes or sills can be traced for very long distances, and any attempt to correlate rocks of this character at widely separated intervals is futile. One of the longest dykes (it was also the earliest to be described) is that on the Tormore shore, which can be traced for about 500 yards. The dyke or sill at the Brodick schoolhouse can be followed for nearly 350 yards into the wood to the west, but its continuation is uncertain. The sill on the Clauchland shore so often described, can be followed southwards, with breaks, for about 330 yards, when it disappears on the foreshore. The dyke or sill south of Dun Fionn is traceable for 300 yards, and it may be continuous with the lower Corrygills sill, when its total length would be about 700 yards. W.G. The pitchstones are closely associated with compact, non-porphyritic, or microporphyritic, felsites in composite dykes; and they are occasionally found to devitrify into identical types. Some felsites appear to pass into pitchstone-like rocks on their cooling margins. Many other examples, however, occur as entirely separate dykes and sills; but their mineralogical and chemical characters, and their modes of occurrence, are so closely allied to those of the pitchstones that the two groups of rocks are most conveniently treated together. G.W.T.

The felsite sheets, which seldom have free quartz and are not usually porphyritic in character, such as those of Holy Island on the one side of Arran and of Torr Righ Beag on the other, are probably of later date than the quartz-porphyries. In the southern part of Arran we can see the felsite dykes and sheets piercing the porphyritic rocks, and in this area we have evidence that the felsite sills are about the most recent of all the intrusive igneous rocks, for we seldom find them pierced by the ordinary basalt dykes. None have been met with in the Torr Righ Beag mass or in the felsite of Holy Island, though dykes are common in the adjacent rocks. A north-west running dyke on the South Corrygills shore does not penetrate the felsite sheet there, though it is traced for long distances on either side of it. The same felsite sheet appears two-thirds of a mile west from this place in a burn between North and South Corrygills, and here again it is clearly later in date than a basalt dyke which crosses the burn at the same spot. The larger felsite sheets in the southern part of Arran are often beautifully columnar, but examples are not common in the north, though one occurs on the north-eastern side of Holy Island. W.G.

One group of Arran pitchstones is closely associated with tholeiites in composite dykes, and thereby shows analogies with the quartz-porphyries treated in the foregoing section. Although no Arran example is known, the quartz-felspar-porphyry of South Bute does pass at one place into a thinning tongue which consists of a beautiful pitchstone-porphyry.<ref>W. R. Smellie, The Tertiary Composite Sill of South Bute, *Trans. Geol. Soc. Glasgow*, vol.xv., part ii., 1915, p. 127.</ref> Intermediate and basic types of pitchstone (cf. leidleite and inninmorite) occur in connection with the craignurite and quartz-dolerite groups (pp. 132, 137). Hence it may be concluded that several magmatic rock types in Arran may, under suitable circumstances, give rise to pitchstone.

The field occurrences of the pitchstones and felsites will be described in order from north to south of the island.

The Northern area

Eighteen occurrences of pitchstone are to be found within the northern granite, and in the rocks adjacent to it, that is to say, in the region north of the String Road from Brodick to Machrie Bay, and exclusive of the Glen Shurig pitchstone which occurs almost on the road. The following are some brief notes on the various occurrences in this area:

Beinn a' Chliabhain— A composite dyke with basic sides and porphyritic pitchstone centre occurs 50 yards north of the highest point (2217 feet), and again 300 yards to the east.

Beinn Nuis — A dark pitchstone dyke 6 feet wide is found about 500 yards south-east of the summit.

Beinn Tarsuinn — A dark pitchstone is visible 150 yards southwest of the summit. There are probably other small outcrops on this hill.

The Saddle — To the east of Cir Mhòr and nearly a quarter of a mile south-east of The Saddle is a greenish grey pitchstone, running W.N.W. Some of it is columnar.

Cir Mhòr — Green porphyritic pitchstone forms the centre of the composite dyke on Cir Mhòr, running east and west, described by Prof. Judd.<ref>On Composite Dykes in Arran, *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, pp. 543–551. This account is prefaced by notices of the work of earlier observers.</ref> The dyke is exposed in a steep gully on the eastern face of the mountain, attainable by a stiff climb from The Saddle between Glen Rosa and Glen Sannox. It consists of five members; two external margins, each about 20 inches thick, of a brown-weathering spheroidal tholeiite, which is blue on a freshly-broken surface; two interior quartz-felsites, a whitish rock with well-marked vitreous contacts against the tholeiite, each band being about 6 feet thick; and finally a central band of pitchstone about 2 feet thick, which narrows in one place to a foot.<ref>A good photograph of the Cir Mhòr dyke is given in J. W. Gregory and G. W. Tyrrell, Excursion to Arran, *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, Plate XXVIB.</ref> The vitreous contact rock of the felsite contains small, rounded, brown inclusions which appear to be xenoliths of the weathered tholeiite. If so, a considerable interval of time must have elapsed between the intrusions of the basic and acid members of the dyke. The microscope shows that the felsite is merely a devitrified phase of the pitchstone: indeed, Judd says there is a passage between the two rocks. Measurements across the dyke about halfway up the gully show that the total width there is about 17 feet. Judd gives the minimum and maximum widths as about 12 and 30 feet respectively.

Caisteal Abhail — On the ridge between Cir Mhòr and Caisteal Abhail a dark pitchstone dyke occurs in the cliff a little south-east of the strong spring, and a quarter of a mile south of the point marked 2735 feet on the One-inch Map.

Caisteal Abhail — A dark columnar pitchstone occurs west of the highest point, and may be traced a considerable distance in a northwest direction by the loose fragments lying at the surface.

Another dark-coloured pitchstone dyke may be found under a crag about 100 yards north of the summit

Creag Dhubh — About a mile north of Caisteal Abhail a pitch-stone dyke about 6 feet wide is visible for a short distance under the scars of Creag Dhubh.

Penrioch — North-east of Penrioch and nearly half a mile E.S.E. of Auchmore or South Thundergay is a remarkable porphyritic pitchstone, only visible for about 6 yards (*see* p. 283, *under* 1928).

Dubh Loch — On the slopes of Beinn Bharrain a quarter of a mile N.W. of the Dubh Loch is a yellowish, streaky pitchstone, 3 to 4 feet wide, which may be traced to the W.S.W. for nearly 200 yards.

Iorsa Valley — In a stream about one mile N.E. of the outlet of Loch Tanna there is a pitchstone dyke 3 to 4 feet wide with a course due north.

Iorsa Valley — Near the heads of two small streams three-quarters of a mile north of Loch Nuis dykes and sills of various kinds of pitchstone crop out in at least four places.

Iorsa Valley — *About* 600 yards S.S.W. of the outlet of Loch Iorsa a dark green pitchstone with a width of 7 or 8 feet is visible for about 10 yards.

Machrie Burn — A dyke of light-green pitchstone 6 feet in width crosses this stream in a N.N.W. direction about three-quarters of a mile N.N.E. of Cnoc na Ceille. The stream here is called Allt Airidh Niall.

Auchagallon — In the stream a quarter of a mile N.E. of the village there are two pitchstone dykes close together, and the more northerly of the two is accompanied by felsite. Both range somewhat north of east.

Auchagallon — A small pitchstone dyke occurs in the old sea-cliff to the west of the village on the north side of a sandstone quarry.

Auchagallon — A brown pitchstone also occurs on the shore about 80 yards south of the ferry.

The felsites in the northern area are few in number. They include three large and long dykes, and several smaller ones. The long dykes are somewhat irregular in direction but have a general north to south trend. One of them begins west of the summit of Caisteal Abhail, runs slightly west of south for half a mile, and then bends round to the S.S.E., passing between Cir Mhòr and A' Chir. Its total length is 1½ miles. A second dyke begins on Beinn Tarsuinn, where it is 150 feet thick, and runs in a direction slightly west of south in front of the great eastern cliff of Beinn Nuis. It crosses the southern foot of the final slope of Beinn Nuis at 2190 feet O.D., and is there thick and flow-banded. Another example, which may be particularized as the Glen Shurig dyke, traverses Glen Shurig along a general N.N.E. to S.S.W. course. Its trend is somewhat irregular, no doubt because it is injected, not into straight-jointed granite, but into the variable, highly-dipping beds of the Lower Old Red Sandstone. The dyke is seen in Glen Shurig, and in most of its tributaries, but the only good exposure is in the Allt an Bhrighide on the north side of the glen, where it has an outcrop at least 100 feet wide. A second felsite dyke, 40 feet wide, occurs a few yards downstream. The main dyke is again seen in the ditch by the side of the String Road near 483 feet O.D., a third of a mile west of the second milestone; and it is likely that a felsite dyke on the ridge immediately east of Windmill Hill (Muileann Gaoithe) is its continuation. If this is so, the dyke has a total length of 1½ miles.

There are several small felsite dykes within the northern granite, of which the most important, perhaps, is that on the ridge called Stacach, about 300 yards north of the summit of Goatfell. This dyke is composed of a light-grey felsite enclosing xenoliths of a darker igneous rock (variolitic tholeiite in thin section). Small pitchstone fragments are scattered all over the outcrop, and as these also contain the basic xenoliths, it is probable that the felsite is merely a devitrified pitchstone.

The Brodick area

There are several interesting occurrences of pitchstone in this area, most of which are olivine-bearing.

Glen Shurig — The Glen Shurig pitchstone, fully described by Dr. A. Scott,<ref>*Trans. Geol. Soc. Glasgow*, vol.xv., part ii., 1915, pp. 147–150, Plate XV.</ref> occurs as a 5-foot thick dyke in the Lower Old Red Sandstone, and is exposed in the bed of the road leading from the String Road to the most westerly house in Glen Shurig. It is a dark-green pitchstone, containing felspar phenocrysts and abundant fresh olivine (p. 230).

Brodick School — The Schoolhouse pitchstone is exposed in the Schoolhouse garden, and in the wood to the west. It appears to be a sill injected into the steeply-dipping New Red Sandstone of that area. It also contains felspar and olivine crystals, and is often beautifully flow-banded.

Glen Cloy — The dark basic pitchstone associated with spherulitic felsite which forms a sill in the Glen Cloy Water, has already been described with the quartz-dolerite series, with which it appears to be genetically connected (p. 137). Dr. A. Scott has given a full account of this occurrence.<ref>A Composite Sill in Glen Cloy, *Trans. Geol. Soc. Glasgow*, vol.xv., part ii., 1915, pp. 140–150.</ref> Two other dark pitchstones, which may be called the Kilmichael pitchstones, occur in Glen Cloy. A black pitchstone, probably a sill, is exposed for 3 or 4 feet a quarter of a mile north of Glenrickard. This rock has been fully described by Dr. A. Harker.<ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 1903, pp. 125–126.</ref> It appears to be practically identical with the pitchstone of the Glen Cloy sill (*see* Scott, *op. cit.*). Dr. A. Scott has found another pitchstone in this locality, which is indifferently exposed in a small burn in the wood to the north-east of Kilmichael, about midway between the other two occurrences. This is a glossy coal-black rock with subconchoidal fracture, and resembles the other Glen Cloy pitchstones, except that it is quite free from de-vitrification or alteration of any sort. Scott regards the Glen Cloy pitchstones as more basic than any other Arran pitchstones, and as belonging to a group of basic glasses which occur in and around the Central Ring Complex. It is believed that this group is allied to the leidleite and inninmorite types of pitchstones, and are the glassy representatives of the quartz-dolerite-craignurite series. They are thus in all probability earlier in time than the main group of pitchstones.

Glen Dubh— Three occurrences of felsite with pitchstone-like margins are believed to belong to the same group as the Glen Cloy examples. A quartz-felsite dyke, about 24 feet wide, and trending N.N.W. to S.S.E., occurs in the Glen Dubh Water about 100 yards above its confluence with the Glen Ormidale Water. This is a grey rock with numeroussmall angular xenoliths of variolitic tholeiite and it becomes a dark, pitchstone — like material at its western contact. An analysis of this rock has been tabulated in a previous chapter (p. 147), and is discussed in a later section (p. 235). Two hundred yards farther up the Glen Dubh Water a massive quartz-felsite sill occurs, intersecting the Permian basaltic breccia horizon (*see* (Figure 5) p. 80). At both lower and upper edges it is chilled to a banded, greenish, pitchstonelike rock, the upper contact being against the breccia, and the lower against a basalt dyke. This sill is of the same petrographic character as the above-described dyke.

Just above the second eastern tributary to the Glen Dubh Water, a quarter of a mile S.S.W. of the confluence with the Glen Ormidale Water, there is a massive felsite dyke, 30 feet broad, and trending N.N.W. to S.S.E. On its western side it appears to have a chilled edge against an 8-foot dyke of porphyritic basalt.

Western Headwater of the Lag a' Bheith — Near the head of the main western branch of the Lag a' Bheith, 2 miles S.S.W. of Brodick Pier, there are exposures of a complex of pitchstone, felsite, and basalt, which are rather hard to interpret. The complex is bounded by a fault on its north-eastern side which brings it down against Triassic marls and cornstones. Basalt adjacent to the fault is much crushed and slickensided. The main exposure of pitchstone occurs at a little fall a few yards higher up the burn. It is mostly a green type, but one band is red owing to partial devitrification. It may be a facies of the wide spread of felsite which occurs to the westward. Both this sill and the pitchstone dyke are earlier than a mass of shattery basalt which cuts across the pitchstone, and thins out beneath the felsite without penetrating it. The exposures are shown in the sketch-map (Figure 28).

Glenloig — In a small stream on the west side of the main valley, two-thirds of a mile south-east of Glenloig Farm, there is a dark pitchstone dyke 2 to 3 feet wide. It runs in a northwest direction and hades south-west. The dyke cuts the explosion breccia of the Central Ring Complex.

Corrygills area

The Corrygills area contains the best-known pitchstones of Arran, and these belong to a single, well-marked type, which is practically non-porphyritic. The locality nomenclature of these occurrences is somewhat confused, the terms Dun Fionn, Corrygills, and Clauchland, being used interchangeably for several different exposures. An attempt is made in the following notes to localize the various exposures exactly, and to give them standard names.

North Corrygills and Corrygills Shore — This is a sill of felsite which at two places has a selvage of pitchstone. It runs from the road near North Corrygills, by a somewhat sinuous course in a general E.S.E. direction, until it reaches the Corrygills shore at a point a third of a mile south-west of the mouth of the Corrygills Burn. Its total length is therefore about one mile. Green pitch-stone is seen near North Corrygills close to the road in the northern branch of the Corrygills Burn. Felsite is seen in the road bottom close by, and also in the southern branch of the burn. The rock is traceable by means of fragments across the fields to the shore, where a remarkable section is exposed. The sill dips with the strata at 35° to the S.S.W., the outcrop being about 48 feet wide. The thickness is consequently about 25 feet. Seaward it thins rapidly, and at low-water mark is only about 4 feet thick. The highly-spherulitic upper contact of the sill is irregular, and plunges steeply through the sediments. Towards its base the sill is split by an intercalation of sandstone. Beneath this it passes down into a finely-banded, fissile felsite, and at its base into a dark-grey, beautifully-spherulitic pitchstone. This is the rock which has so often been figured and described, and may perhaps be regarded as the finest spherulitic rock in Britain. The individual fibres of the spherulites stand out with perfect clearness on the dark glassy background. Its best development is in a deep 'pocket' in the sandstone underlying the sill. The pitchstone is left adhering to the sandstone slabs, and has a wrinkled appearance like ropy lava. The sill apparently breaks through the long north-west to south-east basalt dyke which is so conspicuous a feature of the Corrygills shore.<ref>The writer is not satisfied that the felsite actually breaks through the basalt (*see* p. 2211. The latter, rather, appears to plunge beneath the felsite, for baked sandstone lies across its course, and intervenes between it and the felsite. It looks as if the skin of hard-baked sandstone on the margins of the felsite had proved too difficult an obstacle for the dyke to penetrate. On the south side of the felsite the dyke certainly shows some thinning and irregularity. G.W.T.</ref>

South Corrygills — A second felsite sill runs on an approximately parallel course to the first, and about a quarter of a mile south of it, through the district of South Corrygills. It is well exposed in the road at 264 feet O.D., and is there a beautiful spherulitic rock which is distinctly pitchstone-like in places. It cannot be traced any farther east from this point, but westward it runs as far as Corrygills Wood. Its length is thus approximately half a mile. At a spot 100 yards west of 278 feet O.D. on the road, Gunn found a pitchstone exposure about 25 feet in length. This is probably connected with the felsite sill.

Dun Fionn— The term Dun Fionn pitchstone may property be applied to two exposures on the slope above the Dun Fionn path half-way between Dun Dubh and Dun Fithin, and about 2 miles south-east of Brodick Pier. Another exposure occurs on the southern slope of Dun Fionn itself. The two above-mentioned exposures form sill-like outcrops just beneath the scarp of the Clauchland crinanite sill. The lower one shows a thickness of 20 feet, and the upper of 12 feet. No contacts are visible, and the outcrops cannot be traced more than about 50 yards in any direction when they disappear under the turf. Both sills consist of a green, platy, non-porphyritic pitchstone of the characteristic Corrygills type. Mr. John Smith records the occurrence of large detached spherulites in rabbit-burrows on the hill-slope above Dun Fionn farmhouse.<ref>*Trans. Geol. Soc. Glasgow*, vol.x., part i., 1895, p. 166,</ref> The exposure under Dun Fionn is of the same character, but is partially devitrified and spherulitic. It traverses the Clauchland crinanite, and can be traced westward by means of loose fragments. It is probably a continuation of the lower of the above-mentioned sills.

Clauchland Shore — This is the green columnar pitchstone which has been so often described as the Corrygills pitchstone. It is, however, properly on the Clauchland, and not on the Corrygills, shore. It is visible near the base of the crags for 150 yards, and dips S.S.W. at 30°, nearly as the sandstone below it, but it clearly cuts the sandstone, though there is little alteration effected by it. Nearly 200 yards south of this it is visible on the foreshore for about 50 feet. The maximum thickness may be estimated at 20 feet. Mr. John Smith has figured detached microlites which have weathered out from decomposed bands at the base of the sill .<ref>*Trans. Geol. Soc. Glasgow*, vol.xi., part ii., 1900, p. 275.</ref>

Clauchlands Cottage — On the southern slope of the Clauchland Hills a black pitchstone dyke occurs in the burn near Clauchlands Cottage. Its direction appears to coincide with that of the burn at the point, *i.e.* N.N.W.

Lag a' Bheith — A thick pitchstone occurs in the Lag a' Bheith just above the point where the old Brodick–Lamlash road crosses the burn. It appears to be a sill as it passes beneath the strata of the New Red Sandstone in an obscure section on the upstream side of the exposure. Downstream it is flanked by a basalt dyke. The pitchstone is also exposed in the bed of the old road near by.

Strathwhillan — A dark pitchstone, probably a sill, occurs near the junction of two stone dykes, about a quarter of a mile east of the Brodick and Lamlash road and 650 yards E.N.E. of the Lag a' Bheith outcrop. It runs in an E.N.E. direction, and is approximately on the continuation of the strike of the Lag a' Bheith outcrop.

Felsites in the Corrygills area— The felsites directly connected with pitchstones have been described above. There are, however, two other separate occurrences, which appear to belong to the same set. One, which has been quarried, appears by the side of the road to Lamlash, rather more than a mile south of Brodick pier. It is a somewhat fissile rock, fine grained, of a pale-yellow colour, and minutely spherulitic. It has been described along with other felsites (*Geol. Mag.*, vol.ix., p. 542) by Allport; In all probability this felsite is connected with the Lag a' Bheith pitchstone, and is part of the same intrusion.

A thick dyke or transgressive sill of whitish felsite occurs on the shore 250 yards north-west of Corrygills Point. Its outcrop is 100 feet wide, and it hades to the south-east at 60°. Its thickness is therefore approximately 85 feet. It can be traced through the cliff bordering the raised beach, and thence inland by means of fragments for about half a mile.

Monamore Glen and Tighvein Area

Monamore Glen — In the Monamore Burn, near the farm of Croc, there occur three pitchstones and a felsite dyke. Beginning the section at the small runnel which enters the burn from Croc, and working westward, we first encounter a dyke of hard dark felsite, the direction of which is approximately N.N.W. to S.S.E., judging from its jointing. After a blank interval of 20 feet, a pitchstone sill occurs in sandstone which dips 5° to 10° to the west. The lower part of the sill consists of a much-jointed, bottle-green pitchstone, which is immediately overlain by a green devitrified rock. The thickness of the whole is about 30 feet. After an interval partly occupied by sandstone, a second pitchstone sill consisting of four members appears. At its base there is about 25 feet of green pitchstone, followed by 4 feet of hard, green, platy felsite, then by g feet of spherulitic pitchstone passing upward into a banded variety, and finally at the upper contact there is 5 feet of a banded green rock of felsitic appearance.

The third pitchstone occurs upstream at the Woollen Mill, about 150 yards south-west of the above exposures. It makes a strong bar across the stream, striking north-west to south-east. The rock consists of a brown, banded, spherulitic glass, the banding being parallel to the edge of the dyke. At the margins it becomes red and devitrified. The upstream margin plunges abruptly through the sandstone like a dyke with a steep hade; but the downstream margin appears to overlie a ledge of sandstone in almost horizontal position, and hence is sill-like.

Pitchstones were seen by Gunn in the Allt Lagriehesk, about 300 yards S.S.W. of the Woollen Mill, and at a point on the moor 250 yards E.S.E. of Croc. A pitchstone also occurs in the wood about 100 yards south-west of Cordon, Lamlash, as part of a small felsite sill in that locality.

Near the head of the unnamed tributary which falls into the Monamore Burn, a little above the Mill Dam, at a point 600 yards S.S.W. of the seventh milestone on the Ross Road, there is a well-marked felsite sill which appears to underlie the coarse dolerite of the Monamore complex. This sill has a pitchstone-like facies at the above-defined point.

Numerous sills and dykes of felsite, beside those mentioned above, occur in the region of Monamore Glen. Some of these which intersect the Monamore complex have been previously mentioned (p. 115, and (Figure 8)). Felsite dykes are seen in each of the small road-metal excavations on the Ross Road, near the eighth milestone.<ref>J. W. Gregory and G. W. Tyrrell, Excursion to Arran, *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, Fig. 39, p. 420.</ref> Many of these occurrences are, no doubt, trachyfelsites or felsites belonging to the craignurite series dealt with previously; but others may belong to the pitchstone-felsite suite.

Tighvein area— On the southern shore of Urie Loch a little intrusive boss of spherulitic felsite occurs, breaking through the augite-diorite of that locality. A dyke-like mass of the same character borders the loch close by (p. 134). The former rock contains serpentinous pseudomorphs after olivine, and fresh green pyroxene, which are grouped with felspars in such a way as to suggest that the rock is a devitrified pitchstone.

In the stretch of moorland between Urie Loch and Loch na Leirg there occur two pitchstone exposures which may be parts of one and the same intrusion. One of these appears on the old Lamlash–Kilmory track about half a mile south-east of Urie Loch. It trends north-west to south-east and has a thickness of 18 to 20 feet. What is apparently its continuation occurs half a mile to the south-east, in the eastern branch of a tributary of the Allt Dhepin. Only one face of this dyke is exposed, and its thickness cannot, therefore, be measured. It has a marked platy fracture parallel to its vertical edge, and is traversed by numerous thin veins of felsite up to 3 inches in width, injected roughly parallel to the walls of the dyke. <ref>A. Scott, The Pitchstones of South Arran, *Trans. Geol. Soc. Glasgow*, vol.xv., part i., 1914, p. 17.</ref>

Near the head of the Allt nan Clach, one of the headwaters of the Kilmory Burn, about five-eighths of a mile south-east of the summit of Tighvein, there is an exposure of pitchstone the relations of which are very obscure because it is entirely surrounded by peat. It forms a low, flat-topped knoll elongated in a W.N.W. to E.S.E. direction, and measuring 100 yards by 30 yards. It may form part of a thick dyke, or it is possibly a lenticular swelling on a sill-like mass (*see* (Figure 17)).

Two pitchstone dykes occur near the head of the eastern headwater of the Allt an t-Stuie or An Sloe, the main branch of the Kilmory Burn. The exposure is distant about half a mile S.S.W. of the summit of Tighvein. The An Sloe pitchstones have been very fully described by Corstorphine.<ref>*Tschermaks. Min. u. Petr. Mitth.,* Bd. xiv., 1895, pp. 448–451. </ref> They trend in a N.N.W. to S.S.E. direction. The western dyke cuts felsophyric quartz-porphyry,' the eastern intersects the dolerite of the Tighvein complex.

Glen Ashdale, Allt Dhepin, and Kildonan Areas

Torr an Loisgte.<ref>A. Scott, op. *cit. supra,* p. 22.</ref>—A composite dyke of pitchstone and felsite occurs south of Torr an Loisgte on the south side of Glen Ashdale, cutting the scarp of the Dippin crinanite in that locality. It strikes approximately N.N.W., and can be traced about 70 yards southward, although it cannot be followed on to Torr an Loisgte. The marginal parts of the dyke, each 3 feet thick, are composed of green pitchstone; the central part, 8 feet thick, is a banded, spherulitic felsite. The junctions between the two varieties are perfectly sharp, and the intrusion must therefore be regarded as composite. The dyke hades 45° to the south-west, and appears to occupy a N.N.W. to S.S.E. line of movement.

Boulders of pitchstone are numerous in the burn which descends from Torr an Loisgte to Glen Ashdale, but no pitchstone *in situ* could be found.

Torr na Baoileig — A pitchstone dyke is seen in the depression between Torr na Baoileig and the scarp of the Dippin crinanite sill, at a point about half a mile W.S.W. of Torr an Loisgte. In one exposure it appears to cut the Baoileig felsite (p. 131); in another the crinanite. A boulder of pitchstone was found halfway up the crinanite scarp. The dyke appears to run E.N.E. to W.S.W.

***Cnoc* Mòr** — A little north-east of Cnoc Mòr (867 feet O.D.), on the north side of Glen Ashdale, 1½ miles W.S.W. of Whiting Bay Pier, a pitchstone is exposed. It is black when fresh, slaty-blue when somewhat weathered. From the available evidence it appears to represent a dyke running W.N.W. to E.S.E., and must be from 15 to 20 feet in width.

Cnoc an Fheidh — A N.N.W. to S.S.E. dyke of pitchstone occurs on the slope a quarter of a mile south-east of Cnoc an Fheidh (873 feet O.D.), about three-quarters of a mile N.N.W. of Loch Garbad.

Along the steeply-plunging eastern edge of the Garbad quartzdolerite (p. 132), several of the small burns tributary to the Allt Dhepin disclose exposures of felsite which occasionally have a pitchstone-like facies. With this persistent intrusion may perhaps be correlated a felsite mass in the gorge of the Allt Dhepin, south-east of 634 feet O.D. At one point this is a dyke, but it passes rapidly into a little columnar sill which is injected at the base of the Garbad quartz-dolerite sill.

Numerous dykes and sills of felsite occur in this area, but it is not always easy to decide whether they belong to the quartz-dolerite-craignurite series, or to the later pitchstone-felsitc suite. Many of the larger masses unquestionably belong to the former.

Cheese Hole Felsite — The only noteworthy felsite mass which occurs in the Kildonan district, apart from those belonging to the quartz-dolerite–craignurite series, is that of Cheese Hole, a point on the shore 250 yards south-west of Dippin Head. The rock here is a grey-blue felsite which weathers a dull chalky white. The mass is about 40 feet wide, and has a nearly north to south extension of about 70 yards. It has a plunging contact on its western side dipping 30° to 40° under horizontal sandstones. A few yards farther south there is a basalt dyke 24 feet wide, which is separated from the felsite by a strip of sandstone. Followed to the north this dyke abuts against the western edge of the felsite, and follows it as though deflected by it. The felsite terminates near the base of the Dippin crinanite scarp, and not a trace of it is found above a huge block at this point. It certainly does not cut the Dippin sill. The mass thus seems to be a small boss elongated in a north to south direction,

The south-western area

Burican <ref>A. Scott, *op. cit, supra,* p. 18.</ref> — Just above Glenrie Bridge, on the Sliddery Water, a third of a mile south of Burican, a pink banded felsite is seen, with what appears to be a faulted junction against the Triassic sediments

(Figure 29). The nearly horizontal, slabby joint-planes of the igneous rock turn up until they become almost vertical at the junction. The absence of shattering suggests that the felsite has come up along the fault.

The Burican pitchstone forms a ledge between the road and the Sliddery Water above the felsite. It slopes down towards the river, and has a visible thickness of 20 feet. It seems probable that it represents the upper part of the banded felsite.

Allt an t-Sluic, Kilpatrick — A pitchstone sill is visible in the Allt an t-Sluic, a headwater of the westernmost tributary of the Sliddery Water. The exposure is 2 miles E.S.E. of Kilpatrick Point. About io feet of pitchstone is visible; it forms a ledge in the bank of the stream, in the channel of which red marly sandstone is seen.

Cnocan a' Chrannchuir, Kilpatrick — This occurrence is in a small burn called Allt na Craoibhe, on the north-east side of Cnocan a' Chrannchuir, about 1½ miles south-east of Blackwaterfoot. It is very poorly exposed, consisting of scattered blocks of pitchstone, and a foot or two of the rock *in situ.* From-the fact that baked whitish sandstone is seen near by on the same level, the exposure is adjudged to be part of a dyke.

Felsites of Kilpatrick — This term is applied to the large masses of felsite which appear to cut the quartz-porphyry of Kilpatrick, and are described on p. 199. The above two pitchstones occur within short distances of the eastern edge of the larger of these masses. These rocks, in common with the similar Blackwaterfoot masses, are singularly free from later intrusions, even of the latest series of basaltic dykes, as has been emphasized by Gunn.<ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 1903, p. 91.</ref> They probably belong to the pitchstone suite.

Tormore and Blackwaterfoot area

The pitchstones of the Tormore shore have attracted the attention of geologists from Jameson onwards, and have been rendered classic by the investigations of J. W. Judd, who pointed out their close association in composite dykes with felsites and augite-andesites (tholeiites).<ref>On Composite Dykes in Arran, *Quart. Journ. Geol. Soc.*, vol. xlix., 1893,pp. 551–561.</ref>

Judd's No. I. Dyke (see sketch-map, (Figure 30)) — This is the largest pitchstone intrusion on the Tormore shore. The Tormore shore is the mile-long strip of rocky coast which stretches southward from the southern side of Machrie Bay. The dyke appears at low-water mark 200 yards north of An Cumhann, and runs in a N.N.E. direction. At high-water mark, however, its direction becomes more northerly, and it ultimately passes from sight under boulders and raised-beach material. It reappears at the northern end of the section for 100 yards or so, with a northerly course. Its total exposed length is thus about 600 yards. At the northern end of the outcrop the pitchstone appears to be a vertical dyke, but towards its southern extremity, according to Judd, it hades at less than 60°. At its northern end it consists entirely of pitchstone; the southern exposures, however, show the pitchstone passing on both sides into banded, spherulitic felsite. On its eastern margin, moreover, a band of dark tholeiite intervenes between it and the adjacent sandstone.<ref>Judd, *op. cit.,* Fig. 2 p. 554.</ref>

Judd's No. II. Dyke — This dyke occurs near the north end of the Tormore section. It runs east to west, and appears to intersect the north to south dyke. Its thickness is 30 feet. Its sides are composed of tholeiite weathering in the usual spheroidal fashion, but the centre is a quartz-felsite which occupies about half the width of the dyke. A pitchstone dyke or vein, 6 inches to 2 feet in width, is found sometimes intersecting the felsite, and at other times the adjoining tholeiite.<ref>Judd, op. *cit.,* Fig. 3, p. 555.</ref>

Judd's No. III. Dyke — About 120 yards south of No. II., another composite dyke occurs, which trends north-west to southeast. It is from 40 to 50 feet wide, and is mainly composed of tholeiite. Somewhat asymmetrically placed there is a median band of acid rock about 5 feet thick, of which the central 2 feet consists of pitchstone, and the remainder of quartz-felsite.<ref>Judd, *op. cit.,* Fig. 4, p. 556.</ref>

King's Cave — Five separate exposures of pitchstone occur on the shore and in the cliff bounding the raised beach to the south of King's Cave, half-way between Tormore and Drumadoon. Three of these exposures are in and about a recess in the cliff made by a small stream. Just below the path on the south side of the recess there is a pitchstone sill 20 feet thick, resting on sandstone and dipping S.S.E. at 5° to 10°. A little higher up there is a small mass of shattered pitchstone. At a higher level on the opposite side of the recess there is first a sill of spherulitic felsite about 32 feet thick, and then another of banded pitchstone. Assuming that the spherulitic felsite is the same intrusion as the lowest pitchstone, an assumption for which there is petrographic warrant, the relations of the four igneous masses may be explained as in the section, (Figure 31), by means of a north-west to south-east fault running along the line of the above-mentioned gully.

This fault-plane appears to be occupied by a felsite-pitchstone dyke, for felsite is found on the shore at the north-west end of the line, and a pitch-stone dyke is recorded by Gunn at the south-east end near the head of the gully.

In the cliff bounding the raised beach immediately to the south of the above-mentioned exposures, another sill of pitchstone is exposed, which may represent a third horizon of this rock.

Blackwaterfoot Felsite — A mass of columnar quartz-felsite occurs on the shore on both sides of the mouth of the Black Water. A little west of the river the sediments are steeply upturned against a vertical face of felsite; and in the raised-beach cliff near by, the joint-planes of the felsite curve steeply upwards against a junction with sediments. Although there is a slight break in the continuity of the mass at this point, there can hardly be any doubt but that the Blackwaterfoot sill is the same as that which spreads northwards almost to Machrie Bay, and forms the large area of felsite on the moor east of the Tormore shore (Torr Righ Beag and Torr Righ Mòr). This outcrop is 2 miles in length by a mile in average width, and consequently covers an area of 2 square miles. Not a single basalt dyke appears to cut this felsite mass. On the shore at Blackwaterfoot basalt dykes approach the edge of the felsite, but do not penetrate it. In the absence of an actual junction it is difficult to establish the relative ages of the two rocks. Gunn relied on the Blackwaterfoot shore-section to demonstrate the posteriority of this group of felsites to the basalt dykes (unpublished MS. on Sheet 13) but his own 6-inch scale MS. map (Buteshire, 253 N.E.) shows the dykes, as they approach the margin of the felsite, bending into conformity with it, as though they were influenced by the proximity of the felsite, or found it difficult to penetrate. (Figure 32) also illustrates this feature.

Holy Island

The massive sill which forms the major part of Holy Island, in Lamlash Bay, was formerly regarded as a felsite, but is now known to be a trachyte or orthophyre containing riebeckite and aegirine.<ref>G. W. Tyrrell, The Petrology of Arran, *Geol. Mag.,* 1913, pp. 305–309.</ref> It therefore presents certain analogies with the intrusion of Ailsa Craig, in the Firth of Clyde, 17 miles to the south of Holy Island.

The outcrop has the form of an ellipse elongated in a N.N.W. to S.S.E. direction, the axes of which are one and a half and half a mile long. A traverse across the island yields the view of its structure which is given in (Figure 33). Three main terraces and scarps are encountered, and one or two subsidiary ones. This is interpreted as meaning that the sill was emplaced in at least three pulses of injection. Its total thickness is estimated at 800 feet. It rests on sandstone, which in turn rests upon, and has been intruded by, the Kingscross crinanite sill (p. 116). While in most places the sill rests in approximately horizontal position upon the sediments, in one place on the eastern side below the summit of the island, a vertical contact of the igneous rock against sandstone is seen, and the former shows horizontal columnar structure. It may be suggested that this possibly represents one of the feeding channels of the mass.

When fresh the rock is of a deep blue-grey colour, often with a greenish tinge, and with an occasional small porphyritic felspar.

Notwithstanding its great thickness the rock is very fine grained throughout. It breaks and rings like a phonolite. It is intersected by closely-set vertical joints spaced on the average about half an inch apart, and running in a north-west to south-east direction. A slabby horizontal parting is also sometimes developed. The jointing seems to be potential, and to be brought out by weathering, as good thick specimens can be obtained from the interiors of blocks. In most of the crags, and especially on the western side of the island, the rock shows a massive columnar structure.

The second scarp on the west side (Creag Liath) thickens to the north, and forms a cliff at least 200 feet high. Between it and the summit (Mullach Moir, 1030 feet O.D.) there is a rocky depression.

On the western side of this valley a zone of breccia a few inches wide borders a plane of movement which hades about 70° west (Figure 33). This plane strikes north-west to south-east, and the joint-planes and other features near it are disturbed and twisted. At the extreme northern end of the island a flattish felsite ' feature is seen on the foreshore, and apparently represents the top of a lower sill. Red sandstone occurs immediately to the west of this exposure.

Not a single basalt dyke has been found to penetrate the Holy Island sill. On the other hand the sandstone basement is intersected by dykes which stop short at the margin of the sill. In a section on the south-east coast Gunn mapped a dyke-like north-west to south-east protrusion of 'felsite' which cuts right through a prominent basalt dyke running in nearly the same direction (Bute-shire, Sheet 250 S.W.).<ref>The writer has not seen this section.</ref> This section seems to demonstrate conclusively that the Holy Island sill is later than the north-west basalt dykes, and must therefore be one of the latest, if not the latest, igneous injection in Arran.

Notwithstanding its great thickness the Holy Island sill, in common with the other felsitic masses of Arran, has effected remarkably little alteration on the adjacent sediments. Nowhere is more than a trifling induration caused.

Petrography of the pitchstones and associated rocks

It is not possible in this place to deal fully with the varied and complicated petrography of the pitchstones and their associated rocks, or to discuss in any detail the interesting petrological questions to which they give rise. The most comprehensive description extant is that by Dr. A. Harker in the Memoir on North Arran (1903), which is given below. Dr. Harker gives brief references to the work of previous investigators. Since the appearance of his description the only other modern accounts are those by Dr. A. Scott,<ref>The Pitchstones of South Arran, *Trans. Geol. Soc. Glasgow*, vol. xv., part i., 1914, pp. 16–36. A Composite Sill in Glen Cloy, Arran; *ibid.,* vol. xv., part ii., 1915, pp. 140–150.</ref> who has the distinction of being the first to point out the occurrence of olivine in the Arran pitchstones. Scott has also discussed the physical chemistry of these rocks in some detail. G.W.T.

General description

Dr. A. Harker's general description of the Arran pitchstones and felsites is as follows:<ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 1903, pp. 120–127.</ref>

Since Jameson<ref>Outline of the Mineralogy of the Shetland Islands and of the Island of Arran, 1798, pp. 76–82.</ref> more than a hundred years ago gave descriptions, in the Wernerian fashion of the time, of several varieties, the *pitchstones* of Arran have become more widely known than any other group of rocks in the island. This is owing especially to their very beautiful microstructure, which has been made familiar to all geologists by the descriptions of Sorby,<ref>*Quart. Journ. Geol. Soc.. vol. xiv.,* 1858, pp. 476,477, Plate XVIII.</ref> Zirke1,<ref>*Sitz. Akad. Wiss. Wien,* vol. xlvii., 1863, pp. 260–262, Plates II., III. *Zeit& deuts. geol. Ges.*, vol. xix., 1867, pp. 785–788, Plate XIV. *Ibid.*, vol. xxiii., 1871,pp. 42–46.</ref> Allport,<ref>*Geol. Mag.,* 1872, pp. 1–10, Plate. I., and pp. 53–545. *Ibid.,* 1881, p. 438.</ref> Vogelsang,<ref><ref>Die Krystalliten, 1875, pp. 122–126, Plate XIII., XIV. </ref> Teall,<ref>British Petrography, 1888, pp. 344–347, Plate XXXIV</ref> Judd,<ref>*Quart. Journ. Geol. Soc.*, vol.xlix, pp. 536–564, Plate XIX.</ref> Rosenbusch,<ref>*Mikroskopische. Physiographie der massigen Gesteine,* 1896, pp. 699–702, of 3rd edition.</ref><ref>*Tscherm. Min. Petr. Mitth.,* vol. xiv., 1895, pp. 448–451.</ref> Corstorphine,<ref>Corstorphine records a rhombic pyroxene as occurring, subordinate to augite, in a pitchstone in An Sloc, in the southern part of the island.</ref> and others.

The specimens selected for examination are dark-grey or greenish-grey rocks, sometimes almost black, with the characteristic resinous lustre. They show usually only small crystals visible to the naked eye, rarely more than an eighth of an inch in length, and often rather sparingly scattered. There are, however, some conspicuously porphyritic pitchstones in the island, as described from Brodick Castle, Invercloy, and Cir Mhòr. Thin slices show under the microscope that the general body of the rock consists of a glass more or less crowded with minute crystallites. These are of two orders of magnitude, the larger easily visible, the smaller appearing with a low magnifying power only as a pigment, colouring and rendering turbid the glassy matrix. There are thus four sets of elements in the rocks — the porphyritic crystals, the larger crystallites, the smaller crystallites, and the glassy base, the last enclosing the rest and constituting the principal part of the bulk.

The porphyritic crystals embrace quartz, felspars, augite,n and magnetite, all with idiomorphic outlines, excepting only when they are aggregated in groups, as is frequently seen. In this case the later crystallized minerals are moulded upon the earlier, and it is seen that magnetite has preceded augite, and both have preceded the quartz and felspars. Apatite is found rather rarely. The quartz is in pyramidal crystals, sometimes rounded at the angles and often having considerable inlets of the groundmass. Both quartz and felspars also contain glass inclusions, and the glass often encloses minute crystallites.<ref>*See* Sorby, *loc. cit.,* Plate XVIII., Figs. 57–63; Teall, British Petrography, p. 19 (in felspar), and Zirkel, *loc. cit.,* 2867, Plate XIV., Figs. 16–22 (in quartz). </ref> The felspar is partly striated oligoclase, partly what looks like sanidine; but the latter, as remarked by Prof. Judd, has sometimes a vague appearance of very fine lamellation which is suggestive of cryptoperthite.<ref>Scott has recorded anorthoclase in the Glen Ashdale pitchstone. In some types felspars resembling chequer albite are seen. G.W.T.</ref> The augite is in crystals with the usual octagonal cross-section, and is of a light-green colour.

The larger *crystallites* are in the form of minute rods (microlites) or needles, tapering at one end (belonites of Zirkel), and are constantly transparent and of green colour. The belonites are often aggregated into radiate groups, joined at the base, but not so regularly developed as to form perfect stars. Again, they grow attached to, and set perpendicularly upon, the faces of the porphyritic crystals, so as to appear in the slice as a thick fringe. These larger crystallites themselves have in turn served as starting-point for the growth of the much smaller crystallites of what we have styled the second order, and in this way have been built up elaborate fern-like and arborescent growths which give a very remarkable appearance to a thin slice of any of the Arran pitchstones. The mineralogical nature of the green microlites and belonites in these rocks has been the subject of some discussion. In the specimens examined by us the mineral, whenever sufficiently characteristic, seems to be hornblende. The extinction-angles observed were in all cases low, and pleochroism is often to be detected. It is possible that augite occurs in some of the Arran rocks not examined, and indeed Rosenbusch has noted in some cases, though rarely, extinction-angles up to 35°.<ref>Pyroxene microlites were definitely identified by Scott in the Glen Ashdale pitchstone (Torr an Loisgte). *Op cit. supra,* p. 15. G. W. T.</ref> The largest crystallites show in cross-section characteristic crystal outlines, which are those of hornblende. They are, as Sir J. J. H. Teall<ref>*Loc. cit.,* p. 345, Plate XXXIV., Fig. 4.</ref> has remarked, hollow, the glassy core corresponding in shape with the exterior. In size these larger crystallites vary in different rocks and also within a certain range in a given rock. In different specimens they have a length of 0.005 to 0.01 inch to 0.02 inch, with a width rarely more than 0.0002 or 0.0003 inch. There are often, however, a few rather larger rods, up to 0.04 or 0.05 inch in length. As a rule, these largest crystallites do not, like the rest, act as the trunks of arborescent and other complex growths.

The much more minute crystallitic growths, which represent the latest effort of crystallization in the pitchstone magma, occur in two ways — disseminated uniformly through the glassy matrix and clustered thickly upon the larger and earlier crystallites to form complex arborescent and other aggregates. In the former case they impart to the general matrix a yellow colour and a somewhat turbid aspect in a thin slice, an appearance resolved by the use of a higher magnification. It is then seen to be due to the presence of an immense number of excessively minute bodies usually in the shape of short rods. With the short rods there may be still smaller bodies in the shape of globulites, and less commonly the globulites occur alone or almost alone (Dun Fionn, (S2448) [NS 030 340] [NS 030 340]; Caisteal Abhail, (S2451) [NR 960 440]). The complex growths built up by the aggregation of the minute crystallitic elements about the larger ones assume various forms. A very characteristic one resembles exactly a pine-tree, of which the trunk is made by a belonite and the foliage by a vast number of the smaller bodies. Another beautiful shape is made up by two or three rather small rod-like crystallites of the first order, crossing one another at their middle points, with their four or six extremities bearing complex plumose growths, which unite to form in section a feathery circle having the little rods as diameters. These two forms are well illustrated by specimens from Corrygills and Tormore respectively, and have frequently been figured.<ref>*See, e.g.,* Cohen's *Sammlung von Mikyopholographien*, plate IV., Fig. r of 3rd edition, 1899.</ref> The mineralogical nature of the more minute crystallites cannot be investigated directly, for, excepting their greenish-yellow colour, they do not exhibit any optical properties. It may be inferred, however, with high probability, that they are of the same nature as the larger crystallites, and therefore of hornblende. Those which take part in the complex growths have the same appearance as the trunks of the same growths. Further, it cannot be doubted that the minute crystallites disseminated through the glass are identical with those in the aggregates; for an invariable feature of these rocks is a ring of clear colourless glass surrounding each complex growth, as if the fine crystallitic matter which would otherwise have been scattered through this space had been abstracted to make up the aggregate in the centre.

The glass itself, apart from the minute crystallitic bodies with which it is charged, is always clear, colourless, and structureless. It does not, as a rule, show any perlitic structure. Indeed the pitchstones,' such as those of Meissen in Saxony, which show best this breaking up by minute curving fissures due to contraction, are mostly lava-flows, while these Arran rocks occur exclusively in the form of dykes and intrusive sills. There are, however, exceptions. A specimen (S2451) [NR 960 440] from a dyke at Caisteal Abhail shows very perfect perlitic fissures, which mostly occur immediately surrounding phenocrysts of quartz and sometimes of felspar.

Many of the rocks show no evident indication of flowing movement in the magma subsequent to the beginning of crystallization; but in others fluxional phenomena are seen, and are of various kinds.

Sometimes the porphyritic crystals of felspar are arranged with their long axes parallel to the direction of flow; less commonly the larger crystallites and crystallitic aggregates exhibit a like orientation (Corrygills shore, iii; Cnoc an Fheidh, (S6392) [NS 010 240]). Again, in some examples from Tormore (S5656) [NR 890 320], (S5657) [NR 890 320] and elsewhere the matrix of the rock is finely banded, the narrow bands following flow-lines, and being visible as an alternation of fine darker and lighter stripes upon a hand-specimen. In the slices this appearance is seen to arise from the unequal distribution of the crystallites through the glassy matrix. Stellate, plumose, and other groupings occur abundantly in certain bands and only sparsely in others. The more minute crystallitic elements are perhaps equally plentiful in the two cases; but in the former they are aggregated, leaving the glassy matrix clear, and in the latter they are dispersed, producing a cloudy yellowish appearance.

The pitchstones of Arran, with those of the other western islands of Scotland and of the north of Ireland, differ from all other known acid rocks in their richness in crystallites of a ferro-magnesian silicate. Though always present, these are not always equally abundant, and the differences may be connected with differences of chemical composition. It is also to be remarked that some of the rocks do, and others do not, carry porphyritic quartz. The analyses of pitchstones and associated rocks given in the earlier Arran Memoir (p. 124) show a certain range of chemical composition, some of the rocks being acid and others sub-acid. Our specimens selected for examination probably belong for the most part to the truly acid type, but one, picked out from the rest on account of its richness in the ferro-magnesian element, is perhaps a *sub-acid* rock. It is from a sill at Brodick School (S7537) [NS 009 355]. It does not differ notably from the rest in appearance in a hand-specimen, except that it has a more decided black colour; but its specific gravity is found to be at 2.45, while a more ordinary variety from Corrygills (S110) [NS 040 340] gives only 2.34. In a thin slice this Brodick rock shows a plexus of closely packed fine fibres imbedded in a brown glass. The fibres seem to be, at least in general, of felspar, and the larger ones show a central core of glass. The smaller are arranged in parallel groups attached to the larger and grown nearly at right angles to them, but there is no special orientation of the groups thus built up. The crowding of these crystallitic elements makes it difficult to examine the interstitial glass, but the brown colour is probably proper to the glass itself and not merely due to globulites.

Doubtless other pitchstones of sub-acid and intermediate composition occur in Arran. Delesse<ref>*Ann. des Mines* (*5*), vol. xiii., 1858, p. 356.</ref> mentions a thick sill in the red sandstones which gave the specific gravities 2.532 and 2.548 in the centre and at the margin respectively. The corresponding percentages of water were only 1.65 and 1.75, which are remarkably low figures.

Numerous geologists have noticed the occurrence in Arran of *felsitic rocks* in close association with pitchstones. In the older literature these rocks figure usually under the names 'hornstone' and 'claystone'. Some which have been analysed have a chemical composition not essentially different from that of the pitchstones,<ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 2903, p. 124.</ref> and tliti intimate association of the two rocks decidedly suggests that they are closely cognate and are in some cases parts of the same rock-body, the one having assumed a finely crystalline and the other a vitreous state. Assuming this, it remains a question to be considered in any given case whether the finely crystalline texture is original or is the result of devitrification of a pitchstone. In an example on Cir Mhòr carefully studied by Prof. Judd, that writer arrived at the former conclusion,<ref>*Quart. Journ. Geol. Soc.*, vol. xlix., 1893, p. 551. The expression 'primary devitrification' in this connection seems to be confusing, since devitrification is predicable only of what was once a glass.</ref> but the other alternative may be entertained in other instances. The remarkable microstructure of the pitchstones may not improbably become obscured or obliterated by secondary changes when the glassy character is lost, and the absence of perlitic fissures in most of the Arran pitch-stones usually precludes a criterion which has often been relied upon in other districts as indicating a formerly vitreous condition in rocks now cryptocrystalline or microcrystalline.

There are, nevertheless, specimens in our collection which give many indications of having originally been pitchstones and having lost their glassy texture, though the alteration evinced has been in general of a more radical kind than mere devitrification.

An interesting specimen comes from a quarter of a mile northeast of Kilmichael, Glen Cloy (S7539) [NS 000 350]. It is a dull-grey, compact rock, with numerous minute white spots, which look like spherulites. A thin slice shows in natural light a vast number of little needles answering exactly to those seen in the pitchstones (Zirkel's belonites), but replaced by some chloritic or ferruginous substance. There are also abundant relics of the more minute crystallitic bodies attached like branches and twigs to these trunks, though the delicate arborescent growths which have probably been present have been in great measure destroyed, and clotted patches of the same ferruginous material represent the destroyed crystallites. Polarized light shows that the groundmass is not glassy, but consists of irregularly interlocking and interlacing crystalline areas. An imperfect radiate arrangement is seen in places, but no complete spherulites. The rock has probably been a pitchstone, and has undergone devitrification and other changes. Some little interstitial areas of clear quartz must be regarded as of secondary origin.

A specimen from a dyke north of Torr Righ Mòr (S6405) [NR 880 310] is a dull compact rock mottled with pink and white streaks and with little scattered quartz-crystals. It has something of a fissile structure, corresponding with very evident fluxion-lines. In the slice we see well-developed perlitic fissures traversing the rock everywhere, and, with other circumstances, leaving little doubt that it has been originally a pitchstone. There are still little irregular brown patches which are dark between crossed nicols, and are crowded with what have presumably been crystallites, now replaced by reddish-brown ferruginous matter. The rest of the slice shows double refraction in a blotchy irregular fashion. In natural light there are clearer spots, often coalescing with darker yellowish interspaces. The spots often polarize as individuals. Another rock, comparable with this, comes from Tormore (S6404) [NR 890 320]. This also shows marked flow-structure, with bands of pale green and pale yellow. It has a very compact, almost porcellanous, appearance, and is one of Jameson's hornstones. There are here no perlitic fissures, except occasionally surrounding the little porphyritic crystals. In natural light the appearance is otherwise very similar to that of the preceding rock, the clearer spots and yellow interspaces being strongly marked. Between crossed nicols, however, the groundmass breaks up into a much more fine-textured aggregate than before. The blotchy or spotted appearance of these and similar rocks seems to be connected with changes other than mere devitrification. There are, however, rocks which show no such peculiarity, and in which the only noticeable change from the presumed original pitchstone is the resolution of the glass into minutely crystalline elements.

There are other cases of the association of felsitic rocks with pitchstones in which the two rocks must be considered to represent distinct intrusions. An instructive example is a rock from a dyke in Glen Dubh, 200 yards above its junction with Glen Ormidale. This is a light-grey, compact rock with minute quartz-grains, enclosing rounded patches up to three-quarters of an inch diameter of a darker grey colour. These patches are seen in the slice (S7540) [NR 996 346] to be of the same general character as the matrix, both having a very finely crystalline texture, though with rather different structures. The grey matrix includes, however, other and smaller dark patches, which have all the appearance of a pitchstone under the microscope, except that the glassy base is devitrified, and only the larger and stouter crystallitic bodies retain their shape and groupings.

One well-known dyke on Corrygills shore may be mentioned here as being associated with the pitchstones, though there is nothing to indicate that it has itself been vitreous. Since the rock has been described and figured more than once,<ref>Allport, *Geol. Mag.,* 1872, pp. 540, 541; Bonney, *Geol. Mag.,* 1877, p. 506, with Fig.; Teall, British Petrography, 1888, Plate XXXIX., Fig. 1.</ref> no detailed account is necessary here. It is a spherulitic felsite of dull-grey aspect, the little spherulites appearing in our specimen (S3323) [NS 030 340] as dead white spots one-fortieth to one-eighth of an inch in diameter, often with a dark nucleus and a dark border. There is a flow structure, partly marked by lines of spherulites. The appearance in a thin slice, and especially the blotchy or spotted character already remarked in other rocks, are well shown in Teall's coloured plate, and the rock seems to have suffered alteration of the kind already pointed out in other cases. The spherulites, which make up most of the bulk, have had their radiating fibres replaced by irregularly interlocking narrow sectors, or in the central portion by a merely granular aggregate. This latter structure is seen also in the interspaces between the spherulites. In our specimen, from the edge of the dyke, the flow lines are seen to run uninterruptedly through the spherulites. AH

The pitchstones of Arran may be provisionally classified into four petrographical types, which may be designated as the Corrygills, Glen Shurig, Tormore, and Glen Cloy types respectively. One example of each type has been analysed, and is described below.

Corrygills Type

The analysed rock (S25614) [NS 043 339] is from the lower ledge of the Dun Fionn pitchstone sills (p. 213). It is a dark, olive-green, non-porphyritic pitchstone, with a marked platy fracture. In thin section it reveals a pale biscuit-coloured glass crowded with pleochroic green needles and feathery scopulites. The extinction-angle of these needles varies between 10° and 15° in a great majority of cases, although one of 24° was measured. There does not seem any reason to doubt Dr. Harker's identification of them as hornblende (p. 225). Interspersed amongst the microlites are numerous pale-green flakes of irregular shapes which are faintly-polarizing. These are sometimes bounded by straight prismatic edges and have scopulitic terminations, They probably represent sections parallel to the flat faces of mineral plates of the same nature as the acicular microlites. Finally there are a very few, tiny, irregular spherulites. The refractive index of the glass is 1.492 ± .002.

The majority of the pitchstone occurrences in the Corrygills district belong to this type. The North Corrygills dyke (S25068) [NS 032 348], and the spherulitic rocks on the Corrygills shore (S19), (S3323) [NS 030 340], (S3323A) [NS 030 340], (S24363) [NS 045 343] belong here, as do also rocks from the Corrygills shore (? Clauchland shore) (S2454) [NS 040 340], from the southern slope of Dun Fionn (S24386) [NS 045 338], and from Monamore Glen (A112, B112). Three slices from the Dun Fionn occurrences (S2448) [NS 030 340] [NS 030 340], (S2449) [NS 030 340], (S2450) [NS 030 340] are identical with that of the analysed rock described above.

Tormore and Glen Shurig Types

These types are very much alike and may be described together. They are porphyritic pitch-stones, and in thin section show phenocrysts of quartz, felspars, pyroxenes, and iron-olivine (fayalite), embedded in a colourless or pale-yellow glass crowded with microlites and crystallites of various kinds. The *Tormore* type is relatively rich in pyroxenes as compared with iron-olivine; on the other hand, the Glen Shurig type exhibits a relatively large concentration of iron-olivine. Examples may occasionally be found almost free from both minerals.

In the analysed rock from Judd's No. II. dyke on the Tormore shore (S25621) [NR 880 320] the glassy matrix is pale biscuit in colour, and is crowded with minute specks except in areas adjacent to the numerous green microlites, which show 'courts of crystallization'. The refractive index of the glass is 1.495 ± .002. The phenocrysts include quartz, felspars, pyroxenes, iron-olivine, and magnetite. The quartz-crystals are invariably corroded, rounded, and embayed. The felspars, too, while displaying more euhedrism than the quartz, have nevertheless suffered some corrosion, and exhibit rounded corners and edges. While the majority of the felspar sections are perfectly clear and transparent, a few are turbid like the xenocrystic felspars of other Arran rocks. The mean refractive index of the felspars is 1.55, and the maximum extinction angle of the albite twinning is 17°; the composition is therefore determined as andesine ($Ab_{66}An_{34}$). Many of the crystals are zonal, the exterior zone giving straight extinction (oligoclase). Hence the bulk-composition of the felspar is probably less calcic than is indicated by the composition of the kernels.<ref>It has often been stated that 'sanidine','soda-orthoclase.' 'anorthoclase', etc., occur in the Arran pitchstones; and while not asserting their complete absence, it is well to emphasize their rarity. On close examination the felspars almost invariably show multiple twin striations, and refractive index tests show that they are plagioclases.</ref> The felspar crystals often enclose pyroxene and magnetite, and are associated with them in a 'together-swimming' or synneusis (Vogt) structure, producing a mineral combination recalling that of the tholeiites with which this rock forms composite dykes.

The pyroxenes include both orthorhombic and monoclinic varieties. The orthorhombic variety is a pale or colourless enstatite giving elongated, cross-fractured, prismatic sections. The augite is colourless to pale green, with a maximum extinction-angle of 43° in prismatic sections. The pyroxene crystals almost invariably enclose magnetite, especially around their peripheries.

The iron-olivine (fayalite) forms anhedral crystals which tend to alter to a deep-green serpentine. It is very subordinate in quantity to the pyroxenes in the Tormore rock, but in the Glen Shurig pitchstone it becomes the most important coloured mineral (S25615) [NR 995 366]. In this rock it forms large, anhedral, honey-coloured crystals, which are associated with felspars, green clinopyroxene (iegirine-augite), a little enstatite, and magnetite in synneutic groups. The glass entangled between these crystal groups is biscuit-coloured, and is free from crystallites, whereas the glass outside them is colourless and full of crystallites. The refractive index of the clear glass is 1.495 ± ˉ002. Dr. A. Scott has given a full description of the Glen Shurig pitchstone, with illustrations showing the glomeroporphyritic aggregates and the fayalite crystals.<ref>*Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 147–150, Plate XV.</ref> He also first noted and studied the occurrence of fayalite in the Arran pitchstones.<ref>*Ibid.*, vol.xv., part i., 1914, pp. 18–20.</ref>

It is not possible in this place to enter on a full discussion of the origin of iron-olivine in these silica-rich rocks, and we therefore present only a few brief notes referring to recent views on the subject. Scott suggested two possible modes of origin for the fayalite: (*a*) the glomeroporphyritic aggregates may be partly or wholly of xenolithic origin, the olivine crystallizing from a basic material subsequently inundated by acid magma; (*b*) the formation of the olivine may be analogous to that of magnetite in a granite. Scott believed the first-named hypothesis the more satisfactory of the two. In a recent discussion of the presence of olivine in acid igneous rocks containing a large excess of free silica, Dr. L. Hawkes <ref>On an Olivine-dacite in the Tertiary Volcanic Series of Eastern Iceland, *Quart. Journ. Geol. Soc*., vol.lxxx., part iv., 1924, pp. 549–567.</ref> shows that the only common feature in these olivine-bearing rocks is their poverty in magnesia. He favours the view that, like magnetite and the ferro-magnesian silicates, fayalite is only slightly soluble in siliceous magmas, and forms as a normal magmatic constituent from melts of appropriate composition. As in the Icelandic rock described by Hawkes and in the other rock types cited by him, the olivine in the Arran pitchstone does not show reactional effects, although it is enveloped by a silica-rich and water-rich glass. Nevertheless iron metasilicate does form in these rocks much more often than the orthosilicate, and with CaO and MgO produces pyroxenes, as pointed out by Fenner.<ref>The Katmai Magmatic Province, *Journ. Geol.*, vol.xxxiv., 1926, p. 699.</ref> Hence the presence of the orthosilicate is not due to the inhibition of the formation of iron metasilicate. Fenner favours the view that the formation of silica-poor ferromagnesian minerals in acid igneous rocks is due, partly at least, to the presence of fugitive or volatile constituents, a view supported by the common occurrence of fayalite in lithophys. The Arran pitchstones are rich in combined water (*see* analyses, p. 234), and differences in the concentration of volatile constituents are indicated by different states of the glassy groundmass within and near the glomeroporphyritic aggregates of which fayalite is a prominent constituent. The following are the pitchstones in the Survey collection which conform more or less to the above description. There are numerous variations in the number and relative abundance of the phenocrystic minerals, and in the nature of the glassy ground-mass: Cir Mhòr (S25071) [NR 970 430], (S25617) [NR 973 432], almost free from fayalite, and showing the hyalite-tridymite investments described by Judd,<ref><*Quart. Journ. Geol. Soc.*, vol. xlix., 1893, p. 550./ref> and discussed by Scott<ref>*Trans. Geol. Soc. Glasgow*, vol. xv., part i., 1914, pp. 26–27.</ref>; Caisteal Abhail (S2451) [NR 960 440], (S2452) [NR 960 440], (S3324) [NR 960 440], (S3325) [NR 960 440]; Brodick Schoolhouse (S2453) [NS 009 366], (S3321) [NS 009 366], (S7537) [NS 009 355], (S25616) [NS 009 366], a variable type, some bands being practically free from phenocrysts; the main western headwater of the Lag a' Bheith (S25046) [NS 010 330]; head of Allt nan Clach, south of Tighvein (S24876) [NS 003 267]; Torr an Loisgte (S24870) [NS 039 247]; the stream west of Torr an Loisgte (S24869) [NS 038 250] — the felspar in this rock appears to be distinctly more sodic than that of the type Tormore rock; Cnoc Motˉ, Glen Ashdale (S24872) [NS 026 256]; Cnoc an Fheidh, Allt Dhepin (S6392) [NS 010 240]; Allt an t-Sluic, Kilpatrick (S6380), (S25081) [NR 930 270]; Allt na Craoibhe, Kilpatrick (S25082) [NR 915 273]; Tormore (S3326) [NR 880 320], (S5656) [NR 890 320], (S5657) [NR 890 320] — many felspar microphenocrysts but very poor in ferro-magnesian minerals, as is also Judd's No. I. Dyke (S26520) [NT 0711 9712] and No. III. dyke, Tormore shore (S25624) [NR 880 320].

Glen Cloy Type —This type is somewhat more basic than the pitchstones described above. The glassy base is darker, more opaque, and has a higher refractive index than that of either the Corrygills or Tormore types (n =1.503 ± .002 in

24391, Glen Cloy).

In devitrification there is a tendency to develop spherulitic or variolitic structures, showing felspathic fibres with irregular interstitial quartz (S24390) [NS 004 352], or a meshwork of skeletal fibres or needles of craignuritic type, in which needles of chloritized pyroxene (?) play a prominent part (S25060) [NS 010 330], (S7539) [NS 000 350].

The Survey collection has examples of these rocks from four localities: Glen Dubh, a dyke 24 feet wide 100 yards above the confluence of Glen Dubh Water with the Glen Ormidale Water (S7540) [NR 996 346], (S24389) [NR 995 345], (S24453) [NR 994 346] — the last is the analysed rock); Glen Cloy Water, one mile west of Invercloy, Brodick (S24390) [NS 004 352], (S24391) [NS 004 352], (S24392) [NS 6030 3349], (S24393) [NS 5891 3879], (S24394) [NM 4361 6668], a sill which has been fully described by Dr. A. Scott<ref>*Trans. Geol. Soc. Glasgow*, vol.xv., part ii., 1915, pp. 140–147.</ref> Kilmichael Wood, Glen Cloy (S7539) [NS 000 350]; and from a 5-foot sill in the main western headwater of the Lag a' Bheith (S25060) [NS 010 330] (S25061) [NS 010 330] *see* p. 137).

The phenocrysts present are quartz, felspars, more or less altered Ferro-magnesian minerals, and magnetite. Quartz does not occur in the more glassy parts of the Glen Cloy (24391), or the Lag a' Bheith sill (S25061) [NS 010 330], but it is abundant in the Glen Dubh dyke both as perfectly euhedral crystals, and as irregular, embayed, and corroded forms. The felspar in the Glen Cloy sill (S24391) [NS 004 352] is a clear, euhedral, acid andesine of the same characters as in the other types of pitchstone; but in the Glen Dubh dyke (S24389) [NR 995 345] and the Lag a' Bheith sill (S25061) [NS 010 330] it is either untwinned or simply-twinned, and but rarely shows any trace of albite striations. The mean refractive index of this felspar in (S25061) [NS 010 330] is about 1.535, hence it must be regarded as oligoclase.

A green aegirine-augite is identifiable in the Glen Cloy pitchstone (S24391) [NS 004 352], the crystals being frequently broken up into granular aggregates. In all the other rocks the ferro-magnesian minerals have been thoroughly chloritized.

In most of these rocks the phenocrysts are grouped in the usual glomeroporphyritic aggregates. The Glen Dubh dyke (S7540) [NR 996 346], (S24453) [NR 994 346] occasionally shows little angular xenoliths of a variolitic tholeiite, as though the magma had disrupted a tholeiite dyke in its upward passage. This rock has been described by Dr. A. Harker (p. 229).

Many of the felsites which are closely associated with the pitch-stones in the field have microstructures that clearly show they are due to the devitrification of the pitchstones (p. 227). The grouping of the phenocrysts is the same as in the pitchstones; occasionally microlites and crystallites are still discernible; while in the Cir Mhòr felsite (S25618) [NR 973 432] the hyalite investments around the phenocrysts have been retained. In another specimen of the same rock, however, these traces are almost entirely lost, and the micro-texture resembles that of many Arran felsites which are not obviously connected with pitchstones (S25072) [NR 970 430]. Felsites in the Survey collection which are associated with pitchstone are: Torr an Loisgte (S24871) [NS 039 246], and Judd's No. II. dyke, Tormore shore (S25623) [NR 880 320], in addition to the Cir Mhòr slices mentioned above. Another felsite which appears to be a devitrified pitchstone is a dyke from the tributary to the Allt Dhepin east of Cnoc an Fheidh (S24875) [NS 020 251].

Three other felsite occurrences which deserve mention (apart from those discussed in Dr. A. Harker's account, p. 227) are the Glen Shurig dyke (S24370) [NR 982 370], the sill at Corrygills Point (S25042) [NS 039 350], and the little plug of the Cheese Hole, Dippin (S6363) [NS 049 219]. The Glen Shurig dyke is a remarkably compact, chalk-like felsite in hand-specimens. In thin section it shows a uniform, cryptocrystalline, 'felsitic' material, in which only quartz and an occasional shred of chloritic matter can be identified. The Corrygills rock shows a few microphenocrysts of quartz embedded in a groundmass made up largely of a fine micrographic intergrowth of quartz and turbid alkali-felspar. The Cheese Hole plug in thin section discloses a dense, turbid, cryptocrystalline groundmass, in which only a few shreds of quartz can be identified. In this matrix are embedded little, square, rectangular, or rhomboidal crystals of orthoclase.

Chemical composition

The analyses of three typical Arran pitchstones, those of Corrygills, Glen Shurig, and Tormore, together with an analysis of the Glen Dubh felsite which is believed to be a devitrified pitchstone, are tabulated for comparison below.

(Table 7)

	14.	R.	15.	16.	S.	6.	17.
SiO_2	73.20	73.12	72.33	71.51	71.53	69.26	72.37
Al_2O_3	10.75	12.44	10.45	10.55	12.00	11.60	11.64
Fe_2O_3	0.95	2.09	1.00	0.79	2.90	1.31	1.42
FeO	1.02	1.65	2.14	2.22	2.02	2.57	1.08
MgO	0.15	0.14	0.11	0.52	0.62	1.10	0.52
CaO	0.76	0.88	1.44	1.52	2.33	2.61	1.30
Na_2O	3.78	3.90	4.09	4.12	4.27	2.08	4.15
K_2O	4.20	4.67	3.49	3.48	3.06	3.88	3.98
$H_2O>105°$	4.52	0.24	4.02	407	0.36	1.67	Ign. 4.86
$H_2O<105°$	0.18	0.25	0.16	0.19	0.13	1.61	
TiO_2	0.16	0.39	0.30	0.33	0.64	0.45	—
P_2O_6	0.19	0.09	0.16	0.24	0.17	0.10	—
MnO	0.37	0.17	0.50	0.42	0.36	0.45	—
nt. fd.	nt. fd.	.05	—	—	nt. fd.	1.76	—
FeS_2	—	nt. fd.	—	—	—	nt. fd.	—
(Ni, Co)O	nt. fd.	nt. fd.	nt. fd.	nt. fd.	0.02	nt. fd.	—
BaO	0.05	nt. fd.	0.08	0.08	0.08	nt. fd.	—
Li_2O	nt. fd.	nt. fd.	tr.	nt. fd.	? tr.	nt. fd.	—
Cr_2O_3	—	—	—	—	nt. fd.	—	—
	—	—	—	—	nt. fd.	—	—
	—	—	—	—	nt. fd.	—	—
	100.28	100.08	100.27	100.04	100.49	100.45	201.32

14. ((S25614) [NS 043 339]. Lab. No. 850.) Pitchstone (Corrygills type), sill, lower pitch-stone scarp above path near South Corrygills, quarter of a mile W.N.W. of Dun Fionn, Arran. *Anal.* E. G. Radley.

R. ((S14843) [NM 5497 3843]. Lab. No. 372.) Granophyre of Beinn a' Ghraig ring dyke, Benmore Lodge, western end of Loch Ba, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir,* 1924, p. 20.

15. ((S25615) [NR 995 366]. Lab. No. 851.) Olivine-bearing pitchstone (Glen Shurig type), dyke, farm road 65 yards from String Road, half a mile south-west of Brodick Church, Arran. *Anal.* E. G. Radley.

16. ((S25621) [NR 880 320]. Lab. No. 852.) Pitchstone with ortho- and clino-pyroxenes, and olivine, Judd's No. II. dyke (see map, p. 219), Tormore shore, south of Machrie Bay, Arran. *Anal.* E. G. Radley.

S. (S11734) [NM 376 941]. Porphyritic quartz-felsite, intrusive sheet, Ashval, Rum. *Anal. W.* Pollard. Quoted from A. Harker, The Geology of the Small Isles of Inverness-shire, (Explanation of Sheet 60), *Mem. Geol. Surv. Scotland,* 19 (218, p. 139.

6. ((S24453) [NR 994 346]. Lab. No. 823.) Felsite (devitrified pitchstone), 24-foot dyke in Glen Dubh Water, 100 yards above confluence with Glen Ormidale Water, and 825 yards W. 37° S. of Kilmichael, Brodick, Arran. *Anal.* E. G. Radley.

17. Porphyritic pitchstone, centre of Cir Mhòr dyke. *Anal.* E. C. Thomson. Quoted from J. W. Judd. On Composite Dykes in Arran, *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, p. 545.

The chemical differences between the Corrygills, Tormore, and Glen Shurig pitchstones are relatively slight. The Corrygills pitchstone is the most siliceous, and in it soda is subordinate to potash. The Glen Shurig and Tormore pitchstones are almost identical, although the former is slightly the more siliceous of the two, as is well shown by the comparison of certain items of the norms in the table below. In these rocks the relation between soda and potash is the opposite of that in the Corrygills pitchstone. The greater abundance of ferro-magnesian minerals in the Glen Shurig and Tormore pitchstones, as compared with the Corrygills type, is reflected in their greater amount of FeO and MgO. Another notable chemical feature of the pitchstones is that over 4 per cent. of water is retained in these glasses, an effect certainly due to their excessively rapid solidification.

	% Salic minerals	Q.	or.	ab.	an.
Pitchstone, Corrygills	90.4	33.4	23.0	32.0	—
Pitchstone, Glen Shurig	87.2	32.1	20.6	34.6	—
Pitchstone, Tormore	85.9	30.5	20.6	34.6	0.3
Pitchstone, Cir Mhòr	90.1	30.3	23.3	35.1	1.4
Pitchstone, Glen Dubh	83.6	38.5	22.8	17.8	0.8

Amongst Arran rocks the Corrygills pitchstone compares best with the granophyre of the Central Ring Complex ((Table 5), 9, p. 192), although this rock is richer in silica; and with the Bennan quartz-porphyry ((Table 6)., II, p. 204), although the latter rock is more potassic. The Glen Shurig and Tormore pitchstones resemble the Goatfell granite (Table 3), 7, p. 155), although the latter is at once more siliceous and more potassic than the pitchstones. They have also a fairly close resemblance to the felsites of the craignurite series.

The Glen Dubh felsite or devitrified pitchstone is the most 'basic' of the series, as is shown by its lower silica and alkalies, with higher ferrous oxide, magnesia, and lime, as compared with the other pitchstones. Its affinities are clearly with the rocks at the 'acid' end of the craignurite series, as is shown by the analyses tabulated for comparison with it in (Table 2), p. 147. Relatively to soda these rocks are more potassic than the pitchstones, and in spite of lower silica they are richer in normative quartz.

With regard to rocks of the Cainozoic igneous province of the Western Isles outside Arran, the Corrygills pitchstone compares well with the granophyre of the Beinn a' Ghraig ring dyke in Mull ((Table 7)., R); and the Glen Shurig and Tormore types compare in chemical composition with a porphyritic quartz-felsite from Rum ((Table 7)., S).

Of the earlier pitchstone and felsite analyses tabulated on p. 124 of the 'Geology of North Arran, etc.' (*Mem. Geol. Surv.*), 1903, owing to incompleteness and analytical defects, only one, that of the Cir Mhòr pitchstone, is worth preserving. The summation even of this analysis is much too high for present-day standards. It is recorded in (Table 7)., 17, and should be compared with 15 and 16, the analyses of the Glen Shurig and Tormore pitchstones.

Riebeckite-Orthophyre of Holy Island (p. 222)

The fresh rock is of dark-grey colour, very compact, with minute, flashing, cleavage flakes of felspar, and in the field closely resembles some types of phonolite.

Microscopically the rock (S24461) [NS 063 292] consists of microporphyritic sanidine in a groundmass of smaller lathy crystals of the same mineral, with riebeckite, girine-augite, and iron-ores, and interspersed with a few irregular areas of quartz. The sanidine occurs in euhedral, rectangular, simply-twinned crystals evenly and numerously scattered all over the field. The groundmass consists mainly of subhedral laths of sanidine, closely packed and in places with good flow orientation. Riebeckite occurs mostly in the well-known ophitic, mossy, or sponge-like masses, but there are also a few parallel-sided prismatic crystals. The mineral is often quite fresh, showing the usual pleochroism from indigo-blue, through greenish-blue, to yellowish-green. Occasionally it is altered to an indeterminate yellow mineral. There are also numerous, green, prismatic crystals of girine-augite, with an extinction angle of between 30° and 40°. The short, stumpy, rectangular crystals of sanidine dominate the texture. As they show little approach to parallel arrangement the texture is regarded as orthophyric rather than trachytic; and this, together with the intrusive mode of occurrence, renders the term riebeckite-orthophyre more suitable than riebeckitetrachyte.

The closest geological and petrological affinities of the Holy Island rock in the Clyde region are with the riebeckite-microgranite of Ailsa Craig, 17 miles to the southward. The chemical composition of these rocks is shown in (Table 8), where an analysis of the Holy Island riebeckite-orthophyre is tabulated for comparison with two analyses of the Ailsa Craig riebeckite-microgranite, one by Raoult, in Prof. Lacroix's work on Rockall, and the other by Mr. A. G. Lowndes.

The Holy Island rock contains the largest amount of alkalies yet recorded in any analysed Arran rock. The soda is in excess of potash, as it is also in Raoult's analysis of the Ailsa Craig rock, although in Mr. Lowndes' incomplete analysis this relation is reversed. The silica is high, although the Ailsa Craig rock is even richer in this constituent, corresponding to its greater richness in modal quartz. These two riebeckite-bearing rocks may be further compared with an aegirine-granite, that of Rockall, which may be regarded as belonging to the same petrographical province ((Table 8), W.). While the alkalies and silica are closely comparable, the greater abundance of aegirine (and riebeckite in some specimens) in the Rockall type is shown by a diminution in the amount of alumina, with a corresponding increase in ferric oxide, as compared with the Scottish rocks.

(Table 8)

	18.	T.	U.	V.	W.
SiO_2	68.38	71.56	69.40	63.12	66.62
Al_2O_3	15.87	14.02	15.73	15.44	11.96
Fe_2O_3	1.02	1.26	3.21	1.73	4.19
FeO	1.42	1.46	—	—	3.54
MgO	0.04	0.21	0.00	0.62	0.31
CaO	1.04	0.42	0.21	1.31	1.32
Na_2O	5.70	6.46	4.75	5.81	6.20
K_2O	4.65	3.97	5.76	5.36	4.06
$H_2O > 105°$	0.56	0.43	—	0.44	0.22
$H_2O <$ to 5°	0.30	0.08	—	0.14	0.08
TiO_2	0.24	0.28	—	0.51	0.79
P_2O_3	0.26	t r.	—	0.25	0.21
MnO	0.37	—	—	0.27	0.10
CO_2	0.04	—	—	1.89	—
ZrO_2	0.06	—	—	—	0.38
$(Ce,Y)_2O_3$	—	—	—	—	0.18
FeS_2	nt. fd.	—	—	nt. fd.	—
(Ni, Co)O	0.03	—	—	nt. fd.	—
BaO	0.03	—	—	nt. fd.	—
Li_2O	nt. fd.	—	—	nt. fd.	—
	100.01	100.15	99.06	100.42	100.16

18. ((S24461) [NS 063 292]. Lab. No. 831.) Riebeckite-orthophyre, sill, Creag Liath, half a mile slightly east of north of the Lighthouse on the south-west point of Holy Island, Arran. *Anal.* E. G. Radley.

Riebeckite-microgranite, Ailsa Craig, Firth of Clyde. *Anal.* Raoult. Quoted from A. Lacroix, *Comptes Rendus,* Paris, tome 177, 1923, pp. 437–438.

Riebeckite-microgranite, Ailsa Craig, Firth of Clyde. *Anal.* A. G. Lowndes, *Geol. Mag.*, vol.lx., 1923, p. 268.

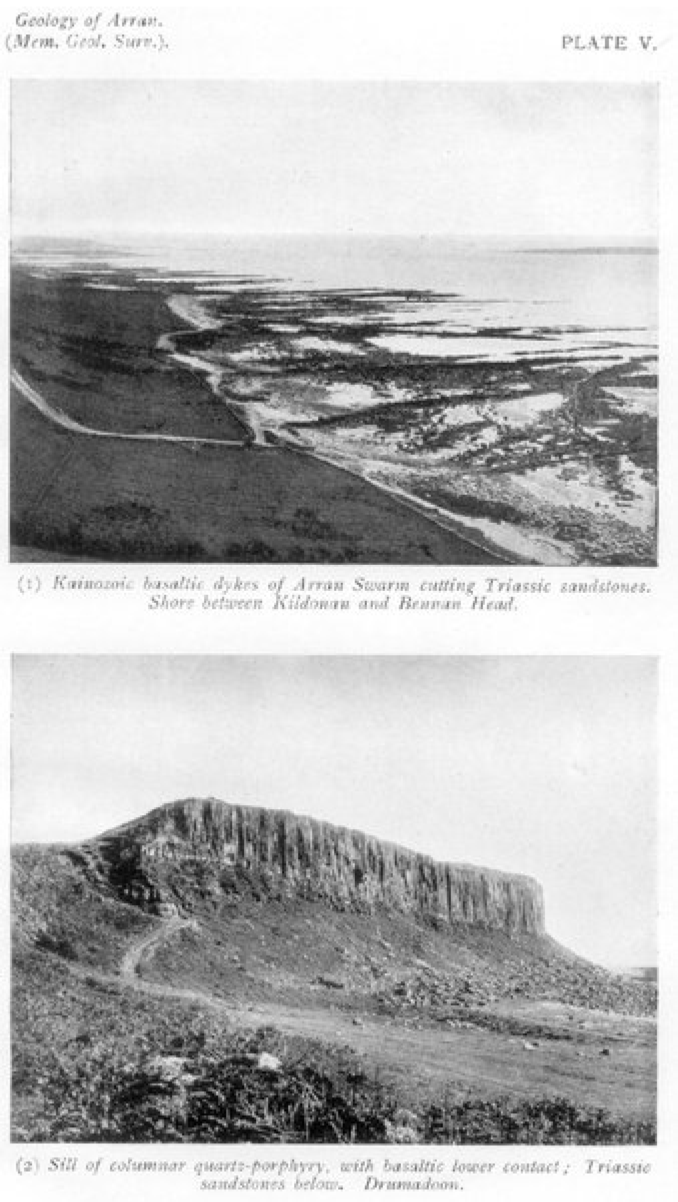
((S14821A) [NM 5429 3866]. Lab. No. 368.) Trachyte, plug in vent, Braigh a' Choir' Mhoir, west of Salen, Mull. *Anal.* E. G. Radley. Quoted from the *Mull Memoir,* 1924, p. 27.

Aegirine-granite, Rockall Bank, dredged 12 miles north of Rockall. Quoted from A. Lacroix, *Comptes Rendus,* Paris, tome 177, 1923, pp. 437–440.

The only other rock which compares at all closely with that of the Holy Island is a trachyte from Mull, a plug in a volcanic vent ((Table 8), V.), This rock also contains aegirine-augite and a soda-amphibole allied to riebeckite. It differs from the Holy Island rock in being much poorer in silica. The above-mentioned rocks are mineralogically compared in the table below, which is based on the normative values of the various constituents.

	Salic %	Q.	or.	ab.	an.	g.
Riebeckite-orthophyre, Holy Island	94.5	14.8	27.8	48.2	3.6	—
Riebeckite-microgranite, Ailsa Craig	91.5	18.4	23.3	49.8	—	4.2
Trachyte, Mull	85.4	4.5	31.7	49.2	—	—
Aegirine-granite, Rockall Bank	77.5	13.7	24.5	38.8	—	12.0

G.W.T.



(Plate 5) (1) Kainozoic basaltic dykes of Aryan Swarm cutting Triassic sandstones. Shore between Kildonan and Bennan Head. (2) Sill of columnar quartz-porphyry, wait basaltic lower contact,- Triassic sandstones below. Drumadoon.

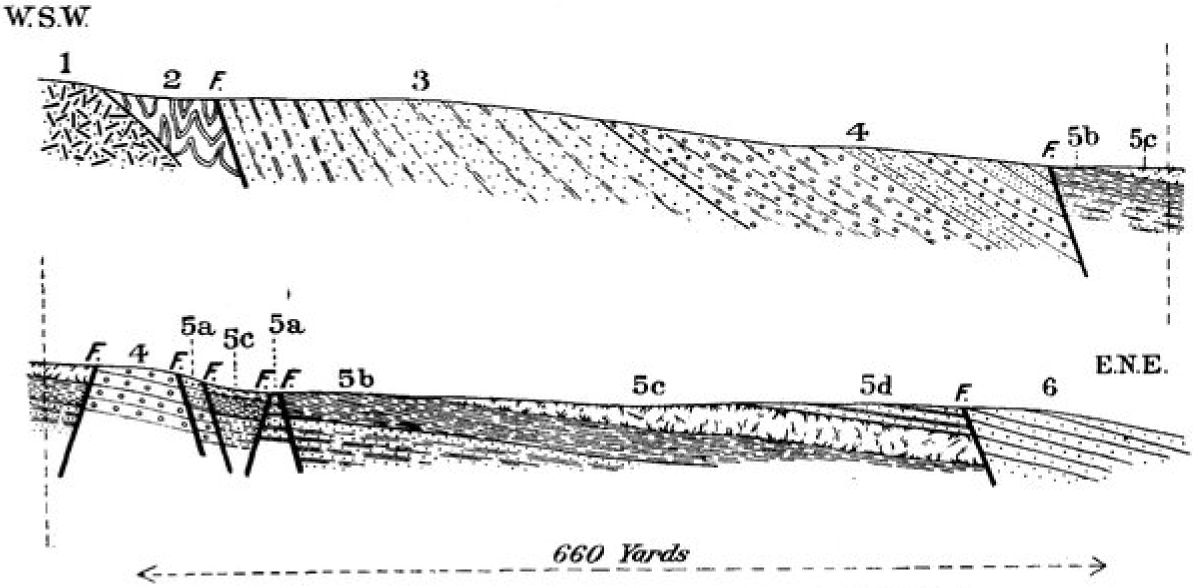


FIG. 2.—*Section along the Uisge nam Fear, half a mile south of High Corrie.*

1. *Granite*; 2. *Dalradian schists*; 3. *Lower Old Red Sandstone*; 4. *Upper Old Red Sandstone*; 5. *Calciferous Sandstone Series*; 5a. *Lower group of sandstones*; 5b. *Basaltic tuffs and red shales*; 5c. *Basalt lavas*; 5d. *Upper sandstones and marls*; 6. *New Red Sandstone (Corrie Sandstone)*; F. *Fault.*

(Figure 2) Section along the Uisge nam Fear, half a mile south of High Corrie. 1. Granite 2. Dalradian schists 3. Lower Old Red Sandstone 4. Upper Old Red Sandstone 5. Calciferous Sandstone Series 5a. Lower group of sandstones 5b. Basaltic tufts and red shales 5c. Basalt lavas 5d. Upper sandstones and marls 6. New Red Sandstone (Corrie Sandstone) F. Fault.

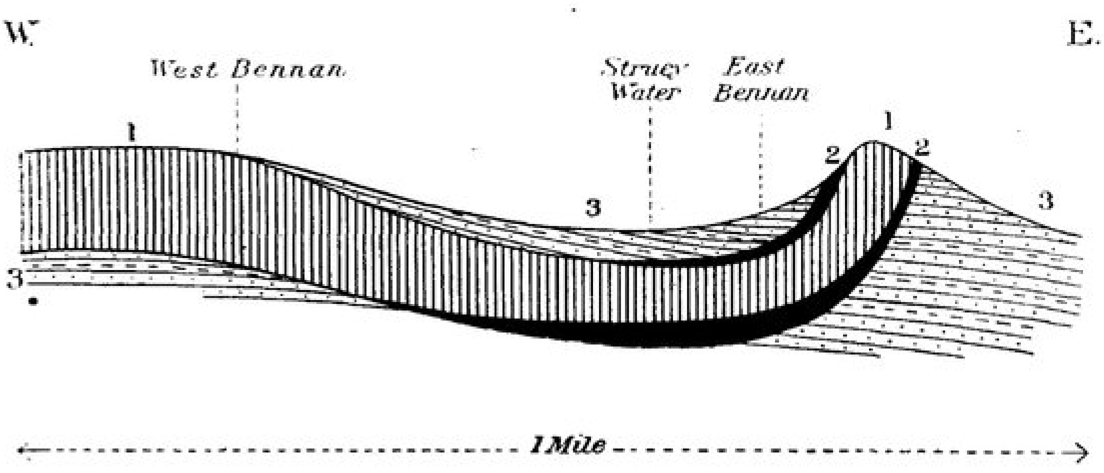


FIG. 24.—*Section across the Bennan composite sill.*

1. *Quartz-porphyry*; 2. *Basalt and dolerite*; 3. *Triassic sediments (sandstones and marls).*

(Figure 24) Section across the Bennan composite sill. 1. Quartz-porphyry 2. Basalt and dolerite 3. Triassic sediments (sandstones and marls).

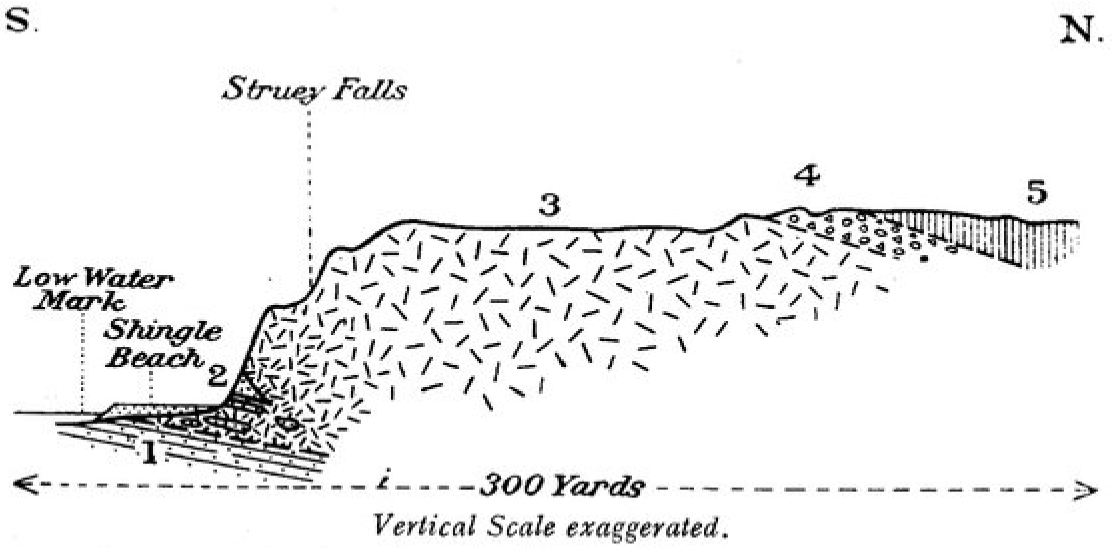


FIG. 25.—*Section along the Struey Water at Bennan Head.*

1. *Triassic sediments ;* 2. *Fine-grained basaltic contact rocks, with large enclosures of sediments, passing up into* 3. *Coarse hypersthene dolerite (increasing size of ornament denotes increasing grain-size) ;* 4. *Zone of coarse xenolithic rock with dolerite fragments in quartz-porphyry matrix ;* 5. *Quartz-porphyry.*

(Figure 25) Section along the Struey Water at Bennan Head. 1. Triassic sediments 2. Fine-grained basaltic contact rocks, with large enclosures of sediments, passing up into 3. Coarse hyper-sthene dolerite (increasing size of ornament denotes increasing grain-size) 4. Zone of coarse xenolithic rock with dolerite fragments in quartz-porphyry matrix 5. Quartz-porphyry.

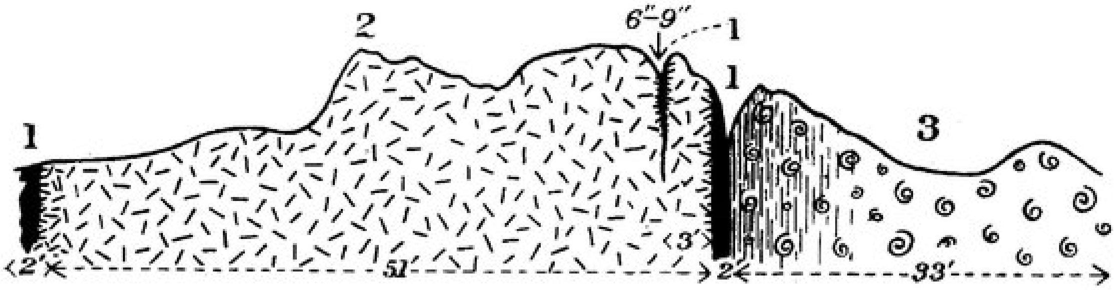


FIG. 26.—*Section across composite dyke at Cleiteadh nan Sgarbh, half a mile north of Drumadoon Point.*

1. *Basaltic margins ;* 2. *Quartz-porphyry with xenolithic contact against basalt ;* 3. *Felsite, banded and sheeted at contact with basalt.*

(Figure 26) Section across composite dyke at Cleiteadh nan Sgarbh, half a mile north of Drumadoon Point. Basaltic margins 2. Quartz-porphyry with xenolithic contact against basalt 3. Felsite, banded and sheeted at contact with basalt.

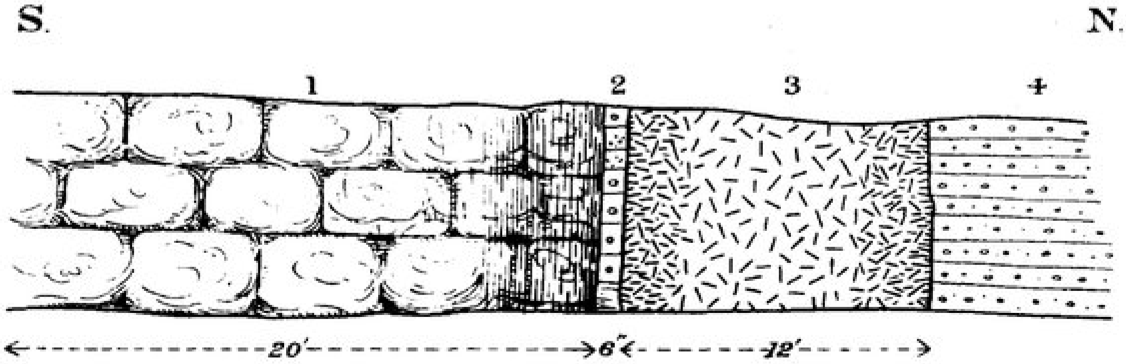


FIG. 27.—*Section across dykes on eastern slope of Sgiath Bhàn, between Glen Dubh and Glen Ormidale, Brodick.*

1. *Massive quartz-felsite becoming banded and pitchstone-like on its northern edge against* 2. *Thin strip of sandstone and conglomerate;* 3. *Basaltic dyke, chilled edges shown by size of stippling;* 4. *New Red Sandstone sediments.*

Petrography of the Quartz-Porphyries and Associated Rocks

(Figure 27) Section across dykes on eastern slope of Sgiath Bhàn, between Glen Dubh and Glen Ormidale, Brodick. 1. Massive quartz-felsite becoming banded and pitchstone-like on its northern edge against 2. Thin strip of sandstone and conglomerate 3. Basaltic dyke, chilled edges shown by size of stippling 4. New Red Sandstone sediments.

TABLE V

	9.	N.	10.	8.
SiO_2 ..	75·65	73.12	53·67	52·43
Al_2O_3 ..	11·89	12·44	15·47	13·50
Fe_2O_3 ..	1·19	2·09	3·24	4·93
FeO ..	1·02	1·65	7·25	7·00
MgO ..	·15	·14	4·90	4·61
CaO ..	·91	·88	8·28	8·25
Na_2O ..	3·44	3·90	2·77	3·27
K_2O ..	4·26	4·67	·80	1·08
$H_2O>105^\circ$	·40	·24	·23	1·64
$H_2O<105^\circ$	·41	·25	1·73	·28
TiO_2 ..	·28	·39	1·28	1·91
P_2O_5 ..	·16	·09	·21	·21
MnO ..	·26	·17	·31	·20
CO_2 ..	·09	·05	·04	·08
FeS_2 ..	nt. fd.	nt. fd.	nt. fd.	·44
(Ni,Co)O ..	·02	nt. fd.	·04	n. d.
BaO ..	·03	nt. fd.	·04	·06
Li_2O ..	nt. fd.	nt. fd.	nt. fd.	·00
Cr_2O_3 ..	—	—	—	·02
	100·16	100·08	100·26	99·91

(Table 5) [no title].

TABLE III

	7	I	J	K
SiO_2 ..	74·87	76·71	72·78	75·00
Al_2O_3 ..	11·24	—	—	13·24
Fe_2O_3 ..	·34	—	—	2·52
FeO ..	1·22	—	—	—
MgO ..	·22	—	—	—
CaO ..	1·30	·47	—	·69
Na_2O ..	3·31	—	4·08	3·07
K_2O ..	5·68	—	5·18	4·33
$H_2O > 105°$	·49	—	—	·80
$H_2O < 105°$	·29	·22	·34	—
TiO_2 ..	·26	—	—	—
P_2O_5 ..	·09	—	—	—
MnO ..	·05	—	—	—
CO_2 ..	·49	—	—	—
FeS_2 ..	·33	—	—	—
Cr_2O_3 ..	·02	—	—	—
BaO ..	·04	—	—	—
Li_2O ..	·00	—	—	—
F	nt. fd.	—	—	—
	100·24	—	—	99·65

(Table 3) [no title].

TABLE VI

	11.	O.	12.	P.	Q.	13.
SiO_2	75·22	71·98	54·83	53·97	54·11	55·79
Al_2O_3	12·22	13·13	14·10	14·65	11·65	15·97
Fe_2O_3	2·30	1·33	3·57	3·62	2·76	12·50
FeO	·22	1·64	5·87	6·32	7·02	—
MgO	·06	·56	4·88	4·49	5·30	2·22
CaO	·84	1·15	7·90	7·98	8·77	7·06
Na_2O	2·22	2·98	2·32	2·54	2·63	2·21
K_2O	4·94	4·93	1·73	1·52	1·75	1·86
$H_2O > 105°$	·52	1·38	1·23	·94	·81	} Ign.
$H_2O < 105°$	·72	·39	·48	1·92	·68	} 2·43
TiO_2	·28	·37	·74	1·24	3·37	—
P_2O_5	·18	·19	·24	·27	·58	—
MnO	·25	·14	·37	·30	·21	—
CO_2	·03	—	1·90	·51	·05	—
FeS_2	nt. fd.	—	nt. fd.	·09	·22	—
(Ni, Co)O	nt. fd.	—	·03	nt. fd.	—	—
BaO	nt. fd.	tr.	nt. fd.	·04	·03	—
Li_2O	tr.	nt. fd.	tr.	tr.	nt. fd.	—
Cr_2O_3	—	—	—	—	·03	—
Cl	—	·01	—	—	—	—
S	—	—	—	—	—	·45
	100·00	100·18	100·19	100·40	99·97	100·49

(Table 6) [no title].

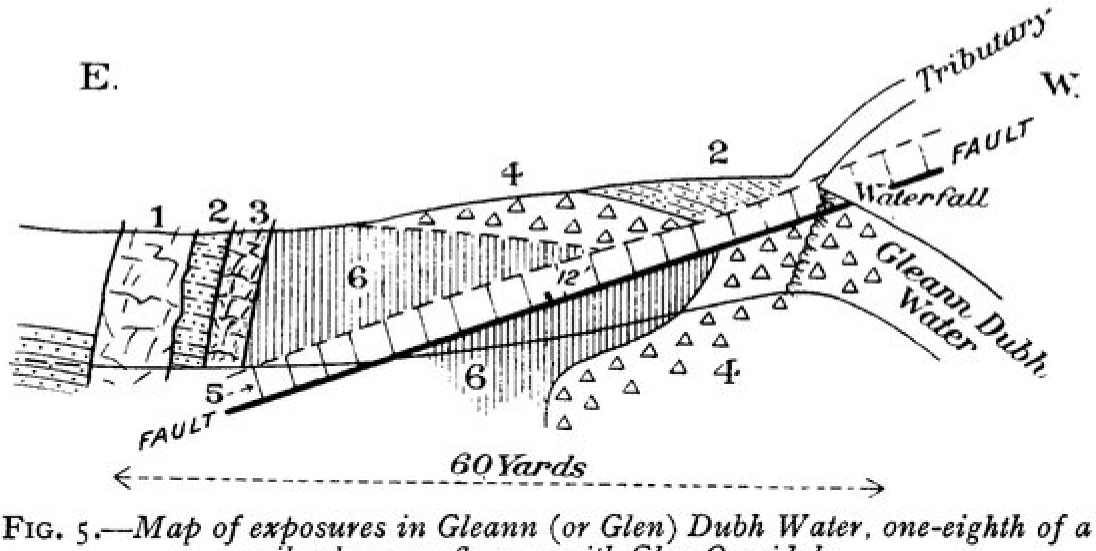


FIG. 5.—*Map of exposures in Gleann (or Glen) Dubh Water, one-eighth of a mile above confluence with Glen Ormidale.*

1. *Porphyritic basalt dyke ;* 2. *New Red Sandstone ;* 3. *Dyke of dense basalt ;* 4. *New Red Sandstone volcanic breccia ;* 5. *Crinanite dyke ;* 6. *Felsite sill.*

(Figure 5) Map of exposures in Glen Dubh Water, one-eighth of a mile above confluence with Glen Ormidale. 1. Porphyritic baslt dyke 2. New Red Sandstone 3. Dyke of dense basalt 4. New Red Sandstone volcanic breccia 5. Crinanite dyke 6. Felsite dyke.

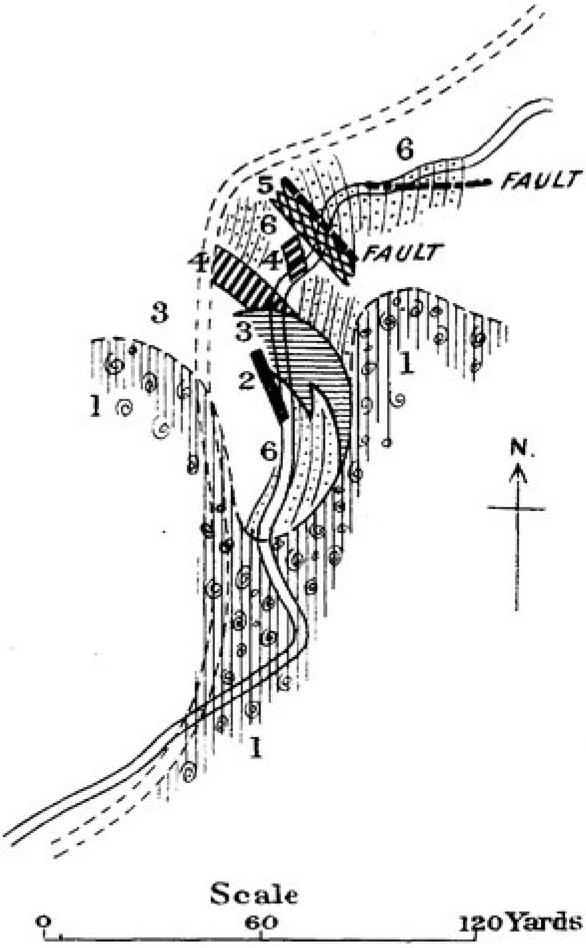


FIG. 28.—*Sketch-map of exposures in main western headwater of the Lag a' Bheith, 2 miles south-south-west of Brodick Pier.*

1. *Felsite sill ;* 2. *Basalt dyke ;* 3. *Shattery basaltic intrusion ;* 4. *Pitchstone dykes ;* 5. *Crushed basalt dyke along fault ;* 6. *Marls, cornstones, and sandstones of the Trias.*

(Figure 28) Sketch map of exposures in main western headwater of the Lag a' Bheith, 2 miles south-south-west of Brodick Pier. 1. Felsite sill 2. Basalt dyke 3. Shattery basaltic intrusion 4. Pitchstone dykes 5. Crushed basalt dyke along fault 6. Marls, cornstones, and sandstones of the Trias.

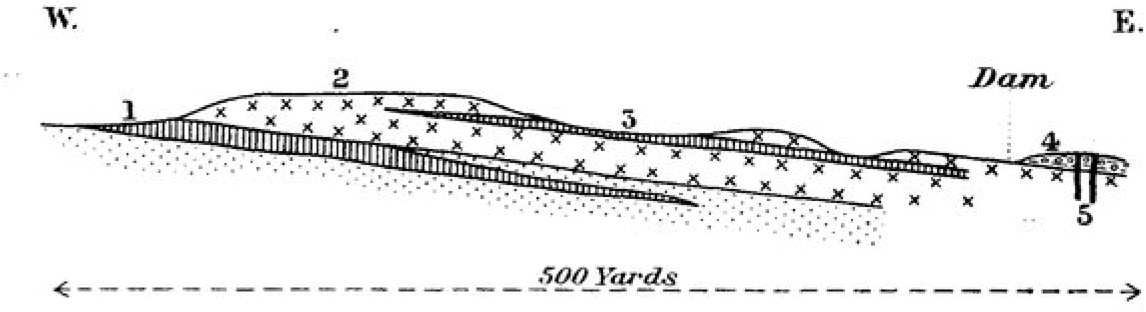


FIG. 8.—*Section along the Monamore Burn, west of Mill Dam.*

1. *Granophyre-felsite sill ;* 2. *Monamore crinanite sill ;* 3. *Felsite sill ;* 4. *New Red Sandstone conglomerate ;* 5. *Basaltic dykes.*

(Figure 8) Section along the Monamore Burn, west of Mill Dam. 1. Granophyre-felsite sill 2. Monamore crinanite sill 3. Felsite sill 4. New Red Sandstone conglomerate 5. Basaltic dykes.

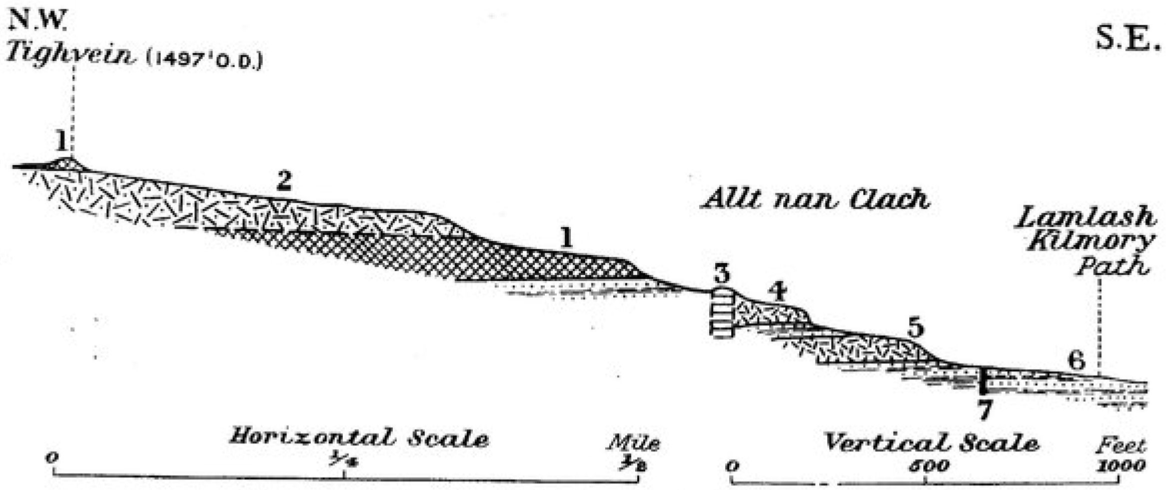


FIG. 17.—*Section from Tighvein to head of the Allt nan Clach.*

1. *Augite-diorite* ; 2. *Micro-granite* ; 3. *Pitchstone* ; 4. *Quartz-dolerite* ; 5. *Craignurite* ; 6. *Triassic sediments* ; 7. *Basaltic dyke.*

(Figure 17) Section from Tighvein to head of the Allt nan Clach. 1. Augite-diorite 2. Micro-granite 3. Pitchstone 4. Quartz-dolerite 5. Craignurite 6. Triassic sediments 7. Basaltic dyke.

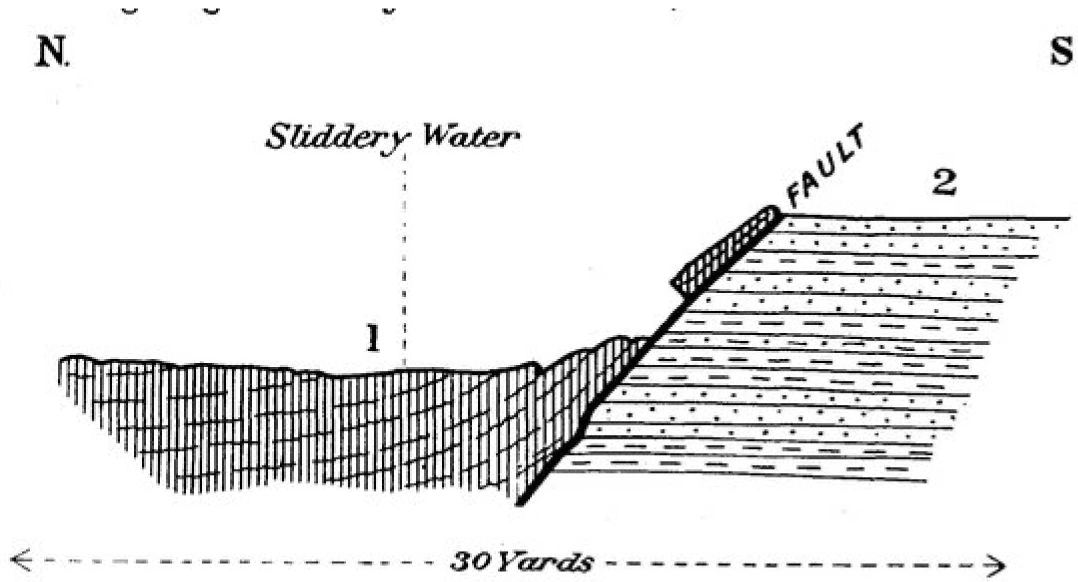


FIG. 29.—*Junction of felsite against Triassic sediments, Sliddery Water, just above Glenrie Bridge.*

1. *Felsite, with slabby jointing* ; 2. *Triassic sediments.*

(Figure 29) Junction of felsite against Triassic sediments, Sliddery Water, just above Glenrie Bridge. I. Felsite, with slabby jointing 2. Triassic sediments.

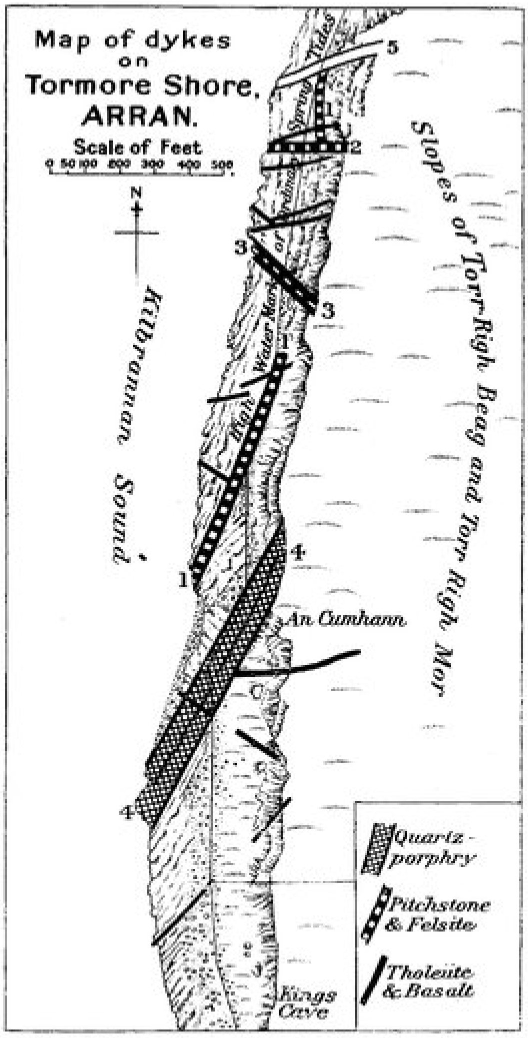


FIG. 30.—*Map of dykes on Tormore shore, based on the map by J. W. Judd (Quart. Journ. Geol. Soc.,* vol. xlix., 1893, p. 552).

1. *Tholeiite-pitchstone composite dyke (Judd's No. I. dyke), composite at south end, but only pitchstone at north end;* 2. *Tholeiite-pitchstone composite dyke (Judd's No. II. dyke);* 3. *Tholeiite-pitchstone composite dyke (Judd's No. III. dyke);* 4. *Composite dyke of quartz-porphyry and tholeiite (Judd's No. IV. dyke), described p.* 201; 5. *Trench with indurated edges; no dyke seen.*

(Figure 30) Map of dykes on Tormore shore, based on the map by J. W. Judd (Quart. Journ. Geol. Soc., vol. xlix., 1893, p. 552). 1. Tholeiite-pitchstone composite dyke (Judd's No. I. dyke), composite at south end, but only pitchstone at north end 2. Tholeiite-pitchstone composite dyke (Judd's No. II. dyke) 3. Tholeiite-pitchstone composite dyke (Judd's No. III. dyke) 4. Composite dyke of quartz-porphyry and tholeiite (Judd's No. IV. dyke), described p. 201 5. Trench with indurated edges no dyke seen.

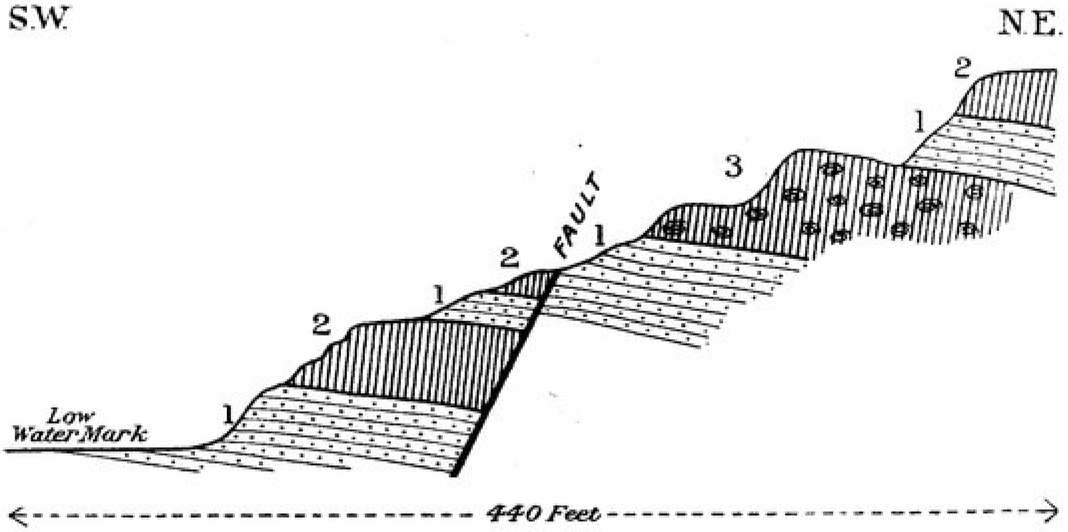


FIG. 31.—*Section across pitchstone exposures south of King's Cave, one mile north of Drumadoon.*

1. *New Red Sandstone sediments ;* 2. *Pitchstone ;* 3. *Spherulitic felsite.*

(Figure 31) Section across pitchstone exposures south of King's Cave, one mile north of Drumadoon. New Red Sandstone sediments 2. Pitchstone 3. Spherulitic felsite.

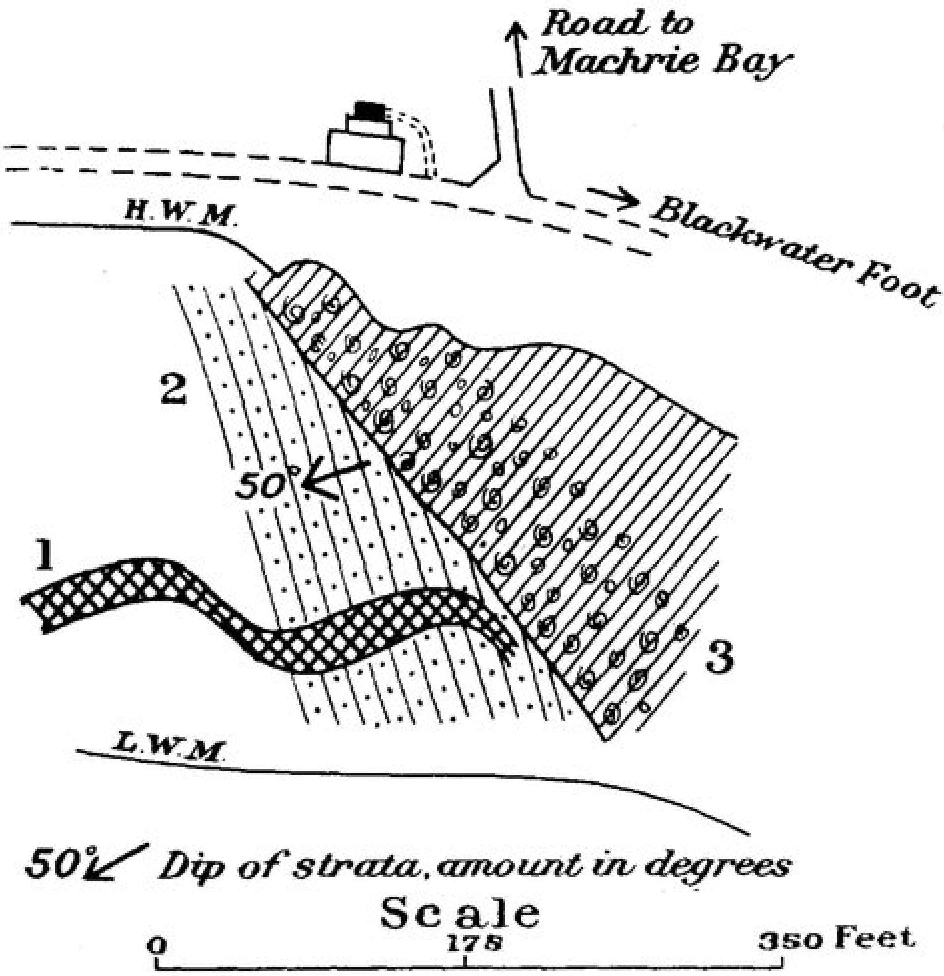


FIG. 32.—*Plan of exposures on shore, one-twelfth of a mile north-west of Blackwaterfoot.*

1. *Basalt dyke ;* 2. *Triassic sediments ;* 3. *Felsite.*

(Figure 32) Plan of exposures on shore, one-twelfth of a mile north-west of Blackwaterfoot. 1. Basalt dyke 2. Triassic sediments 3. Felsite.

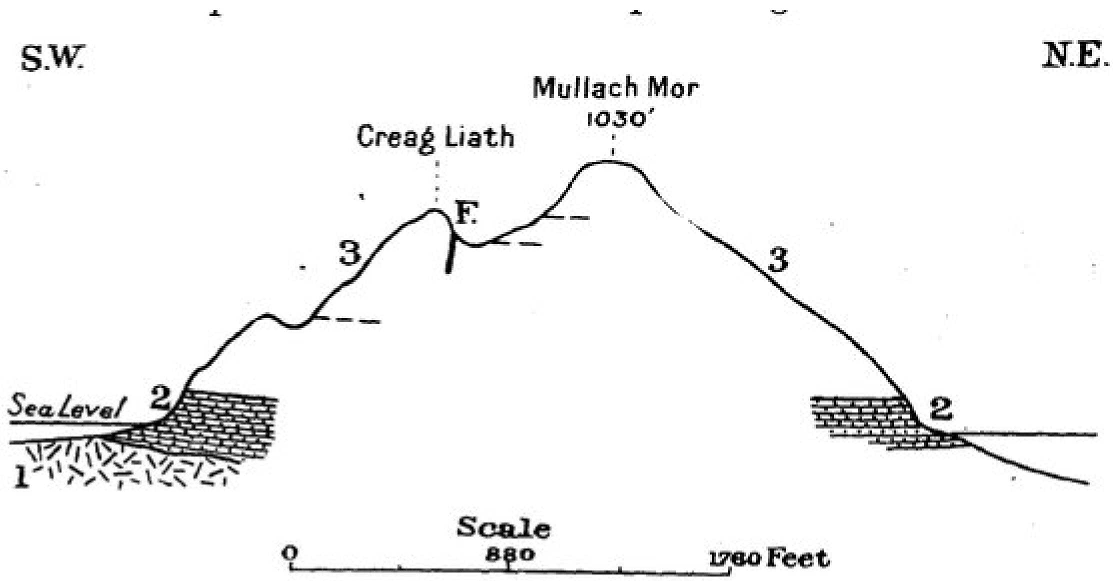


FIG. 33.—*Section across Holy Island, Lamlash Bay.*

1. *Kingscross crinanite sill;* 2. *New Red Sandstone sediments;* 3. *Riebeckite-ægirine–orthophyre sill;* F. *Zone of breccia;* ---- *Possible boundaries of supposed sheets.*

(Figure 33) Section across Holy Island, Lamlash Bay. T. Kingscross crinanite sill 2. New Red Sandstone sediments 3. Riebeckite-cegirine—orthophyre sill F. Zone of breccia ---- Possible boundaries of supposed sheets.

TABLE VII

	14.	R.	15.	16.	S.	6.	17.
SiO_2	73·20	73·12	72·33	71·51	71·53	69·26	72·37
Al_2O_3.. ..	10·75	12·44	10·45	10·55	12·00	11·60	11·64
Fe_2O_3.. ..	·95	2·09	1·00	·79	2·90	1·31	1·42
FeO	1·02	1·65	2·14	2·22	2·02	2·57	1·08
MgO	·15	·14	·11	·52	·62	1·10	·52
CaO	·76	·88	1·44	1·52	2·33	2·61	1·30
Na_2O	3·78	3·90	4·09	4·12	4·27	2·08	4·15
K_2O	4·20	4·67	3·49	3·48	3·06	3·88	3·98
$H_2O > 105°$ ..	4·52	·24	4·02	4·07	·36	1·67 }	ign.
$H_2O < 105°$ ..	·18	·25	·16	·19	·13	1·61 }	4·86
TiO_2	·16	·39	·30	·33	·64	·45	—
P_2O_5	·19	·09	·16	·24	·17	·10	—
MnO	·37	·17	·50	·42	·36	·45	—
CO_2	—	·05	—	—	nt. fd.	1·76	—
FeS_2	—	nt. fd.	—	—	—	nt. fd.	—
(Ni, Co)O ..	nt. fd.	nt. fd.	nt. fd.	nt. fd.	·02	nt. fd.	—
BaO	·05	nt. fd.	·08	·08	·08	nt. fd.	—
Li_2O	nt. fd.	nt. fd.	tr.	nt. fd.	? tr.	nt. fd.	—
Cr_2O_3.. ..	—	—	—	—	nt. fd.	—	—
S	—	—	—	—	nt. fd.	—	—
V_2O_3	—	—	—	—	nt. fd.	—	—
	100·28	100·08	100·27	100·04	100·49	100·45	101·32

(Table 7) [no title].

TABLE II

	4	E	F	5	6	G	H
SiO_2	54·00	52·16	55·82	71·58	69·26	70·70	71·30
Al_2O_3 ..	13·09	11·95	11·47	12·20	11·60	11·78	11·24
Fe_2O_3 ..	3·53	4·86	3·68	1·51	1·31	1·32	1·80
FeO	8·45	9·92	7·66	1·77	2·57	3·45	2·84
MgO	3·49	3·77	4·08	·50	1·10	·53	·61
CaO	5·55	7·14	7·88	1·98	2·61	1·30	1·56
Na_2O ..	3·27	2·36	2·53	2·83	2·08	2·48	3·44
K_2O	1·80	1·74	2·00	3·86	3·88	4·71	4·66
$H_2O > 105°$ ..	1·71	1·95	1·88	·76	1·67	1·14	1·04
$H_2O < 105°$ ..	1·26	·56	·66	1·10	1·61	·50	·39
TiO_2	2·83	3·25	1·62	·44	·45	1·27	·58
P_2O_5	·31	·24	·23	·13	·10	·26	·22
MnO	·37	·18	·40	·31	·45	·07	·31
CO_2	·25	·18	·08	1·07	1·76	·51	—
S	—	·18	—	—	—	·08	—
FeS_2	·14	—	·09	nt. fd.	nt. fd.	—	nt. fd.
(Ni, Co)O ..	nt. fd.	—	·04	nt. fd.	nt. fd.	—	nt. fd.
BaO	·02	—	·03	nt. fd.	nt. fd.	—	·07
Li_2O	tr.	—	tr.	tr.	nt. fd.	—	? tr.
	100·07	100·44	100·18	100·04	100·45	100·10	100·06

(Table 2) [no title].

TABLE VIII

	18.	T.	U.	V.	W.
SiO_2	68·38	71·56	69·40	63·12	66·62
Al_2O_3	15·87	14·02	15·73	15·44	11·96
Fe_2O_3	1·02	1·26	3·21	1·73	4·19
FeO	1·42	1·46	—	3·53	3·54
MgO	·04	·21	·00	·62	·31
CaO	1·04	·42	·21	1·31	1·32
Na_2O	5·70	6·46	4·75	5·81	6·20
K_2O	4·65	3·97	5·76	5·36	4·06
$H_2O > 105°$ ..	·56	·43	—	·44	·22
$H_2O < 105°$ ..	·30	·08	—	·14	·08
TiO_2	·24	·28	—	·51	·79
P_2O_5	·26	tr.	—	·25	·21
MnO	·37	—	—	·27	·10
CO_2	·04	—	—	1·89	—
ZrO_2	·06	—	—	—	·38
$(Ce, Y)_2O_3$ ..	—	—	—	—	·18
FeS_2	nt. fd.	—	—	nt. fd.	—
(Ni, Co)O	·03	—	—	nt. fd.	—
BaO	·03	—	—	nt. fd.	—
Li_2O	nt. fd.	—	—	nt. fd.	—
	100·01	100·15	99·06	100·42	100·16

(Table 8) [no title].