Chapter 16 The Cainozoic igneous rocks (*Continued*)The Arran Dyke Swarm

Introduction

The Arran dykes are replete with geological interest and petrological importance. Their extraordinary numbers and their variety of geological occurrence have attracted the attention of geologists from the time of Ami Boue onwards. Since in his wonderfully detailed field-maps on the six-inch scale, the late W. Gunn gave not only the exact directions, but also the thicknesses, of hundreds of dykes, statistical analysis of these data yields material for a full comparison of the Arran dykes with those of the Mull and Skye centres. The only other attempt in this direction is the elaborate tabular classification of 149 Arran dykes by L. A. Necker de Saussure,<ref>Documents sur les Dykes de Trap d'une partie de 1'Ile d'Arran, *Trans. Roy. Soc. Edinburgh*, vol.xiv., part ii., 1840, pp. 677–698.</ref> of which mention has already been made (p. 13).

A thick congregation or assemblage of dykes stretching across country in a more or less constant direction, or arranged radially about a common centre, has been called a *swarm.* The Cainozoic dyke swarms of the West of Scotland are connected with the centres of igneous activity in Skye, Rum, Mull, and Arran,<ref>*Mull Memoir,* 1924, ch. xxxiv.</ref> and have a general N.W. to S.E. trend, although dykes in other directions may be locally abundant. The Mull Swarm, beginning in Coll, has its focus in the igneous centre of south-eastern Mull, and continues with a general south-easterly trend across Lorne, Loch Awe, upper Loch Fyne, to the Clyde estuary between Cowal and the Renfrewshire–Ayrshire mainland. The country between the Mull and Arran Swarms, including the Ross of Mull, the northern part of Jura, Knapdale, and lower Loch Fyne, is relatively poor in dykes.<ref>*Ibid.,* map, p. 357.</ref> The Arran Swarm comes to the south-west of this relatively barren zone. Beginning in Colonsay, it stretches across southern Jura, Islay, Gigha, the central part of the Kintyre peninsula, and Arran, where the dykes become extremely abundant, indicating that the focus of the swarm is here reached. The general direction of the swarm across Islay, Jura, and Kintyre, is N.W. to S.E., but in Arran the trend changes gradually to N.N.W. to S.S.E. The latter direction is now maintained for the southern part of the dyke swarm, which may be traced across Ailsa Craig to the mainland coast between Girvan and Ballantrae. According to the published geological maps the Arran dyke swarm fades out a few miles to the south of this region, as no dykes of the Cainozoic direction are mapped in southern Ayrshire and Wigtownshire on the direct line of continuation of the swarm. The Arran Swarm thus suffers a decided change of direction from N.W. to N.N.W. at its focus in Arran.

Special features of the dykes will be dealt with in succeeding sections of this chapter.

Components of the Arran Dyke Swarm

While the Arran dyke swarm may be held to comprise all Cainozoic dykes of whatever direction, composition, or age, within the island, the principal component is an immense number of basaltic dykes which belong to a late stage of the igneous activity. There are undoubtedly, however, dykes belonging to each main phase of the Cainozoic igneous period. Thus some of the analcite-olivine-dolerite or crinanite dykes belong to the early period of basaltic eruption; others, of quartz-dolerite, craignurite, or felsite composition, were no doubt connected with the intrusion of the great suite of quartz-dolerite sills (Chapter 12). The intrusions of the northern granite and the Central Ring Complex were also probably attended by dyke injection; and many of the still later acid intrusions are in the form of dykes. These rocks have already been described in the preceding chapter under the headings of quartz-porphyry, felsite, and pitchstone.

The greater number of dykes in the swarm belong, however, to a very late phase of the igneous activity, and cut all other Cainozoic igneous bodies except a few acid sills, such as that of Holy Island. It is a matter of extreme difficulty to disentangle the various dyke periods, not only because of the general scarcity of critical and decisive sections, but also because of the recurrence of identical, or almost identical, rock types at different periods. The above statements are based mainly on petrographic evidence, and much more field-work will be necessary in order to substantiate them fully. The field evidence as to age relations will be given in a subsequent section.

A short sketch of the broad petrographical features and classification of the Arran dykes may be conveniently given here as a necessary preliminary to the discussion of their directional, age, and tectonic characters. The rocks correspond closely on the whole to the types described from the Mull Swarm. Firstly there is a group of olivine-basalts, olivine-dolerites, and crinanites, of plateau-basalt type,<ref>*Mull Memoir,* 1924, p. 368.</ref> containing labradorite, purplish augite, olivine, and iron-ores, with interstitial analcite and radial zeolites in the crinanite section. These rocks usually have an ophitic texture, are non-porphyritic, and rarely develop glassy matter even on the rapidly-cooled margins of dykes. In some of the coarser doleritic types devoid of analcite, the augite is of somewhat paler tint, olivine dwindles in amount, and the rocks thus approach closely to the coarser and more basic types amongst the quartz-dolerite–tholeiite group. There were probably two surges of this magma; one at the beginning of the Cainozoic igneous period, corresponding in time and petrographical character to those remnants of the plateau-basalt episode that are involved in the Central Ring Complex (p. 181); the other occurred towards the end of the igneous period, but preceded the appearance of the later injections of the quartz-dolerite–tholeiite magma. The first group generally consists of coarse-textured, analcite-bearing rocks occurring in thick dykes. The darker minerals are segregated to some extent, producing a coarse maculation on the weathered surface which renders this type easily recognizable in the field as 'spotty crinanite'. The dykes of the later group are generally thin; the rocks are rich in olivine and occasionally analcite, possess a deeply-coloured purple augite, and have a fine ophitic texture. Unlike the rocks of the quartz-dolerite — tholeiite group described later, the rocks derived from the plateau-basalt magma remain very uniform in type, and show little tendency towards differentiation.

There also occurs amongst the dykes a small sub-group of porphyritic basalts and dolerites of varying characters, but united in the abundance of large felspar phenocrysts, which may correspond to the dykes of 'porphyritic central-lava' type described from Mull.<ref>*Mull Memoir,* 1924, p. 369.</ref> Some examples, however, may perhaps be more correctly described as highly porphyritic members of the tholeiite group.

The great majority of the Arran dykes belong to an oversaturated group which, from its most abundant types, may be designated as the quartz-dolerite–tholeiite group. These rocks are characterized by their wide compositional and textural range. The minerals present are basic plagioclase (labradorite to anorthite), a pale diopsidic augite with occasionally uniaxial augite (or enstatite-augite) and orthopyroxenes, iron-ores, quartz, and alkali-felspar, with the two last-named minerals becoming abundant in the more acid varieties. Intergranular (in the quartz-dolerites, etc.), and intersertal (in the tholeiites) textures are extremely common; but ophitic texture only occurs in the coarser and more basic members of the group. A holocrystalline series with a general intergranular or occasionally an ophitic texture, and ranging from olivine-dolerite or olivine-basalt, dolerite or basalt, quartz-dolerite or quartz-basalt, to craignurite or 'porphyrite', in order of decreasing basicity, may be distinguished from a parallel series with a certain amount of glassy base and an intersertal texture, of which the members are olivine-tholeiite (Largs type),<ref>G. W. Tyrrell, Some Tertiary Dykes of the Clyde Area, *Geol. Mag.,* 1917, p. 353.</ref> olivine-tholeiite (Salen type),<ref>*Mull Memoir,* 1924, p. 370.</ref> porphyritic olivine-tholeiite (Corrie type),<ref>Tyrrell, *op. cit.,* p. 352.</ref> tholeiite (Brunton type),<ref>Mull *Memoir,* p. *372.*</ref> and tholeiite (Talaidh type),<ref>*Ibid.,* p. 284.</ref> corresponding generally to the compositional range of the holocrystalline types as given above. Unlike the olivine-dolerite–crinanite group there is a marked tendency in these rocks for the production of glassy matter; and when glass becomes a prominent constituent a third series of textural types parallel to those given above may be formulated. Some of these rocks have been given special names, and are, in order of decreasing basicity, tachylyte, leidleite,<ref>*Mull Memoir,* 1924, p. 281.</ref> cumbraite,<ref>Tyrrell, *op. cit.,* p. 306.</ref> and inninmorite.<ref>*Mull Memoir,* p. 282.</ref> A variolitic texture may occur in any of these rocks, and the variolitic and tachylytic types are often found on the margins of the tholeiite dykes.

Closely associated with the above rocks in composite dykes are certain acid types, quartz-porphyries, felsites, and pitchstones, which reveal their consanguinity with the quartz-dolerite--tholeiite group by the relative abundance of plagioclase felspar and pyroxenes. Felsites and pitchstones, not so clearly related to the quartz-doleritetholeiite group, and of thoroughly acid character, also occur, and may be the fine-grained, cryptocrystalline, and glassy dyke-representatives of the magmas which gave rise to the northern and central granites.

Some large dykes of olivine-dolerite, dolerite, quartz-dolerite, craignurite (or porphyrite '), and felsite, are believed to have been injected at the same time as the great suite of quartz-dolerite–craignurite-felsite sills (Chapter 12); but the great majority of the dykes of this group were injected during the main dyke phase towards the end of the Cainozoic igneous activity. Almost invariably, where junctions are visible, the dykes of this group cut the dykes of the olivine-dolerite-crinanite group, thus repeating the sequence that occurred towards the beginning of the igneous period (p. 112).

Direction, Distribution, and Hade of the Dykes (Figure 34) — It has been shown above (p. 238) that, on the whole, the Arran Swarm bends from a N.W to a N.N.W. direction as it passes through Arran. It follows that N.W. and N.N.W. are the most favoured directions for the dykes of the swarm, although other directions, notably north, are to be found. In order to establish the relative importance of the various dyke directions a statistical study of 525 dykes recorded on Gunn 's six-inch maps was undertaken. These dykes are exposed across the entire width of the swarm on the east and south coasts of the island between North Sannox and Brown Head. In the majority of cases Gunn had recorded the thicknesses of the dykes. In order to determine the distribution of the dykes the region studied was divided into seven two-mile-wide N.W to S.E. strips, and the numbers, directions, and thicknesses of the east and south coast dykes were tabulated for each. The outline map (Figure 34) shows the position of these strips, which are situated as follows:

Strip I. Near Brown Head, to shore half a mile west of Bennan Head. Strip II. Shore half a mile west of Bennan Head, to Port a' Bhuidh, Kildonan.

Strip III. Port a' Bhuidh, Kildonan, to Dippin Head.

Strip IV. Dippin Head, to mouth of Kingscross Burn.

Strip V. Mouth of Kingscross Burn, to Innean Beag, north side of Lamlash Bay.

Strip VI. Innean Beag, north side of Lamlash Bay, to Merkland Point.

Strip VII. Merkland Point, to Creag nam Maol, North Sannox.

Each of these strips is two miles wide in the N.E. to S.W. direction, with the exception of Strip VII., which is 2.8 miles wide.

The dykes were tabulated as W.N.W., N.W., N.N.W., N., N.N.E., N.E., E.N.E., and E.; and a dyke was reckoned as belonging to one of these categories if its true direction was within 11¼ degrees on either side of the direction in question. The following table presents the results of the statistical study. For each direction the left hand part of the column gives the number of dykes in each strip, the right hand part their aggregate thickness.

The table shows that 393 dykes, or nearly 75 per cent. of the total number, run in the N.W., N.N.W., or N. directions; and that, of these three, N.N.W. is the most favoured direction. The predominance of dykes in these directions is shown still more strikingly by the fact that 81 per cent. of the aggregate thickness of the dykes occurs in them. The diagram, (Figure 35), graphically displays the distribution of the dykes according to direction. The numbers and aggregate thicknesses of the dykes in each direction are plotted along directional lines radiating from a centre. If the points thus obtained are joined up, a characteristic figure is produced with its greatest elongation in the N.N.W. direction. The figure in thick, unbroken line represents the numbers, and that in broken line the aggregate thicknesses, of the dykes in the various directions. The shapes of the two figures are closely similar, and indicate strikingly the predominance of the N.N.W. direction, as well as the paucity of dykes in the N.E. and E.N.E directions. It is clear that the main direction of tension in the earth's crust over the Arran region during the Cainozoic igneous period was E.N.E. to W.S.W. Necker de Saussure's observations (*op. cit.*), while they indicate predominance of north and north-west dykes, nevertheless show relatively many more N.N.E. and N.E. dykes than the tabulation given above. This is probably because Necker de Saussure's observations were confined to the north-eastern and east central parts of Arran, where N., N.N.E., and N.E. dykes are relatively more abundant than in other parts of the island.

Strip No.	W.N.W.		N.W.		N.N.W.		N.		N.N.E.		N.E.		E.N.E.		E.		Total No.	Aggregate Thickness.	Average Thickness.
	No.	feet	No.	feet	No.	feet	No.	feet	No.	feet	No.	feet	No.	feet	No	feet	No.	feet	feet
I	1	100	16	64	46	483	50	750	17	170	1	3	1	3	0	0	132	1573	11.9

II	0	0	13	182	45	855	23	368	2	6	1	3	0	0	0	0	84	1414	16.9
III	5	175	25	325	23	161	11	330	1	24	0	0	0	0	0	0	65	1015	15.6
IV	17	187	37	407	5	30	0	0	2	5	0	0	0	0	8	28	69	657	9.5
V	8	40	20	180	8	120	3	18	1	3	0	0	1	23	8	40	49	424	8.7
VI	10	60	15	217	16	160	12	60	15	75	3	6	1	13	3	3	75	594	8.0
VII	4	8	3	21	14	133	8	72	6	66	6	15	6	30	4	28	51	373	7.3
Total No.	45	—	129	—	157	—	107	—	44	—	11	—	9	—	23	—	525	—	—
Aggregate Thickness	—	572	—	1396	—	1942	—	1598	—	349	—	27	—	69	—	99		60.50	—
Average Thickness	—	12.7	—	10.8	—	12.4	—	15.0	—	8.0	—	2.5	—	7.7	—	4.3	—	—	11.5

The division of the island into two-mile N.W. to S.W. strips according to the above-described scheme is somewhat arbitrary, but nevertheless brings out well the salient facts of the geographical distribution of the dykes. The table (p. 244) shows that the dykes congregate most thickly in I., the extreme south-western strip, and that the number of dykes gradually decreases towards the north-east, although there is an increase in their number in Strip VI., which includes the prolific Corrygills shore.

The same progression is shown by the aggregate thicknesses of the dykes in the successive strips. The facts are further brought out by means of the diagram, (Figure 36), where the aggregate thickness of all dykes, and the aggregate thicknesses of dykes in the four principal directions, are plotted for each strip. The directional curves illustrate the interesting fact that the maximum aggregate thickness for each direction, as shown by the position of the summit of each curve, occurs in different strips. Thus northerly dykes reach their maximum aggregate thickness in Strip I., N.N.W. dykes in Strip II., N.W. and W.N.W. dykes in Strip IV. Apparently the effect of the flexure of the Arran Swarm towards the south is first experienced — in the south-west of the island, so that the dykes in Strip I. are most sharply turned towards the N. to S. direction.

The above generalizations are based on the study of the very numerous dykes exposed along the eastern and southern shores of Arran, but it can be assumed with considerable probability, that they apply also to the equally numerous, but less well-exposed dykes of other parts of the coast and of the interior of the island. Nevertheless, there are many local variations from the general directional scheme. Attention has already been drawn to the dykes intruded into the northern granite (p. 162, and (Plate 3)). They run in three main directions, approximately N.W. to S.E., N. to S., and E. to W., basalts (tholeiites) being predominant in the N.W. to S.E. direction, and felsites in the N. to S. direction. The rectangular system of dykes orientated N.N.W. to S.S.E., and W.S.W. to E.N.E. on Sgiath Bhan, between Glen Dubh and Glen Ormidale, has also been previously noted (p. 202). Between. Drumadoon Bay and Leacan Ruadha (Tormore), and also between Machrie Post Office (Cleiteadh Buidhe) and Dougrie, there is a great predominance of dykes approximating to an E. to W. direction. We may also note the relative paucity of dykes in the ring of Dalradian schists and Old Red Sandstone around the Northern Granite, and in the Central Ring Complex, which is certainly not due to lack of exposure.

It may be suggested that some of these variations in number and direction were due to accidental circumstances arising from the form, attitude, structure, degree of hardness, homogeneity or heterogeneity, and susceptibility to regular fracture and jointing, of the rocks into which the dykes were injected, whereby the general E.N.E. to W.S.W. tension was resolved into somewhat different directions, or failed, partially or entirely, to come into operation. Thus the heterogeneity of the rocks within the Central Ring Complex, and the structure and attitudes of the rocks surrounding the Northern Granite, with the consequent relative lack of uniformly-directed fractures, may account for the paucity of dykes in these areas. On the other hand, the uniformity of the northern granite, and its susceptibility to regularly-directed jointing, may explain the relative abundance of dykes in this country-rock. A similar explanation may be given of the extraordinary abundance of dykes penetrating the New Red Sandstones in the normal direction, as shown by the wonderful sections along the south coast of Arran ((Plate 5), 1).

The majority of the dykes in the Arran Swarm fill vertical or nearly vertical fissures, but where inclinations have been observed the dykes most often hade to the N.E. or E.N.E. at an angle of 60° to 70°. An especially good example of this inclination is to be observed in the 'Mile-dyke,' the long north-west dyke which is exposed between tide-marks on the

Corrygills and Clauchlands shore. G.W.T.

Length, thickness, and aggregate bulk of dykes in the Arran swarm

The absolute lengths of the dykes can only be determined in a very few cases where they are seen to die out on the foreshore or in inland cliffs. Probably a good many of the small dykes, which are only visible in burn sections, have a very short course, at all events above ground. As regards others mapped for some distance, we can but say how far they have been traced. The large Imachar dyke can thus be said to have a course of about one mile, and the North Penrioch dyke can be traced for three-quarters of a mile. In the granite area west of Loch na Davie, a north-west running dyke has been followed over Beinn Bhreac for one and a quarter miles, and some W.N.W. dykes near Goatfell can be traced almost as far. One of the longest and most remarkable is that which forms the deep rift of Ceum na Caillich, east of Caisteal Abhail, crosses in a southerly direction the head of Glen Sannox, makes a. gorge on the north side of the Saddle by no means easy to traverse, and runs for some distance down Glen Rosa, being altogether more than z miles in length. Probably it extends much farther in both directions; a dyke which appears in the bed of the Rosa Burn for some distance about three-quarters of a mile above the Garbh Allt being a probable continuation to the south. This dyke is 24 feet wide at Ceum na Caillich, 12 to 15 feet at the rift in The Saddle, and farther south in Glen Rosa about 10 feet. W.G.

Two further examples of dykes which may be traced continuously for more than half a mile are the 'Mile-dyke ' along the Corrygills–Clauchland shore, forming a conspicuous trench on the foreshore for the greater part of its course; and a N.N.W. dyke that intersects the Dippin crinanite sill, and runs parallel to its outcrop, in the district of Largymeanoch, 1.5 miles south of Whiting Bay Pier (*see* (Figure 16)).

The dykes vary greatly in width. The range is from less than a foot to at least 100 feet, which thickness is reached by the great quartz-dolerite dyke at Imachar on the west coast. There are, however, dyke-complexes, multiple, and composite dykes, whose aggregate thickness may be as great, or even greater, than this.

Examples are the composite dyke at Cleiteadh nan Sgarbh, north of Drumadoon (p. 200, (Figure 26)); a composite dyke of felsite and basalt recorded by Gunn at Eilean Mairi, on the shore 1.5 miles west of Bennan Head, which attains a maximum width of 200 feet; and a dyke-complex occurring on the shore a quarter of a mile east of Kildonan Castle, which consists of at least six members composed of different varieties of basalt, and aggregates about 150 feet in thickness. The following are single dykes of 50 feet or more in width: a N.N.E. dyke 60 feet thick on the shore north of An Cnap, North Sannox; a north-west dyke 70 feet thick on the shore opposite the Free Church, Kildonan; a N.N.W. dyke 50 feet thick on the Auchenhew shore, half a mile west of the Free Church, Kildonan; a north dyke 60 feet thick on the shore one-third of a mile north-east of the mouth of the Struey Water, Bennan Head; a N.N.W. dyke 70 feet thick on the shore 200 yards west of the Struey Water; another N.N.W. dyke 50 feet thick 200 yards west of the above; a W.N.W. dyke 100 feet thick on the shore near Torr nan Uain, one mile west of Bennan Head; and a W.N.W. crinanite dyke 50 feet thick at Rudha Ban, three-quarters of a mile north of Pirnmill. Many other dykes have widths ranging between 20 and 50 feet.

Dykes of 20 feet or more in width almost invariably belong to the olivine-dolerite–crinanite group; and the larger ones are generally of the 'spotty crinanite' type which is believed to be of comparatively early date. The tholeiite dykes are in general thinner than the crinanites.<ref>J. W. Gregory and G. W. Tyrrell, Excursion to Arran, Proc. Geol. Assoc., vol. xxxv., 1924, p. 406.</ref>

Gunn was of the opinion that the majority of the Arran dykes were less than 10 feet wide.<ref>The Geology of North Arran, etc., (Explanation of Sheet 21), Mem. Geol. Surv., 1903, p. 100.</ref> That this was an underestimate is shown by the table (p. 244), in which the average thickness of Arran dykes, based on many hundreds of measurements, works out at 11.5 feet. The average thickness of the Mull dykes, as computed from 432 measurements, is 5.8 feet,<ref>Mull Memoir, 1924, p. 360.</ref> only half that of the Arran dykes. The average thickness of the 149 Arran dykes tabulated by Necker de Saussure (*op. cit.*) works out at 9 feet.

The table (p. 244) further shows that the north dykes are the thickest of the directional sets, and that the dykes in the directions west of north are considerably thicker than those in directions east of north. This is no doubt due to the fact that the thick crinanite and olivine-dolerite dykes tend to take north-westerly directions, whereas the thinner tholeiite dykes predominate in directions to the east of north. As regards geographical distribution the table shows that the average thickness of the dykes increases from Strip VII. to Strip II., *i.e.* from north-east to south-west across the island, but that in Strip I., the extreme south-western part, the average thickness again diminishes.

The aggregate thickness of the dykes exposed across the Arran Swarm in Arran amounts to 6050 feet, if totalled without regard to the directions of the dykes. If the general direction of tension in the earth's crust over the Arran region, of which the dykes constitute evidence, be taken as E.N.E. to W.S.W., *i.e.* perpendicular to the most common dyke-direction, 6050 feet will be an overestimate for the amount of stretching the crust has undergone in this region owing to the intrusion of the dykes. Resolving the stretching in each case into the E.N.E.-W.S.W. direction, we obtain the following figures:—

Stretching perpendicular to	feet
Stretching perpendicular to N.N.W., *i.e.* in E.N.E — W.S.W. direction	1942
Stretching perpendicular to N.W., resolved in E.N.E — W.S.W. direction	1280
Stretching perpendicular to N.	1476
Stretching perpendicular to W.N.W.	433
Stretching perpendicular to W.	37
Stretching perpendicular to N.N.E.	232
Stretching perpendicular to N.E.	10
Stretching perpendicular to E.N.E.	—
Total	5410

Thus the total stretching of the earth's crust in the E.N.E.–W.S.W. direction amounts to 5410 feet, a little over a mile. This elongation has taken place over a belt of country 14.8 miles wide. Hence over the Arran region there is one mile of elongation in the E.N.E.–W.S.W. direction for 14.4 miles of crust. The comparable figures for the Mull Swarm are 2504 feet of stretching in 12.5 miles,<ref>*District memoir,* 1924, p. 360.</ref> or one mile of elongation in about 26.4 miles of crust. Hence the intrusion of the Arran Swarm has necessitated about twice as much stretching of the crust as the Mull Swarm.

Age of the dykes

The relative ages of the dykes with respect to the other age or petrographical groups of Cainozoic igneous rocks in Arran, and the relations of the dykes amongst themselves, are perplexing problems. While it is certain that the majority of the dykes in the swarm belong to a late stage of igneous activity, yet unquestionably there were dykes associated with each of the earlier stages. A recurrence of identical types, at least once, makes the question even more difficult. The dykes of the Arran Swarm may be found cutting the crinanite sills, the quartz-dolerite–craignurite-felsite composite sills, the northern granite, the Central Ring Complex, and quartz-porphyries and associated rocks. They are, however, very rarely found intersecting the compact felsite sills or dykes. While this may be due in some cases (*e.g.* Holy Island) to the fact that some of the acidic intrusions are later than the dykes, in at least two cases (Corrygills, p. 213, and Blackwaterfoot, p. 221) it is due to a curious reluctance of the dykes to penetrate the very compact unfissured felsites and their contact rocks. Hence some, at least, of the Arran dykes are later than the late felsites.

Another fact which shows that some of the tholeiite dykes are of later date than certain members of the pitchstone-felsite group is that xenoliths of pitchstone have been found within the tholeiite dyke that cuts the Dippin crinanite at the roadside quarry near the twelfth milestone, on the main road at Dippin.<ref>G. W. Tyrrell, The Petrography of Arran, III., *Geol. Mag.*, vol. liii., 1916, pp. 193–196.</ref>

Not a single dyke unequivocally belonging to the olivine-doleritecrinanite set has been found within the northern granite. Most of the dykes intersecting the granite belong to the tholeiite group, and are of the Corrie and Brunton types. There are also many examples of a coarse, porphyritic dolerite, frequently with a little olivine (as, *e.g.,* the long north to south dyke that crosses The Saddle, Glen Rosa). These rocks are merely coarse-grained basic tholeiites, asis shown by their profusely porphyritic character, and by the presence of the zoned mechanical inclusions within the felspars that are so characteristic of the rocks of the tholeiite group, especially the olivine-bearing, porphyritic, Corrie type. Exactly similar types are represented by the basic dykes that cut the Central Ring Complex, and no definitely crinanitic dykes have been found within the boundaries of this structure.

On the other hand, as has been previously mentioned (p. 158), some dyke rocks have clearly been metamorphosed by the granite. An example which has been sliced is that of a dyke occurring in the Cnocan Burn below the Mill Dam (S7442) [NR 99 39]. The slice shows a contact between a coarse granophyric vein and an altered dolerite (described on p. 158). Despite the alteration the general aspect of the slice strongly suggests that the original rock belonged to the olivinedolerite-crinanite group. The evidence, tenuous as it is, nevertheless suggests that some dykes of the olivine-dolerite-crinanite group pre- dated the granite, whereas many dykes of the tholeiite group clearly post-dated the granite. No explanation, however, can be yet offered of the fact that none of the later crinanites (p. 240), which were closely associated with the tholeiites in the main period of intrusion of the Arran Swarm, are to be found in the granite. The centre of distribution of these dykes, as far as present information goes, seems to lie in the south, and especially in the south-east, of Arran.

The study of the Survey collection of slices of the dyke-rocks has brought to light the interesting and important fact that a dyke of porphyritic basalt (S9420) [NR 980 330], labelled: 'Dyke in Glen Cloy between Creag na h' Iolaire and Creag nam Fitheach', and thus collected within the aureole of altered rocks surrounding the Central Ring Complex, has clearly shared the propylitization, the soaking with epidote, etc., which these rocks have undergone. Otherwise it is a typical member of the group of the porphyritic basalts (p. 240). Hence some of these dykes must have pre-dated the Central Ring Complex.

As regards interrelations between the dykes themselves it has been found that in all the observed intersections, dykes of the tholeiitic group cut those of the olivine-dolerite-crinanite group, or other tholeiites. A noteworthy case occurs on the shore opposite Breadalbane House, Kildonan,<ref>Figured in *Proc. Geol. Assoc.*, vol.xxxv., part iv., 1924, p. 417.</ref> where a tholeiite dyke with a tachylytic margin intersects a coarse, decomposed olivine-dolerite of the crinanite affiliation. In this late magmatic recurrence the evidence thus clearly points to the same succession of undersaturated by oversaturated magma as was observed between the crinanite sills and the sills of the quartz-dolerite series (p. 117).

Petrography

A sketch of the broader petrographical features of the Arran dykes has already been given (p. 239). Unfortunately these rocks are only sparingly represented in the Survey collection. The crinanite type is represented by two specimens, that of a dyke forming a roadside crag above Cordon, Lamlash (S25052) [NS 020 290], and the first-described Arran crinanite from the shore near the Schoolhouse, Whiting Bay (S26383) [NS 047 267]. In thin section these rocks consist of an ophitic plexus of labradorite laths and deep-purple augite, with abundant olivine (mostly serpentinized) and ilmenite. Fresh anal-cite occupies many of the interspaces between these constituents. An analysis of the Whiting Bay rock is given and discussed later (Table 1), 3; and (Table 9)., 3.

Porphyritic basalts with phenocrysts of felspar are represented by four specimens. Two of them, at any rate, probably represent, in Arran, those dykes of 'porphyritic central-lava' type which have been described from Mull,<ref>*Mull Memoir,* 1924, p. 369.</ref> the petrographical characters of which are very similar. A dyke from Glen Dubh (S14199) [NR 890 280] shows large glomeroporphyritic aggregates of basic plagioclase (approaching bytownite in composition) with a curious micaceous alteration, in an intergranular groundmass consisting of plagioclase laths (labradorite), colourless augite, a little serpentinized olivine, and iron-ores. A somewhat similar rock, with a dense decomposed groundmass, and interspersed with epidote in veins and patches, is that of a dyke from between Creag na h' Iolaire and Creag nan Fitheach at the head of Glen Dubh (S9420) [NR 980 330], which has already been mentioned (p. 250). A different type is represented by a dyke from east of Rinn a' Chrubain, Corriecravie (S6364) [NR 920 220]. This shows sparse phenocrysts of basic plagioclase in an ophitic groundmass of plagioclase laths and purple augite, with abundant serpentinized olivine. A beautifully fresh rock of the same character, but with smaller and more abundant porphyritic felspars, comes from a dyke by the roadside a twelfth of a mile north of Birchpoint, miles south of Corrie (S25057) [NS 033 208]. The two last-named rocks may be merely coarse-grained porphyritic representatives of tholeiites of Corrie and Salen types (*see* later).

The remaining sliced dyke-rocks in the Survey collection are of tholeiitic characters (p. 240). While typical tholeiites in the restricted sense (*i.e.* non-porphyritic)</ref>*Mull Memoir,* 1924, p. 280.</ref> are abundant in Arran, other types with phenocrysts of basic labradorite, and occasionally of augite, are also abundant. With increasing coarseness of grain and the approach of holocrystallinity, the more basic types of tholeiite tend to pass into ophitic olivine-bearing dolerites which are sometimes not easily distinguishable from rocks belonging to the crinaniteolivine-dolerite group. The more acid types of tholeiite tend to pass into quartz-dolerites and craignurites indistinguishable from the more fine-grained rocks of the quartz-dolerite sills.

The most basic types of tholeiite in Arran are the olivine-rich rocks which have been distinguished as the Largs type.<ref>G. W. Tyrrell, Some Tertiary Dykes of the Clyde Area, *Geol. Mag.,* 1917, p. 353.</ref> A dyke of this character occurs in the gorge known as Creag Shan in the Allt M6r, Whiting Bay (S25077) [NS 030 260]. In thin section this rock contains numerous microphenocrysts of labradorite and fresh olivine, sometimes aggregated into glomeroporphyritic groups, in a groundmass consisting of plagioclase laths, augite plates, skeletal iron-ore, and partially devitrified brown glass. An analysis of this rock is given in (Table 9), 19, below. An extraordinary rock which probably forms an extreme member of this group occurs as a thin dyke in the schists west of Creag Rosa, Glen Rosa (S9405) [NR 980 380]. It shows very numerous, large, euhedral phenocrysts of olivine, mostly serpentinized, in a .groundmass of brown glass the only crystalline elements of which are microlites of plagioclase.

The olivine-tholeiites of Salen type common in Mull<ref>*Mull Memoir,* 1924, pp. 285, 370.</ref> are unrepresented in Arran, unless it is by a dyke in Glen Rosa at the junction of the Rosa Water with a tributary from Goatfell, half a mile south of The Saddle (S25045) [NR 980 418]. This rock is a coarse ophitic aggregate of labradorite and pale augite, with a little serpentinized olivine, and some dark, green-stained, mesostasis which, at one place, is aggregated into a fine-grained vein. A somewhat similar rock forms the basic member of Judd's No. III. composite pitchstone-basalt dyke on the Tormore shore (S25625) [NR 880 320].

Olivine-bearing tholeiites which carry phenocrysts of basic plagioclase are rather common in Arran, and have been designated as the Corrie type.<ref>Tyrrell, *op. cit., supra,* p. 352.</ref> An analysed (Table 9), 20, and figured example<ref>*Ibid.,* p.351, and *Trans. Geol. Soc. Glasgow,* vol. xiii., part iii., 1909, Plate XIX., Fig. 5.</ref> is the rock of a N.N.E. dyke on the shore a quarter of a mile north of Birchpoint, and Z miles south of Corrie Hotel (S26384) [NS 028 404]. This rock carries numerous small phenocrysts of bytownite-anorthite, often corroded into curiously irregular shapes, and enclosing glassy particles in a thick marginal zone which faithfully follows the fantastic outlines of the crystals. The groundmass consists of laths of labradorite (Ab_1An_1) intermingled with granular or short prismatic crystals of a pale augite which is the most abundant constituent. Minute grains of olivine, partially or wholly serpentinized, with euhedral magnetite crystals, are uniformly scattered over the field. The interstices are occupied by a colourless glass containing numerous black globulites; and small spherical vesicles are filled with the same material.

Another good example of the Corrie type is the east to west dyke along the gully by which the descent of The Saddle into Glen Sannox is made (S25070) [NR 979 432]. The glass-filled vesicles in this rock are surrounded by concentric felspar laths, producing an ocellar structure.

The olivine-free Brunton type of tholeiite<ref>Mull Memoir, 1924, pp. 285, 372.</ref> is unrepresented amongst the Survey collection of Arran rocks, although it occurs frequently in the Arran Swarm. But a type carrying microphenocrysts of basic plagioclase, augite, and occasionally orthopyroxenes, with a Brunton type of groundmass in which the glassy mesostasis or its devitrified equivalent is more abundant than in the typical Brunton tholeiites, is quite common in Arran, and is represented by several specimens in the Survey collection. Rocks of this type especially rich in glass have been described as the Cumbrae type of tholeiite or *cumbraite.*<ref>Tyrrell, op. cit. supra, p. 306.</ref>

The analysed rock of this type (S25622) [NR 880 320] is the basic member of Judd's No. II. pitchstone–tholeiite composite dyke on the Tormore shore (p. 220). The mesostasis is devitrified with the production of quartz, alkali-felspar, and chloritic substances, and there are a few xenocrysts of quartz with coronas of granular augite, and turbid corroded crystals of andesine which may represent material obtained from a pitchstone or quartz-porphyry magma.

The basic member of the Cir Mhòr composite dyke (S25073) [NR 970 430], (S25619) [NR 973 432] is an even more typical example of this group as it is devoid of xenocrystic material. It shows excellent examples of magma-invaded vesicles, as does also the Tormore rock. An old analysis of this rock is quoted in Table IX., 22.

The rock of the dyke which cuts the Dippin crinanite in the quarry on the roadside at the twelfth milestone near Dippin (S6362) [NS 050 227] belongs to the above-described group, but is richer in mesostasis than the Tormore or Cir Mhòr examples. It contains bytownite, augite, and enstatite, named in order of abundance, as phenocrysts. It is a comparatively coarse, devitrified member of the Cumbrae group of tholeiitic rocks, and in the field it has been found to contain xenoliths of pitchstone.<ref>G. W. Tyrrell, The Petrography of Arran, Geol. Mag., 1916, pp. 193–195.</ref>

A rock of the same mineralogical composition as the above, but in which the felspar and augite form elongated prismatic crystals in an abundant, partially devitrified groundmass, comes from Traghariabhach, a little south of the twelfth milestone at Dippin (S6880) [NS 049 229], and is an excellent example of the Talaidh type of tholeiite.<ref>Mull Memoir, 1924, pp. 284, 372.</ref>

Finally we may mention the tachylyte which is frequently found on the margins of the tholeiite dykes, and occasionally forms the whole of a thin dyke. Two good examples of tachylyte dykes, respectively 12 inches and 18 inches thick, occur in the Allt an Bhrighide, five-eighths of a mile W.N.W. of West Glenshurig, Glen Shurig. The thinner dyke has been sectioned (S24371) [NR 982 372], and shows a dark, almost opaque glass, containing a few needles and microporphvritic crystals of labradorite. In places the glass is less opaque, and then shows an obscure variolitic structure of minute felspar needles.

Another tachylyte forms a thin sill-like mass intersecting the western part of the great dyke-complex on the shore a quarter of a mile west of Kildonan Castle (S25058) [NS 04 21]. The dark glass is charged with acicular microlites of felspar and opaque globulites, and envelops numerous small crystals of labradorite and colourless augite.

Chemical composition

One analysis of a crinanite dyke, and three of tholeiitic dykes, are now available, and are set out in Table IX. below.

(Table 9)

	3.	**19.**	**19A.**	**X.**	**20.**	**Y.**	**Z.**	**21.**	**13.**
SiO_2	43.95	42.55	46.6	47.35	48.60	47.24	51.53	54.52	55.79
Al_2O_3	27.60	16.93	28.6	13.90	18.27	18.55	12.05	14.53	15.97
Fe_2O_3	1.43	3.43	3.8	5.87	3.19	6.02	2.73	2.21	12.50
FeO	11.89	6.82	7.5	8.96	7.17	4.06	20.98	6.06	—
MgO	6.95	6.05	6.7	5.97	6.29	5.24	5.21	5.61	2.22
CaO	8.54	12.64	8.5	10.65	10.15	11.72	9.68	8.08	7.06
Na_2O	3.66	2.18	2.4	2.73	1.63	2.42	3.48	3.66	2.21
K_2O	0.35	0.32	0.4	0.54	0.45	0.15	0.86	1.14	1.86
H_2O>105°	0.82	1.30	1.4	2.26	2.65	2.24	1.26	0.93	2.43
H_2O<105°	0.94	1.78	1.9	1.04	2.60	0.21	0.71	1.95	—
TiO_2	3.42	1.80	1.9	1.75	0.70	1.46	1.57	0.87	—
P_2O_5	0.11	0.11	0.1	0.24	0.09	0.26	0.22	0.21	—
MnO	0.10	0.12	0.1	0.23	0.24	0.31	0.45	0.24	—
CO_2	nt. fd	3.85	—	0.32	nil	0.19	0.08	—	—
FeS_2	—	—	—	—	—	nt. fd.	0.26	—	—
S	tr.	0.13	0.1	0.23	tr.	—	—	—	0.45
BaO	—	—	—	—	—	nt. fd.	nt. fd.	0.03	—
Li_2O	—	—	—	—	—	nt. fd.	—	nt. fd.	—
(Ni,Co) O	nt. fd	nil	—	nt. fd.	nil	0.05	nt. fd.	nt. fd.	—
	99.76	100.00	100.00	100.94	100.03	100.12	100.07	100.04	100.49

3. (S26383) [NS 047 267] Unnanite, dyke on shore near Schoolhouse, Whiting Bay, Arran. *Anal. W.* H. Herdsman. Quoted from *Trans. Geol. Soc. Glasgow*, vol. xviii., part ii. (in the press).

19. Olivine-tholeiite (Largs type), dyke, Creag Bhàn, Allt Mòr, Whiting Bay, Arran. *Anal.* W. H. Herdsman. Quoted from *Trans. Geol. Soc. Glasgow,* vol. xviii., part (in the press).

19A. The same, freed from $CaCO_3$, and recalculated to 100.

X. ((S16808) [NM 5593 4670]. Lab. No. 407.) Olivine-tholeiite (Salen type), dyke, shore, quarter of a mile S.S.E. of Kintallen, and 2½ miles N.N.W. of Salen, Mull. *Anal.* F. R. Ennos. Quoted from *Mull Memoir,* 2924, p. 17.

20. (S26384) [NS 028 404] Olivine-tholeiite (Corrie type), dyke, shore, quarter of a mile north of Birchpoint, 1¾ miles south of Corrie Hotel. *Anal.* W. H. Herdsman. Quoted from *Trans. Geol. Soc. Glasgow*, vol.xviii., part ii. (in the press).

(S18469) [NM 5640 2847], Lab. No. 445. Basalt lava, porphyritic central type, half a mile S.S.W. of Derrynaculen, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir,* 1924, p. 24.

(S168) [NX 47 35] to. Lab. No. 406. Tholeiite (Brunton type), dyke, shore, quarter of a mile east of Arla, 51 miles south-east of Tobermory, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir,* 1924, p. 17.

21. (S25622) [NR 880 320]. Lab. No. 853. Tholeiite (cf. Brunton type), basic member of composite pitchstone-tholeiite dyke, Judd's No. 11. dyke (Fig. 30, p. 219), Tormore shore, Arran. *Anal.* E. G. Radley.

13. Tholeiite (cf. Brunton type), basic member of composite pitchstone-tholeiite dyke, Cir Mhòr, Arran. *Anal.* J. A. Schofield. Quoted from J. W. Judd, Composite Dykes of Arran, *Quart. Joun. Geol. Soc.,* vol. 49, 1893, p. 545. Repeated from (Table 6).

The analysis of the crinanite dyke from Whiting Bay has already been commented on (p. 122), and its close resemblance to that of the Dippin crinanite noted. It is remarkable for high alkalies, especially soda, in association with relatively low silica. The total (FeMg)O is very high, indicating abundance of olivine, and the analysis shows the highest amount of TiO_2 (3.42 per cent.) so far recorded in an Arran rock.

The specimen of olivine-tholeiite (Largs type) from Creag Bhan, Whiting Bay, which was selected for analysis, unfortunately contained a large amount of calcite in vesicles. When, however, the $CaCO_3$ content of the analysis is deducted, and the remaining figures recalculated to roo, the result (Table 9), 19A exhibits the close relationship of this type to the olivine-tholeiite of Salen type from Mull (Table 9), X, and also to the other type of olivinetholeiite from Corrie (Table 9), 20. The Arran rocks differ chiefly from the Mull type in containing a larger amount of Al_2O_3, indicating a higher proportion of felspar. While all of these three types of tholeiitic rocks contain modal olivine, they can, on calculation of the norms, be shown to possess a slight excess of silica, and are therefore magmatically over-saturated. The affinities of the olivine-tholeiites, especially the Largs and Salen types, are with the Staffa types amongst the basalt lavas of the Western Isles, and with the non-porphyritic central-basalt magma-type of Mull in general, as is shown by the close similarity of their analyses.<ref>*Mull Memoir,* 1924, p. 17. See also remark concerning the tholeiitic characters of the Staffa basalt type (p. 146).</ref> On the other hand, the Corrie type (Table 9), 20 shows a certain likeness to the porphyritic central-magma type of Mull, and an analysis of a lava of this type is given for comparison (Table 9), Y.

The remaining analysis, that of the tholeiite from the Tormore shore (Table 9), 21, is distinctly more acid than any of the foregoing. Notwithstanding its somewhat higher silica, which may be partly due to the presence of xenocrysts of quartz, its closest affinities amongst true tholeiites, are with the Brunton type of Mull, an analysis of which is given for comparison (Table 9), Z, and with the Talaidh type, also of Mull.<ref>*Mull Memoir,* 1924, p. 17.</ref>

Defective and incomplete as it is, the analysis of the tholeiite member of the pitchstone-tholeiite composite dyke of Cir Mhòr (Table 9), 13, given by Judd, nevertheless betrays its likeness to the Tormore rock. Another Arran rock of comparable composition is the hypersthene-dolerite of Bennan Head (Table 6), 12. This rock bears the same field-relation to quartz-porphyry (p. 196) as do the Tormore and Cir Mhòr tholeiites to pitchstone. The analysis of the quartz-dolerite of the Allt Dhepin is again not markedly different from that of the Tormore rock (Table 2), 4. G.W.T.

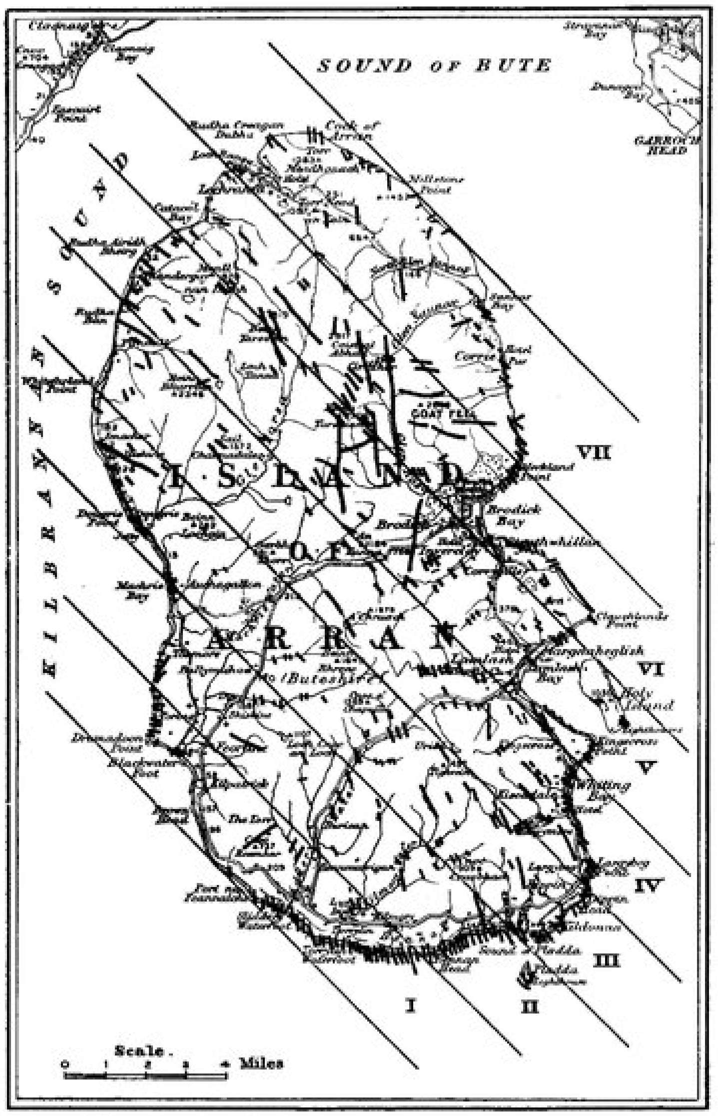


FIG. 34.—*Map showing distribution of the Arran Dyke Swarm, and the subdivision of the island into N.W.–S.E. strips* (see *p.* 241).

(Figure 34) Map showing distribution of the Aryan Dyke Swarm, and the subdivision of the island into N.W.—S.E. strips (see p. 241).

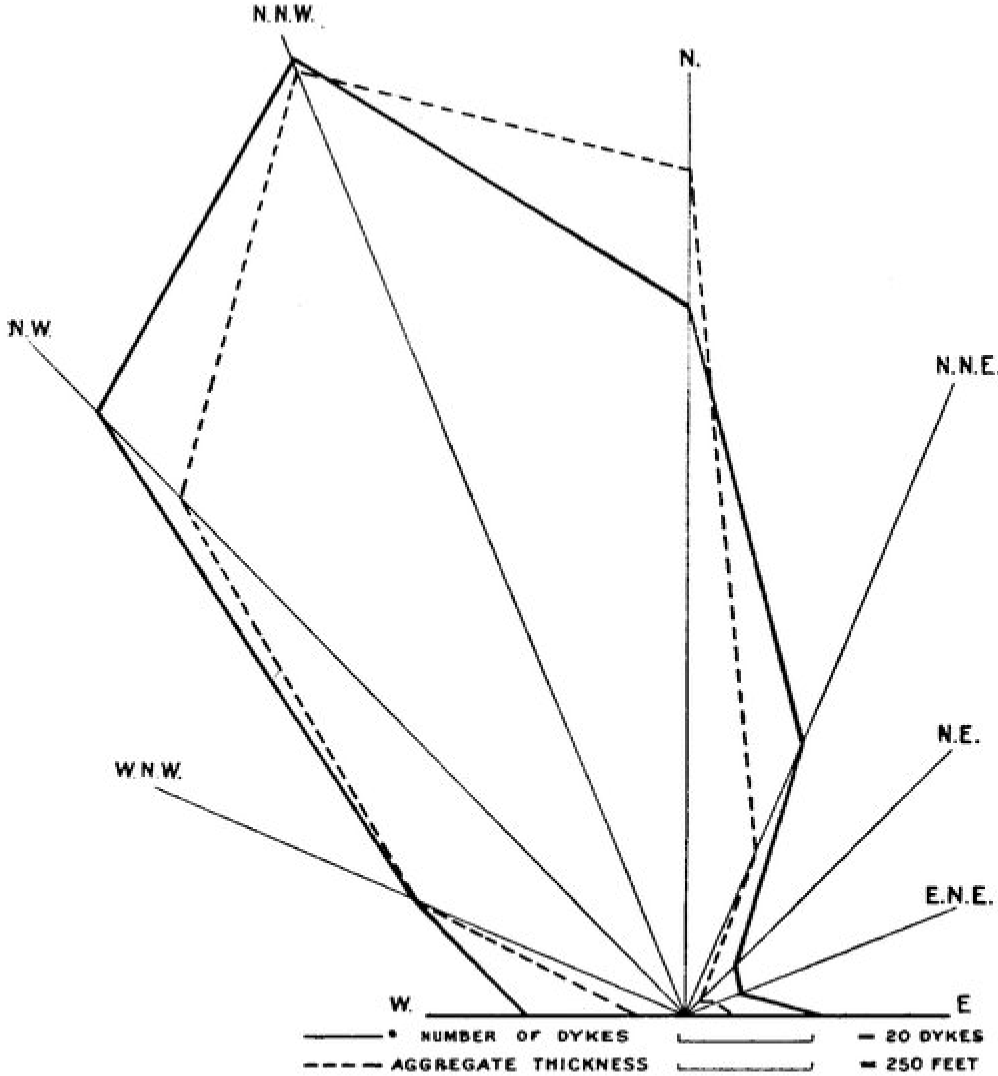


FIG. 35.—*Diagram illustrating relations between direction, number, and aggregate thickness of dykes in the Arran Swarm.*

(Figure 35) Diagram illustrating relations between direction, number, and aggregate thickness of dykes in the Arran Swarm.

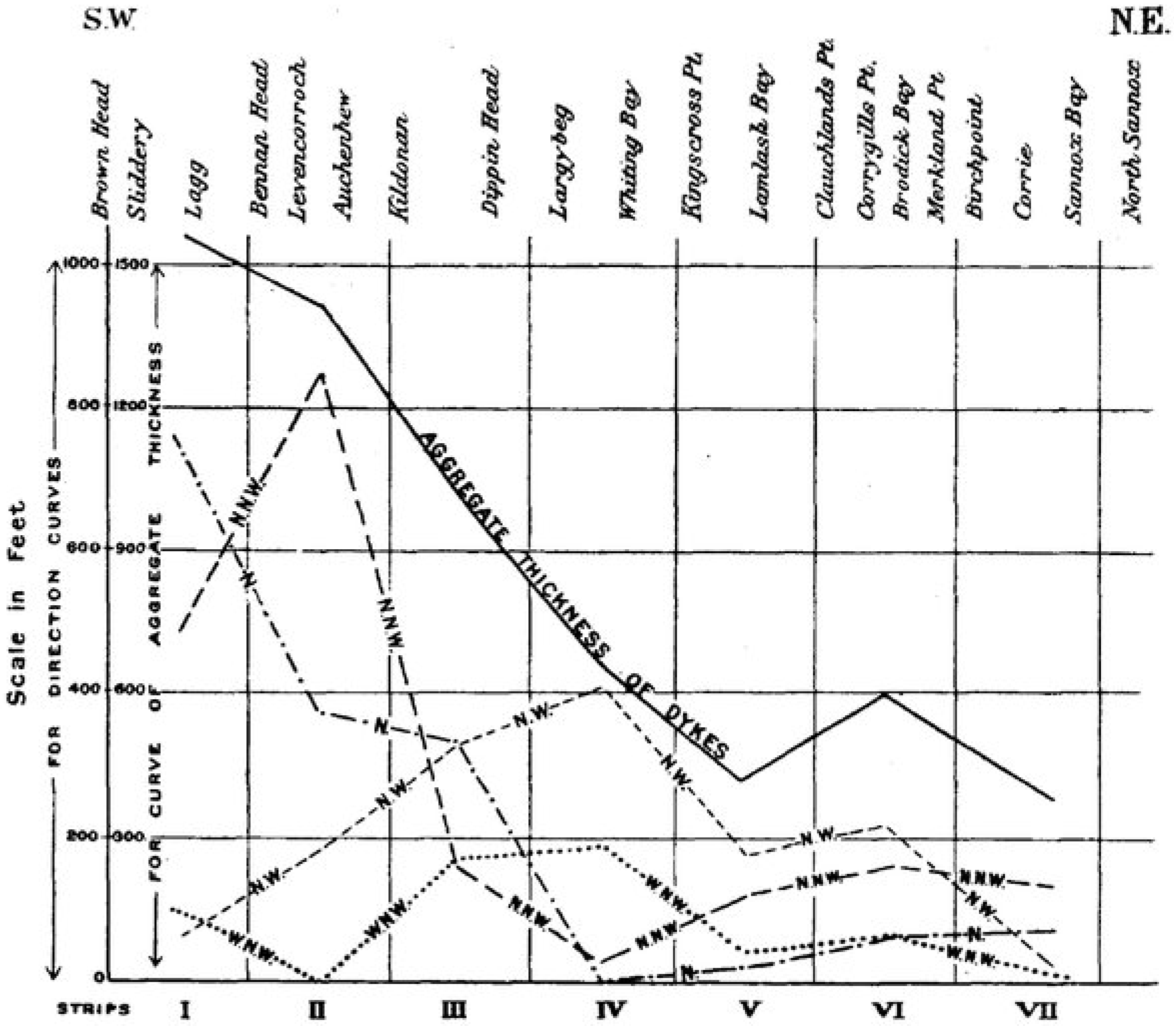
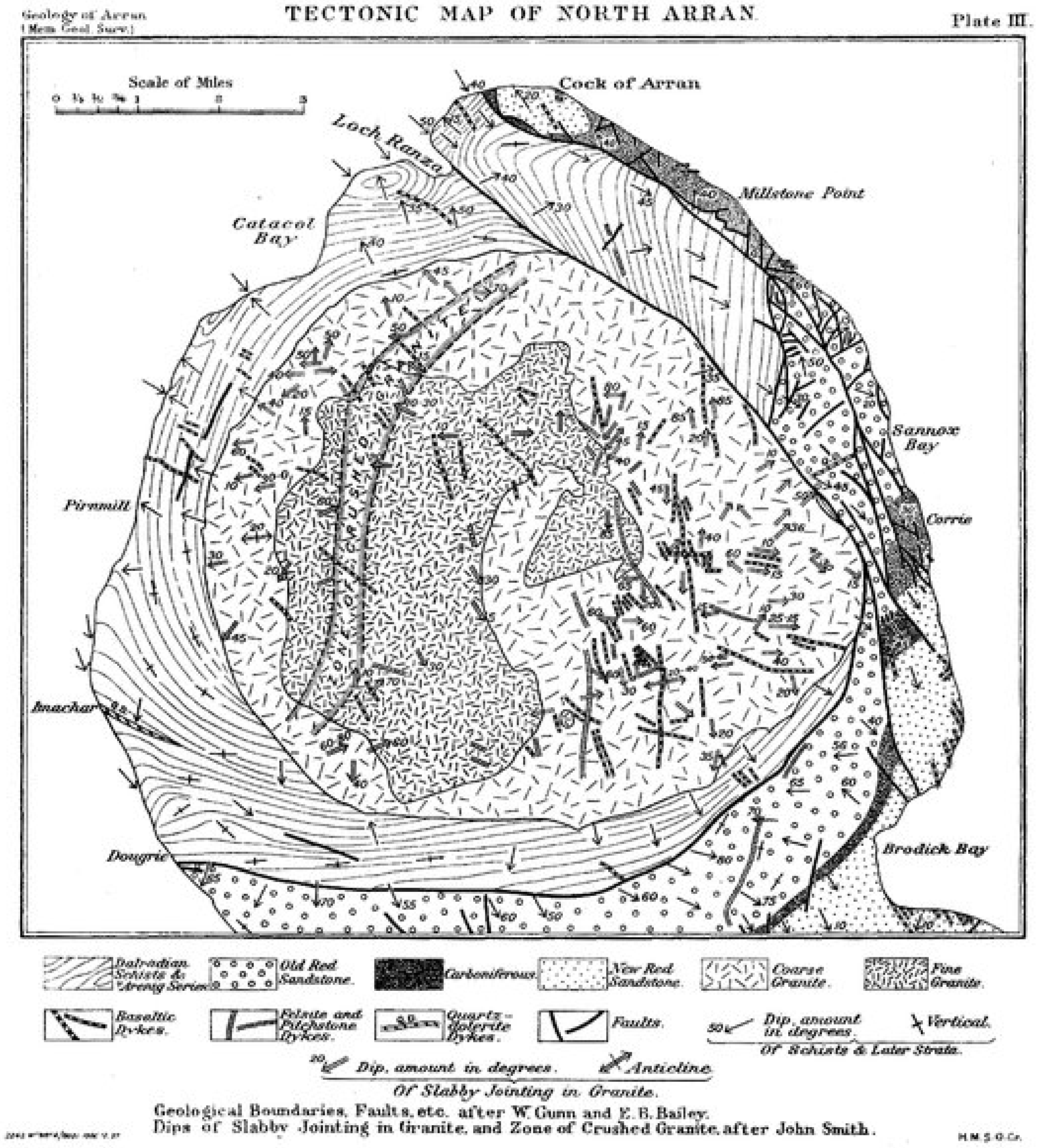


FIG. 36.—*Curves illustrating geographical distribution of dykes in the Arran Swarm (p. 245).*

(Figure 36) Curves illustrating geographical distribution of dykes in the Arran Swarm (p. 245).

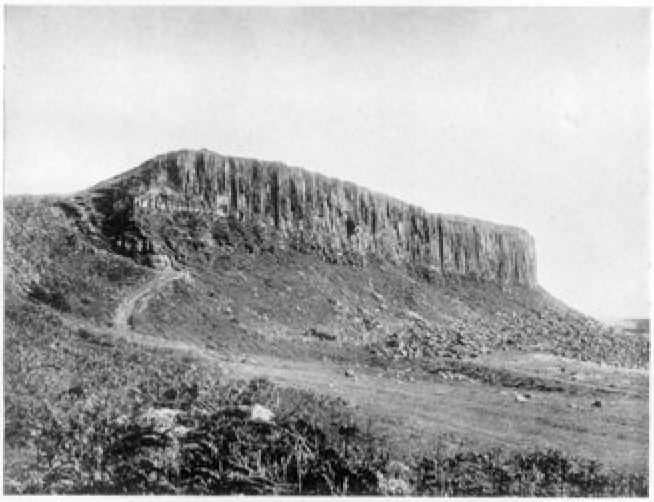


(Plate 3) Tectonic map of North Arran.

Geology of Arran.
(Mem. Geol. Surv.).

PLATE V.

(1) *Kainozoic basaltic dykes of Arran Swarm cutting Triassic sandstones. Shore between Kildonan and Bennan Head.*



(2) *Sill of columnar quartz-porphyry, with basaltic lower contact; Triassic sandstones below. Drumadoon.*

(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.

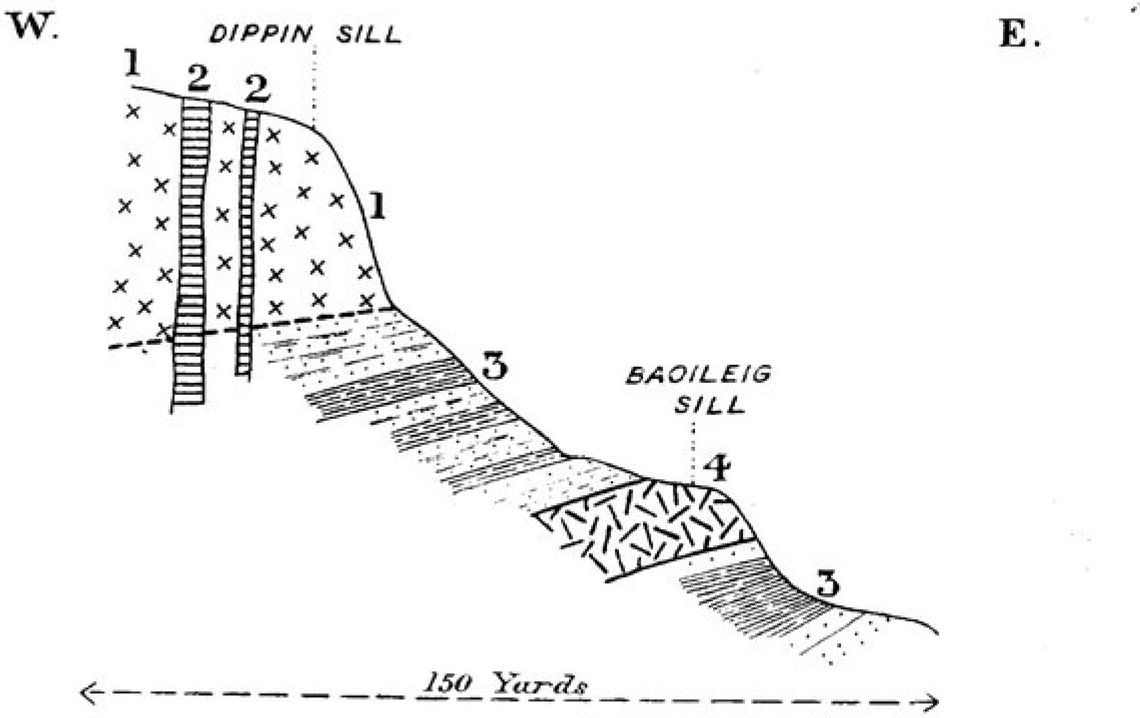


FIG. 16.—*Section in the southern headwater of the Allt Crompucaidh, Largymeanoch, Whiting Bay.*

1. *Dippin crinanite sill;* 2. *N.N.W. Basalt dykes;* 3. *Red Sandstones and shaly marls (New Red Sandstone);* 4. *Baoileig quartz-dolerite sill. Vertical scale exaggerated.*

(Figure 16) Section in the southern headwater of the Allt Crompucaidh, Largymeanoch, Whiting Bay. I. Dippin crinanite sill 2. N.N.W . Basalt dykes 3. Red Sandstones and shaly marls (New Red Sandstone) 4. Baoileig quartz-dolerite sill. Vertical scale exaggerated.

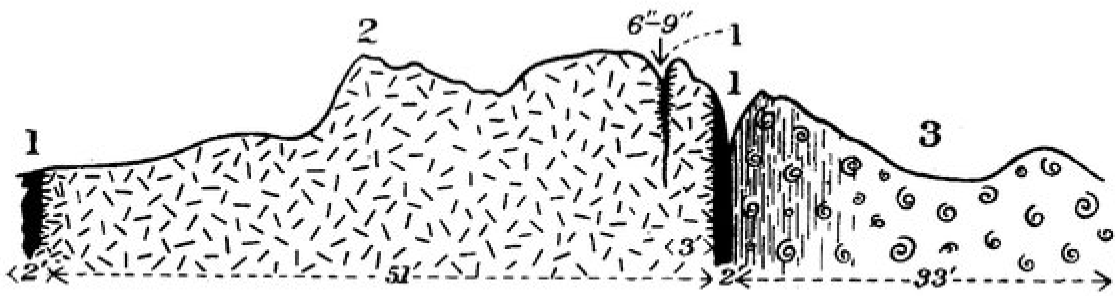


FIG. 26.—*Section across composite dyke at Cleiteadh nan Sgarbh, half a mile north of Drumadoon Point.*

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.

TABLE I

	1[1]	2	3	A	B	C	D
SiO_2	44·68	46·50	43·95	43·94	44·69	45·57	45·8
Al_2O_3 ..	16·37	22·86	17·60	14·03	14·17	14·95	15·0
Fe_2O_3 ..	4·31	3·30	1·43	1·95	3·35	2·82	3·8
FeO	8·11	4·63	11·89	11·65	10·86	7·35	9·5
MgO	6·59	2·52	6·95	10·46	6·41	6·19	8·2
CaO	8·70	9·50	8·54	8·99	10·28	8·27	9·4
Na_2O ..	3·28	4·53	3·66	2·68	3·64	4·33	2·5
K_2O	·21	·39	·35	·33	2·01	2·16	·5
$H_2O>105°$ ..	1·69	3·25	·82	2·31	2·53	3·93	1·8
$H_2O<105°$ ..	2·99	·80	·94	·85	1·05	·97	·9
TiO_2	2·51	1·30	3·42	2·45	·46	2·41	2·4
P_2O_5	·15	·26	·11	·20	·45	·67	·2
MnO	·32	tr.	·10	·32	·31	·31	·3
CO_2	·06	nt. fd.	nt. fd.	·16	nt. fd.	·18	—
S	—	nt. fd.	tr.	—	—	—	—
FeS_2	nt. fd.	—	—	·04	—	—	—
Fe_7S_8 ..	—	—	—	·06	—	—	—
(Ni, Co)O ..	·05	nt. fd.	nt. fd.	—	—	—	—
BaO	·02	—	—	nt. fd.	tr.	·07	—
Li_2O	nt. fd.	—	—	—	—	—	—
Cr_2O_3 ..	—	—	—	tr.	—	—	—
	100·04	99·84	99·76	100·42	100·21	100·18	100·3

[1] The Arran analyses are indicated by consecutive numerals. Other analyses tabulated for comparison are indicated by capital letters.

(Table 1) [no title].

TABLE IX

	3.	19.	19A.	X.	20.	Y.	Z.	21.	13.
SiO_2 ..	43·95	42·55	46·6	47·35	48·60	47·24	51·53	54·52	55·79
Al_2O_3 ..	17·60	16·93	18·6	13·90	18·27	18·55	11·05	14·53	15·97
Fe_2O_3 ..	1·43	3·43	3·8	5·87	3·19	6·02	2·73	2·21	12·50
FeO ..	11·89	6·81	7·5	8·96	7·17	4·06	10·98	6·06	—
MgO ..	6·95	6·05	6·7	5·97	6·29	5·24	5·21	5·61	2·22
CaO ..	8·54	12·64	8·5	10·65	10·15	11·72	9·68	8·08	7·06
Na_2O ..	3·66	2·18	2·4	2·73	1·63	2·42	3·48	3·66	2·21
K_2O ..	·35	·32	·4	·54	·45	·15	·86	1·14	1·86
$H_2O>105°$	·82	1·30	1·4	1·16	1·65	2·24	1·26	·93	2·43
$H_2O<105°$	·94	1·78	1·9	1·04	1·60	·21	·71	1·95	—
TiO_2 ..	3·42	1·80	1·9	1·75	·70	1·46	1·57	·87	—
P_2O_5 ..	·11	·11	·1	·24	·09	·26	·22	·21	—
MnO ..	·10	·12	·1	·23	·24	·31	·45	·24	—
CO_2 ..	nt. fd.	3·85	—	·32	nil	·19	·08	—	—
FeS_2 ..	—	—	—	—	—	nt. fd.	·26	—	—
S ..	tr.	·13	·1	·23	tr.	—	—	—	·45
BaO ..	—	—	—	—	—	nt. fd.	nt. fd.	·03	—
Li_2O ..	—	—	—	—	—	nt. fd.	—	nt. fd.	—
(Ni,Co) O	nt. fd.	nil	—	nt. fd.	nil	·05	nt. fd.	nt. fd.	—
	99·76	100·00	100·0	100·94	100·03	100·12	100·07	100·04	100·49

(Table 9) [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].

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].