MONOGRAPHS

1. TERTIARY IGNEOUS GEOLOGY AND PETROLOGY OF SOUTH-EAST ARRAN.

2. THE DYKE ROCKS OF DONEGAL AND THE ADJOINING PART OF Co. TYRONE, IRELAND.

A THESIS SUBMITTED

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TERTIARY IGNEOUS GEOLOGY

AND

PETROLOGY OF SOUTH-EAST ARRAN.

C O N T E N T S

I. INTRODUCTION AND PREVIOUS RESEARCH

In the British Tertiary Province the isle of Arran stands out conspicuously for its varied epochs of igneous activity in the Tertiary period. Nearly half the area of the island is occupied by these igneous intrusions which have afforded ample scope for investigation. The present paper is the outcome of a detailed field and laboratory study of the igneous rocks of the south-east part of the island, mainly confined within the limits of Lamlash-Sliddery road in the north, Glen Ashdale in the south, sea shore in the east and Tighvein in the west, though here and there occasional references to localities south of Glen Ashdale are made. The area mapped and dealt with here thus comprises sheets CCLV NW and parts of sheets CCLV SW, CCL SW, CCLIV NE and CCXLIX SE of the six-inch Ordnance Survey sheets, Buteshire. It is conspicuous by the occurrence of two sills of crinanite and many composite sills of quartz-dolerite and granophyre, basalt and felsite with intermediate types such as craignurite, besides their more or less plutonic equivalents such as quartz-augite-diorite and microgranite in its western part. In addition, minor acid intrusions, both/

both as dykes and as thin sills, of pitchstone, felsite and related acid craignurite occur. Above all, the igneous activity manifested itself as dykes in great profusion, constituting but a part of the Arran swarm and consisting mainly of tholeiite and basalt.

The previous literature pertaining to this area is scanty and is more or less of the nature of pioneer observations made in the early days by MacCulloch (1819) and Bryce (1872). Mostly, the pitchstones seem to have attracted the attention of several geologists, among whom were Zirkel (1871), Corstorphine (1895), Gunn, Harker and Others (1903)and Scott (1913). Gregory and Tyrrell (1924) have recorded and described along with profile sections the occurrence of sills of crinanite and of 'blue-basalt,' as also dykes of 'blue-basalt' and quartz-felsite in a few localities. The most recent work by Tyrrell (1928) is to be found in the Arran memoir wherein an elaborate account of the geology and petrology of the area has been given, though, under the limitations of a volume of its kind, without much comment on petrogenesis. The latest geological map of the island published in 1947 incorporates all the previous research.

II. TERTIARY IGNEOUS EPOCHS OF INTRUSION.

The different episodes of Tertiary igneous activity are well represented in this part of the island. Most of the intrusions are in the Permian and Triassic sediments, while some of the smaller ones, mostly of acid rock, cut the earlier basic ones. The absence of any Kainozoic sediments in the area renders the definite assignment of each of these epochs to a particular age within the main Tertiary period difficult. Still, among themselves, they can be clearly demarcated.

The first episode of igneous activity was of the undersaturated plateau-basalt magma which is represented as large sills of crinanite and of allied olivine-dolerite extending in an E-W direction. These are the Monamore and Kingscross sills. This phase of intrusion of undersaturated magma was followed by a great development of oversaturated magma manifesting itself as numerous sills and dykes, which, in places, intersect the sills of the former category. These saturated masses are of quartz-dolerite, quartz-basalt etc. In the same phase, the acid magma was injected, the sills, e.g. Glenashdale and Badleig sills among others, rendered composite/

composite and multiple and xenolithic enclosure and hybridization of the basic material, all turned out to be common features. The final epoch of igneous activity was the intrusion of numerous small acid sills and dykes of pitchstone, quartz-felspar-porphyry etc., and the injection of basalt and tholeiite as dykes in great profusion, most of which, wherever occurring in intimate association with the sills, cut them. These constitute a part of the Arran swarm and are well seen on the sea shore.

The different intrusions are treated below, starting with the crinanite sills at the outset, in accordance with their order of injection.

A. CRINANITE SILLS:

Two big crinanite sills - the Monamore sill and the Kingscross sill - are exposed in this area. Both of them extend in an E-W direction, thinning out towards the west. It is hence surmised that the focus from which the rock magma was derived must be somewhere towards the east under the waters of the Firth of Clyde.

(i) Field Relations:

(a) Monamore Sill: On the one-inch geological map of Arran of 1947, this sill is represented as extending up to about ¼ mile E. of Sguiler (1332 O.D.) and stopping short of the felsite sill there. But detailed mapping of this bit of country reveals some interesting peculiarities. From the attached geological map (Plate XII), it is clear that the sill extends westward or in a WSW direction right up to and further west of the Sguiler burn. It is seen that the 1044 O.D. and 1192 O.D. masses just west of the burn are of crinanite, the eastward or ENE continuation of which is the same Monamore sill, exposed well in the region NE of Sguiler where it has its maximum thickness. Thus, the Monamore sill has actually a far greater extent than/

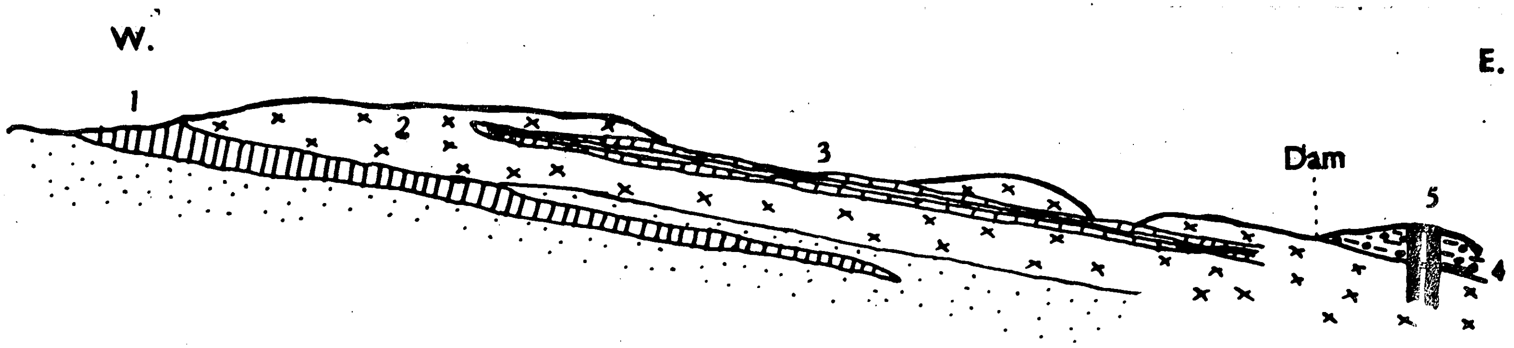


Fig. 1. Section along the Monamore Water, west of Mill Dam.

HORIZONTAL SCALE :- 1 INCH 60 YARDS

1. Quartz - felsite sill with pitchstone facies.
2. Monamore crinanite sill.
3. Composite intrusion of quartz - felsite and tholeiite.
4. New Red Sandstone Conglomerate.
5. Basaltic dykes.

than what is represented in the published maps of 1910 and 1947.

Again, the felsite sill about ¼ mile south of Monamore Water and about ⅓ mile NNE of Sguiler is definitely to be taken as a sill-like sheet injected at a higher horizon within the crinanite. Proceeding further eastward, one notices that at nearly the east end of the crinanite sill, at the Dam in Monamore Water, are exposed a felsite sill and a composite intrusion, a section of which is shown in Fig.1.

In the figure, while 1. is a sill of quartz-felsite with pitchstone facies developed here and there, 3. is a composite intrusion of quartz-felsite and tholeiite with the acid member in the middle, flanked on either side by the basic one and not a felsite sill as shown in the Memoir (p.115). It is difficult to say whether it is a sill or a dyke since it intrudes not a sedimentary formation but another sill with no joint planes.

(b) <u>Kingscross Sill</u>: The geological map of Arran of 1947 shows the Kingscross sill as extending from Kingscross Point westwards for about two miles. But an examination of the area shows (vide attached map) that towards the western/

western end of the sill where there is an intercalation of sandstone between its northern and southern branches, part of the southern mass has been found to be a sill of an altogether different rock, viz., xenolithic quartz-dolerite, intruded more or less parallel to the crinanite sill and occurring in close association with it. It is quite likely that it was more or less contemporaneous with the other quartz-dolerite sills of the district. Hence, it is clear that the Kingscross sill does not cover the area shown in the published maps of 1910 and 1947.

At the eastern end of the sill near Kingscross Point, the base of the sill is seen to be fine-grained changing into a coarse-grained type of rock within about two feet and traversed by numerous acid veins half an inch to two inches thick. Pegmatitic facies are found close by. Almost at the same locality, viz., at Kingscross Point, the crinanite shows a most striking penetration and veining by a dense black-basalt (Plates I and II) which becomes tachylytic towards the margins. A similar basalt is seen to constitute two thin sills exposed on the shore, about a quarter of a mile S of Kingscross Point. It becomes rather difficult to correlate the basalt of these thin sills and veins with others because of its unique character. But, though/

though it is very fine-grained and exhibits a tachylytic facies like many dyke rocks of similar composition, the author believes it to be related to the phase of composite and multiple intrusions of quartz-dolerite - craignurite nature which occasionally show fine grained and glassy facies like the one under consideration. This occurrence is of great significance in that it establishes beyond any doubt the priority of the crinanite sills as compared with all the rest.

Another point of interest is the representation in the 1947 geological map of the sill SE of Gortonallister and E of Lag an Daer and close to the Lamlash - Whiting Bay road as of crinanite and teschenite when it is, in fact, of quartz-dolerite.

(ii) Petrography:

The two sills described above are made up to a large extent of crinanite, though analcite-free varieties of the same - petrographically olivine-dolerites - are equally common. In fact, the dominant rock of the Monamore sill is an olivine-dolerite of very coarse-grain. Occasionally, both olivine and analcite are missing (W 145) but there is the characteristic titanaugite with or without some/

some zeolite proving their affinity to crinanite. Some types are poor in olivine but enriched in analcite so as to correspond to teschenites.

C r i n a n i t e: In hand specimen, it is a dark, generally coarse-grained - though occasionally medium- to fine-grained - rock with an ophitic texture and with some variation in the relative proportion of two of its essential constituents - augite and felspar - with consequent variation in specific gravity between 2.73 and 2.88, the former value being that of a pegmatoid variety and the latter that of a gabbroid type from the Monamore sill.

In thin section, the rock shows a typical ophitic texture and consists essentially of olivine, titanaugite, labradorite and iron-ore along with analcite, zeolite, apatite, alkali-felspar and occasionally some biotite as accessory minerals, besides secondary constituents such as serpentine, calcite, epidote etc.

Olivine is abundant and occurs as euhedral, microporphyritic crystals up to 3 mm. in diameter. It is mostly broken and altered to greenish-brown, massive or fibrous serpentine or, rarely, bowlingite. Titanaugite found/

found as ophitic plates is lilac-coloured and pleochroic to violet. Here and there it has given rise along its margins to aegirin-augite, grass green in colour and pleochroic to olive green. Very rarely is diopside met with as colourless or very pale green crystals with resorbed margins. Labradorite is in the form of crystals with elongated, rectangular sections and is twinned on albite law. Black iron-ore - mostly ilmenite - is plentiful as euhedral or rather skeletal crystals sometimes intergrown with biotite. Analcite is interstitial, has a turbid appearance and generally exhibits anomalous polarization. Apatite is very common as little prisms, and fibrous zeolite - mostly natrolite with positive elongation - as large vesicular masses. Anorthoclase is interstitial.

It is worth noting that though there is some variation in this group of rocks, on the whole it is not wide. Mostly, it is the minor proportion of analcite that varies; in itself, again, quite considerably, sometimes the constituent totally missing. As a matter of fact, the richness or poverty of a rock in analcite is more a local phenomenon, since out of the two thin sections (W 131) and (S 233) from almost exactly the same locality it is seen/

seen that one contained analcite while the other did not have even a trace of it.

The crinanites and olivine-dolerites from the Kingscross Point veined as they were by basalt, are of considerable interest. A microsection (S 230) shows the olivine-dolerite penetrated by tachylytic basalt which is chilled against the former. But, in another section (W 131), the contact between the two types is characterised by the absence of any chilling, implying that the basalt there has been successful in bringing the olivine-dolerite in its vicinity to a molten state and inducing recrystallization in the latter under pressure. The effects of such crystallization are seen in the assumption by the dolerite of a granulitic texture; the labradorite being broken up and showing bent twin lamellae and undulose extinction and the augite strain effects. The tachylytic basalt is made up for the most part of typical skeletal iron-ore. Further, it is traversed by veins of pure tachylyte without any chilling effects suggesting, again, that the latter has intruded while the former was still molten. The tachylytic basalt and tachylyte also occur as thin sills S of Kingscross Point. The two can be regarded as two different phases in/

in the deep-seated acidification of the basic magma, the relatively acid tachylyte phase intruding later than the basic. Their mode of occurrence as sills and the fact that they are found as basic xenoliths in some of the intermediate and acid rocks such as craignnrite and felsite of the composite intrusions, establish their contemporaneity with the composite and multiple sills.

The genesis of crinanites, related olivine-dolerites, dolerites and teschenitic types is dealt with on a later page along with similar dyke rocks.

B. COMPOSITE AND MULTIPLE INTRUSIONS.

This subject is of great moment and has engaged the attention of many geologists for over half a century. Though much has been said, still several of the problems connected with it, viz., the mechanism of intrusion, the origin of the magmas, the role of assimilation etc., remain controversial. A composite sill, according to Daly (1933, p. 79), is a compound intrusion of sill form and relations which is the result of successive injections of more than one kind of magma along a bedding plane, while a multiple sill is the result of successive injections of one kind of magma; though, according to Bailey, Thomas and Others (1924, p. 32), the latter type of intrusion may be composed of rocks of different composition but should have interior contacts. From his classic work on the intrusions in Skye, Harker (1904) arrived at some definite conclusions, that the acid intrusion is always posterior to the basic one and that "divisional lines of any true significance hardly exist between several members in the field" and postulated the existence of local magma reservoirs. Later work, mostly in Mull by Bailey, Thomas and Others (1924) and in Ardnamurchan by Richey, Thomas and Others (1930), while mainly confirming his observations, has pointed to some/

some abnormalities in the order of injection as deduced from the field relations.

The southern half of Arran is celebrated for the varied phenomena of composite sills and dykes in the soft Triassic strata. These intrusions constitute the main element in its scenery which is marked by a scarp and terrace topography. Some of these which occur in the area in question are treated below. In almost every case the basic member is a quartz-dolerite or a quartz-basalt and the acid one is a quartz-felsite or a granophyre, the end-members being nevertheless connected by many intermediate varieties of craignurite affinities.

(i) Field Relations:

1. Composite Sills:

(a) Glenashdale Sill: This is one of the largest composite sills in the area with a maximum estimated thickness of about 210 feet. It extends in an approximately E-W direction for nearly a mile south of Glen Ashdale and on the north side of it for nearly a mile and a half but there veering towards NE-SW and NNE-SSW. The best section of the sill is to be seen in Glen Ashdale - Allt Dhepin. This has/

has been figured and described in detail by Tyrrell (1928, pp. 124-125). Compact, banded quartz-felsite which forms the lower contact is well seen resting on baked sandstones. The felsite becomes coarser as it is traced upwards, grades into 'blue-basalt'-of roughly intermediate composition - which passes at the top of the waterfall into a medium-grained quartz-dolerite. Just E of the waterfall, the bed of the stream contains two basaltic dykes. The transition between the 'blue basalt' and the quartz-dolerite above referred to is seen in the hillock just close to and about 100 feet N of the waterfall. It is a slabby, highly leucocratic quartz-dolerite. Further upstream, NW of the fall, quartz-dolerite again grades into the 'blue-basalt' which here has dark xenoliths and is exposed only for a short distance. From there onwards it is the quartz-dolerite, rather less basic than the one below, that is seen till at the top of the sill a thin band of felsite similar to the one seen at the lower contact outcrops. Thus, the Glenashdale sill is definitely composite in having basic and acid rocks as its components, though in their relative arrangement, it departs from the established type with acid centre and basic flanks. Its structure as encountered from/

from the top is briefly as follows:-

Upper felsite.
Quartz-dolerite, felspathic.
Quartz-dolerite.
Lower felsite.

A full linear section of the sill is computed from a study of the several rock types collected from different horizons in the sill and the order of intrusion is discussed in detail on a succeeding page.

The Glenashdale sill is also very well exposed to the north of Glen Ashdale and gives some very good sections in the Burn B and in the Burn A where it bifurcates, the sandstone coming in between. Its eastern branch extends in a northerly direction across the Golf Course and is exposed well in Allt Ceirde, as also in a burn to its south. N of Allt Ceirde a thin basalt dyke cuts the sill. The western branch thins out towards the north into the sediments.

(b) Baoileig Sill: West of the Glenashdale sill and on a higher level is the Baoileig sill well seen as huge columns resting on the bedded sandstone (Plates III and IV) in the gorge of Allt Dhepin at the confluence of Baoileig Burn. The width of its outcrop is roughly 200 yards, while its estimated thickness is about 40 feet. The base of the sill/

sill is made up of an exteriorly chilled, compact, glassy looking quartz-felsite, though similar material could not be discerned at the top near the waterfall in Allt Dhepin just NW of 436 O.D. The major part of the sill is constituted of a dark grey to light grey, fine-grained, very acid 'blue-basalt' with a few phenocrysts of felspar and sometimes with dark xenoliths of basalt - evidently a partially basified acid rock. In the middle of the sill there is a band, about 5 feet in width, of medium- to fine-grained quartz-dolerite with many vesicles and druses. The sill is, thus, composite.

North of Glen Ashdale, the sill extends in a NNE direction enclosing a lenticle of sediments in Burn C, being faulted in the gorge of Burn A and dying out about ½ mile N of Allt Garbh as two thin branches and not at Allt Garbh as shown in the geological map of 1947.

(c) Allt Dhepin - Loch na Leirg Sill: On a horizon higher than that of the Baoileig sill is the Garbad multiple sill, described later. Sediments which overlie the Garbad sill are intruded by the Allt Dhepin - Loch na Leirg composite sill estimated to be over 300 feet thick. Strictly/

Strictly speaking, this has no claims to be regarded as composite sill, except for the fact that the sill rock - fine-grained acid 'blue-basalt' - incorporates relics of basic material as dark xenoliths of quartz-dolerite and quartz-basalt, evidently representing the destruction and partial digestion of the basic component of the sill.

At the waterfall near 786 O.D. in Allt Dhepin, the sill is seen to overlie the sandstones. From there it extends over a vast area to all sides except the south where it is limited by the Garbad quartz-dolerite sill whose relationship to the former is disclosed from a section in the gully entering the Allt Dhepin from the east opposite 739 O.D. Tyrrell (1928, p. 127) has figured it well proving conclusively that the Allt Dhepin - Loch na Leirg mass lies on a higher horizon than that of the Garbad sill. The sill of spherulitic felsite in the section referred to above shows commonly a very compact almost glassy facies of felsitic rock with much resemblance to pitchstone. There is no doubt that it is a separate minor acid intrusion. The Allt Dhepin sill extends as far SE as Cnoc Mor (867 O.D.) Just SSE of Loch na Leirg near 1051 O.D. occur a few outcrops of occasionally spherulitic felsite and granophyre. Further south for over/

over half a mile, the region is all peat-covered. The sill is exposed well on either side of Allt Dhepin till almost the very source of the said burn in the north near 1215 O.D. The bed of the stream especially between 824 O.D. and 1118 O.D. is occupied by several small basalt dykes. W of Loch na Leirg on the moor land also occur several slabby felsitic rocks which are identical with those S of the loch and those on either side of Allt Dhepin. The writer is of the opinion that the Loch na Leirg felsite intrusion which extends as far SE as Borrach (869 O.D.) and NW as 1280 O.D. close to Urie Loch and thus seems to occur on a slightly higher level than the base of the Allt Dhepin intrusion, is really part of the latter, the two being one and the same.

(d) Other sills: Under this heading are grouped all the smaller composite sills of the area other than those dealt with above. These are, to mention but a few, the craignurite-felsite sill between the Garbad and Baoileig sills and a similar one just W of the Glenashdale sill. Another sill constituted of craignurite-felsite and extanding NW-SE is the one which runs almost close to and parallel to the eastern margin of the Allt Dhepin - Loch na Leirg sill and very well exposed as long columns (Plate V) in/

in the gorge at Sloc Ruaridh. It is shown in green colour in the 1947 Geological map, when it should have been represented in orange like the felsite mass to its west. A sill of quartz-dolerite occurs SW of Auchencairn between the two main masses of crinanite in that locality. Exposures are found in the Auchencairn Burn, just W of the Whiting Bay town boundary line. Another sill of quartz-dolerite is the one in Knockenkelly. It is at about 100 feet above sea-level. West of this region is a big sill of craignurite-felsite very poorly exposed in the peat. In North Kiscadale, injected at about 75 feet above sea-level is a sill constituted in toto of a typical, compact, occasionally xenolithic 'blue-basalt' of approximately intermediate composition. An exactly similar rock forms the sill at Gortonallister, E of Lag an Daer. In the region S of Monamore Glen and NE of Urie Loch, occur two or three disconnected sills of basified felsite. Lastly, there is the Creag Dhubh sill (Plate VI) of about 30 feet thickness injected just a few feet above sea-level at the south end of Whiting Bay and exhibiting the composite character very well with a highly felspathic quartz-dolerite in the middle and basified felsite at the top and at the bottom. The lower contact is seen to rest on sandstone dipping 20° WSW.

2. Multiple Sills:

That the multiple sills are characterized by one or more interior contacts is an established fact. As pointed out earlier, the authors of the Mull Memoir believe that they may be composed of rocks of different composition. Only one multiple sill occurs in this area and even that, unfortunately, has chilled almost always against the country rock of sandstone and not against its different members. But still, the wide variety in composition in the rock types that form the intrusion leave no doubt as to the validity of the view above referred to.

Garbad Sill: This is by far the biggest quartz-dolerite sill in the area, with a thickness estimated at 250 feet and extending from S of Cnoc na Garbad (959 O.D.) in an approximate N-S direction for over a mile up to about 539 O.D. in the gorge of Allt Dhepin wherefrom it bifurcates, the western branch continuing along Allt Dhepin in the same direction for over half a mile, while the eastern one runs NNE nearly a mile and abruptly ends against felsite near Creag Bhan in Allt Garbh. As usual, Allt Dhepin affords a clear section of the intrusion which is described in detail by Tyrrell (1928, p. 126). The section along the tributery to Allt Dhepin, N of Cnoc an Fheidh, though containing/

containing innumerable dykes is very revealing, intercalations of sandstone within the quartz-dolerite being met with and the dolerite of each injection being chilled against the country rock. The base of the sill is seen S of Cnoc na Garbad where the dolerite assumes vitreous aspect. Further north, the same is coarse-grained and very felspathic, in places thin veins of a light yellowish white felsite traversing it. The upper contact of the sill is to be seen in the western headwater of Burn A, north of Glen Ashdale, the rock there being a compact, ash-grey, acid 'blue-basalt' i.e. craignurite. Thus, the sill rock shows considerable apparent variation in appearance and composition and permeation by acid material, the sill itself with its interior contacts illustrating, in all definiteness, a multiple character.

3. Tighvein and Sguiler Intrusions:

These occupy the western end of the area dealt with in this paper and consequently a full and complete study of their mode of injection and mutual relations could not be made. Only the region east of an imaginary N-S line through/

through Tighvein (1497 O.D.) is traversed and due to the paucity of exposures and to the thick covering of peat, it has been difficult to decipher the nature of the intrusions. As such, they are treated here merely as intrusions genetically related to the rest in the area.

A section of the formations from Tighvein SE towards Allt nan Clach figured by Tyrrell (1928, p. 134) clearly shows a diorite mass constituting Tighvein underlying which in the peat could be recognised blocks of microgranite which, again, after being exposed for about 500 yards, give place to the dioritic rock. At the source of Allt nan Clach is the New Red Sandstone which is intruded by a pitchstone dyke. A traverse along the burn shows a sill of quartz-dolerite about 50 feet thick overlying the sandstone which is intruded by a basalt dyke. Underlying the sandstone is, again, a sill of acid 'blue-basalt' - basified felsite. The section (ibid, p. 135) towards the E of Tighvein in the western headwater of Allt Dhepin, S of 1215 O.D., reveals almost the same intrusions except the microgranite which lies at a higher horizon. On all sides of Urie Loch in the crags occur many large blocks of a coarse, partially decomposed diorite which at 1280 O.D. and/

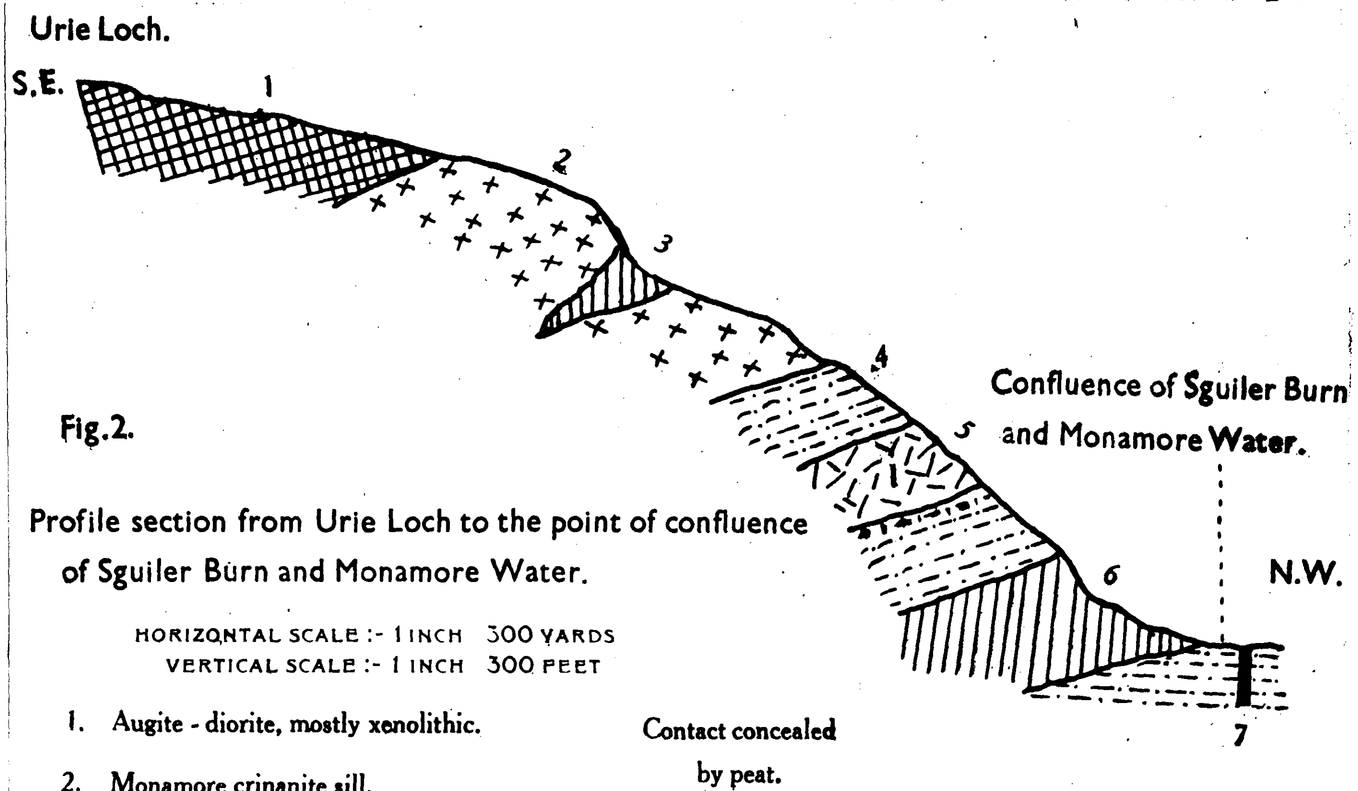


Fig.2.

Profile section from Urie Loch to the point of confluence of Sguiler Burn and Monamore Water.

HORIZONTAL SCALE :- 1 INCH 300 YARDS
VERTICAL SCALE :- 1 INCH 300 FEET

1. Augite - diorite, mostly xenolithic.
2. Monamore crinanite sill.
3. Craignurite - felsite sill.
4. Sandstone.
5. Quartz - dolerite sill.
6. Quartz - felsite sill.
7. Basaltic dyke.

and at the cairn just to its N contains xenoliths of dark 'blue-basalt,' the whole veined by whitish felsite.

The nature of the northern part of the Sguiler intrusion is seen from a section (Fig.2) along the Sguiler Burn whose eastern tributery rises from Urie Loch and flows NW into Monamore Water.

From the Urie Loch up to nearly the confluence of the western and eastern tributeries to form Sguiler Burn, in the peat could be seen occasional scattered exposures of augite-diorite, the rock becoming xenolithic towards the NW end of the mass. At the summit and a few yards S and SW of Sguiler (1332 O.D.) the diorite has very big xenoliths of dark, fine-grained basalt, the margins of the xenoliths being very brownish suggesting reaction. From the confluence above referred to, crinanite outcrops in the bed of the burn as also to its west and occupies the hill masses 1044 and 1192 O.D. The contact of this sill with the augite-diorite mass is concealed under peat. In the burn, close to 1192 O.D., is exposed due to faulting a thin sill of felsite which when traced NE proves to be the same as the one just N of Sguiler. The crinanite begins to be exposed/

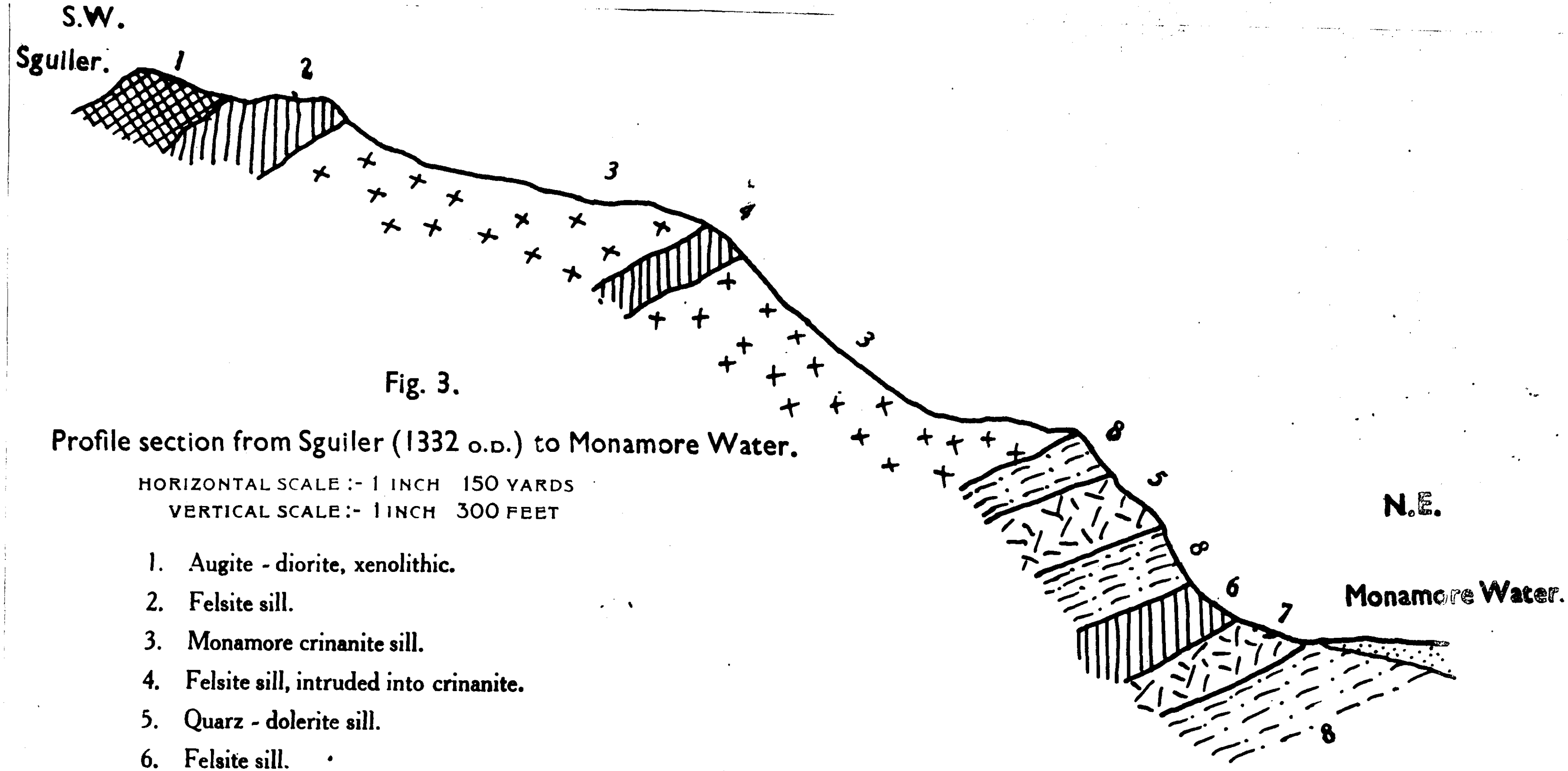


Fig. 3.

Profile section from Sguiler (1332 O.D.) to Monamore Water.

HORIZONTAL SCALE :- 1 INCH 150 YARDS
VERTICAL SCALE :- 1 INCH 300 FEET

1. Augite - diorite, xenolithic.
2. Felsite sill.
3. Monamore crinanite sill.
4. Felsite sill, intruded into crinanite.
5. Quarz - dolerite sill.
6. Felsite sill.
7. 'Blue - basalt' sill.
8. Sandstone.

exposed again in the burn till nearly the big waterfall about 100 yards S of 938 O.D. is reached. The fall is over the sandstones which occupy the bed of the burn for over 100 yards. Then a sill of quartz-dolerite is encountered which gives place below to sandstone. A few yards S of 642 O.D., a quartz-felsite sill outcrops and is exposed till past the point of confluence of Sguiler Burn and Monamore Water.

A section, more or less similar to the former, from Sguiler towards its NW to Monamore Water (Fig.3) is of interest in that it brings to light the various igneous intrusions, with that of Sguiler at the top, in the region.

Intruded below the Sguiler mass of xenolithic augite-diorite is a felsite sill which overlies the massive Monamore crinanite into which again is intruded a thin sill of felsite. On a horizon lower than the base of the crinanite sill is a quartz-dolerite sill which is but an eastern extension of that exposed in Sguiler Burn. Further down, almost close to Monamore Water is a composite mass of felsite and 'blue-basalt' resting over the Permian sandstone which is well seen occupying the bed of/

of Monamore Water. This section thus differs from the one figured by Gregory and Tyrrell (1924, p. 419) in that it uncovers one more quartz-dolerite sill in its lower reaches, as also in the fact that the Sguiler mass is of xenolithic augite-diorite and not of crinanite.

(ii) Petrography:

The rocks of the different intrusions described above, all belong to the saturated and oversaturated groups and invariably contain free silica. They exhibit considerable variation in texture, grain size and mineral composition. Broadly, they can be classified into two groups - the basic and the acid - with several transitional rock types belonging more or less to an intermediate group. The members of the various composite and multiple intrusions are dealt with first, those from the Tighvein and Sguiler intrusions being treated separately.

(a) Composite and Multiple Intrusions:

The/

The rocks of these intrusions vary from basic through sub-basic and intermediate to acid types. They range in texture from compact, almost glassy varieties through fine-grained to medium-grained ones. Their mineral assemblages also differ considerably. They are described below in order of decreasing basicity.

Q u a r t z - b a s a l t: This is by far the most basic rock in the area being occasionally encountered as definite, thin, xenolithic bands sharply demarcated in a sub-basic, intermediate or sub-acid rock. The enclosing rock always exhibits diminution in grain size, in some cases not very pronounced, as the contact with the xenolith is approached.

The quartz-basalt is dark and fine-grained. In thin section (W 74), it occurs as a big xenolith constituted of augite, a little plagioclase, some hornblende and biotite, very abundant iron-ore, big vesicles of calcite and little or no mesostasis (Plate VII, fig.1). But towards the contact with the enclosing rock, viz., felspathic quartz-dolerite, it is thoroughly veined and permeated with felspathic material -evidently from the quartz-dolerite - which/

which decreases in amount progressively inwards of the xenolith. Also, the quartz-dolerite in its turn at the contact is relatively fine-grained and is notable for the presence of biotite and a high proportion of iron-ore, presumably derived from the xenolithic band.

Augite, common as irregular crystals and short rounded prisms, is rarely fresh having given place to calcite. Also, it is enveloped to a great extent by pseudomorphs of brownish hornblende or pale green scrappy chlorite. Iron-ore is unusually abundant and typically skeletal and rod-like, sometimes with 'ghost-like' outlines. It is leucoxenized. The shape and alteration are strongly suggestive of intensive and extensive reaction with the enveloping magma.

The light-coloured material which is reduced to a minimum is plagioclase occurring as a few small laths and showing undulose extinction. In some cases (W 147) there is a rather dusty mesostasis of alkali-felspar in some amount. Two big vesicular areas characterize the quartz-basalt and thus confirm Harker's (1904, p. 185) observation of the association of druses with xenoliths. They occur close to the contact with the quartz-dolerite and/

and are made up of calcite - probably dolomite - with a grain of quartz and of unreplaced plagioclase in between. What is significant is the growth of idiomorphic crystals of green-brown hornblende and, more so, of flaky fawn-brown biotite on the edges of the vesicles outwards into the acid mesostasis. That such ferromagnesian minerals as these are the result of reaction between the xenolith and the late-formed acid residuum of the quartz-dolerite magma is indubitable. Also, the gas-filled pores seem to assist this interchange of material, a fact inferred by Fenner (1926, p. 724).

Q u a r t z - d o l e r i t e: The commonest basic member of most of the sills is a quartz-dolerite almost identical with the Talaidh type of quartz-dolerite in Mull. In hand-specimen, it is a dark grey, mostly fine-grained - very rarely with a medium grain size - nonporphyritic, minutely-crystalline rock. It constitutes the central parts of the Glenashdale and Baoileig sills besides of several other smaller ones such as Knockenkelly sill and in its limited phases of variation forms the main mass of the Garbad sill. The type specimens from the Glenashdale and Garbad sills show, under the microscope, the characteristic ophitic/

ophitic texture with well-shaped plagioclase laths, pyroxene prisms and iron-ore euhedra in an abundant dusty-brown mesostasis containing blebs of quartz and needles of apatite (Plate VII, fig. 2).

The plagioclase occurs as stumpy laths being mostly singly-twinned and fresh, though faintly zoned. It generally exhibits undulose extinction suggestive either of crystallization under pressure or of stress on an already crystallized fabric, more probably the former since there is neither any breaking in the crystals nor any particular linear disposition of minerals in the rock. Where the mineral is in contact with the turbid mesostasis, it is invested with the same and exhibits signs of corrosion and reaction. Studied on Federov's Universal Stage, it gave 2V over Z $74.0^{o} - 75.5^{o}$ on several measurements suggesting according to Winchell (1933, p.318) a composition of Ab_{45-44} An_{55-56}.

The commonest pyroxene is a colourless, occasionally very pale green augite in beautiful prismatic crystals and with the salite striation on (001). It is mostly fresh but here and there shows marginal alteration to a yellowish-green hornblende. It encloses and also has moulded on it crystals/

crystals of iron-ore. Determinations of 2V for at least twenty crystals in different microsections confirm it as augite, the optic axial angle mostly ranging between 46.0° and 47.5° and occasionally reaching 50.0° and $Z \wedge c$ maximum 47.5°, thereby corroborating Hess (1944, p. 625) that the pyroxene of most diabases and basalts is really augite with 2V approximately 45° and not pigeonite.

Besides augite, there is true rhombic pyroxene which occurs as long columnar crystals with well-developed cleavage and mostly altered to bastite, some iron-ore having been liberated during the alteration. Part of it is enstatite with 2V over Z 68° and $Z \wedge c$ 0° - 2.5° while the rest is hypersthene with 2V over X 75° and $Z \wedge c$ 0° - 22.5° and pleochroism as X: yellow, Y: pale pink, and Z: pale green. No true pigeonite is anywhere recorded here.

Iron-ore is abundant and seen as euhedra sometimes rather modified and presenting skeletal appearance.

The turbid mesostasis is mostly made up of dusty alkali-felspar resembling anorthoclase which seems to be in intergrowth/

intergrowth with quartz to give rise to micropegmatite, the quartz occurring as minute blebs and threads in the intergrowth besides irregular areas. Considerable variation in the coarseness and relative proportions of the two constituents in the intergrowth is noticed. Veins of microcrystalline felsitic material occasionally traverse the rock. Apatite is the most frequent and important accessory mineral found as acicular crystals, singly or in clusters.

The different facies of this exceedingly common rock type - quartz-dolerite - call for attention. Firstly, its most basic representative which might form the connecting link with the most basic quartz-basalt above described, is Olivine-bearing quartz-dolerite. It forms the component of one of the successive intrusions in the Garbad multiple sill and is met with in the scarp E of Cnoc Mor (867 O.D). It is similar to the quartz-dolerite in every respect except that it contains, in addition, several microphenocrysts of an iron-rich olivine in well-marked euhedra, the mineral being thoroughly altered to dark greenish-brown bowlingite. The rhombic pyroxene exhibits schiller structure and alteration/

alteration to a rather dark green serpentine. Mesostasis is poorly developed, quartz being less in amount and micropegmatite definitely rare. Augite, iron-ore and apatite occur as usual (Plate VII, Fig.3). The co-existence of fayalite and quartz is a common phenomenon in some pitchstones of intermediate composition in Arran and in some Icelandic dacites. Hawkes (1924) explains it by giving consideration to the fact that fayalite is capable of being in solution long after the pyroxene and plagioclase have crystallized and also that its solubility in the magma in the presence of silica to some extent is greater than in silica-poor magmas. In the rock type in question the iron-rich olivine is not improbably of a similar origin.

Next, the chilled pitchstone-like facies of quartz-dolerite are worthy of note. A specimen (Ar. 359 b) from one of the intrusions in the eastern part of the Garbad mass, as exposed ¼ mile S of Torr na Baoileig, shows, under the microscope, prismatic crystals of augite and rhombic pyroxene, laths of acid labradorite which here and there assume microporphyritic dimensions and partly leucoxenized titaniferous euhedral and granular iron-ore in a characteristic brownish-grey glassy base with some acicular crystals/

crystals of pyroxene and rod- and string-like iron-ore. Further, the base contains small amounts of pale green chlorophaeite. The section (Plate VII, fig.4) while being distinctive in itself bears a very close resemblance to the S t o n y t y p e o f B a s i c L e i d l e i t e described and figured in the Mull Memoir (p.282). Such a sort of variation in the quart-dolerite towards a basic leidleite is nothing new, having been recorded by the Authors of the Mull Memoir (1924, p. 287) in the Loch Scridain district of Mull and attributed to segregation phenomena.

The other variants of quartz-dolerite are more towards its acid side and these in many respects show contamination effects. A G r a n o p h y r i c q u a r t z-d o l e r i t e (S 319) which forms the transition between the typical quartz-dolerite and much less basic rocks in the Glenashdale sill at about 60 feet from the base is particularly interesting. Under the microscope, it is seen to be less coarse-grained than the normal quartz-dolerite and very rich in the granophyric base. In fact, the ophitic or sub-ophitic texture has, to a great extent, given place to the granophyric. There is no fresh pyroxene. Instead, chlorite/

chlorite and idiomorphic, fibrous, brown hornblende are present. The lath-shaped labradorite is albitized and replaced partly by calcite. In addition, the abundant coarse micropegmatite of the mesostasis seems to encroach on the plagioclase with apparent obliteration of the latter's boundaries and it is observed in some cases that the felspar of the intergrowth is optically continuous with that at the margins of the lath indicating simultaneous crystallization from the magma. Besides micropegmatite, some areas of intergrowth free of any quartz and made up only of felspar suggest microperthite. Interstitial quartz is fairly high in amount. Iron-ore is more or less skeletal. Thus, all the above-mentioned characters, not excluding the formation of pyrogenetic hornblende, point to an acidification of the quartz-dolerite.

Another rock type comparable with the former comes from the centre of the Creag Dubh sill on the S shore of Whiting Bay. It is a S p h e r u l i t i c q u a r t z - d o l e r i t e (S 314) with no fresh ferromagnesian mineral but abundant relatively clear albitized plagioclase in a turbid typically spherulitic matrix, the fully developed spheres being composed of alkali-felspar - soda-orthoclase - and/

and occasionally containing very small laths of multiply-twinned albite. The iron-ore is finely granular and also skeletal and apatite is very frequent (Plate VIII, fig.1). Similar rock types containing, in addition, partially digested xenoliths of fine-grained basalt and constituted of skeletal and rod-like iron-ore (e.g. W 138) are encountered in the Auchencairn sill. Spherulitic structure in sub-basic rocks is, as a rule, definitely rare and in the present instance it is not unlikely that it is due to mixing of a rather viscous acid magma in the magma chamber with a basic magma.

These types appear to be analogous to, though not exactly identical with, the basic craignurites of Mull.

Hybrids: A few rock types of more or less intermediate composition are comprised under this category and, because of the difficulty of further subdividing them into exact compositional groups, are dealt with under a few sub-headings.

'Thorough' hybrid: Most of the rock types that lie close to and on either side of the central band of/

of quartz-dolerite and seen grading into less basic rocks towards the flanks of the sills are characterised by a peculiar appearance, viz., having a few dark spots or clots in a very felspathic medium and sometimes containing dark xenoliths. From a microscopic study they are found to correspond to no normal igneous rock type - hence their nomenclature. One such from the Glenashdale sill is rather fine-grained and blackish grey in colour with a specific gravity of 2.71 while the adjoining quartz-dolerite has 2.79. In thin section (W 12), one notices that the rock is the result of mixing of (i) a pyroxene, plagioclase- and iron-ore-bearing material and (ii) a micropegmatite-bearing rock. The rock shows hornblende, a little biotite, some pyroxene, plagioclase and iron-ore in a very abundant granophyric mesostasis (Plate VIII,fig.2). Hornblende is very conspicuous as idiomorphic, irregular or rather rounded crystals with a red-brown tint and little or no pleochroism, no cleavage but very strong dispersion. There is no doubt at all that here it is a hybrid mineral formed from a contaminated magma. Characterised by lack of form and cleavage, the crystals of biotite exhibit pleochroism from

yellow/

yellow-brown to blood red. Augite and hypersthene are present. Besides some dusty brown limonite, iron-ore occurs as small euhedra and fine granules. In places, it is very skeletal and dusty. It is less in amount than that in the quartz-dolerite.

The plagioclase with its rather low relief seems to grade into the clear felspar of the mesostasis. It occurs as squarish laths commonly untwinned and where twinned, generally singly, the twinning in such cases being superimposed on the zoning inherent in the crystals. Its 2V almost invariably is 82° over X indicating a constant composition of Ab_{72} An_{28} and proving it to be basic oligoclase.

The abundant mesostasis which is characteristically granophyric shows the considerable mechanical disintegration of the sub-ophitic texture effected in the rock. It is conspicuous by its clear and pellucid character and its apparent insensible gradation to the plagioclase. It is made up mostly of micropegmatite, the word being used here in the broad sense to include albite as a component of the intergrowth. In fact, there is little or no dusty type of alkali-felspar. Quartz, besides that in the intergrowth, is commonly interstitial. Apatite is very frequent and

what/

what is more, zircon also occurs as an accessory. Some members belonging to this rock type contain, in addition, partially digested xenoliths of fine-grained basalt.

Very leucocratic hybrid: In the sills, this rock forms the outward flanks of the 'thorough' hybrid. It (Ar 340) has definite affinities to quartz-dolerite in having a rough glomeroporphyritic or sub-ophitic texture besides the granophyric. It differs from the type just described in being much poorer in ferromagnesian minerals - hornblende and biotite - and free from pyroxene and in having a higher proportion of coarse micropegmatite to plagioclase.

All these different hybrids thus afford conclusive proof of the association of two contrasting types of mineral assemblages.

Next in the series, there appears to be a short gap since no rock type connecting the intermediate type of doleritic parentage just described with the type to follow, viz., an intermediate 'normal' craignurite of a characteristic and distinctive mode of crystallization.

Intermediate 'normal' craignurite:

As/

As observed by Tyrrell (1928, p.141), rocks showing the characteristic texture and mode of crystallization of craignurites are definitely rare in Arran. Still, by virtue of their composition and mode of occurrence as members of composite and related intrusions some rocks of this area fall under the category of craignurite which, as described here, corresponds well with that of the 'normal' intermediate type of Mull.

This rock type occurs as definite bands in the sills. In handspecimen, it is fine-grained and light grey-coloured with hardly any recognisable constituents. Under the microscope, it (W 239) consists of a few microporphyritic crystals of plagioclase in a network of long narrow prisms of altered augite, skeletal crystals of acid plagioclase and iron-ore set in a fine-textured base (Plate VIII. Fig.3). The microporphyritic plagioclase is basic oligoclase to acid andesine sometimes exhibiting undulose extinction. The plagioclase of the matrix is oligoclase or even albite-oligoclase occurring as aggregates of crystals. The acicular pyroxene is characteristic. It is never fresh being pseudomorphed by chlorite and occasionally/

occasionally also by limonite. The alteration has disengaged some iron-ore seen as numerous rods and strings of leucoxene moulded on the narrow prisms. Primary iron-ore is invariably skeletal with a variety of shapes suggestive of thorough reaction. The total amount of the ore is quite considerable.

The matrix is crypto- or microcrystalline and made up mostly of dusty untwinned alkali-felspar - soda-orthoclase or albite. Interstitial quartz is very common. No micrographic intergrowths, unlike in the Mull rock, are discernable. Apatite is unusually high in amount. Zircon is occasionally present. In several cases (W 43 etc.) very large vesicles of calcite are met with. Veining by acid felsitic material and incipient hybridization (Ar 440) are fairly common. The absence of any fresh ferromagnesian mineral, the abundance of chlorite and magnetite along with the very high proportions of alkali-felspar and interstitial quartz are features of this rock type; the general richness in calcite and the abundance of apatite for an accessory - all point to the rock being abnormal. It is this rock type that constitutes the entire mass of the two thin sills - North Kiscadale sill and/

and Gortonallister sill - in the eastern part of the area.

Sometimes, as in the Creag Dubh sill, the highly contaminated felsite (S 316) exhibits a typical spherulitic structure (Plate VIII, fig.4) and felsitic texture, the crystallization characteristic of craignurite being not developed. Again, several quartz-dolerites and quartz-basalts on extensive acidification give rise to rather intermediate types which while still partly retaining their original characters very rarely develop anything like a skeletal mode of crystallization. Considering all these variations in the intermediate group and the rather wide departures that the members of this group exhibit from the so-called 'normal' craignurite, they are all referred to as hybrid rocks with close affinities to craignurite. In other words, the 'normal' craignurite, according to the author, is but one of the many facies of crystallization from a contaminated magma of approximate intermediate composition.

Lastly, the occurrence of relics of digested xenoliths of quartz-dolerite in these intermediate craignurite rocks has to be mentioned (S 318). The contact between/

between the xenolith and the enclosing rock is not at all sharp, a gradational relationship between each other being universal. The rock which is a contaminated felsite is characterised by the hybrid mineral - hornblende - and contains skeletal iron-ore and drusy and vein-like quartz in unusual abundance which has been successful in impressing a general microgranitic texture on it. This sort of a change in the rock from a felsitic to a microgranitic texture which has been noted by Harker (1904, p.215) is, as remarked by him, due to inclusion of basic material. Further, the rock in question has plenty of apatite and a grain or two of sphene to support the above-mentioned view.

Felsite of craignurite affinities:

This rock and the one to be described next are, by far, the most common types of the area and represent the acid members of the sills. The felsite constitutes almost the entire mass along the Allt Dhepin from 789 O.D. northwards and thus forms part of the Allt Dhepin - Loch na Leirg sill. Most often, relics of slightly darker xenoliths of coarser crystallization are encountered in these rocks (Ar 367 a, W 99) of yellowish-white colour and/

and fine grain. The xenoliths are either of quartz-dolerite or less coarse-grained quartz-basalt and are much acidified containing idiomorphic hornblende, skeletal iron-ore, albitized plagioclase and fairly high proportion of quartz and alkali-felspar with or without micropegmatite. The acid rock as such shows a few microphenocrysts of soda-orthoclase and of albite and albite-oligoclase with 2V mostly 87^{o} to 88^{o} (rarely 90^{o}) over X suggestive of An_{15-19}, in a minutely-crystalline, very abundant, turbid, felspathic base. Ferromagnesian element is represented by a little chlorite and disseminated scrappy iron-ore. Interstitial and drusy quartz abounds. Apatite is an important accessory.

G r a n o p h y r e o f c r a i g n u r i t e a f f i n i t i e s:

The former type grades into this one by its having a granophyric instead of a felsitic texture and by containing micropegmatite in increasing amounts. The granophyre, well exposed on the Loch na Leirg plateau and to the SE of Urie Loch, is, in handspecimen, an aphanatic flesh-coloured rock with some greenish streaks and clots. In thin section, it (Ar 374) contains microporphyritic crystals/

crystals of quartz rounded and corroded with the formation of a green corrosion border as also indented by the groundmass material and of albite-oligoclase with rectangular outlines, the mineral being in some places optically continuous with the felspar of the intergrowth. Chlorite and limonite are pseudomorphous and big crystals of skeletal leucoxenized iron-ore are present. Crystalline hematite is occasionally seen. The matrix shows variation in the coarseness of the graphic intergrowth (Plate IX, fig.1). Clear albitic felspar and quartz, bleb-like and vermicular, are the invariable constituents. Apatite and zircon are the accessories. Xenoliths of basic rock are not uncommon in this type of acid rock.

The petrographic account, thus brings to light the wide variation in the rock types of the sills, from the basic to the acid end.

(b) <u>Tighvein and Sguiler Intrusions</u>:

Because of their petrographical peculiarities these intrusions are treated separately here. A vast majority of the rocks of the Sguiler intrusion are characterised by a rather coarse grain and a pronounced black/

black and white mottling. They correspond with more or less similar rock types from Mull, viz., quartz-gabbro and augite-diorite which are easily distinguished from the relatively much finer-grained and markedly dark grey quartz-dolerite of almost identical composition. Likewise, the large acid intrusion which forms part of the Tighvein plateau is of a light greyish-yellow minutely granular microgranite and corresponds to the granophyric associate of the quartz-gabbro of Mull. But, to describe the rocks of these two intrusions as widely different from those treated in the previous pages would not be justifiable. A detailed account of the different rock types starting from the basic to the acid is set forth below.

Q u a r t z - a u g i t e - d i o r i t e (almost invariably xenolith-bearing): This is the commonest rock of the Sguiler intrusion and is well exposed in the region between Sguiler (1332 O.D.) and Urie Loch and also to the SE of the latter. It (S 265) is light grey in colour, coarse-grained and has a mottled aspect. The microscope shows numerous euhedral rectangular and columnar crystals of plagioclase with short prisms of pyroxene and euhedral and skeletal iron-ore embedded in an abundant mesostasis of turbid/

turbid and clear alkali-felspar and quartz which combine to form a micrographic intergrowth (Plate IX, fig.2). Besides, the rock has a xenolith of fine-grained quartz-dolerite. The contact with the xenolith is sharp. The sub-ophitic texture of the latter has given place to granulitic. Its augite and rhombic pyroxene occur as recrystallized prisms. Hornblende and biotite are present, though in minute amount. The twinning in the plagioclase is mostly obliterated and the mineral albitized as also replaced along the periphery of the laths by coarse micropegmatite. Titaniferous iron-ore occurs as recrystallized grains. Apatite is unusually and significantly abundant in the form of large crystals, a fact referred to by Nockolds (1933) in connection with his studies on contaminated rocks, and indicates preferential absorption of volatiles by the xenolith. In almost every respect the xenolith has been acidified.

In the enclosing diorite the elongated plate-like plagioclase which has a R.I. slightly higher than that of Canada balsam is occasionally zonal and shows undulose extinction very frequently. It has a considerable variation in composition as judged by its 2V values which are mostly

84°/

84° over Z to 87° over X indicating a range of An_{36-45}. Two different twinned crystals gave rather widely contrasting values, one with 82° over X and the other with 79.5° over Z suggesting compositions respectively as An_{32} and An_{47}. Thus, it is clear that the plagioclase is all andesine varying ffom its very sodic to its very calcic end, the majority of it roughly corresponding to $Ab_{62.5}An_{37.5}$.

The pyroxene which has a feeble green tint occurs as short prisms or as columns with salite striation and with curved cracks suggesting movement while in growth. Studies on its 2V in twenty different grains showed that it varied very little, being mostly $50.0^{\circ} \pm 1.5^{\circ}$ over Z, only one value being 47°. $Z \wedge c$ ranged from 18° to 43°. Thus, it is undoubtedly augite. Rhombic pyroxene is almost an accessory, only one grain of enstatite with 2V 68° over Z and $Z \wedge c$ 2.5° having been noticed. Chloritization of the pyroxene is common. There is idiomorphic hornblende, green-brown in colour, moderately pleochroic and with strong dispersion and $Z \wedge c$ 16° to 20°. The same is, in places, fibrous and rather dark brown - presumably iron-rich - being associated with iron-ore. Ilmenite-biotite intergrowths are not uncommon. Titaniferous iron-ore is partly granular and/

and euhedral and partly skeletal with typical 'honeycomb' structure and is often leucoxenic. The amount of chlorite and iron-ore in the rock is definitely greater in the vicinity of the xenolith than in the rest of the section.

The mesostasis is very abundant and made up of widely-dispersed, relatively-clear or dusty areas, the former of rather coarse intergrowth between clear albite and quartz and the latter of cryptopegmatite constituted of dusty alkali-felspar and quartz. The former appear to encroach upon and 'eat' into the latter whose outline is patchy. Probably they belong to two different magmas- granophyre and gabbro respectively - represented here as being due to interaction and thereby incorporation of the latter by the former. Quartz, which is on the whole abundant, is in part corroded and replaced by micropegmatite and in part recrystallized as hexagonal and irregular crystals. This contaminated rock type thus compares very well with its allies from Camphouse in Ardnamurchan and from the Gaodhill mass in Mull, though these rarely seem to contain xenoliths.

Variants of the type described above include G r a n o p h y r i c q u a r t z - a u g i t e - d i o r i t e s, richer in acid material than the former and/

and rocks wherein the xenolithic member is a finer-grained quartz-basalt instead of the quartz-dolerite. <u>S p h e r u l i t i c   q u a r t z - a u g i t e - d i o r i t e, with xenoliths of quartz-basalt</u>: This abnormal rock type (W 236) (Plate IX, fig.3), though essentially similar to its non-spherulitic analogue is so enriched in the acid material and its acid and basic constituents so contrasted as to form a class by itself. The marginal parts of the xenolith are resorbed and by reaction have been rendered typically craignuritic in texture. They consist of the usual string-like and rod-like iron-ore, alongside a few euhedra and thin platy pyroxenes, besides some hornblende. The conspicuous feature here is the lack of apatite. On the other hand, the diorite is very rich in apatite and is constituted, besides plagioclase, of big spherulitic areas which have here and there been broken up and veined by albite and quartz. Also, along the contact with the xenolith recrystallization has resulted in the assumption of a microgranitic texture with numerous subhedral grains of quartz and with hornblende in between.

Mention has to be made here of the occurrence

in/

in the Sguiler intrusion of acidified felspathic quartz-dolerites some of which are rather spherulitic and also of typical craignurite and even of craignurite-felsite - all exactly like those from the composite and multiple intrusions.

B a s i f i e d   g r a n o p h y r e, sometimes with xenoliths of quartz-basalt: This represents the sub-acid division of rocks. Where free from xenoliths, it (S 261) is seen to contain short, stout laths of zoned oligoclase-andesine. Its pyroxene is rarely fresh, pyrogenetic hornblende being developed. Iron-ore occurs as big crystals, euhedral or nearly so. The abundant mesostasis is of micropegmatite and quartz. Apatite is abundant for an accessory. Zircon is also present. The xenoliths are, as usual, partly acidified.

Thus, from the rock types encountered, it is evident that there is considerable variation towards the acid end in the Sguiler - Urie Loch basic mass, a feature which, according to Richey (1924, p. 217), is common to the Gaodhill mass in Mull.

M i c r o g r a n i t e: This rock (Ar 380) which forms the acid intrusion, as seen just NE of Tighvein (1497 O.D.), is light greyish-yellow, minutely granular and has sporadic rectangular/

rectangular microphenocrysts of felspar. Under the microscope, the typical micrographic texture can be seen, the bulk of the crystals of quartz and felspar being allotriomorphic (Plate IX, fig.4). The microporphyritic felspar is partly albite-oligoclase and partly soda-orthoclase, both with a kind of fingerprint structure like the one figured by Smellie (1912-13). The rest of the turbid felspar is mostly soda-orthoclase or albite. Anhedral quartz is abundant and dovetails the felspar, suggesting a micrographic intergrowth. Pale yellow pseudomorphous chlorite and a few specks of iron-ore are the sole mafic constituents. Zircon is a prominent accessory.

The frequent occurrence of xenoliths in the Sguiler - Urie Loch mass and their slight modification by the enveloping magma points to the fact that contact hybridization as between a solid or a quasi-solid rock and a liquid magma has been very little or rather negligible and where it did take place to some extent, obviously much hindered by lack of superheat, a fact recognised by Bowen (1928).

(iii)/

(iii) Chemical and Volumetric Composition.

Two of the rock types above described, viz., quartz-basalt and quartz-augite-diorite have been analysed for this paper and the analyses are presented here along with those of quartz-dolerite and craignurite-felsite from the area which are quoted from the Arran Memoir. Each of these four analyses is compared with two or three similar ones from the Western Isles. The volumetric compositions of the four analysed rocks and three others from the composite intrusions in the area have been determined with the help of the Dollar Integrating Micrometer and are correlated with the corresponding norms from the analyses.

The modes (volume %) of the quartz-basalt and quartz-dolerite are as follows:-

TABLE I.

MINERALOGICAL COMPOSITION (VOLUME PERCENTAGE).

see p. 27

	Quartz-basalt.	Quartz-dolerite.
Pyroxene	15.6	23.4
Iron-ore	30.2	10.6
Plagioclase	18.3	28.7
Mesostasis)		30.1
Quartz -free)	20.4	4.6
Apatite	...	1.9
Dolomite	15.5	0.7

The quartz-dolerite is richer in all the felsic constituents and also pyroxene as compared with the quartz-basalt which has higher proportions of iron-ore indicating its original mafic nature, and of dolomite which shows the influence of volatiles of the enveloping magma in replacing the pyroxenic and felspathic material. The mode of quartz-basalt when freed from dolomite and recalculated to 100, shows:-

Pyroxene	18.5
Iron-ore	35.7
Plagioclase	21.7
Mesostasis	24.1

confirming the validity of the remarks made above.

The analyses of the two rock types along with those of the comparable ones are given in Table II together with their Niggli values.

That the quartz-basalt is more acid than the other two becomes evident from its higher <u>si</u> and its positive <u>qz</u>. Likewise, the quartz-dolerite is much more acid than that from Ardnamurchan and more or less like the basic craignurite from Mull, though it is even slightly less basic than the latter, as judged by its higher <u>al</u> and <u>alk</u> values and lower <u>c</u> and <u>mg</u> values. But its/

its lower qz value is rather anomalous and is probably to be taken as due to the greater amount of alkalies to be saturated. Thus, the rock is, strictly speaking, a felspathic variety of basic craignurite, taking that from Mull as the standard type.

TABLE II. CHEMICAL COMPOSITION OF TERTIARY BASIC ROCKS.

	1	A	B	2	C	D
SiO_2	49.66	49.76	50.10	54.00	55.82	50.67
Al_2O_3	13.48	14.42	12.08	13.09	11.47	11.89
Fe_2O_3	2.68	3.95	4.35	3.53	3.68	8.61
FeO	9.81	7.77	11.18	8.45	7.66	7.08
MgO	3.82	5.30	3.93	3.49	4.08	3.94
CaO	7.64	10.22	8.85	5.55	7.88	7.75
Na_2O	2.32	2.49	3.06	3.27	2.53	2.94
K_2O	1.20	1.83	0.96	1.80	2.00	1.50
H_2O +	0.56	1.03	1.01)	)- 2.97	1.88	0.77
H_2O -	0.73	2.04	0.53)		0.66	1.05
CO_2	5.94	0.06	trace	0.45	0.08	0.21
TiO_2	1.93	0.94	2.98	2.83	1.62	2.88
P_2O_5	0.23	0.21	0.17	0.31	0.23	0.55
MnO	0.22	0.20	0.25	0.37	0.40	0.20
(Ni,Co)O	..	..	..	..	0.04	..
BaO	..	0.04	0.05	0.12	0.03	..
FeS_2	..	0.04	0.28	0.14	0.09	0.02
Fe_7S_8	..	..	0.02	..	..	..
SO_3	..	..	..	..	..	0.38
Organic matter.	..	..	..	..	..	0.01
	100.22	100.30	99.80	100.07	100.18	100.47
			Niggli Values			
si	141.5	123.0	129.1	162.4	162.0	135.7
qz	+ 7.1	- 12.6	- 7.3	+ 9.7	+18.8	- 4.7
al	22.5	20.9	18.3	23.1	19.5	18.6
fm	45.7	43.2	48.1	45.7	45.1	49.0
c	23.2	27.0	24.5	18.0	24.6	22.3
alk	8.6	8.9	9.1	13.2	10.8	10.1
ti	4.1	1.8	5.7	6.3	3.5	5.8
p	0.2	0.1	0.1	0.4	0.3	0.7
k	0.26	0.33	0.17	0.28	0.34	0.25
mg	0.35	0.45	0.31	0.30	0.40	0.32

1: (W 74) Quartz-basalt from the Auchencairn sill, 100 yards W of Sheepfold by the side of Kingscross Burn, Whiting Bay, Arran. Anal: W. H. Herdsman.

A: (20581, Lab.No.669) Basalt, Staffa type. Lava which encloses Macculloch's Tree, Rudha nah-Umaha, Mull. Anal: E. G. Radley: Quoted from Mull Memoir, 1924, p.17.

B: (22819, Lab.No.788) Quartz-dolerite, Talaidh type, Cone Sheet, Centre 2, Ardnamurchan. Quarry west of Crofts at Tom a' Chrochaidh, ½ mile E. of Kilchoan: Anal: B. E. Dixon: Quoted from Ardnamurchan Memoir 1930, p.82.

2: (24459, Lab.No.828) Quartz-dolerite from the Garbad sill, gorge in Allt Dhepin, 1/3 mile ENE of 873 feet O.D. Cnoc an Fheidh, Whiting Bay, Arran. Anal: E. G. Radley: Quoted from Arran Memoir 1928, p.147.

C: (16800, Lab.No.412) Basic craignurite, Cone Sheet, Allt an Dubhchoire, 1220 yards above junction with Scallastle River, Mull. Anal: E. G. Radley. Quoted from Mull Memoir 1924, p.19.

D: (21253, Lab.No.737) Quartz-dolerite, Ben Hiant intrusion, Centre 1, Ardnamurchan, Cliffs 700 feet above Shore, Camas nan Clacha Mora, Ben Hiant. Anal: B. E. Dixon. Quoted from Ardnamurchan Memoir 1930, p.82.

The C.I.P.W. norms of the basalt and dolerite are given in Table III.

TABLE III.

NORMS.

	1	2
Quartz	20.04	10.26
Orthoclase	7.23	11.12
Albite	19.39	27.77
Anorthite	...	15.29
Corundum	8.36	...
Diepside	...	(3.36 (1.58 (1.70
Enstatite	9.50	7.00
Hyperethene	13.07	7.00
Magnetite	3.71	5.11
Ilmenite	3.65	5.32
Apatite	0.34	0.68
Calcite	13.30	1.00
	98.59	97.19
Water	1.29	2.97
	99.88	100.16

When each of these is compared with the corresponding mode, it is seen that in the quartz-basalt most of the normative pyroxene is represented as iron-ore while in the quartz-dolerite where there is very close agreement between the norm and the mode, part of the quartz, the entire orthoclase and/

and about a third of the total albite and anorthite having been represented as mesostasis. As noted earlier, the plagioclase of this type has an almost constant composition of $Ab_{45}An_{55}$ and its mesostasis represents a uniform cryptographic intergrowth of alkali-felspar and quartz with little free alkali-felspar. Thus, after allotting the albite and anorthite and a little orthoclase of the norm in the respective proportions to make up the 29.4% by volume of plagioclase, and eliminating the amount of free quartz from the normative value, is obtained the composition of the mesostasis: $Or_{9.8}$ $Ab_{16.1}$ $Q2_{5.6}$, or in other words, $Fel_{25.9}$ $Q_{5.6}$, or expressed in whole numbers as Fel_{82} Q_{18}.

A study of the Niggli values of the two types under consideration and of the related rocks, and their comparison with those of some of the magma types described by Niggli (1936) shows that while the values of the Arran and Mull basalts to a great extent resemble those of the "normalgabbrodioritisch" and "miharaitisch" magmas respectively, the Ardnamurchan quartz-dolerite (B of Table II) differs in not fitting into any of the magma types. Even in the former two there are some discrepancies, the Arran rock being very low in mg and the Mull one very high in/

in k for the corresponding magmas. On the whole, the rather close correspondence of the Niggli values of the Arran quartz-basalt to one of the magma types may perhaps be taken as an indication of its relatively negligible amount of contact hypabyssal acidification consequent probably upon its occurrence almost always as xenoliths. In the case of the quartz-dolerite, or rather felspathic basic craignurite, from Garbad sill, Arran, it is seen that its alk value is aberrantly high and along with the rest does not fall into any of the normal magma types, though the nearest approach is to "si-gabbrodioritisch" magma. The basic craignurite of Mull belongs to the same magma type but does not correspond exactly. It has a very high k value and a rather low mg value indicating its enrichment in alkalies, preferably potash, with a concomittant reduction in the proportion of magnesia. The Ardnamurchan quartz-dolerite (D of Table II) is, likewise, conspicuous by having a very low mg value for the magma type which it appears to belong, viz., "normalgabbrodioritisch," and thus appears to represent a less hybridized basic magma as compared with 2 and C. The supposedly intermediate rock, quartz-augite-diorite, here with all its augite replaced by chlorite has its chemical and mineralogical composition shown in Table IV.

TABLE IV. CHEMICAL COMPOSITION OF TERTIARY INTERMEDIATE ROCKS.

	3	A	B
SiO_2	52.49	53.67	56.22
Al_2O_3	13.36	15.47	12.45
Fe_2O_3	1.23	3.24	3.09
FeO	11.35	7.25	7.58
MgO	1.96	4.90	2.78
CaO	6.24	8.28	5.93
Na_2O	3.18	2.77	3.82
K_2O	1.42	0.80	2.67
H_2O +	1.24	0.23	1.35
H_2O −	0.30	1.73	0.44
CO_2	5.06	0.04	0.05
TiO_2	1.21	1.28	2.74
P_2O_5	0.84	0.21	0.50
MnO	0.32	0.31	0.43
(Ni,Co)O	..	0.04	nt.fd
BaO	..	0.04	..
	100.20	100.26	100.09

N i g g l i V a l u e s

	3	A	B
si	163.8	144.4	177.0
qz	+ 14.2	+ 9.6	+ 10.6
al	24.5	24.4	22.8
fm	42.3	43.0	40.8
c	20.8	23.9	19.8
alk	12.4	8.7	16.6
ti	2.8	2.6	6.3
p	1.1	0.2	0.5
k	0.23	0.16	0.31
mg	0.21	0.46	0.31

3

MODE:		Mode freed from dolomite and recalculated to 100.
Plagioclase	32.0	34.9
Chlorite	8.9	9.7
Iron-ore	8.1	8.8
Mesostasis	33.9	37.3
Quartz	6.5	7.1
Apatite	2.0	2.2
Dolomite	8.6	

C.I.P.W. NORM

Quartz	17.40
Orthoclase	8.34
Albite	26.72
Corundum	6.63
Enstatite	4.90
Hypersthene	18.48
Magnetite	1.62
Ilmenite	2.28
Calcite	11.10
	97.47
Water	2.38
	99.85

<u>3</u>: (W162) Quartz-augite-diorite, SE corner of Urie Loch, Lamlash, Arran. Anal: W. H. Herdsman.

<u>A</u>: (24455, Lab.No.825) Diorite of Central Ring Complex, quarry at bridge over Allt nan Calaman, at road side, Gleann an t-Suidhe, Arran. Anal: E. G. Radley. Quoted from Arran Memoir 1928, p.192.

<u>B</u>: (18461, Lab.No.440) Glen More Ring Dyke, Allied to Craignurite, Fully ¼ mile SSE of Cairn on Cruach Choireadail, Mull. Anal: E. G. Radley. Quoted from Mull Memoir 1924, p.29.

It is evident that the quartz-augite-diorite is more acid with its higher si and alk values and lower c value than the diorite of the Arran Central Ring Complex and slightly more basic - higher fm and lower si and alk values - than the craignuritic rock from the Glen More ring-dyke. It has, however, a much higher p value than the other two. Comparison of the same with the basic craignurite of Mull (C of Table II) shows that they are more or less identical, though the former is slightly less femic and more alkali-rich. In short, it is very similar to the quartz-dolerite - or the felspathic basic craignurite - of the area but for its relative paucity in femics and slightly greater amount of free quartz.

The norm of the quartz-augite-diorite wherein the CO_2 is in excess of the 1:1 proportion in the dolomite, when compared with the corresponding mode shows almost the same quantity of dolomite and apatite put together. From the average composition of plagioclase in the rock determined as $Ab_{62.5}$ $An_{37.5}$ and allotting part of corundum to form chlorite etc., the composition of the mesostasis, roughly, turns out to be $Or_{7.5}$ $C_{2.0}$ $Q_{16.5}$ or nearly, $Fel_{17.4}$ $Q_{16.5}$ or/

or simply, $Fel_{52}\ Q_{48}$ whose relative proportion of quartz to felspar is higher compared to that in quartz-dolerite, thereby indicating the potent influence of the acid quartz-rich granophyre magma on the originally basic magma and thus corroborating its hybrid nature.

Further, though most of its Niggli values almost agree with those of 'lamprodioritisch' sub-magma in the 'dioritische' group of magmas, thus supporting Nockolds's (1934) observation of the production of normal rock types by processes of contamination, still the fact that its <u>mg</u> value is very much lower than the standard value, viz., 0.5, is of great significance and one due to the breakdown of the originally normal magnesia-rich basic magma and its hybridization by acid material. In a similar manner, while all the Niggli values of the diorite of the Arran ring complex fall well within the range of 'normalgabbrodioritisch' magma, those of the allied rock type from Glen More ring-dyke do not at all fit into any of the magma types. This fact, while it seems to confirm the abnormal nature of the craignuritic rock from Mull, further sheds light on the observation that a presumably normal rock such as the diorite of the Arran ring complex does not exclude the possibility of the operation of hybridization processes in its production.

Next/

Next, in order of decreasing basicity are the very contaminated rock types - 'thorough' hybrid and 'normal' craignurite - whose modes as determined are given below:

TABLE V.

MINERALOGICAL COMPOSITION (volume %)

	'Thorough' hybrid	Intermediate 'normal' craignurite.
Plagioclase	18.3	12.8
Pyroxene	8.8	14.3
Hornblende and biotite	7.4	...
Iron-ore	7.1	10.4
Quartz	6.4	4.7
Mesostasis (apatite etc. included).	52.0	57.8

Both of them appear to be more or less of the same composition, though the craignurite seems slightly more basic than the other. But a comparison of the 'thorough' hybrid with the quartz-dolerite reveals some interesting facts. While the latter contains 10.6% iron-ore and 23.4% pyroxene, in the former there is only 7.1% iron-ore, the remaining 3.5% of which probably along with/

with an equal amount of pyroxene and a little silica and alumina having tended to form hornblende and biotite. As for the pyroxene, only 8.8% of it is seen as such with, again, probably half of this amount in hornblende and biotite. Thus, out of a total of 34.0% femics in the quartz-dolerite, there is only 23.3% in the 'thorough' hybrid, the remaining 10.7% having been replaced by salic material. Likewise, the proportion and the anorthite content of the plagioclase in the hybrid is less - An_{28} compared with An_{55} of quartz-dolerite. On the other side of the picture there is a greater amount of free quartz and great enrichment in the amount of mesostasis which by virtue of its coarse grain and quartz- and albite-rich nature, as compared with the quartz-poor and alkali-felspar-rich intergrowth of the quartz-dolerite, speaks of the paramount influence of the acid granophyre magma on the partially contaminated magma of basic craignurite composition. Further, as will be seen, the amount of apatite is directly proportional to the amount of hybridization since in the quartz-dolerite it is 1.8%, in the quartz-augite-diorite 2.0% and in the 'thorough' hybrid where it could not easily measured, it is is definitely of the order of 3%. In other words, volatiles greatly influence hybridization.

The acid components of the intrusions - craignurite-felsite and microgranite - have the following mineralogical composition.

TABLE VI.

MODES.

	Craignurite-felsite	Microgranite.	
Microporphyritic acid plagioclase	8.0	Felspar (as laths)	9.7
Microporphyritic soda-orthoclase	10.5	Chlorite	1.2
		Iron ore	4.6
		Quartz(free)	29.2
Pyroxene and chlorite	3.2	Matrix	55.3
Iron ore	3.5		
Quartz (free)	10.1		
Mesostasis	60.6		
Calcite	4.1		

The two rocks are more or less similar in their mineralogical constitution, the microgranite, unlike most other granites, containing a high proportion of iron-ore for its normal composition and thus proving its contaminated/

contaminated nature. Also, compared to the felsite it has less felspar - though of the same composition, viz. albite-cligoclase and soda-orthoclase - and more free quartz and seems to bear support to Tyrrell's (1928, p. 145) view as being the most fully crystallized representative of the partial contaminated magma which gave rise to the acid craignurites and craignurire-felsites.

The analyses of craignurite-felsite and two other related types as also the norm of the felsite are given in Table VII.

TABLE VII. CHEMICAL COMPOSITION OF TERTIARY ACID ROCKS

	4	A	B
SiO_2	71.58	71.30	68.42
Al_2O_3	12.20	11.24	13.54
Fe_2O_3	1.51	1.80	2.53
FeO	1.77	2.84	2.02
MgO	0.50	0.61	0.22
CaO	1.98	1.56	2.13
Na_2O	2.83	3.44	5.12
K_2O	3.86	4.66	4.08
H_2O +	0.76	1.04	0.15
H_2O −	1.10	0.39	0.25
CO_2	1.07	..	0.06
TiO_2	0.44	0.58	0.81
P_2O_5	0.13	0.22	0.38
MnO	0.31	0.31	0.10
BaO	..	0.07	0.03
FeS_2	..	..	0.05
	100.04	100.06	99.89

Niggli Values

	4	A	B
si	396.3	364.4	314.0
qz	+ 181.1	+ 135.6	+ 75.6
al	40.0	34.3	36.7
fm	19.6	24.9	18.2
c	11.6	8.6	10.5
alk	28.8	32.2	34.6
ti	2.0	2.1	2.7
p	[illegible]	0.5	0.7
k	0.47	0.43	0.35
mg	0.20	0.18	0.09

4

C.I.P.W. NORM

Quartz	37.74
Orthoclase	22.80
Albite	24.10
Anorthite	2.22
Corundum	2.55
Enstatite	1.20
Hypersthene	1.85
Magnetite	2.10
Ilmenite	0.92
Apatite	0.33
Calcite	2.40
	98.21
Water	1.86
	100.07

4: (24458, Lab.No.827) Felsitic end member of the craignurite series from the Allt Dhepin sill, at Waterfall in Allt Dhepin near 786 feet O.D., half a mile SSW of Loch na Leirg, Whiting Bay, Arran. Anal: E. G. Radley. Quoted from Arran Memoir 1928, p.147.

A: (16803, Lab.No.394) Granophyre allied to craignurite, Cone Sheet, Craignure Bay, shore 50 yards NNW of U.F.C. Manse. Anal: E. G. Radley. Quoted from Mull Memoir 1924, p.20.

B: (22820, Lab.No.789) Augite-granophyre, Major intrusion, Centre 2, Ardnamurchan, 800 yards S 30° E of Grigadale. Anal: B. E. Dixon. Quoted from Ardnamurchan Memoir 1930, p.84.

It will be seen that the allied granophyres from Mull and Ardnamurchan are more basic than the Arran rock. The norm and mode of the felsite coincide well as regards the quantities of iron-ore, pyroxene etc. though calcite is actually rather high. After allotting albite and anorthite between 8% of the modal plagioclase in the proportion of 82.5 : 17.5 and albite and orthoclase between 10.5 for the soda-orthoclase in the proportion of 70 : 30, the composition of the micropegmatite is deduced to be $Fel_{30.1}\ Q_{30.5}$ or, expressed in round figures, $Fel_{50}Q_{50}$. In this connection, it is necessary to recall Vogt's idea of the constancy of quartz-felspar proportions in graphic intergrowths which has been refuted by recent work among others by Schaller (1925) and Fenner (1926, p. 750). The study of the intergrowths in the different rock types of this area has brought to light the wide range of variation in their composition from $Fel_{82}\ Q_{18}$ in quartz-dolerite to $Fel_{50}Q_{50}$ in craignurite-felsite. The author, hence, agrees with Schaller (1925) when the latter says that micropegmatites etc. have been formed by prolonged circulation of mineral-bearing solutions and that their minerals are due to a series of paragenetic transformations.

The/

The craignurite-felsite and the Mull and Ardnamurchan granophyres are conspicuous in having high fm values for their si ranges and do not correspond to any known normal magma types.

(iv) Petrogenesis:

The foregoing detailed petrographic and chemical account, while dealing with several basic and sub-basic hybrid rocks, fails to show any really and strictly normal intermediate rock type. Though Bowen (1928) accounts for the absence of such intermediate types by high fractionation, it is apparent that in the present case there does not exist any straightforward differentiation relation between the different members of the intrusions. In addition, there are the basic xenoliths that definitely demonstrate some stages in the process of hybridization. Hybridization is treated here as belonging to two phases - contact and deep-seated. The latter type which is, by far, the more prevalent is to be seen in all the rocks, the former in their xenoliths and aureoles of contamination.

The course of contact hybridization has been one of transfer of calcic material from the xenoliths to the acid/

acid material and the migration of alkali molecules to the basic material, a process demonstrated under the name of reciprocal reaction by Read (1924) and by Thomas (1922). The presence of fine-grained basalt xenoliths is a common feature in the craignurite-felsite and granophyre of the Allt Dhepin - Loch na Leirg sill. The evidence of reaction followed by mechanical disintegration of xenoliths is always forthcoming in the enrichment of alkali-felspar and of volatiles as calcite, apatite etc. by the basalt besides the skeletal structure impressed on it. Similar phenomena on a much grander scale are exhibited in the xenolithic diorites and granophyres of Sguiler. That here the basalt was shattered and brecciated at the contact when solid and that the relatively acid material then filled up the intervening spaces and was hot enough to produce some solutional and hybridizational effects such as the development of biotite etc. is evident. But the fact that the whole of the solid material could not be incorporated, proves the contention of Bowen (1928) that the superheat in a consolidating magma is meagre and also that the limited assimilation is retarded by hastened cooling processes.

To/

To explain the origin of the range of widely contrasting rock types, it is necessary to invoke two different magmas - basic and acid - which appear to be capable of co-existing in the same magma chamber, though there may be several local reservoirs from which the injection might take place. Here, these two widely distributed magmas would have crystallized out as Talaidh type of quartz-dolerite and felsite respectively, had there been no intercrustal mixing and reaction between them. But the fact that they did not crystallize out as such is an indication of a deep-seated hybridization process. The quartz-dolerite magma has been much contaminated by the acid magma to give rise to what looks like quartz-dolerite but which, in point of fact, is actually a felspathic basic craignurite; to quartz-augite-diorite, similar to the former, though showing greater contamination; and to the basic leidleite which is but its partly glassy representative. Likewise, the felsite magma has been basified, though here not to the same extent as the basic magma was acidified. Its consolidated products - felsites and granophyres of craignurite affinities, contaminated microgranites etc. - wherever they occur, bear testimony for this mode of origin in their richness

in/

in iron-ore and other femic minerals. That the hybridization was undoubtedly of the deep-seated type and also that it was prior to the intrusion of the respective magmas, is proved by the fact that all the consolidated products, though anomalous from chemical and petrographical viewpoints, are perfectly homogenous and in some cases even closely resemble the corresponding normal rock types.

Lastly, the genesis of the 'thorough' hybrid and the intermediate 'normal' craignurite and their variants remains to be considered. The former with the sub-ophitic and granophyric textures in close association, and with pyrogenetic hornblende, is undoubtedly the result of crystallization of a deep-seated contaminated magma. To ascertain the extent to which mingling of the two contaminated primary magmas - quartz-dolerite and craignurite-felsite - took place, the four essential and compositionally-uniform groups of minerals of quartz-dolerite, viz., femics, iron ore, quartz and the rest of salics are grouped together in Table VIII, each with the corresponding ones from the craignurite-felsite in the proportion of 2 : 1.

TABLE VIII/

TABLE VIII

MAGMATIC MIXTURES.

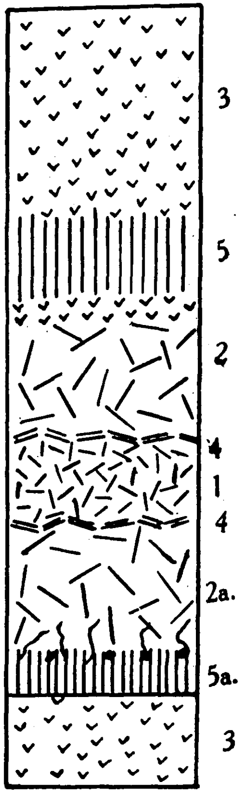
Mineral constituents.	Quartz-dolerite	Craignurite felsite	Result of mixture in the proportion 2:1	'Thorough' hybrid.	Intermediate 'normal' craignurite.
Femics	23.4	3.2	16.7	16.2	24.7
Iron-ore	10.6	3.5	8.2	7.1	
Quartz. (free)	4.6	10.1	6.4	6.4	75.3
Rest of salic minerals	61.4	83.2	68.7	70.3	

It is seen that there is close correspondence between the values of the resulting mixture and those of the 'thorough' hybrid. Thus, it can safely be said that the 'thorough' hybrid is the result of consolidation of a rock magma which is due to intermingling of the two contaminated primary magmas, respectively basic and acid, in the proportion of 2 : 1. That the same explanation of deep-seated mixing in almost the same proportion applies to the so-called intermediate 'normal' craignurite which has more or less the same ratio of femics to salics as in the 'thorough' hybrid is certain though in this case due to/

to the entire reconstitution of many minerals such as acicular pyroxene, skeletal iron-ore and felspar, several additional reactions must have been involved. The very leucocratic dolerites etc. must be of a like origin.

Thus, the existence of a basic and an acid magma and their intermingling in depth could give rise to a wide variety of rock types. But the ultimate source of the two magmas is still a matter of controversy. Harker (1904) maintains that they are complementary differentiates from a single parent magma, while Bailey and Thomas (1924, p. 33) confirming the view further suggest that the basic differentiate was regenerated as a magma by the melting of sunken crystals. But in view of Grout's (1926, p. 549) important calculation that "as a maximum, one tenth of an average basaltic magma may become granite," it becomes difficult to explain so large a volume of acid magma as to dominate the basic in these intrusions. Even granting that such a differentiation did result in a huge volume of acid rock, it is most improbable that there should not be any primary rocks whatever of a composition truly intermediate between the acid and the basic. Hence we are forced to the conclusion that these two/

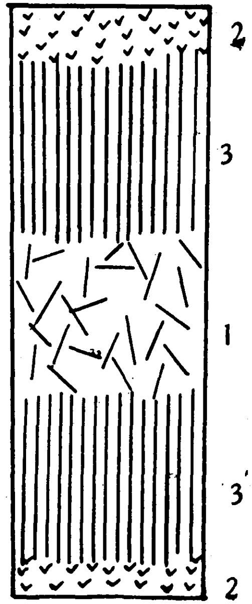
two different magmas could not have been derived from a parent basalt magma by any sort of differentiation whatsoever. In this connection it is interesting to recall similar occurrences such as the composite sill in South Bute studied by Smellie (1912-13), the Sron Bheag composite intrusion in Ardnamurchan studied in detail by McMath (1947) and from outside the British Tertiary Province, e.g. a composite dyke from Eastern Iceland described by Guppy and Hawkes (1925), a contaminated complex dyke at Cape Neddick, Maine, studied by Haffe (1941), Breven dolerite dyke investigated by Krokström (1932), besides dykes of augite-diorite with micropegmatite in Southern India described by Holland (1897), though in the last mentioned case, there is no reference to the intrusions being composite. From these various studies as also from the present one, it becomes clear that the vast volume of acid magma could only have been produced by crustal refusion as advocated by Holmes (1931) and as recently confirmed under the name of rheomorphism by Krokström (1937) from his investigations on the Swedish intrusions. Such a generation of magma must involve some contamination of the basaltic magma and any small amount of incorporation of one by the other should be able to produce the prevalent types of sub-basic and sub-acid composition - felspathic basic craignurite and craignurite-felsite and granophyre.



a

BAOILEIG SILL

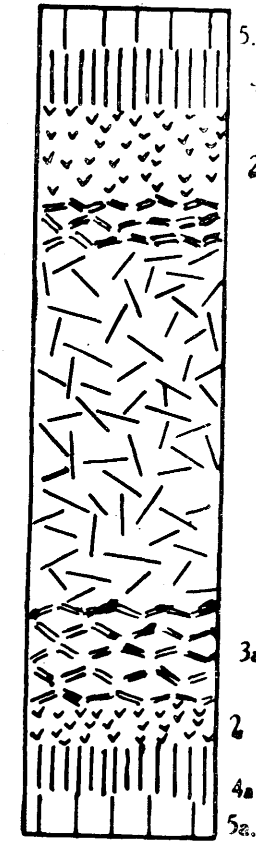
SCALE :- 1 INCH 10 FEET



b

CREAG DUBH SILL

SCALE : 1 INCH 10 FEET



c

GLENASHDALE SILL

SCALE 1 INCH 50 FEET

Fig. 4. Structures of some composite sills.

a. Baoileig Sill

1. Quartz - dolerite, in places vesicular.
2. Thoroughly acidified quartz - dolerite.
2a. The same, veined by felsite.
3. Thoroughly acidified basalt of intermediate craignurite affinities.
4. 'Thorough' hybrid.
5. Felsite of craignurite affinities.
5a. The same, almost glassy at the lower contact and xenolithic at the upper one.

b. Creag Dubh Sill

1. Spherulitic and granophyric quartz - dolerite.
2. Intermediate craignurite.
3. Contaminated spherulitic felsite and felsite of craignurite affinities.

c. Glenashdale Sill

1. Acidified quartz - dolerite (felspathic basic craignurite).
2. Intermediate craignurite, xenolithic.
3. 'Thorough' hybrid.
3a. The same, xenolithic.
4. Felsite of craignuritc affinities.
4a. The same, xenolithic.
5. Non-banded or banded spherultic felsite.
5a. Banded devitrified felsite.

(v) Mechanics of Intrusion:

While as pointed out by Tyrrell (1928, p.141) many of the sill-rocks dealt with here resemble closely those of the Cnoc Carnarch group of composite sills in Skye, the same cannot be said to hold good as far as the constitution and relative arrangements of the components in the sills are concerned. The constitution in the majority of cases is not triple in the sense that a basic member lies on either flank of the acid centre but, much more complex. The time sequence, in other words, the order of intrusion, always seems to obey the general rule, viz., from basic to acid.

From a detailed petrographic study of about twenty microsections from different horizons of the comparatively thin Baoileig composite sill, the arrangement of the rock types in the sill could be represented diagrammatically as in Fig.4a.

Generally speaking, the sill is quintuple like the one in South Bute described by Smellie (1912-13), with a main central mass of acidified quartz-dolerite which on either side has a band of felsite of craignurite affinities which, again, is flanked by thoroughly acidified basalt of intermediate craignurite affinities. The sequence of intrusion/

intrusion is clear and can be explained as follows:

Firstly, the fine-grained quartz-dolerite which has suffered pre-intrusive acidification is injected. This was followed almost immediately by a further acidified quartz-dolerite. Almost in the same phase was injected the highly acidified basalt of intermediate craignurite affinities which both at the top and at the bottom of the sill was chilled exteriorly against the sandstone. More or less simultaneously, the 'thorough' hybrid must have been intruded, eviscerating the central mass of acidified quartz-dolerite. All the above-mentioned intrusions exhibit nowhere any diminution in grain size indicating that each member was sufficiently hot when the succeeding one was injected. At this stage, there seems to have been a slight pause before the final injection of the contaminated acid magma as felsite of craignurite affinities along the planes of weakness between the main central mass of acidified quartz-dolerite and the flanking craignurite took place. This is evidenced by the facts that the basal felsite at its bottom contact becomes fine-grained and very nearly glassy and also that it has picked up along its upper contact with the central mass xenoliths and has been successful/

successful in partially digesting them and at the same time sending veins into the quasi-liquid acidified quartz-dolerite as seen in some specimens (Ar 344 etc.) taken from that horizon. Towards the top, the same component has, probably by contact hybridization with the central sub-basic mass, given rise to a very thin band of rock of intermediate craignurite characters and composition.

Thus, it becomes clear that though the sill is not of any great thickness, still it is characterised by quite a few injections of magma of varying composition, the variation always tending from basic to acid.

An equally complicated story has to be invoked to explain the quintuple constitution of the thin Creag Dubh sill (Fig.4b).

Dr. Tyrrell's extensive collection from the Glenashdale composite sill along with that of the writer has been studied in great detail to elucidate the structure of the sill which is presented diagramatically in Fig.4c.

Broadly speaking, it is at least a seven-component sill. The top and bottom two varieties of felsite are treated together, though they actually represent two definite injections, the felsite of craignurite affinities appearing comparatively/

comparatively more basic. Probably because of its very viscous nature, the later-intruded almost glassy or occasionally spherulitic felsite failed to penetrate the previous one, viz. felsite of craignurite affinities, and only flanked it forming the very top and bottom of the sill with pronounced exterior chilling. When these felsites are thus considered as injections, each separate from the other, as they appear to be in point of fact, the sill actually becomes nine-fold.

The Garbad multiple sill could not be studied in full since it outcrops, for the most part, outside the area chosen for this work. But as far as the study reveals, it exhibits variation in components from as basic a type as olivine-bearing quartz-dolerite through quartz-dolerite, acidified quartz-dolerite and glassy facies of the same of basic leidleite characters, to an intermediate craignurite, thus supporting the view of the Authors of Mull memoir that a multiple sill is similar to a composite one in containing widely varied rock types.

Lastly, the association of the different widely contrasting rock types is revealed from a study of the microsection (W 147) which is represented diagramatically in/

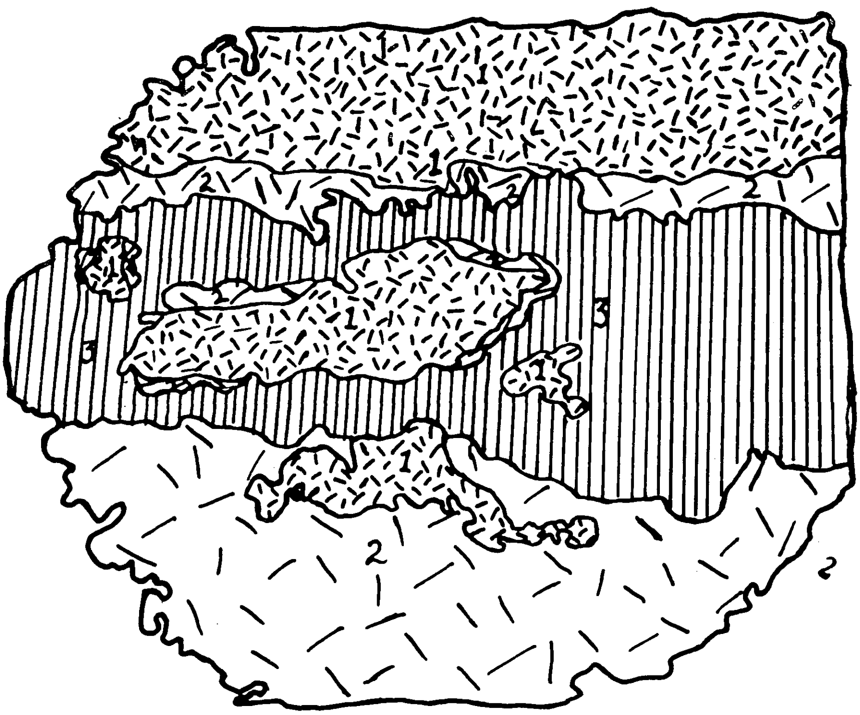


Fig. 5. A microsection showing association of different rock types.

MAGNIFICATION 4

1. Quartz - basalt.
2. Felspathic basic craignurite (or, quartz - dolerite).
3. Felsite of craignurite affinities.

in Fig.5.

It is seen that felspathic basic craignurite invaded the quartz-basalt along the margin and also has picked up the same as xenoliths. Both these were invaded by felsite of craignurite affinities which cuts the felspathic basic craignurite and has picked up xenoliths of quartz-basalt which invariably are surrounded by the later-formed felspathic basic craignurite. The rims constituted of the latter are lost for some xenoliths signifying, again, the incorporation of the same by the acid rock. This section further affords conclusive proof of the invariable basic to acid order of injection in these intrusions under consideration.

The author from his studies on the composite sills is inclined to believe that in intrusions of this type the originally hybridized magma is injected in quick succession in several pulses, each tending to acid in composition, these various compositionally-different pulsations commingling to the utmost again to give rise ultimately to the rocks that constitute these igneous bodies.

C. MINOR ACID INTRUSIONS.

Under this category are grouped all the thin sills and dykes of acid rock that occur in the area. These include pitchstones and allied felsites and quartz-felspar-porphyries. The pitchstones for which the Isle of Arran has long been celebrated have been the subject of detailed study by several geologists. For a summary of work on this subject the reader is referred to the Memoir (p.224).

(i) Field Relations: In the Glen Ashdale region a few thin dykes of pitchstone and felsite and one thin sill of spherulitic felsite with affinities to pitchstone are exposed. A little NE of Cnoc Mor (867 O.D.), just N of Glen Ashdale, a black pitchstone dyke running WNW - ESE penetrates the adjoining thin sill of craignurite-felsite thereby proving that it is definitely of a later date than the composite intrusions. Two dykes of felsite of pitchstone affinities occur in this area, one in the tributary to Allt Dhepin, E of Cnoc an Fheidh and another a few yards SE of 539 O.D. in Allt Dhepin. A thin sill of spherulitic felsite is seen at the source of the tributary E of 739 O.D., Allt Dhepin, resting on sandstones. A NNW-SSE dyke of quartz-felspar-porphyry outcrops in the bed of Allt Dhepin about 100 yards S of 739 O.D. In the peat,/

peat, about ½ mile S of Sheepfold near Kingcross Burn, is exposed a thin NW-SE dyke of a similar rock.

In the Allt Dhepin - Tighvein region also there are a few exposures of acid dykes and sills. The Allt Dhepin section between 539 O.D. and 982 O.D. contains some thin dykes of craignurite-felsite. At about 1/3 mile W of Loch na Leirg, at the head of a tributary to Allt Dhepin, occurs a NNW-SSE striking porphyritic pitchstone dyke, only one face of it having been exposed. Another dyke, possibly the continuation of the Allt Dhepin dyke, can be seen in the peat about ½ mile SE of Urie Loch. Just about ¼ mile W of this locality, in the tributary to the W of Allt Dhepin, is a NW-SE quartz-felspar-porphyry dyke. Another, probably its south-eastern continuation, is seen about 1/6 mile SE of the former in Allt Dhepin at 1055 O.D. About 1/3 mile SW of this, at the head of Allt nan Clach, is a dyke of porphyritic pitchstone striking NW-SE. A quartz-felspar-porphyry dyke with a NW-SE trend is seen at 1215 O.D. at the source of Allt Dhepin. On the southern shore of Urie Loch occurs an intrusive boss of spherulitic felsite.

Of the Monamore Glen pitchstones, the largest exposures are in Monamore Water at Croc and at the Mill. The former contains three closely associated pitchstone sills/

sills and a fourteen-foot wide felsite dyke cutting them, the pitchstones having suffered pronounced devitrification and resembling felsite. The Mill exposure consists of two thin masses, one a sill and the other a dyke. These occurrences are described in detail by Scott (1913) and by Tyrrell (1928, p.214-215). Further W, near the Dam occur two dykes and one well-marked sill of quartz-felsite having here and there pitchstone facies. South of Monamore Glen, along Allt Lagriehesk, about 1/6 mile N of Meallach's Grave, occurs a sill of pitchstone running NW-SE and resting on sandstone. What apparently is its north-western continuation is seen within 150 yards from it at the confluence of Allt Lebnasky and Allt Domhain. Three thin sills of pitchstone occur near Glenarry, ¼ mile E of Monamore Bridge. Again, dykes of quartz-felsite of craignurite affinities occur in the quarry at the eighth milestone on the Lamlash - Sliddery road. They occur singly with a maximum width of 12 to 15 feet and also as components of composite dykes with concomittant contamination effects.

From what has been said above, it is evident that while the pitchstones and the allied felsites occur as dykes, as thin sills and as intrusive bosses, the quartz-felspar-porphyries are found only as dykes and are/

are comparatively rare. While the majority of these acid intrusions trend NW-SE or NNW-SSE and have in general a maximum thickness of about 20 feet, exceptions to this rule are observed e.g., in the dyke near Cnoc Mor (867 O.D.) with WNW-ESE strike, and in the Croc group of sills with a rough E-W trend where two of the sills are respectively 30 and 60 feet thick. The length of the intrusions is nowhere over 100 feet. The determination of definite age relations is almost impossible due to lack of good sections but, as pointed out earlier, some of the dykes are definitely later than the last acid phase of injections in the composite and related intrusions, while some others e.g., dykes of felsite of craignurite affinities, might be of the same age as their analogues in the sills. But, nowhere in the area is a minor acid intrusion seen to be cut by a member of the composite intrusions. Thus, the group of intrusions described here are, as far as age is concerned, either contemporaneous with or later than the last phase of injection in the composite and related intrusions.

(ii) Petrography:

Inninmorite-pitchstone: The glassy rocks of this group with vitreous lustre show a wide variation/

variation in colour from black through various shades of dark brown and green to light yellowish-green. The majority of them are porphyritic while the rest, though megascopically nonporphyritic, contain, as seen in thin section (W 106), microporphyritic crystals of very basic plagioclase, augite and rhombic pyroxene which are embedded in a turbid, glassy matrix rich in crystallites of varying dimensions (Plate X, fig.1.). The mineralogy which Harker (1903) has vividly described in the North Arran Memoir is referred to here rather briefly.

The pyroxene is an augite with highly resorbed margins. Because of its high birefringence, 2V could not be measured directly. No pigeonite seems to occur. Equally abundant or even more abundant, are stout prismatic crystals of hypersthene, strongly pleochroic as X: pale yellow, Y: yellowish-green, and Z: pale green to bottle-green, and with 2V over X varying between 50° and 53.5° indicating (Winchell 1933, p.218) an iron-rich variety with 52 to 58 per cent of the $FeSiO_3$ molecule in its constitution. $Z \wedge c$ 0° to 21°. Enstatite with 2V 66° over $Z \wedge c$ 0° to 7^{0} is also recorded. It is, on the whole, rather rare. In addition to the pyroxenes, there is hornblende and biotite, the former of two varieties viz., as recrystallized prisms of brownish hue and as greenish microlites/

microlites in the glassy base. The latter variety which, when crystallites of the same mineral are attached to it, assumes arborescent shape and is, by far, the most abundant and in some cases reaches a proportion almost equal to that of all the pyroxenes combined. Associated occasionally with this, are augite and aegirin-augite as acicular crystals, sometimes clustered together with resulting stellate forms and also at times with cervicorn habit. Biotite intergrown with ilmenite is, on the whole, rare. Titaniferous iron-ore is seen as euhedra mostly leucoxenized and rendered skeletal. Also, it is common in dusty and spongy masses.

The phenocrystic plagioclase occurs as stumpy tabular crystals with rounded corners. It has a high relief, is sometimes zoned and mostly twinned polysynthetically, optical discontinuity in one and the same crystal being observed and attributed to the operation of pressure during crystallization. Thick investments of groundmass round it are common. Measurements of 2V show a range between 88° over Z to 82° over X, indicating an anorthite content of An_{32-41} or An_{70-80}. The high relief and the high extinction angles suggest it to be the latter i.e., acid to mid-bytownite. Besides the common basic plagioclase, one or two microporphyritic crystals/

crystals of anorthoclase occur. This constituent was first recorded in a pitchstone from S of Glen Ashdale by Scott (1913). Here it is untwinned and has the usual low birefringence. Its 2V, when determined, is found to be peculiar -- 58.0° over X -- and in this respect it shows an approach to anorthoclase. Still, the mineral cannot strictly be assigned to this species, since the latter, according to Winchell (1933, p.367), has 2V over X ranging between 42° and 54°. The writer is inclined to feel that in these pitchstones, which represent contaminated acid rocks, the molecular structure and chemical composition of the alkali-felspar in the original acid magma must have been modified as a result of introduction of some extraneous element -- presumably, lime from the basic magma -- which could account for the observed anomaly.

The matrix is made up of microlites of hornblende, aegirin-augite and augite and some crystallites of hornblende, besides the abundant, turbid, glassy base. In a few cases, devitrification of the groundmass has resulted in marked banding, with narrow and broad bands alternating, the former ones being richer in microlites and crystallites than the other. Ill-developed minor spherulites/

spherulites of alkali-felspar are occasionally found. Apatite and rarely zircon are the accessory minerals. Many rocks of this type show relics of incorporated xenoliths as concentrations of skeletal ore and acicular pyroxene. The absence of perlitic cracks is conspicuous. The foregoing description, which except for the lack of enstatite-augite closely agrees with that of the Inninmorite of Mull, entitles the rock to be called Inninmorite-pitchstone.

But, the type is not without some minor variations. Some of the pitchstones in Monamore Glen contain, in addition, phenocrystic quartz in quite prominent proportions, though not as high as that of plagioclase. The phenocrysts have rounded corners and thick investments and inlets of groundmass. A specimen from Allt nan Clach shows, in microsection (Ar 397b), veining of the pitchstone by alkali felspar and albite, the latter with chess-board structure. These different types could be described as the acid varieties of the Inninmorite-pitchstone division.

Felsite --- Devitrified pitchstone:

The occurrence of felsitic rocks in Arran in close association with pitchstone is nothing new and one which/

which has long back been noticed by many geologists.

A specimen (W 31) from the sill E of 739 O.D., Allt Dhepin, has a vitreous lustre in some patches and a minutely crystalline aspect in others. Under the microscope, the microporphyritic quartz is seen broken. It has thick investments and inlets of groundmass material. Crystals of plagioclase have round them hyalite investments which are isotropic. The plagioclase itself has been rendered turbid and has given place to soda-orthoclase with fingerprint structure, and also veined by alkali-felspar. Biotite is developed from augite.

As for the groundmass, it is banded and has relics of dark brownish glass together with some secondary biotite in an abundant fine-grained matrix of whitish alkali-felspar riddled with minute specks and dots of brownish scrap (Plate X, fig.2.). Of the bands, some are much devitrified while the others are dark and glassy. The former contain spherulitic alkali-felspar and some interstitial quartz. No micropegmatite is seen anywhere.

In the fine-grained augite-quartz-felsite of the acid intrusive boss on the S shore of Urie Loch, devitrification/

devitrification of the pitchstone has proceeded to completion. But, probably almost concomittant with devitrification, invasion of the contaminated acid rock or felsite by a more acid soda-rich granophyre took place so that the very fine-grained felsite is veined and thoroughly impregnated by a slightly coarser-grained, but nevertheless fine-grained, granophyre with abundant micropegmatite and very poor in femic minerals (Plate X, fig.3). The insensible gradation of one rock to the other without anything like chilling or contact is proof, again, of the liquid state in which they both mixed with each other. It seems to be a case of injection of slightly contaminated acid magma in pulses of increasing acidity.

Thus, the development of finely-crystalline felsitic structure, of banding, and along with it devitrification, more pronounced along some bands than along others, are proof of the devitrification of the pitchstone. Further, the coexistence of relics of glass and of clear areas of spherulitic alkali-felspar and quartz add weight to this view.

Q u a r t z - f e l s p a r - p o r p h y r y: This type, scantily represented in the area, shows in microsection/

microsection (W 36), phenocrystic quartz and felspar in a microcrystalline felsitic groundmass (Plate X, fig.4.). The pyramidal crystals of quartz are corroded and their corners rounded. They have inlets and 'inclusions' of the groundmass. Glomeroporphyritic aggregates of untwinned anorthoclase sometimes with fingerprint structure and rarely with zoning, abound. The mineral has 2V ranging between 46.0° and 49.5° over X and Z∧c 0° to 2°. True acid plagioclase — albite or albite-oligoclase — is much less frequent. In addition to a very small amount of skeletal iron-ore, there are idiomorphic crystals of biotite suggesting crystallization from a contaminated magma. The groundmass which represents a devitrified glassy base has felsitic texture and contains dusty and clear areas respectively of spherulitic alkali-felspar and of albite and quartz. Slender prisms and acicular crystals of some brownish-coloured femic mineral (? hornblende) occasionally occur. Zircon is an accessory.

One of the porphyries (Ar 373) contains two or three small partially digested xenoliths of quartz-dolerite, coarse-grained compared to the base in which they occur. The contact is sharp, the xenolithic dolerite with a sub-ophitic texture being made up of colourless short/

short prisms of augite and almost straight-extinguishing rhombic pyroxene, pseudomorphous chlorite and a little biotite besides some iron-ore dust. Its mesostasis is of turbid alkali-felspar -- soda-orthoclase -- with fingerprint structure. In places where the quartz-dolerite is completely assimilated, only abundant disseminated black iron-ore dust in association with some interstitial and drusy quartz could be seen.

It thus becomes evident that the porphyry magma was not only contaminated at the source but also assimilated some of the basic material by a contact hybridization process.

Quartz-felsite of craignurite affinities: With its relics of digested xenoliths of fine-grained quartz-basalt and of quartz-dolerite and with its general contamination effects, this rock type is similar to its analogue in the composite intrusions.

(iii) Mode, Petrochemistry and Petrogenesis:

Of the acid rocks described in this chapter, only the Inninmorite-pitchstone has been analysed and the/

the mode determined, the results of which, along with those of comparable analyses, are entered in Table IX.

From the table it is obvious that the Inninmorite-pitchstone of Arran is a very acid variety in comparison with the Mull and Ardnamurchan types. It, however, bears a close resemblance in chemical composition to the Craignurite-felsite (4 of Table V11) of the Allt Dhepin sill and thus seems to represent a slightly contaminated acid magma. Naturally, it does not fit into any of the magma types of Niggli (1936), though it rather closely approaches the 'rapakivitisch' type. Even for this, the c value instead of being 9 is higher than that, and the alk value instead of being about 32 is only 28.0. These observations prove enrichment in lime at the expense of alkalies, a fact which explains the highly calcic nature of the plagioclase and also probably the peculiar (? rather calcic) anorthoclase. For the same magma type, k and mg values in the Arran rock are, likewise, low. When, on the other hand, comparison is instituted with the allied 'yosemitgranitisch' magma type, the pitchstone is seen to have a fm value very much higher than the standard one viz., 14.0, which explains the occurrence of iron-rich hypersthene. Also its/

TABLE IX. CHEMICAL COMPOSITION OF INNINMORITE-PITCHSTONES.

	5	A	B
SiO_2	69.78	64.13	66.06
Al_2O_3	12.47	13.15	13.14
Fe_2O_3	0.59	1.08	2.27
FeO	3.06	6.31	2.84
MgO	0.39	1.08	0.77
CaO	1.72	3.62	2.75
Na_2O	3.43	3.64	4.28
K_2O	2.52	2.32	1.54
H_2O −	4.08	2.71	3.38
H_2O −	1.70	0.36	0.74
CO_2	..	..	0.37
TiO_2	0.23	1.19	1.08
P_2O_5	nil	0.31	0.09
MnO	trace	0.27	0.31
BaO	..	0.09	..
SO_3	..	..	0.16
Organic matter	..	..	0.02
	99.97	100.26	99.80

5

MODE

Plagioclase	10.8
Anorthoclase	2.0
Pyroxene (porphyritic)	3.1
Hornblende and pyroxene (microlitic)	4.0
Iron-ore	1.3
Quartz	1.3
Mesostasis	77.5

C.I.P.W.NORM

Quartz	33.84
Orthoclase	15.01
Albite	28.82
Anorthite	8.12
Corundum	0.92
Enstatite	1.00
Hypersthene	4.62
Magnetite	0.93
Ilmenite	0.46
	93.72
Water	5.78
	99.50

N i g g l i   V a l u e s

	5	A	B
si	399.3	260.7	310.1
qz	+ 187.3	+ 78.7	+114.1
al	41.4	31.5	36.3
fm	20.1	32.2	25.8
c	10.5	15.8	13.9
alk	28.0	20.5	24.0
ti	1.0	3.7	3.7
p	..	0.5	..
k	0.33	0.30	0.19
mg	0.17	0.20	0.21

5: (W 39) Inninmorite-pitchstone, dyke, 1/3 mile W of Loch na Leirg, at the source of the tributary to Allt Dhepin, Whiting Bay, Arran. Anal: W. H. Herdsman.

A: (15990, Lab.No.387). Fairly glassy Inninmorite or Inninmorite-pitchstone. Sheet, 3/16 mile SW of Trig. Station on Beinn an Lochain, Mull. Anal: E. G. Radley. Quoted from E. M. Anderson and E. G. Radley, Q.J.G.S. LXXI, p.212.

B: (21255, Lab.No.739). Inninmorite Pitchstone, Lava. In stream bank 5/8 mile S.12^{o} E of Trignometrical Station at 1729 feet, Ben Hiant and $\frac{1}{2}$ mile W 3 S of Bourblaige, Ardnamurchan. Anal: B. E. Dixon. Quoted from Ardnamurchan Memoir 1930, p.84.

k and mg values are low. The story is more or less the same with the Mull and Ardnamurchan types which have very low k and mg values for the 'opdalitisch' and 'farsunditisch' magma types which they respectively seem to resemble. Thus, in every respect, the pitchstone represents a basified acid magma, the deep-seated basification involving an enrichment in lime and iron oxides, the former at the expense of the alkalies, more particularly at the expense of potash, and the latter at the expense of magnesia.

A similar hybrid origin applies to the other acid rocks which, as described above, invariably show contamination effects. The importance of contact hybridization has again to be stressed in the generation out of the quartz-basalt and quartz-dolerite xenoliths of phases stable with the incorporating acid rock such as quartz-felspar-porphyry.

Lastly, as regards the different types of pitchstone viz., inninmorite, basic leidleite etc., which are met with in this area, the author agrees with Tyrrell (1928, p.207) that they could be derived from several magmatic types under suitable circumstances.

D. DYKES.

The numerous widely distributed Tertiary dykes of this Whiting Bay - Lamlash area constitute a part of the Arran swarm which has been studied by Tyrrell (1928). Its general trend, as recorded, is NNW-SSE, more or less coinciding with the general NW-SE trends of the other swarms of Skye, Rum, Mull and Northern Ireland. A statistical study of the various dykes here, reveals that much over half of them strike NW-SE while about a quarter have a NNW-SSE trend, the rest running NE-SW, N-S, WNW-ESE and E-W in order of decreasing frequency.

As regards the components of the dykes, they show a very wide range of variation. While most of them belong to the basaltic division, there are some which are of acid composition and of contemporaneous intrusion, these having already been dealt with in the preceding chapter.

No attempt has been made here to demarcate sharply the periods of intrusion of the different basic dykes. All the same, from field and petrographic evidence, broadly, some periods are disentangled from the main phase of Tertiary dyke activity. From the viewpoints/

viewpoints of petrography and composition, the dykes could be arranged in order of decreasing basicity as follows:

(a) crinanites and allied olivine-dolerites.

(b) tholeiites and quartz-dolerites of sub-basic composition.

(c) rocks of intermediate composition.

(d) rocks of acid composition.

This sort of grouping cannot be taken as strict and rigid since there are always gradational and transitional rock types.

(i) Field Relations and Petrography:

(a) Crinanites and allied Olivine-dolerites:

For the most part, these dykes strike NW-SE, veering at times to NNW-SSE and only in one case has a N-S strike been noticed. Their width is almost always over 8 feet, being generally 10 to 13 feet, exception being the five-foot dyke on the Lamlash shore, S of Cordon. All of them are intruded into the New Red Sandstone and are mostly cut by tholeiite dykes on the Whiting Bay shore. But, one occurrence is of great importance in this connection. About ½ mile N of Pier, on/

on the Whiting Bay shore, a crinanite dyke striking NNW-SSE and extending for nearly 500 yards cuts three tholeiite dykes close by which strike respectively NW-SE, WNW-ESE and E-W. Thus, while most of the observed instances point to a relatively early age for the crinanite dykes, more or less contemporaneous with the big sills of crinanite, still, in one case at least there is definite proof of a crinanite dyke being later than that of tholeiite. This instance modifies Tyrrell's (1928, p.250) important observation that "in all the observed intersections, dykes of the tholeiite group cut those of the olivine-dolerite-crinanite group."

Since the petrography of this group of rocks has already been dealt with, only some mineralogical details are included here.

The olivine which mostly occurs as fresh microporphyritic crystals (Plate XI, fig.2.) has an almost constant 2V of 84° over X indicating a composition of Fo_{72} Fa_{28} (molecular percentage). Further, oblique extinction, a feature possible, according to Johannsen (1937, p.212-213), for all orthorhombic minerals and recorded for several of the enstatite and hypersthene grains in the rocks described in the previous pages,/

pages, is here quite common with Z c 38^{o} as maximum.

The pyroxene is invariably a titanaugite with 2V over Z 58.0^{o} - 1.5^{o}, easily distinguishable from the normal augite (with 2V rarely over 50^{o}) of all the rocks of most other intrusions. It is pleochroic as follows: X: yellowish - red, Y and Z: violet, $Z \wedge c$ 42^{o} - 47^{o}.

The plagioclase is always twinned and rarely zoned. The big lath-shaped crystals in ophitic intergrowth with titanaugite have 2V over X round about 88^{o} indicating a composition of Ab_{28} An_{72}, while some of the smaller ones with 2V over Z 74.0^{o} to 75.5^{o}, are of acid labradorite with $An_{55 - 58}$. Thus, the felspar varies between labradorite and acid bytownite.

The other minerals have the same characters as described earlier.

The analysis of the dyke of crinanite from the Whiting Bay shore is compared in Table X with two others from the West of Scotland.

The two Arran rocks are very much alike while that from Jura with its higher <u>fm</u> and lower <u>si</u> values appears to be slightly more basic. Again, there is very close agreement between the norm and the mode. According to Winchell (1932, p.374), labradorite is capable/

TABLE X. ANALYSES OF CRINANITES

	6	A	B
SiO_2	43.95	44.68	43.94
Al_2O_3	17.60	16.37	14.03
Fe_2O_3	1.43	4.31	1.95
FeO	11.89	8.11	11.65
MgO	6.95	6.59	10.46
CaO	8.54	8.70	8.99
Na_2O	3.66	3.28	2.68
K_2O	0.35	0.21	0.33
H_2O +	0.82	1.69	2.31
H_2O −	0.94	2.99	0.85
CO_2	..	0.06	0.16
TiO_2	3.42	2.51	2.45
P_2O_5	0.11	0.15	0.20
MnO	0.10	0.32	0.32
(Ni,Co)O	..	0.05	..
BaO	..	0.02	..
FeS_2	..	..	0.04
Fe_7S_8	..	..	0.06
	99.76	100.04	100.42

Niggli Values

	6	A	B
si	98.2	108.4	92.2
qz	− 35.8	−24.0	−31.0
al	23.1	23.2	17.3
fm	48.0	48.7	56.7
c	20.4	20.0	20.2
alk	8.5	8.1	5.8
ti	5.9	4.5	3.8
p	..	0.1	0.2
k	0.06	0.05	0.06
mg	0.49	0.49	0.59

6

MODE

Olivine	18.0
Titanaugite	13.6
Iron-ore	7.7
Plagioclase	54.1
Analcite	4.9
Zeolite	1.7

C.I.P.W.NORM

Orthoclase	2.22
Albite	22.01
Nepheline	4.83
Anorthite	30.30
Diopside	4.64
	2.40
	2.11
Forsterite	10.50
Fayalite	10.00
Magnetite	2.10
Ilmenite	6.55
Apatite	0.34
	98.00
Water	1.76
	99.76

6: (26383) Crinanite, dyke on shore near Schoolhouse, Whiting Bay, Arran: Anal: W. D. Herdsman. Quoted from Arran Memoir 1928, p.254.

A: (24456, Lab.No.830) Analcite-olivine-dolerite (crinanite) sill, shore 340 yards N 9° W of Clauchlands Point, Arran. Anal: E. G. Radley. Quoted from Arran Memoir 1928, p.121.

B: (14174) Crinanite or analcite-dolerite, Kainozoic dyke, Slac nan Sgarbh, one mile north of Inver Cottage, Jura. Anal: E. G. Radley. Quoted from 'The Geology of Knapdale, Jura and North Kintyre', Mem. Geol. Surv. 1911, p.118.

capable of taking up to about 6% of orthoclase into its constitution and consequently, the 2.22% of normative orthoclase can be taken to be in solution with the total plagioclase of 52.31%. Part of the olivine and a portion of the ilmenite of the norm must have gone into the titanaugite.

When the Niggli values of the three crinanites are correlated with those of some of Niggli's (1936) magma types, it is seen that they all fit in well with the 'essexitgabbroid' type in the 'Natrongabbroid' division of magmas, though the Jura rock has a slightly higher fm value.

The crinanite suite of rocks with their characteristic features of an ophitic texture, of lack of glass even on the rapidly cooled margins and above all, of an almost constant quantitative mineralogical composition, present but little evidence of differentiation. The only variations met with in this suite are in respect firstly to the relative diminution and in rare cases even the complete absence of olivine and secondly from an unusual richness to a total lack of analcite. The undoubted primary nature of these different basic types is revealed in their derivation from a soda-rich gabbroid magma which corresponds/

corresponds to the Plateau-basalt magma of the Authors of the Mull memoir (1924) and to the Olivine-basalt magma of Kennedy (1933).

(b) T h o l e i i t e s a n d Q u a r t z - d o l e r i t e s:

This group of dyke rocks constitutes, by far, the larger proportion of the Arran dyke swarm as represented in this area. Their general trend is mostly NW-SE, veering in quite a few instances to NNW-SSE and also to WNW-ESE. Occasional trends of N-S noticed only in those occupying the Allt Dhepin section and of NE-SW, conforming to the general Caledonian trend, and seen mostly in cases where a tholeiite or a quartz-dolerite dyke happened to cut a crinanite dyke of a previously established NW-SE strike, as in the group of dykes just underneath and about 50 yards N of the Whiting Bay pier, are observed. Most of the dykes of this group, as a whole, extend for very short distances, rarely over 150 to 200 yards. They exhibit considerable variation in thickness from as low as 3 feet to about 12 or 13 feet, with in one case -- the dyke $\frac{1}{8}$ mile SE of 634 O.D., Allt Dhepin -- as much as 21 feet. While a vast majority are exposed in sandstone, some of them cut the crinanite sills and/

and dykes and felsite sills and are in turn cut by crinanite dykes and in some composite dykes, as the one at Dam in Monamore Water, and that in the quarry at the eighth milestone on the Lamlash - Sliddery road, by quartz felsite. Thus, it becomes difficult to establish their exact age but the author feels that the tholeiite dykes are later than most but not all of the crinanite dykes and felsite sills and older than some of the acid intrusions that occur as components in the composite dykes, and that the dykes of quartz-dolerite are either contemporaneous with the basic intrusions in the sills or belong to a separate basic phase in the dyke activity.

The term tholeiite is used here to designate rocks, non-porphyritic or porphyritic, with an intersertal texture. They are medium - to fine-grained, very dark grey or bluish-grey in colour. Several varieties -- olivine-bearing and olivine-free -- have been described by various authors and in the following account they are treated under the headings:

i) Largs type of tholeiite,

ii) Olivine-tholeiite of Brunton type,

iii) Anorthite-bearing Brunton type of tholeiite,

iv) /

iv) Talaidh type of tholeiite,

v) Porphyritic tholeiite with affinities to Cleveland type.

i) Largs type of tholeiite:

This type of tholeiite has been figured and defined by Tyrrell (1917, p.353) and is based upon a dyke on the shore of Largs, Ayrshire.

This most basic olivine-rich rock occurs in the gorge known as Creag Bhan at Allt Mor, Whiting Bay, and has been described in the Memoir (p.252). Besides, it also forms the dyke in the bed of Glen Ashdale at 150 O.D. Under the microscope, it (S 191) contains numerous microphenocrysts of basic plagioclase 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 (Plate XI, fig.2).

The olivine has a 2V over X $87.0^\circ - 1.5^\circ$ indicating a composition between $Fo_{83}\ Fa_{17}$ to $Fo_{75}\ Fa_{25}$ (molecular percentage). Oblique extinction with extinction angles round about 10° is not uncommon. The pyroxene appears to be an enstatite-augite, along with some normal augite. No 2V determinations could be made because of the very small dimensions of the crystals.

Iron-ore/

Iron-ore is finely granular and rod-like. The phenocrystic plagioclase occurs as big tabular crystals and is multiply-twinned and zoned with patches of mesostasis as 'inclusions'. A series of 2V determinations gave values ranging from 79.5° to 86° over X indicating a compositional range of Ab_{25} An_{75} - Ab_{17} An_{83} and proving it to be bytownite. The mesostasis is very scanty. It has devitrified brown glass and some iron-ore, besides some small laths which with a 2V of 75° over Z suggest an approximate composition Ab_{42} An_{58} i.e., mid-labradorite.

The analysis of the rock is quoted here from the Memoir and compared in Table XI with allied ones.

While the Salen type of olivine-tholeiite from Mull is a little more basic, the Corrie type is slightly more calcic but less basic, than the Largs type. The fact that the norm shows some, though very little, quartz can be taken to indicate the saturated nature of the rock, though apparently with its 16% by volume of olivine it looks undersaturated. The mode when compared with the modes of similar rocks from North of England studied by Holmes and Harwood (1929, p.14) shows clearly that it has a very high proportion of olivine and of plagioclase and low proportions of pyroxene/

TABLE XI. CHEMICAL COMPOSITION OF TERTIARY OLIVINE - THOLEIITES.

	7	A	B
SiO_2	42.55	47.35	48.60
Al_2O_3	16.93	13.90	18.27
Fe_2O_3	3.43	5.87	3.19
FeO	6.81	8.96	7.17
MgO	6.05	5.97	6.29
CaO	12.64	10.65	10.15
Na_2O	2.18	2.73	1.63
K_2O	0.32	0.54	0.45
H_2O +	1.30	1.16	1.65
H_2O -	1.78	1.04	1.60
CO_2	3.85	0.32	nil
TiO_2	1.80	1.75	0.70
P_2O_5	0.11	0.24	0.09
MnO	0.12	0.23	0.24
S	0.13	0.23	tr
	100.00	100.94	100.03
	Niggli Values		
si	111.5	108.8	117.2
qz	-13.3	-18.4	- 0.8
al	26.1	18.8	25.9
fm	45.9	48.2	43.4
c	21.8	26.2	26.2
alk	6.2	6.8	4.5
ti	3.4	3.0	1.3
p	..	0.2	..
k	0.10	0.12	0.16
mg	0.52	0.43	0.52

7

MODE

	Plagioclase	42.6
	Olivine	16.0
Meso-	Iron-ore (free)	5.8
sta-	Pyroxene	17.6
sis.	Rest of mesostasis	12.6
	Calcite	5.4

C.I.P.W. NORM

Quartz	0.78
Orthoclase	1.67
Albite	18.34
Anorthite	35.58
	(0.93
	-(0.60
	(0.26
Enstatite	14.50
Hypersthene	6.73
Magnetite	4.87
Ilmenite	3.34
Apatite	0.34
Calcite	8.70
	96.64
Water	3.21
	99.85

7: Olivine-tholeiite, (Largs type) dyke, Creag Bhan, Allt Mor, Whiting Bay, Arran. Anal: W. H. Herdsman. Quoted from Arran Memoir 1928, p.254.

A: (16808, Lab.No.407) Olivine-tholeiite, (Salen type), dyke, shore, quarter of a mile SSE of Kinatallen, and 2½ miles NNW of Salen, Mull. Anal: F. R. Ennos. Quoted from Mull Memoir 1924, p.17.

B: (26384) Olivine-tholeiite, (Corrie type), dyke, shore, quarter of a mile north of Birch Point, 1¾ miles south of Corrie Hotel. Anal: W. H. Herdsman. Quoted from Arran Memoir 1928, p. 254.

pyroxene and mesostasis, thus revealing, in general terms, its very basic nature in the group of saturated basic rocks.

There is perfect agreement between the Niggli values of the two Arran rocks and those of the 'miharaitisch' magma type in the 'gabbroid, femisch' division of magmas, while the 'normalgabbroid' magma of the same division has its consolidation product in the rock type from Mull.

ii) Olivine-tholeiite of Brunton type: This is a common member of the Arran dykes being seen in the quarry at the eighth mile-stone on the Lamlash - Sliddery road; on the Whiting Bay shore close to the Temperance Hotel, and again on the same shore just underneath the Pier cutting the crinanite dyke and having developed tachylytic margins. In hand-specimen it is generally a light grey, fine-grained rock with a platy structure. Under the microscope, it (W 122) is seen to consist of a few microphenocrysts or glomeroporphyritic aggregates of felspar and of rather altered olivine set in a plexus of felspar laths, augite granules and finely granular rod-like iron-ore. The olivine is invariably serpentinized with liberation of minor/

minor amounts of scrappy-looking iron-ore. The fibrous, feebly pleochroic, pale green serpentine seems to be chrysotile. The augite occurs as ophitic plates and granules and is colourless and non-pleochroic. The labradorite except for one or two microporphyritic, tabular, twinned and zoned crystals is seen as small twinned laths. Stellate grouping of the laths, characteristic of the Brunton type, is frequent. Iron-ore is altered and granular. The mesostasis is very abundant and made up of greenish-black glass, here and there devitrified to give rise to some specks of iron-ore.

iii) Anorthite-bearing Brunton type of tholeiite: Of the olivine-free tholeiites, this type seems to be abundant. Two exposures each parallel to the other could be seen on the Whiting Bay shore respectively about 100 and 150 yards S of the Pier.

Macroscopically, it is a dark fine-grained rock with some glistening plates of felspar. In thin section, it (W 113) is seen to consist of glomero-porphyritic aggregates of felspar in a fine-grained matrix of augite plates and plagioclase laths with abundant interstitial glassy base. The felspar phenocrysts/

are in the form of laths and squarish sections, twinned and frequently showing slight zonary banding. The high R.I. and the high angle of extinction round about 40° indicate it to be bytownite-anorthite. Occasionally, the phenocrysts have fretted edges and present a corroded appearance. They contain 'inclusions' of the groundmass. In the groundmass, the labradorite laths are usually much elongated and clustered and aggregated in such a way as to give rise to the characteristic stellate structure which indicates crystallization from several common initial points. The augite which is approximately equal in amount to the felspar is colourless or very pale brown and is mostly replaced by serpentine. Iron-ore occurs as very small crystals. The mesostasis is very abundant and is of dark glass occasionally with some microlites.

There is considerable variation in this group from the type just described, since in some rocks, while all the characters are more or less the same, the glassy base is very small or negligible in amount -- much less than about 10% by volume. Also, one such dyke rock in the bed of Allt Dhepin, a few yards N of 634 O.D., in thin section (W 33), is seen to be veined by a typical fine-grained intermediate craignurite which suffers no chilling or reduction in grain size, indicating invasion while/

while the former was still hot. This vein rock, while containing the usual acicular pyroxene and disseminated skeletal iron-ore in a fine-grained matrix of alkali-felspar and quartz, has picked up as xenocrysts two or three big tabular crystals of plagioclase from the adjoining tholeiite. These have been much rounded, fissured, cracked and even replaced by calcite with some chlorite moulded on them. This observation is in conformity with the general order of injection viz., basic to acid, even in the dyke phase of igneous activity.

iv) Talaidh type of tholeiite:

The dyke at the Greatfall in Glen Ashdale belongs to this type. The microsection (S 299) contains conspicuous xenocrysts of quartz and is constituted of sheaf-like aggregates of rather altered augite, lath-shaped and microporphyritic labradorite, abundant granular and skeletal iron-ore with some mesostasis of dusty alkali-felspar and clear interstitial quartz. Devitrification is almost complete and small patches of mesostasis of typical craignuritic texture and composition are developed. Glass and apatite are accessories. The xenocrystic quartz wherever it occurs has rounded and corroded margins which are invested with dusty-brown alkali-felspar/

alkali-felspar and with greenish chlorite or, as in Ar 347, with radiating columnar crystals of pyroxene, the result of reciprocal reaction between the acid xenocryst and the sub-basic magma. Some of the xenocrysts are cut by veins of calcite that run through the rock. The quartz must have been derived from some acid rock such as quartz-porphyry or quartz-felspar-porphyry.

v) Porphyritic tholeiite with affinities to Cleveland type:

The dyke on the Whiting Bay shore N of the Pier and close to Manse, in microsection (W 121) shows long crystals of labradorite along with prismatic crystals of enstatite-augite as microphenocrysts. The pyroxene is much altered. There is abundant skeletal iron-ore. The mesostasis is quite prominent and is made up of dark glass. In all respects, this dyke rock has affinities to the Cleveland type of tholeiite described and figured by Holmes and Harwood (1929).

Thus, the last two types and also some rocks belonging to the Brunton type of tholeiite exhibit certain effects of assimilation of foreign material, as also in their invasion by the same. This is of great genetic significance and will be referred to again on a later/

later page.

<u>Quartz-dolerite, commonly xenolithic:</u> This is the commonest dyke rock of the area and is more or less like the corresponding type from the composite and multiple sills, though here it is comparatively fine-grained. It (L 18) invariably contains partially digested xenoliths of fine-grained basalt. Where the xenoliths are lacking, there are xenocrysts of quartz with reaction rims of columnar rhombic pyroxene.

The quartz-dolerite as such, is contaminated, its sub-ophitic labradorite partly replaced by soda-orthoclase with fingerprint structure. Hornblende and chlorite, besides pyroxene, occur. Iron-ore is rendered finely granular and skeletal. Another characteristic feature of the rock is as regards the mesostasis which occurs as pockets of typical craignuritic texture and mineralogical composition. Very rarely, there is a little zeolite associated with these pockets of mesostasis. Quartz is interstitial.

<u>Porphyritic quartz-dolerite:</u>

This type which is represented by a dyke 1/6 mile ESE of 982 O.D., Allt Dhepin, is merely a modification of/

of the quartz-dolerite towards the development, due probably to intratelluric crystallization, of a porphyritic texture with felspar as the phenocrystic constituent. The rock (Ar 370) corresponds very well with the anorthite-bearing Brunton type of which this can be taken as the hypabyssal, holocrystalline representative.

The phenocrysts occur as tabular crystals of labradorite, twinned and generally zoned. The zoning is peculiar in that the extinction instead of being spread over uniformly is seen to occur at the same position for two or more disconnected zones. This sort of zoning, referred to as oscillatory zoning, is common in andesites and dacites and related intermediate rocks and, according to Fenner (1926, p.700), is due to the accession of the original magma at intervals on the already crystallizing matter such that the composition of the latter reverts to the original. Thus, this remarkable feature in the plagioclase goes to confirm the commingling of different types of magmatic material for the whole rock.

<u>Porphyritic basalt</u>: This is very similar to the above-mentioned type but differs only in having a fine-grained, granulitic, devitrified groundmass/

groundmass instead of an intersertal or sub-ophitic texture. Dykes of this type occur in the Monamore Glen section cutting the crinanite sill there, as also in the bed of Allt Dhepin e.g., $\frac{1}{8}$ mile S of 739 O.D. The Allt Dhepin rock carries, in addition, accessory olivine.

Most of the rock types dealt with so far belong to the basic and sub-basic divisions and have their analogues in various adjacent regions, as for example, in Bute as described by Brown (1929).

(c) D y k e s o f I n t e r m e d i a t e C o m p o s i t i o n:

The members of this group present many difficulties in respect of nomenclature and classification because of their aphanatic or glassy groundmass and microlitic and variolitic structures. They are very poorly represented in the collection. Wherever they are found, they strike NW-SE without exception. Like those of the former group, these dykes also extend for short distances and are very thin.

The following types arranged roughly in order of decreasing basicity are recognized:

i) Andesitic dolerite,

ii)/

ii) Augite-andesite,

iii) Sub-variolitic andesite,

iv) Tachylyte,

v) Craignurite.

i) <u>Andesitic dolerite</u>: In the tributary to Allt Dhepin, about ½ mile W of Loch na Leirg, occurs a long dyke. It is a fine-grained greyish tholeiite which (S 189) under the microscope, shows microporphyritic crystals of albitized plagioclase in a matrix of augite granules and plagioclase laths with fairly abundant mesostasis of quartzo-felspathic composition.

The plagioclase seen as stout laths is, to a great extent, replaced by soda-orthoclase which has a fingerprint structure; occasionally some relics of the original andesine are left behind. The pyroxene, except for one or two prismatic crystals, is mostly granular and generally serpentinized or replaced by calcite. The lath-shaped acid plagioclase is twinned on albite law. Iron-ore is abundant as euhedra, rendered skeletal. The rock is rich in mesostasis which is made up of untwinned alkali felspar -- anorthoclase or albite --, interstitial quartz standing out prominently. Apatite as numerous acicular crystals is/

is very frequent.

Thus, the rock with an invariably albitized plagioclase, abundant acid mesostasis and a general intermediate composition is here referred to as andesitic dolerite.

ii) Augite-andesite: Only one dyke of this type occurs in this area at Creag Bhan in Allt Garbh, Whiting Bay. Macroscopically, it is fine-grained and non-porphyritic. Under the microscope, it (S 192) is seen to have a microlitic texture with small felspar crystals arranged in a criss-cross pattern -- the pilotaxitic texture of Rosenbusch. The groundmass is filled with microlites of augite, grains of iron-ore and abundant colourless to pale green glass (Plate XI, fig.3.).

Augite occurs as innumerable small prismatic crystals or as irregular grains. It is mostly colourless, very rarely of pale green tint, non-pleochroic, has resorbed margins, very low birefringence and almost straight extinction. In all probability, it is pigeonite. Titaniferous iron-ore and some pyrite occur as small euhedra. Except for two or three rather rounded, microporphyritic crystals of twinned, undulose-extinguishing/

extinguishing andesine, the rock is made up of several small laths of twinned oligoclase arranged in criss-cross pattern. The mesostasis which is hemihyaline contains some microlites of augite, specks of iron-ore and needles of apatite in a base of very pale green glass.

iii) Sub-variolitic andesite:

This type is represented by a dyke which cuts the crinanite sill and exposed in the lower reaches of Monamore Water. In thin section, it (L 5) shows a few microporphyritic crystals of plagioclase and several radiating and branching crystals of plagioclase, augite and abundant skeletal iron-ore, all of which constitute the variolites in a groundmass rich in chlorite (Plate XI, fig. 4).

The plagioclase is albitized and its boundaries partly transgressed by the material of the groundmass. That which forms part of the variolites is of the same acid variety. Iron-ore is, on the whole, very abundant. The glassy base is more or less devitrified and scarcely fresh being occupied by chlorite, calcite and dusty iron-ore. The usual felspathic material and interstitial quartz are lacking here. Apatite is very frequent/

frequent and zircon less so.

Because of the poor development of the variolites, the rock is named a sub-variolitic andesite.

iv) T a c h y l y t e: A dyke cutting the crinanite sill towards the eatern end of Monamore Glen belongs to this type. Similar rocks are exposed on the sea-shore about ¼ mile S of Kingscross Point. Besides, several other tholeiite dykes on the shore and some in the bed of Glen Ashdale near the big waterfall, have tachylyte selvages.

The monamore dyke is chilled against the adjoining sill-rock -- olivine-dolerite of crinanite affinities. The dolerite in the vicinity has been granulitized due, probably, to the heat of the intrusion. The dyke has a sharp contact with the dolerite. In microsection, it (L 3) is made up of a few micro-porphyritic crystals of andesine or acid labradorite, and an occasional grain of augite. Almost the entire bulk of the rock is of dark glass, here and there devitrified to give rise to some disseminated dust and granules of iron-ore.

v) C r a i g n u r i t e: A dyke in Monamore Water cutting the crinanite and granophyre of that locality and/

and another in the quarry close to Gortonallister on the Lamlash - Whiting Bay road, among others come under this category. The microsections exhibit the characteristic acicular and skeletal crystallization. The rocks compare very well with their analogues from the sills.

(d) Rocks of Acid Composition:

These include the pitchstones, their devitrified variants of felsitic nature, felsites of craignurite affinities and quartz-felspar-porphyries occurring as dykes. They have all been dealt with in detail in the previous chapter.

(ii) Petrogenesis:

The foregoing field and petrographic study of the dyke rocks of this area reveals several interesting points. Firstly, the wide variation in composition from the very basic and under-saturated types such as crinanite through sub-basic tholeiites of different varieties and quartz-dolerites and through more or less intermediate members such as andesites, tachylytes, craignurites etc., to the acid components such as pitchstones, quartz-felspar-porphyries, quartz-felsites etc., is very significant. Secondly, there is the inescapable fact that except for the crinanite and the related olivine-dolerite, all the rest show some sort of abnormality in composition in the sense that the apparently basic members are not really basic but sub-basic and the acid types similarly are sub-acid. Thirdly, such abnormality is exhibited within very limited ranges. Fourthly, the so called intermediate rocks are not half as common as any of the other groups taken singly.

These observations, while they are of great significance, are not very new and as was noted earlier, pertain as well to the rocks of the sills. Again, in this/

this connection, it would be interesting to note the similarity of the rock types of the dykes with those of the composite and multiple sills. In short, the problems concerning the genesis of this wide variety of rocks are the same as those that confronted us earlier in connection with the rocks of the sills.

To explain this diversity, two magmas of contrasting basic and acid composition need to be invoked, and the established basic to acid order of injection given due recognition. In the very early stages of the dyke activity, when the crinanites were first injected, only the basic magma must have been available. The absence of any concentrated acid residuum and the almost constant mineralogical and chemical composition of the dyke rocks of this phase point to little or no contamination of the magma as also to its limited differentiation. In the later stages, when tholeiites, quartz-dolerites etc. of basic to sub-basic composition were formed, the basic magma must have been contaminated by the acid magma right at the source. That this contamination did play a bigger role is evident from some of the very sub-basic tholeiites and quartz-dolerites and from the more or less/

less intermediate types such as andesites, craignurites etc. That, besides the above-mentioned type of deep-seated contamination, there was the play of contact hybridization is clear from the numerous partially digested xenoliths encountered in these rocks. The acid dyke rocks, likewise, represent crystallization from an acid magma which has suffered deep-seated hybridization. Lastly, though there is no evidence of a very basic dyke rock cutting the last-formed acid one, still, the fact that some of the crinanite dykes cut dykes of tholeiite and related intermediate rocks, is proof of the recurrence of the phase of basic magma towards the close of the Tertiary dyke activity. Thus, the igneous sequence in the dyke activity of this area is surmised to be as follows: basic -- sub-basic -- intermediate -- acid -- followed again by basic, unless, again, some evidence is brought forward to prove a second basic to acid order of injection. This sequence is very much in accordance with that established for the Mourne dyke swarm by Tomkeiff and Marshall (1935).

III. SUMMARY AND CONCLUSIONS.

The Whiting Bay - Lamlash region in the SE of Arran is made up of many Tertiary igneous intrusions belonging to different epochs of igneous activity in the era. These are found in the country rock of New Red Sandstone. The first episode of igneous activity was of the undersaturated plateau-basalt magma which is represented as large sills of crinanite. This phase of intrusion was followed by a great development of oversaturated magma manifesting itself by the intrusion of numerous sills, composite and multiple. They exhibit a marked but orderly variation in the composition of the magma that filled the fissures. Their basic members include quartz-dolerites, olivine-bearing quartz-dolerites, quartz-augite-diorites, felspathic and spherulitic quartz-dolerites and quartz-augite-diorites. Their pyroxene is a normal augite and not a pigeonite. The prevalent basic types viz., quartz-dolerite and quartz-augite-diorite from the viewpoint of chemistry are much more felspathic than the basic craignurite of Mull and do not fit into any of the magma types of Niggli. Rocks of more or less intermediate composition are represented by types such as 'thorough' hybrid, leucocratic/

leucocratic quartz-dolerite, intermediate craignurite etc. Their mineralogical composition indicates a mixture approximately in the proportion of 2 : 1 of the sub-basic and contaminated acid magmas. The acid components of the sills are felsite, granophyre and microgranite, all contaminated and with acicular and skeletal crystallization, besides spherulitic, felsitic and granophyric. These types are abnormal from every point of view. It is concluded that graphic texture is not due to eutectic crystallization but due to a series of paragenetic transformations between its constituents. The genesis of the different members of the sills is attributed to the deep-seated hybridization of two magmas of contrasting basic and acid composition. The origin of the acid magma is thought to be by a process of crustal refusion. The importance of contact hyabyssal hybridization in the digestion of xenoliths is pointed out. The order of injection of magma is shown to be invariably from basic to acid though the spatial sequence varies greatly in the sills. Their complicated structures are ascribed to a series of pulsations of contaminated magma with its composition tending progressively in the acid direction.

The/

The minor acid intrusions which occur as thin sills and as dykes with a general NW - SE trend include inninmorite-pitchstone, quartz-felspar-porphyry, quartz-felsite etc. They owe their origin to an acid magma basified in the magma-chamber.

The dykes have a general NW-SE trend. Petrographically, they fall into four categories -- basic crinanites, sub-basic tholeiites and quartz-dolerites, intermediate andesites, craignurites etc., besides the acid rocks mentioned above. The crinanites are due to the differentiation of a plateau-basalt magma while the rest are again due to consolidation of contaminated basic and acid magmas. From the evidence at hand, general sequence of dyke intrusion is shown to be: basic -- sub-basic -- intermediate -- acid -- again basic.

In conclusion, the writer wants to make it clear that the conclusions, whatever they be, that might have been arrived at from a study of this region cannot be taken to apply invariably to any other similar area in the British Tertiary Province.

IV. ACKNOWLEDGMENTS.

The author is very much indebted to Dr. G. W. Tyrrell for suggesting this work, for placing his entire collection of rocks and microsections at his disposal and for much kind and helpful guidance, constant encouragement and critical discussion. He is deeply grateful to Dr. A. T. J. Dollar for kindly loaning his own Integrating Micrometer for use in the volumetric determinations of minerals of some of the rocks, and to the Director, Geological Survey, Great Britain, for lending the relevant microsections of the Arran rocks for comparative study. His thanks are due to Mr. A. E. Ferguson for skilful preparation of a large number of rock-sections and photomicrographs. Finally, he desires to acknowledge gratefully a scholarship from the Government of India without which he would not have been enabled to undertake this investigation.

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EXPLANATION OF PLATES.

PLATE I. The Kingscross crinanite sill veined by basalt at Kingscross Point.

PLATE II. A closer view of the same, showing black veins of very fine-grained basalt in the whitish coarse-grained crinanite boulder.
Locality: Kingscross Point.

PLATE III. The Baoileig composite sill resting on the horizontall-bedded weathered sandstone (seen towards the bottom of the picture).
Locality: Confluence of Baoileig Burn and Allt Dhepin.

PLATE IV. A closer view of the same, showing the hard igneous rock and the weathered sandstone. The hammer-base is resting on the contact of the two types of rock, the contact being wavy.
Locality: About 30 yards W of the confluence of the two streams above referred to.

PLATE V. Columnar structure in the felsite sill in the gorge at Sloc Ruaridh. The two planes of jointing each parallel to the other (seen to the left side of the picture) are worthy of note.

PLATE VI. The Creag Dubh sill exposed at the south end of Whiting Bay and on the shore with the moss and the sea-water in the foreground.

PLATE VII.

Fig.1. Quartz-basalt, Auchencairn sill. Skeletal iron-ore, small laths of labradorite and augite granules. Large vesicle of calcite together with some anhedral quartz. Dark prisms of hornblende and a flake of biotite. X 50.

2. Quartz-dolerite, Garbad multiple sill. Well-shaped labradorite laths, augite and rhombic pyroxene prisms and iron-ore grains in a brown, turbid mesostasis of alkali-felspar intergrown with quartz and containing numerous needles of apatite. X 50.

3/

PLATE VII
(cont)

Fig. 3. Olivine-bearing quartz-dolerite, Garbad multiple sill. Very much like the former but containing, in addition, crystals of iron-rich olivine altered to dark brown bowlingite seen as dark spherical areas in the picture. X 75.

4. Basic leidleite, Stony type, Garbad multiple sill. Labradorite laths, prismatic crystals of pyroxene and granular iron-ore in an abundant dark glassy base. Nicols crossed. X 50.

PLATE VIII.

Fig. 1. Spherulitic quartz-dolerite, Creag Dubh composite sill. No fresh ferromagnesian mineral; albitized plagioclase, granular and skeletal iron-ore in an abundant turbid typically spherulitic matrix rich in needles of apatite. X 50.

2. 'Thorough' hybrid, Glenashdale composite sill. Pyroxene, dark hornblende and biotite, a little skeletal iron-ore and some plagioclase in an abundant granophyric mesostasis with some interstitial quartz and accessory apatite. X 50.

3. Intermediate 'normal' craignurite, Gortonallister sill. Microporphyritic oligoclase-andesine, acicular, altered pyroxene, skeletal crystals of iron-ore and of acid plagioclase and some interstitial quartz in a fine-textured base. X 50.

4. Spherulitic quartz-felsite, Glenashdale composite sill. Phenocrystic pyramidal quartz invested with big spherulites of intergrown alkali-felspar and quartz in a felsitic or cryptographic groundmass. X 50.

PLATE IX

Fig.1. Granophyre of craignurite affinities, Allt Dhepin-Loch na Leirg sill. Pseudomorphous chlorite, granular iron-ore and small crystals of acid plagioclase/

PLATE IX (cont)

Fig.1. plagioclase in a granophyric base, the degree of coarseness of intergrowth varying greatly. Nicols crossed. X 50.

2. Quartz-augite-diorite, Sguiler - Urie Loch mass. Coarse-grained. Stout laths of andesine, pseudomorphous chlorite, skeletal iron-ore and anhedral quartz in an abundant mesostasis of turbid felspar and bleb-like quartz in micrographic intergrowth. X 50.

3. Spherulitic quartz-augite-diorite with xenolith of basalt, Sguiler - Urie Loch mass. Abundant anhedral quartz and skeletal iron-ore in a turbid spherulitic mesostasis of cryptopegmatite. Xenolith of craignuritic texture and with abundant skeletal iron-ore. Small dark-coloured prisms of hornblende at the contact of the two types. X 50.

4. Microgranite, Tighvein mass. Microgranitic texture. Anhedral quartz, microporphyritic alkali plagioclase, pseudomorphous chlorite and granular iron-ore in a matrix of micropegmatite. X 50.

PLATE X.

Fig. 1. Inninmorite-pitchstone, dyke $\frac{1}{3}$ mile W of Loch na Leirg. Microporphyritic tabular crystals of labradorite-bytownite, a few augite and hypersthene prisms and a grain or two of iron-ore in a turbid glassy matrix rich in crystallites and microlites of hornblende. X 50.

2. Felsite: Devitrified pitchstone, sill $\frac{1}{3}$ mile NW of Cnoc Mor. Rounded phenocrystic quartz with thick investments of groundmass material. Groundmass partially devitrified to micrographic intergrowths. Relics of dark brown glass. X 50.

3. Augite-quartz-felsite veined by granophyre, Boss S shore of Urie Loch. Felsite with phenocrystic quartz, acicular pyroxene and a little granular iron-ore in a cryptographic base. The granophyre is/

PLATE X (cont)

Fig.3. is coarser-grained and more acid than the felsite and contains abundant micropegmatite and interstitial quartz. X 50.

4. Quartz-felspar-porphyry, dyke at 1055 O.D., Allt. Dhepin. Phenocrystic quartz and anorthoclase in a microcrystalline felsitic groundmass. X 37.

PLATE XI.

Fig.1. Crinanite, dyke on shore near Schoolhouse, Whiting Bay. Ophitic texture. Microporphyritic olivine crystals, titanaugite prisms, labradorite laths, titaniferous iron-ore euhedra with interstitial analcite and zeolite and accessory apatite. X 50.

2. Olivine-tholeiite, Largs type, dyke in Creag Bhan, Allt Mor, Whiting Bay. Microphenocrysts of olivine and labradorite-bytownite in a groundmass of plagioclase laths, augite plates, skeletal iron-ore and brown glass. X 50.

3. Augite-andesite, dyke in Creag Bhan, Allt Mor, Whiting Bay. Microlitic texture. Plagioclase crystals in a criss-cross pattern. Groundmass of microlites of augite, grains of iron-ore and small areas of glass. X 50.

4. Sub-variolitic andesite, dyke in Monamore Water, Lamlash. Fan- and sheaf-like aggregates of felspar: augite and skeletal iron-ore microlites in partially devitrified brown glass. Small vesicles with calcite. X 50.

PLATE XII. Map of the Whiting Bay - Lamlash region, showing the distribution of the various Tertiary igneous intrusions, 6 inches to a mile, or 1 : 10,560.

PLATE I

PLATE : II

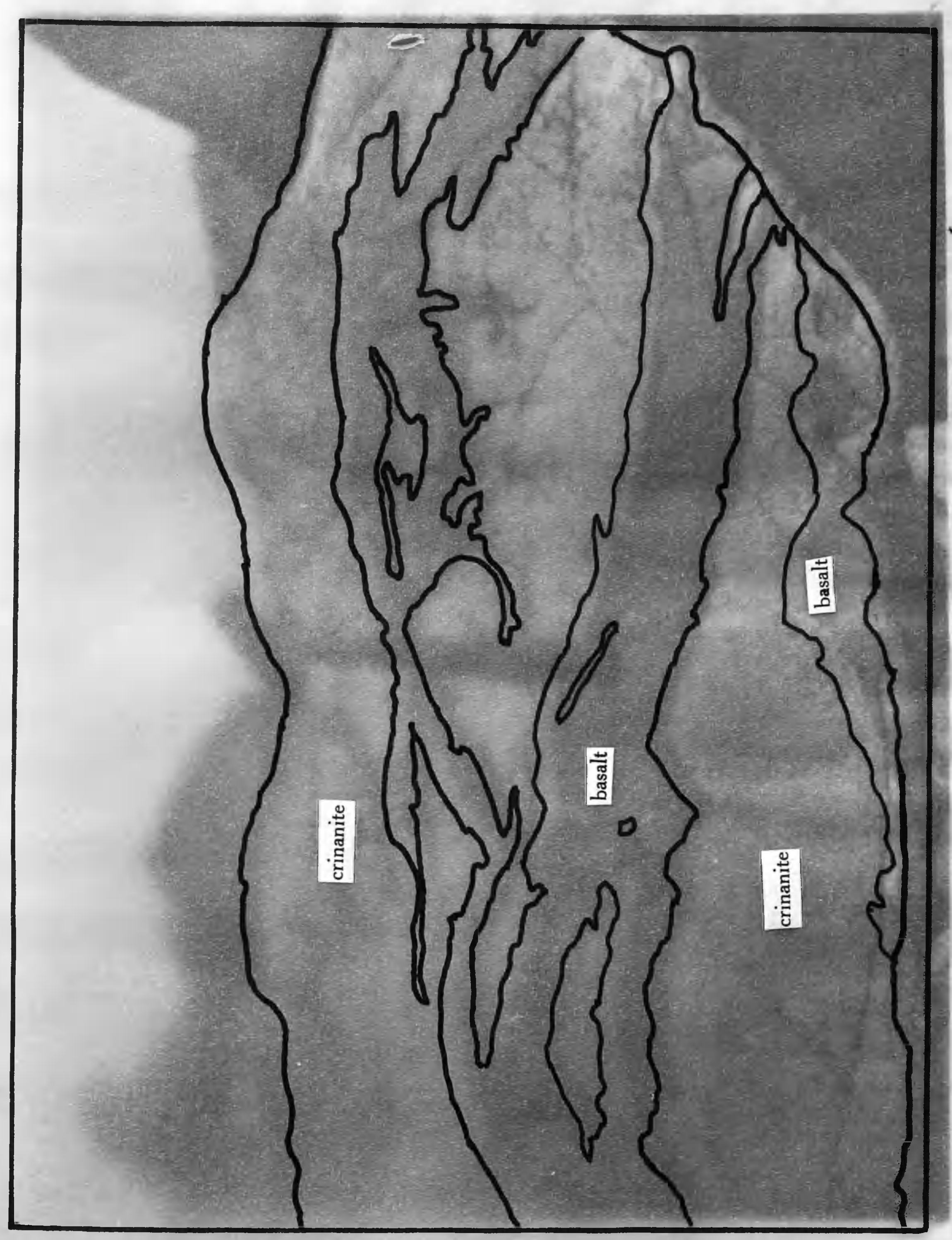

PLATE II

PLATE III

PLATE IV

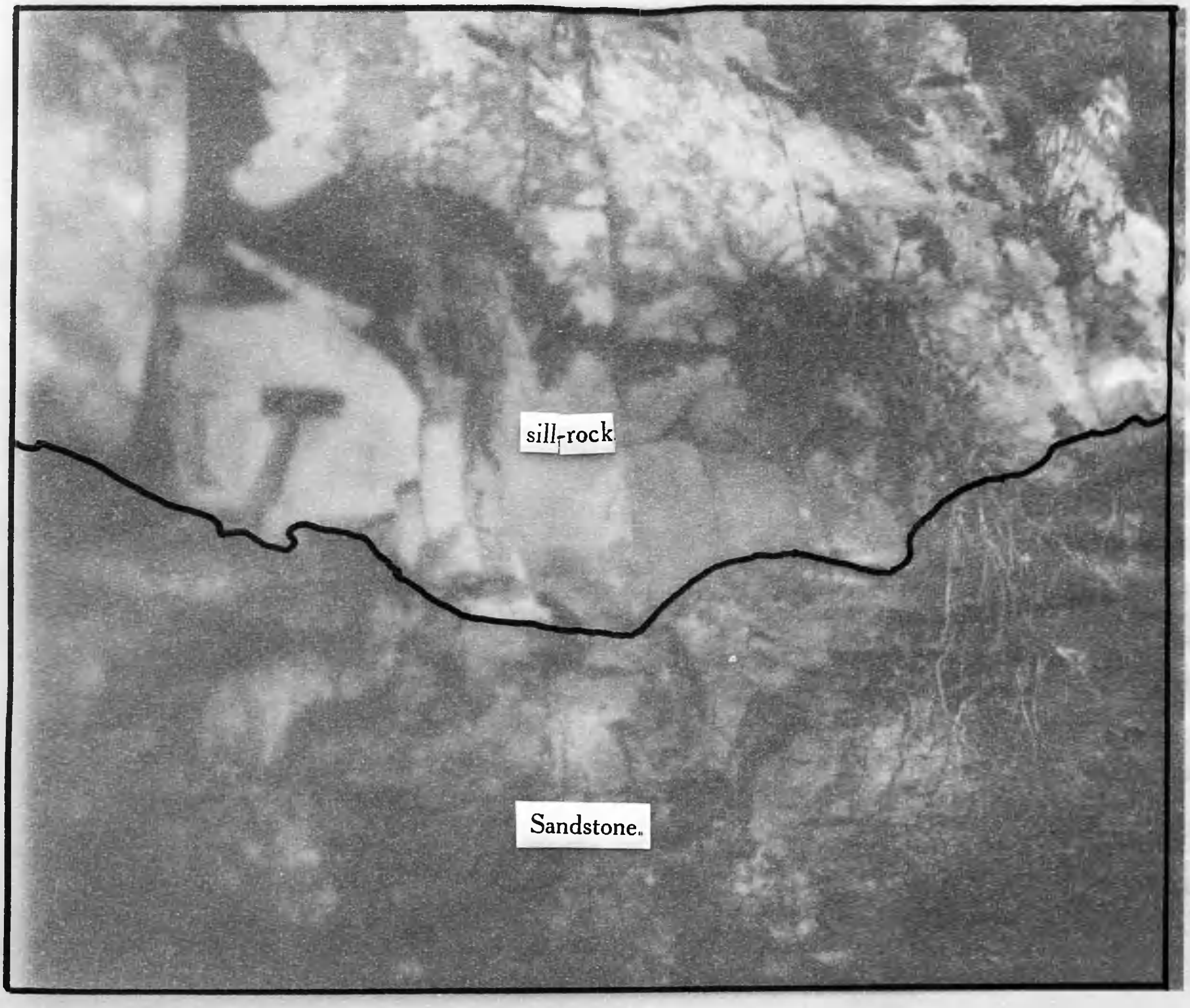

PLATE IV

PLATE V

PLATE VI

PLATE VII

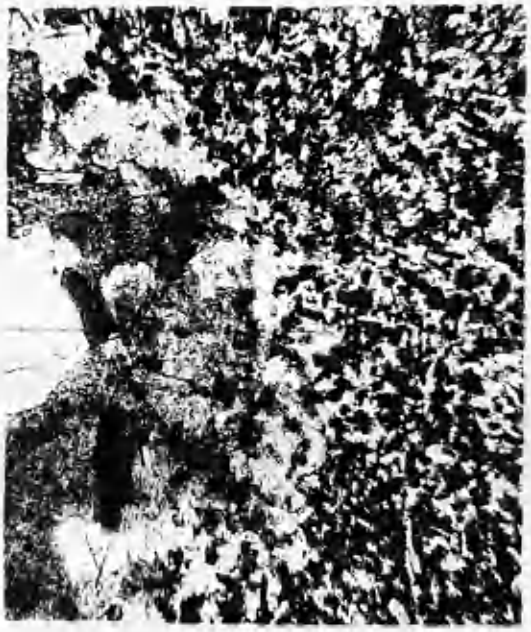

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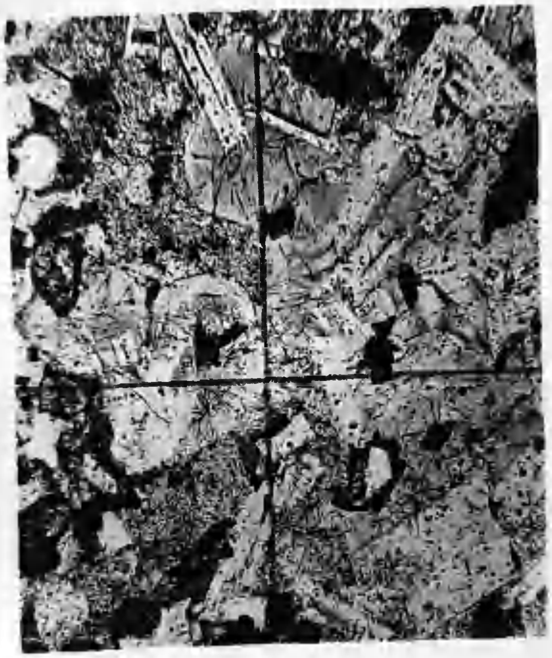
PLATE VIII



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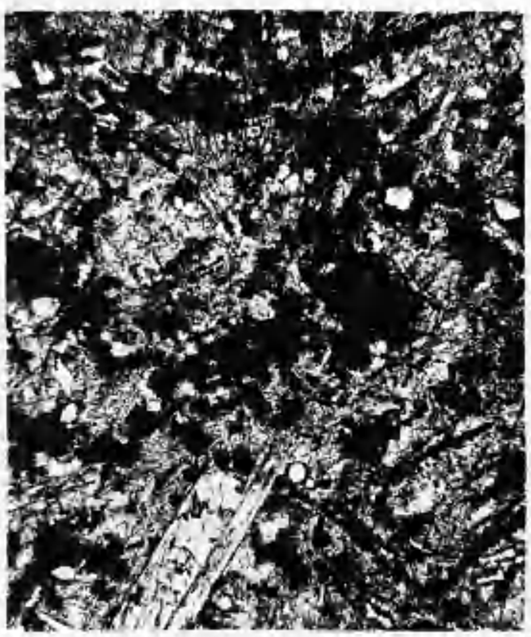

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PLATE IX

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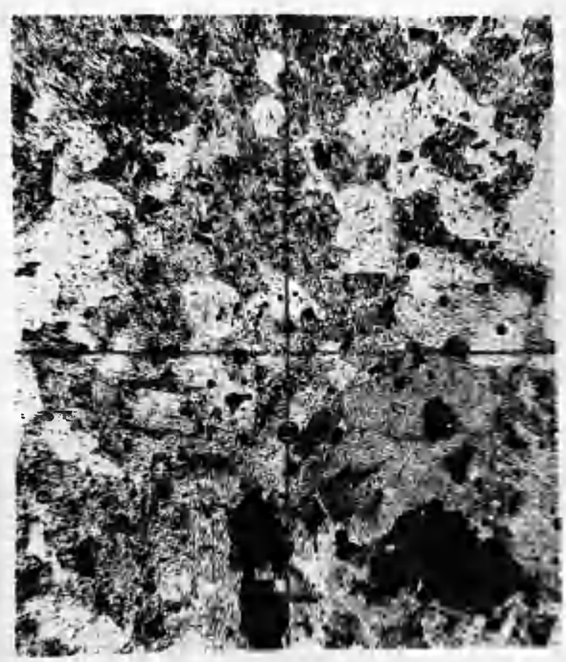

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PLATE X

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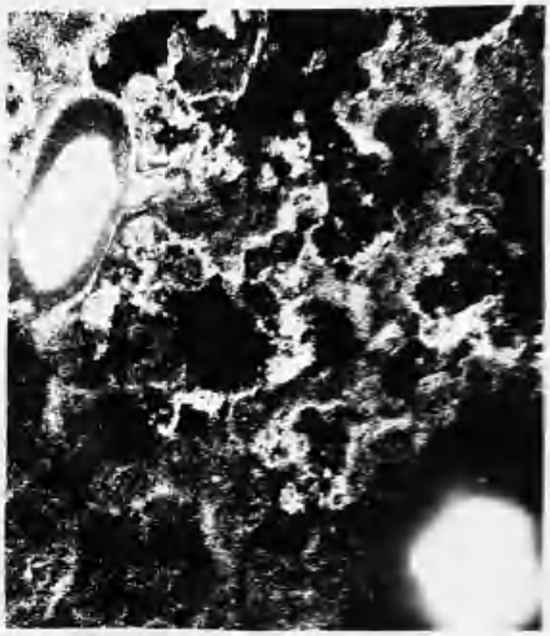

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PLATE XI

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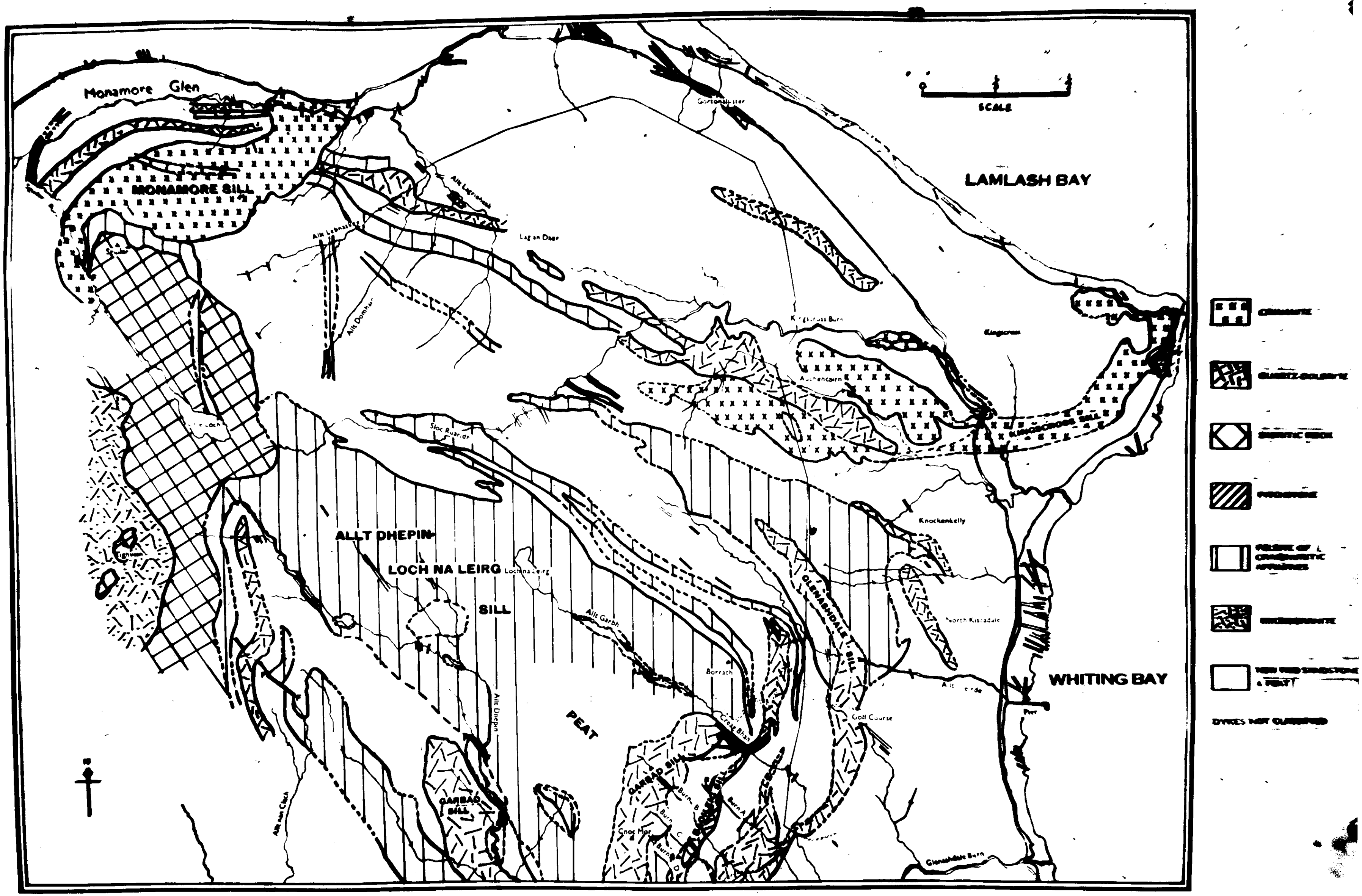

GEOLOGICAL MAP OF THE REGION AROUND LAMLASH AND WHITING BAY.

THE DYKE ROCKS OF DONEGAL AND THE ADJOINING PART OF COUNTY TYRONE, IRELAND.

(Accepted for Publication in the Transactions of the Geological Society of Glasgow).

C O N T E N T S

INTRODUCTION AND PREVIOUS LITERATURE.

The material on which this paper is based was collected by Dr. W.J. McCallien, formerly of the Department of Geology, University of Glasgow, and has been made available to the author by Dr. G.W. Tyrrell under whose direction the present investigation was carried out.

The dyke rocks of Donegal and parts of Tyrone counties, as also of the adjoining islands of Inch and Inishtrahull in the north of Ireland, comprise different members of the Epidiorite group, Spilite-Keratophyre group, Lamprophyre-Porphyrite group, Camptonite-Monchiquite group and Crinanite-Olivine-basalt-Tholeiite group belonging respectively to the Dalradian, Ordovician, Caledonian, Permian and Tertiary igneous epochs. A detailed petrographical account of the Caledonian and Tertiary rocks is given here and their genesis discussed. The geology of the area is briefly alluded to.

A review of the scanty previous literature indicates that the petrology of the area has not been studied in detail. The earliest reference to some dykes in the region is perhaps by Berger (7), who gave an account/

account of their occurrence. Later, Haughton (15) described pitchstones and pitchstone-porphyries from the vicinity of Lough Esk in Donegal. But the most authentic geological records are the explanatory memoirs by Hull and others (18) (19) wherein are set forth some details regarding the mode of occurrence and distribution of the dykes, together with their petrography. Recently, however, Hartley (14) has described some dykes of porphyrite and porphyry from Tyrone.

GEOLOGY.

The Donegal and Tyrone counties of Northern Ireland contain for the most part rocks belonging to a metamorphic series, which is but an extension of the south-west and central Highlands of Scotland. They consist of crystalline schists, quartzites, limestones and dolomites of Dalradian age. Intrusions into this series comprise firstly, epidiorites (indicated in geological maps as Hornblendic Igneous Rocks); afterwards, spilites and keratophyres; later, lamprophyres and porphyrites (described in geological maps as felstones and felstone-porphyries); still later, camptonites and monchiquites and, more recently, crinanites, basalts and tholeiites (referred to in maps as basalts and dolerites). The region is also, to a considerable extent, occupied by ranges of granite which is later than the epidiorite but older than the other dykes.

The Caledonian dykes have a N.E.- S.W. trend, while the Tertiary dykes strike N.W. - S.E. or N.N.W.-S.S.E., veering at times to E. - W. The older epidiorites are transgressed by the later lamprophyres and porphyrites, which in turn are cut by the Tertiary basalts and crinanites. These later ones also cut across the oldest metamorphics/

metamorphics and epidiorites. As regards the dimensions of the dykes, it is to be noted that all the Caledonian and Tertiary ones occur as minor stringers of but a few feet (2 to 12) in width and anything like a few tens of feet to about half a mile in extent. All these have been involved in and affected by the minor faults that took place in the region.

A study of Dr. McCallien's field notes discloses the following facts concerning the distribution of the different dyke rocks:

(i) that the lamprophyres (minettes, vogesites and spessartites) and porphyrites are distributed mostly in the western half of Inishowen, round about Lag, Ballyliffin, Dunaff Head, Dunree Head, Stragill, King and Queen of Mintiaghs, Buncrana, Inch Isle and Rathmullan, as also in Strabane and Artigarian of Tyrone county,

(ii) that the camptonites and monchiquites are mostly concentrated in the northern portion of the Inishowen promontory, in Malin Head, round about Lag and Inishtrahull Island and that they are also met with in Inch Isle, Buncrana and Fanad, and

(iii) that the distribution of the tholeiites, basalts/

basalts and crinanites is practically ubiquitous, though there appears to be some concentration in the eastern half of Inishowen.

PETROGRAPHY.

The Caledonian and Tertiary dykes, which only are dealt with here comprise several petrographic types.

(a) Caledonian Dyke Activity.

From a petrographic point of view, the Caledonian dyke rocks are broadly classified as follows:- Vogesite, Spessartite (with variation to appinite), Markfieldite, Minette, Hornblende-porphyrite (with variation to hornblende-biotite-porphyrite), Albitophyre, Plagiophyre, Alkali-felspar-porphyry, Quartz-porphyry and Quartz-felsite.

1. Vogesite. The rocks of this division are characterised by a panidiomorphic structure and are, generally, dark green in colour with a mottled or speckled appearance, being composed of dark prisms of a mafic mineral with scattered patches of white or pinkish felspar.

Vogesite is a non-porphyritic, granular rock

with/

with stout prismatic crystals of hornblende (and rarely diopside) in a fine-grained matrix of felspar and hornblende with minor amounts of quartz and iron-ore with accessory apatite, pyrite and green glass. Hornblende usually occurs as elongated prisms or plates which may be five to six times as long as broad with a variation in length from 1 to 3 mm. It is also found as crystals with regular hexagonal outline with the two sets of cleavages at the usual oblique angle. It is hypidiomorphic. It is green in colour with a faint brownish tint, the pleochroic scheme being

X - yellowish green: Y - dark green: Z - brownish green.

It exhibits oblique extinction, with $Z \wedge c$ ranging from 11° to 23°, and twinning on (100) face. In addition to its above-mentioned form and characters, it is also found as small acicular crystals often aggregated into clusters in the groundmass. It is generally fresh but is sometimes partly altered to chlorite or, rarely, serpentine. The chlorite appears to be of two different kinds: one variety, which is very light green in colour with feeble or no pleochroism and 'ultra blue' interference colours, is penninite/

penninite and the other, with moderate pleochroism and normal grey polarisation, is, in all probability, antigorite. Limonite is generally associated with these secondary minerals. In a very few cases the chloritisation of hornblende is so complete that not even a vestige of the original mineral is left behind. In addition to these alterations, hornblende sometimes shows on the terminal faces outgrowths of a fibrous, greenish, pleochroic mineral of slightly lower R.I. in optical continuity with it. It thus seems to be actinolite.

Diopside is not common in vogesites, but does occur. It is rarely equal in amount to hornblende. It is found in stout prismatic or euhedral crystals, sometimes aggregated. It is colourless or very pale green and often shows polysynthetic twinning. The optic axial angle (2V) as measured on Federov's Universal Stage is $55^{\circ} \pm 3^{\circ}$ over Z. Uralitization of the pyroxene, as also its replacement by calcite, is common.

Felspar, the predominant constituent of the matrix, is in the form of small lath-shaped anhedral crystals or radiate groupings of tablets and is mostly potassic, being/

being orthoclase or anorthoclase, though plagioclase is not absent. All the felspar is coated with fine hematite dust which is concentrated more towards the margins so that they stand out in relief. The alkali-felspar - orthoclase - is twinned generally on Carlsbad law. More often, the twinning is obscure, the mineral showing quadrille structure and patchy extinction, when it is identified as anorthoclase. Most of the alkali-felspar is altered to kaolin and sericite, the determinations being thus rendered difficult. Albite, with beautiful twin lamellae, is present in minor amount and is subhedral. In some rocks it is almost equal in quantity to the alkali felspar, when difficulty in nomenclature arises. In many cases it is replaced by calcite.

Quartz is present in minor quantity and is interstitial. In some sections it is quite a prominent constituent, occurring as rounded or irregular discontinuous patches, but all the same optically continuous. In some such cases, chlorite is also seen along the margins of the patches, a feature first recorded by Reynolds (30). Here the quartz is definitely xenolithic. (Plate I. Fig. 1).

Magnetite/

Magnetite is found in euhedral or skeletal crystals and pyrite in small specks. Apatite is the chief accessory mineral occurring as acicular crystals in the matrix. Green glass is also present, but in variable amounts.

One feature worthy of note is that there is a gradual insensible transition between the vogesites and the spessartites.

2. Spessartite. Lamprophyres of this group are medium-to coarse-grained dark rocks with a panidiomorphic structure (Plate I, Fig. 2). Some of them show dark bands - evidently concentrations of mafic minerals. Also, the disposition of the dark minerals suggests influence of flow.

The features that serve to distinguish spessartite from vogesite are firstly, the nature of the hornblende which occurs mostly as crystals with regular hexagonal outlines, having a characteristic brown colour and pleochroism in different shades of brown with a faint greenish tint; secondly, the predominance of plagioclase over alkali-felspar; and lastly, the frequent occurrence of diopside either exclusively as the chief mafic mineral or/

or in conjunction with hornblende.
Hornblende differs to some extent from that of the vogesites. It commonly occurs as big euhedral and panidiomorphic porphyritic crystals and less frequently as elongated prisms. It is brown in colour and markedly pleochroic in

X - greenish brown: Y - brown: Z - dark brown

and $Z \wedge c$ up to 24°. Its optic axial angle (2V) varies between 76° and 85° with X as the acute bisectrix. It has dark brown resorption rims and strong dispersion. It is generally twinned. Outgrowths of actinolite are observed. Alteration is, as usual, to chlorite - penninite or antigorite - which is here and there replaced by quartz or calcite.
Diopside occurs in clusters of idiomorphic, stout, prismatic crystals or short grains generally associated with hornblende but in some cases as the only mafic mineral of the rock. It is colourless, has $Z \wedge c$ 46° and 2V: 54° ± 1.5°. It is rarely fresh, being partially or completely uralitized or replaced by carbonates.

The matrix is felspathic with some acicular hornblende and/or small grains of diopside with interstitial quartz/

quartz and green glass. Veins of calcite run through some rocks.

Felspar which occurs as anhedral laths with a tendency to radiate grouping is coated with hematite dust and is albite-oligoclase (An_{17-18}) with distinct albite twin lamellae. Potash felspar is also present but is subordinate to the plagioclase. Most of it is altered to kaolin and sericite and the plagioclase to saussurite with the formation of fine flakes of chlorite and granules of epidote. Its replacement by calcite is common.

Quartz is xenolithic and primary, the latter being interstitial. Magnetite, apatite and green glass are the common accessories. A few grains of red spinel - picotite - were observed in one section.

There are some spessartites which are so very coarse-grained that hornblende occurs as very stout euhedral crystals and felspar in prominent laths. Such rocks are best described as appinites.

3. Markfieldite. Under the microscope, the rock is seen to consist of abundant euhedral crystals of brown hornblende in a granophyric matrix of plagioclase, quartz and micropegmatite with long needles of apatite, crystals of/

of iron-ore and small patches of green glass, besides chlorite as the secondary constituent. (Plate I, fig.3).

The brown hornblende which is euhedral and panidiomorphic, has the usual characters - marked pleochroism, strong dispersion and slightly oblique extinction ($Z \wedge c$ 20°). It is here and there chloritized.

The felspar, sprinkled with hematite dust, is almost entirely albite-oligoclase in euhedral, lath-shaped crystals. It is twinned and exhibits straight extinction. It is rarely zoned but is generally sericitized and kaolinized, the sericite being aligned as fine flakes in the direction of the maximum length of the lath. Albitization has resulted in the formation of irregular patches of clear albite in the plagioclase. Micropegmatite, a fine intergrowth of quartz and potash felspar, is one of the important constituents of the rock occurring in the interstices and along the margins of the plagioclase laths. The secondary albite in some cases seems to have replaced some of the micropegmatite as judged by the embayed margins of the former in the latter. Quartz, apatite, iron-ore and green glass are the accessories.

4. Minette. The rock is highly crushed and presents a foliated appearance/

appearance. In thin section, it is seen to be composed of long trains of biotite in a highly granulitic matrix of felspar and quartz with apatite and magnetite as accessories and chlorite and calcite as secondary products. (Plate I, fig. 4).

Biotite occurs as glomeroporphyritic aggregates of small flakes which are all aligned in the same direction, a few of them bent. It is fawn-brown in colour with a faint greenish tint, suggesting its decomposition to chlorite. Not infrequently is calcite found intruded along the cleavage planes.

Felspar is the important constituent of the matrix which is typically granulitic, giving a mosaic structure to the rock as a whole. It is very fresh and idiomorphic anorthoclase. Albite-oligoclase is also present.

Quartz is also abundant, being almost equal to felspar in amount. It occurs as numerous small, irregular grains along with the felspar, but sometimes is found in long rows replacing the felspar. Evidently, most of it is of replacement origin.

The accessory minerals are the same as in the other rocks. Calcite is common as a replacement product/

product and several veins of it run through the section, cutting biotite, felspar and quartz.

5. Hornblende Porphyrite. The porphyrites and the porphyries described below differ from the lamprophyres mainly in the texture. They are porphyritic with phenocrysts of felspar exclusively or with hornblende and biotite. Thus, the felspar occurs in two generations, as contrasted with a single generation of felspar in the lamprophyres.

Hornblende-porphyrite, like the vogesite and the spessartite, is a common rock type of the area. It consists of phenocrysts of plagioclase and hornblende in a medium- to fine-grained matrix of minute felspar laths and prisms and interstitial quartz grains with apatite, magnetite and green glass as the accessory minerals and chlorite, calcite and albite as the secondary constituents. Hornblende occurs as euhedral, prismatic crystals and is idiomorphic. But some elongated prisms are two to three times as long as they are broad. The mineral is of the ordinary green type with pleochroism.

X - yellowish green: Y - green: Z - deep green.

It has generally as inclusions slender short prisms of apatite/

apatite. It is generally in an altered condition with such secondary minerals as penninite, antigorite, epidote, calcite and, rarely, biotite either in part or completely taking its place. Associated with the chlorites is magnetite in minor rods and granules. Plagioclase forms well-defined, lath-shaped to squarish phenocrysts (Plate II, fig. 1). Detailed determinations on the Universal Stage prove it to be basic oligoclase to acid andesine in composition with $An_{24 \text{ to } 35}$. It is twinned and generally zoned with andesinic cores and albitic exteriors. The commonest change to which it is subject is albitization. Perfectly clear, colourless patches of albite are found replacing the original plagioclase. The secondary albite is untwinned and is frequently moulded irregularly on the outer parts of the laths. Replacement of this albitized plagioclase by quartz or calcite is seen. In fact, veining of the rock by quartz and calcite is very common.

The matrix is fine-grained and cryptocrystalline with microlites of felspar, grains of quartz and rare prisms of hornblende. The felspar is all altered to kaolin and sericite. Both plagioclase and anorthoclase are/

are there in roughly equal amounts. All variations in size between the big felspar phenocrysts and little microlites are met with. Replacement by calcite is common. Accessories include apatite, iron-ore and green glass.

Variations from this rock type beginning with the entry of primary biotite in small amounts up to the stage of its equality in quantity to hornblende are to be traced in some rocks which are best referred to as biotite-bearing hornblende-porphyrites and hornblende-biotite-porphyrites. These correspond perhaps with malchites of Ben Nevis. (5).

6. Albitophyre. This is also one of the common types among the porphyrites. It is purple-coloured and though not conspicuously porphyritic has, for the most part, big stout pink felspar laths with here and there some streaks and clots of green chlorite. Pockets of quartz and veins of calcite are also noticed.

In thin section, the phenocrysts of plagioclase occur as euhedral laths with prominent outlines. The mineral is twinned basic oligoclase, generally albitized. The only mafic constituent of the rock is chlorite in pseudomorphs/

pseudomorphs, suggesting the form of original biotite. The matrix is fine-grained and microfelsitic with much of felspar, some disseminated quartz and calcite (Plate II, fig. 2). Kaolin dust, sericite flakes and epidote granules are secondary after felspar which includes both alkali-felspar and plagioclase. Accessories are the same as in the other rocks. Quartz, besides being interstitial, is found in narrow veins. Calcite is also present.

Minor variations in texture as, for example, the imperceptible gradation from porphyritic to orthophyric texture, as also the change in mineralogical composition with relatively high amount of chlorite etc., are observed in different rock sections. Still, on the basis of their several common characters, those are relegated to this same group.

7. Plagiophyre. The rock has a speckled appearance with variegated colours of dark green and pink, the pinkish felspar patches presenting a glomeroporphyritic aspect. It stands midway between the mafic-rich lamprophyre and the leucocratic porphyry-porphyrite in that it contains roughly equal amounts of felspar and hornblende, biotite and/or/

and/or chlorite derived therefrom. Also, some transition types between this rock and spessartite or vogesite are met with.

Under the microscope, the rock is seen to be medium-to coarse-grained with rectangular laths of euhedral plagioclase arranged in a criss-cross pattern together with flakes or fibrous pseudomorphs of chlorite after biotite and hornblende. (Plate II, fig. 3). Very rarely, rectangular flakes of biotite and prismatic crystals of hornblende are seen fresh. The plagioclase is much altered to some opaque product. It is twinned and sometimes zoned and is acid andesine (An_{30-33}) with extinction angles up to 15^{o} or 17^{o} in the zone (010). Clear, untwinned, secondary albite is moulded on the outer zones of the plagioclase. Replacement of this again by calcite is common. Quartz and green glass occurring in small amounts are interstitial, while apatite and magnetite are the other accessories.

8. Alkali Felspar Porphyry. This is highly felspathic and porphyritic with big phenocrysts of felspar in a fine-grained pink matrix of felspar with some quartz and scraps of chlorite.

Under/

Under the microscope, phenocrysts of potash felspar and albite are seen with rectangular or squarish outlines. The orthoclase is twinned on Carlsbad law and the anorthoclase has the characteristic patchy extinction. The albite shows the polysynthetic twin lamellae. Most of the felspar is, in general, sericitized.

The matrix consists of small euhedral crystals of orthoclase, anorthoclase and albite together with a certain amount of cryptocrystalline material of quartzo-felspathic composition in interstices. (Plate II, fig 4). The felspar is considerably altered. Rare elongated pseudomorphs of chlorite also occur. Their form suggests derivation from biotite. The accessories are apatite in fine needles, iron-ore in skeletal crystals and pyrite in irregular specks. Veins of quartz are found in some rocks and they send fingering processes into felspar and thus effect replacement.

9. Quartz Porphyry. The rock has a well-developed porphyritic texture and consists of phenocrysts of quartz and occasionally anorthoclase in a fine-grained groundmass composed of quartz, orthoclase and anorthoclase. (Plate III, fig; 1).

The/

The phenocrystic quartz occurs in good bipyramidal or rounded crystals, the latter form being evidently due to magmatic corrosion. At times, the crystals are seen to have glass inclusions. The anorthoclase is altered and decomposed, forming kaolin and sericite.

The groundmass shows signs of devitrification in the presence of cracks of variable width and where fairly wide, filled up with quartz. The matrix too, is an aggregate of quartz, orthoclase and anorthoclase, the entire felspar of which is rarely fresh; while rare bleached chlorite flakes with calcite infillings represent original biotite. Calcite is also seen eating its way through the quartz phenocrysts. The accessories besides glass include skeltons of iron-ore.

10. Quartz Felsite. This rock, which is closely similar to the previous one, differs from it only in some microscopic details. The typical porphyritic texture has given place to glomeroporphyritic aggregates of quartz crystals in a micrographic groundmass of fresh or sericitized felspar and quartz. Even in this most acid rock tiny flakes of chlorite/

chlorite with forms suggestive of primary biotite are seen. Small irregular patches of calcite are moulded on these. Accessories, as usual, include apatite and iron-ore.

(b) Tertiary Dyke Activity.

This is represented here by crinanites, olivine-basalts and tholeiites.

11. Crinanite. Under the microscope, the rock shows a typical opthitic texture and consists essentially of olivine, augite, labradorite, analcite, zeolite and iron-ore with apatite, calcite, biotite and alkali-felspar as the accessory minerals besides secondany constituents like serpentine, epidote etc. (Plate III, fig.2).

Olivine is abundant and occurs as euhedral crystals (with up to 2 mm. diameter) or as irregular crystal grains poikilitically enclosed by augite and plagioclase. It is sometimes fresh but mostly broken, fissured, cracked and altered to ordinary serpentine or bowlingite, the latter being yellowish-brown in colour and pleochroic to greenish-brown. The olivine is variable in optical sign, the optic axial angle (2V) varying very little on either side of/

of 90^{o}. Measurements on different grains showed a variation of 2V from 93^{o} to 88^{o} over X. Only two grains gave values as low as 84^{o} and 82^{o}. Thus it is predominantly forsterite, an observation quite in accordance with the fact that it was one of the first constituents to crystallize.

Augite, found as ophitic plates, is light purple in colour and is, in all probability, titanaugite. It is pleochroic with

X - brownish green: Y - pale brownish violet:
Z - pale purple:

with distinct green margins where adjacent to zeolites. The 2V varies between 48^{o} and 59^{o}, but mostly it is round about 50^{o} $\pm$ 0.5^{o}, while $Z \wedge c$ is 48^{o}. Some grains show good polysynthetic twinning and others hour-glass structure. In some analcite-rich rocks, the augite assumes a definite greenish colour, indicating an enrichment of soda. It is aegirinaugite with pleochroism as follows:-

X - grass green: Y - olive green: Z - yellow.

The optic axial angle (2V) is 68^{o} over Z, while $Z \wedge c$ is 59^{o}.

The/

The <u>plagioclase</u> crystals give elongated rectangular sections with lengths up to six or seven times the breadths. The mineral is basic labradorite mostly (with 2V $81^\circ \pm 1^\circ$ over Z, indicating a composition of An_{63-65}), though an acid variety (with 2V 77° i.e. An_{53}) is also present. This, at times, is altered to epidote, the latter occurring as fine granules. Also replacement by calcite is exhibited.

<u>Analcite</u> is rather turbid with brownish alteration products and is isotropic. It shows idiomorphic boundaries towards the zeolites, indicative of its earlier crystallization. The fibrous <u>zeolites</u> are usually abundantly developed interstitially and in large vesicular masses. Of these, only natrolite with its rather low R.I., straight extinction and positive elongation of the fibres, could be identified with certainty.

Iron-ores - magnetite and ilmenite - are skeletal or euhedral and are largely leucoxenized. Apatite is common in acicular crystals. Ilmenite-biotite intergrowths are observed. Biotite is also rarely secondary after augite. Anorthoclase is a rare accessory.

<u>Olivine</u>/

12. Olivine-Basalt. This is a non-porphyritic, fine-grained Plateau type of basalt. In thin section, except for a few microphenocrysts of olivine, the rock is an ophitic aggregate of augite and labradorite, with here and there some vesicles filled with zeolite. (Plate III, fig. 3).

The olivine is never fresh, being broken and altered to some isotropic material (?), or replaced entirely by calcite on which is sometimes superposed a chalcedonic banding. The augite is pale purple and feebly pleochroic to pale brown. The labradorite (Ab_1An_1) is replaced by calcite. Iron-ore is abundant. Zeolite is also plentiful. In fact, it can be called a vesicular olivine-basalt.

Tholeiite. From a study of the microsections, the tholeiites are broadly classified as follows:-

(a) olivine-bearing: Largs type.

(b) olivine-free: Cumbraite, Brunton type and Talaidh type.

13. Largs type. This is the only olivine-bearing type of tholeiite of this area and is by far the most abundant. In thin section, it is seen to contain phenocrysts of olivine/

olivine in a coarse-grained ophitic aggregate of labradorite and augite together with some iron-ore and accessory glass. (Plate III, fig. 4). Minor variations from this description in the direction of the occurrence, in addition to olivine, of labradorite as microphenocrysts in a fine- to medium-grained groundmass of augite plates, plagioclase laths, iron-ore and glass (in more than accessory amounts) are observed. On the whole, the rock is characterised by abundant olivine and very little of glassy mesostasis.

The phenocrystic olivine which is found in euhedral crystals is undoubtedly the first constituent to crystallise out from the magma. It is rarely fresh, being partly or completely serpentinized. The serpentine is a fibrous, dark green-brown pleochroic variety - bowlingite. The fresh olivine has an optic axial angle (2V) varying between 78^{o} and 74^{o} over X, indicating 42 to 50 per cent. of the fayalite molecule in its constitution.(42). Thus, the fact that the serpentine (bowlingite) is iron-rich and that much of magnetite which occurs as irregular streaks inside olivine grains is released during serpentinization/

serpentinization, corroborate the fayalitic nature of the olivine, as contrasted with the forsterite of the crinanite.

The augite occurring as ophitic plates or grains is colourless or pale yellow and faintly pleochroic, the intensity of pleochroism increasing in grains that are in contact with titanomagnetite. Its 2V is $44.5^{\circ} \pm 3^{\circ}$ over Z. But, in some grains, it is as low as 24° while a few others showed a perfectly uniaxial interference figure. Thus, it is clear from the above data that the augite, unlike that of crinanite and basalt, is pigeonitic. The extinction angle ($Z \wedge c$) is 48°.

Hypersthene with its characteristic pleochroism between pale pink and pale green occurs in accessory amounts. Its 2V is 78° over X.

The plagioclase which is lath-shaped is in ophitic relationship to augite and it also occasionally occurs as microporphyritic crystals. It is twinned and has a symmetrical extinction of 38° to 40°. Hence, it is basic labradorite.

The iron-ores - titaniferous magnetite and

ilmenite/

ilmenite - are altered to grey leucoxene. Brown glass, mostly insignificant, is sometimes present to about 10 per cent. by volume.

14. Cumbraite. This is a fine-grained olivine-free tholeiite with a well-developed intersertal texture, the mesostasis being entirely made up of clear to pale brown glass. (Plate IV, fig. 1).

The augite and basic plagioclase occur as microphenocrysts, besides being found as microlites in the glassy base. Iron-ore is common. Some vesicles filled with zeolite are observed.

15. Brunton type. This tholeiite, which is very closely related to the previous one, differs only in the relative increase in the proportion of augite and plagioclase at the expense of glass such that all the three constituents are present in almost equal amounts.

The elongated laths of plagioclase are generally aggregated in such a way as to present a stellate structure. (Plate IV, fig. 2). The pyroxene is granular and occurs as aggregates. The mesostasis, which separates these, is all glass with globulites and microlites which inter-penetrate. The iron-ores occur as threads in the base.

This/

This type is at times seen to have tachylytic selvages.

16. Talaidh type. This is a fine-grained tholeiite with intersertial texture. The augite occurs in clusters and shows cervicorn structure. (Plate IV. fig. 3). It is very slender and elongated and ophitic towards plagioclase which is labradorite. The iron-ores are leucoxenized. The mesostasis which contains some microlites is glassy but, glass, on the whole, is small in amount.

PETROGENESIS AND COMPARISON WITH RELATED OCCURRENCES.

(a) Caledonian Dykes.

From a study of the Caledonian dyke swarm which comprises rock types like minettes, vogesites, spessartites, albitophyres, plagiophyres, porphyrites, porphyries, felsites etc., it is clear that there is considerable variation in the group. Moreover, there are several rocks which are transitional between the different members mentioned above. Thus, it is evident that the variation is strikingly gradational.

With this point in view, the origin of this diverse series of rocks is best explained by the differentiation under hypabyssal conditions of a basic magma, lamprophyric in composition. By crystal sinking, the pyroxene settled down first. Later on, hornblende began to separate out, resulting in the enrichment of alkalies in the magma which, at that stage, reacted with the crystallized material forming biotite. The residual magma, which is alkali- and silica-rich, gave rise to felspar and finally, quartz. But that is not all. In all these rocks several other minerals of comparatively late formation are seen and they have to be accounted for.

The activity of the hydrothermal solutions in bringing/

bringing about mineral transformations is well manifested in the breakdown of the primary minerals - hornblende, biotite, plagioclase, orthoclase etc. - with the formation of such exceedingly common secondary products as chlorite, sericite, saussurite, calcite etc. In addition to this, the occurrence of chlorite in long streaks or scraps, albite in big irregular patches, quartz and calcite in veins, indicates the intense activity of the hydrothermal solutions manifested, under favourable conditions, in vein formation. Thus, when the succession of the above-mentioned replacement phenomena is considered, it is found that albitization of the plagioclase has taken place first, this having been followed by chloritization of the ferromagnesian minerals. Evidence for this fact is in the penninite fibres which, in many cases, cut albite patches. Irregular fingering processes of quartz in albite and its embayments into chlorite are proof of its later formation. Since veins of calcite cut across quartz veins, the former is formed still later or last. Thus, the following order for the replacement phenomena is established:-

(i) albitization (of the plagioclase).

(ii)/

(ii) chloritization (of the ferromagnesian minerals).

(iii)replacement by quartz, and

(iv) replacement by calcite.

Thus, it is surmised that much of the albite (except that in alkali-felspar-porphyry), chlorite, quartz (excluding that of quartz-porphyry and quartz-felsite) and calcite is due to the autometasomatism of the rocks by the hydrothermal solutions.

Mention is here made of the xenoliths of quartz in some lamprophyres. The quartz is very much resorbed and, in general, has a thin margin of chlorite, as described earlier. Thus, corrosion by the basic magma and its reciprocal reaction with the xenolithic quartz with acidic oxides entering the former and basic oxides the latter, explains the observed facts.

Lastly, since all the lamprophyres and porphyrites, the minettes are invariably crushed and present a foliated aspect, it is quite probable that the latter belong to an earlier period of intrusion than the rest, with crushing effected by diastrophic movements following intrusion.

The/

The Caledonian dykes of Donegal and Tyrone counties bear a very close resemblance to those in Co.Down, as also to those in the Western Isles and Scotland. Lamprophyres - vogesites, spessartites, crushed minettes etc. - together with Hornblende-porphyrite and Alkali-felspar-porphyry are common to Donegal, Tyrone and Down (29 (26). Again, the markfieldite from the intrusion at Slievenagriddle (27) in Co. Down is identical in every petrographic detail with that of Co. Donegal. In the presence of rounded quartzose xenoliths and xenocrysts too, they compare well with each other, as also with the Cornish (32) and Sedbergh (33) lamprophyres. But while the dykes of this area seem to have much variety in their felspathic members, the same is not so apparent in those of Co.Down.

In Scotland, the Ben Nevis (2) and Etive (3) dyke swarms have felsites, porphyrites, albitized porphyrites and lamprophyres which are all identical in every respect with the corresponding Irish rocks and throw light on such replacement phenomena as albitization which seem to be universal and not confined to any one particular area. In the Southern Uplands, the felspathic intrusives like/

like porphyrites, albitophyres and plagiophyres of Kirkcudbrightshire (23) are similar to Donegal rocks from the viewpoint of petrography including replacement phenomena. Lamprophyres and porphyrites from Galloway (12) and from Criffell (25) also compare well with the Irish rocks. Again, the Newmains dyke of markfieldite in Dumfriesshire (22) compares well with that of Donegal. But, while the mica-lamprophyres of Wigtownshire (28) are mostly kersantites, together with some minettes, and are having ocelli, the few minettes of Donegal are conspicuous by the absence of ocelli in them. In the Highlands, in Aberdeenshire (8) (9) and Argyllshire (40), several minor intrusions are constituted of the same petrographic types as in Donegal.

In the Western Isles, the lamprophyres (mostly vogesites and spessartites), porphyrites and felsites of Knapdale, Jura (11), Colonsay, Oronsay, Ross of Mull (6), Cowal (10), Islay (41) and Outer Hebrides (20), are remarkably similar to those of Donegal and Tyrone.

(b) Tertiary Dykes.

The crinanites and olivine-basalts and the associated/

associated tholeiites are to be regarded as the products of differentiation of the Plateau Basalt (Olivine-Basalt of Kennedy) type of magma and the Non-porphyritic Central type (Tholeiite of Kennedy) of magma respectively.

The differentiation of the olivine-basalt magma, according to Kennedy (21), results in the formation of alkaline rocks, as contrasted with the calc-alkaline rocks from the tholeiite magma. This fact is best explained in the crinanites which are quartz-free rocks with a high content of alkali-rich minerals like analcite, zeolite, aegirinaugite etc. Also, the olivine is forsterite, as it should be.

Thus, by the differentiation of the olivine-basalt magma, olivine (forsterite) crystallized out first and was followed by a simultaneous crystallization of augite and plagioclase resulting in ophitic texture. Lastly, the alkali-rich residuum of the magma consolidated as analcite etc.

On the other hand, the tholeiite magma has, by crystal settling, given rise first to augite which is pigeonitic and then to labradorite. Lastly, the mesostasis which represents the residuum of silica and alumina/

alumina of the magma has consolidated as glass or, under especially favourable circumstances, as quartz and micropegmatite.

The formation of such rock types as Largs (Salen and olivine-bearing Brunton) tholeiites is due to the failure of reaction between the early-crystallized olivine and the residual magma.

In view of the lack of definite knowledge about the field characters of these Tertiary dykes, it is very difficult to judge their inter-relationship, much less their relative ages. Still, comparison is made from the petrographic point of view and it is found that the Donegal rocks are similar to those in Co.Antrim and much more so with those of Co. Down (35 (36), where there is immense variety in the olivine-free tholeiites. Thus, Tomkeieff's observation (35) that the Donegal and Down dykes form one set receives confirmation. Among the occurrences in the Western Isles, the crinanites of Colonsay (6), South Jura and Kintyre (11), Arran (39), Outer Hebrides (20), the tholeiites and basalts of Arran, Mull (4), Ardnamurchan (31), Skye (13), Kintyre (24), Outer and Inner Hebrides, Cumbrae Islands (38), Firth of/

of Clyde (37) and Argyll (1) have many characters in common with the corresponding Irish rocks. Lastly, mention is also made of similar tholeiites of the north of England (17) and the Whin sill (16) and related dykes.

SUMMARY OF CONCLUSIONS.

The dyke rocks of Donegal and adjoining parts of Co. Tyrone include epidiorites, spilites and keratophyres, lamprophyres and porphyrites, camptonites and monchiquites and lastly, crinanites, olivine-basalts and tholeiites belonging respectively to the igneous epochs of Dalradian, Ordovician, Caledonian, Permian and Tertiary ages.

Detailed studies on the Caledonian and Tertiary rocks show that the former is represented by different petrographic types as vogesite, spessartite (with variation to appinite), markfieldite, minette, hornblende-porphyrite, albitophyre, plagiophyre, alkali-felspar-porphyry, quartz-porphyry and quartz-felsite, while the latter is represented by crinanite, olivine-basalt and tholeiite which in itself, again, has the Largs, Cumbrae, Brunton and Talaidh types. A petrographical account of all these types is given.

The origin of the different Caledonian rocks is attributed to differentiation of a lamprophyric magma and the importance of replacement phenomena like albitization, chloritization, formation of quartz and calcite, as also the/

the reciprocal reactions between the xenoliths and the magma is established. Comparison with similar occurrences in Ireland, Scotland, Western Isles and England are instituted.

The genesis of crinanites and olivine-basalts is ascribed to the differentiation of an olivine-basalt parent magma and of the tholeiites by the differentiation of a tholeiite parent magma. It is shown that these rocks compare favourably well with similar rocks from counties Antrim and Down in Ireland and from Scotland, Western Isles and England.

ACKNOWLEDGMENTS.

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Explanation of Photomicrographs.

Plate I, Figs. 1, 2, 3 and 4.

(1) Vogesite: Prismatic crystals of hornblende in a matrix of felspar. Corroded quartz xenocryst with a rim of chlorite.

Ordinary Light X 22.5

(2) Spessartite: Typical panidiomorphic structure, euhedral crystals of brown hornblende in a groundmass of felspar.

Ordinary Light X 22.5

(3) Markfieldite: Phenocrysts of euhedral hornblende in a granophyric matrix of plagioclase, quartz and abundant micropegmatite.

Nicols Crossed X.33

(4) Minette: Exhibiting foliation with long trains of biotite in a granular matrix of felspar and quartz.

Ordinary Light X 22.5

Plate II, Figs. 1, 2, 3 and 4.

(5) Phenocryst of plagioclase in Hornblende-porphyrite: It shows replacement by albite which is seen as clear, colourless, irregularly moulded patches.

Ordinary Light X22.5

(6)/

(6) **Albitophyre**: Phenocryst of albitized plagioclase and pseudomorphs of chlorite cut by a quartz vein.

Ordinary Light X 22.5

(7) **Plagiophyre**: Rectangular, euhedral laths of plagioclase and flakes of chlorite with a tendency to orthophyric texture.

Ordinary Light X 22.5

(8) **Alkali-Felspar-Porphyry**:

Phenocrysts of orthoclase anorthoclase and rare albite in a groundmass of felspar with pockets of quartz.

Plate III, Figs. 1, 2, 3 and 4.

(9) **Quartz-Porphyry**: Bipyramidal crystal of quartz as phenocryst in a fine-grained matrix of felspar, quartz and rare chlorite.

Ordinary Light X 22.5

(10) **Crinanite**: Microporphyritic crystals of serpentinized olivine in an ophitic aggregate of augite plates and plagioclase laths. Also, patch of analcite (in the centre) and (adjoining it) fibrous zeolite together with iron-ore.

Ordinary Light X 22.5

(11)/

(11) __Olivine-basalt__: A few phenocrysts of olivine (replaced by quartz, calcite etc). in a groundmass of augite, plagioclase and iron-ore.

__Ordinary Light X 22.5__

(12) __Largs tholeiite__: Phenocrysts of olivine in an ophitic groundmass of augite and plagioclase with iron-ore and little or no glass

__Ordinary Light X 22.5__

Plate IV, Figs. 1, 2, and 3.

(13) __Cumbraite__: Microphenocrysts of augite and basic plagioclase in an abundant glassy mesostasis.

__Ordinary Light X 22.5__

(14) __Brunton tholeiite__: Intersertal texture: stellate groups of plagioclase laths and granules of augite in a glassy mesostasis.

__Ordinary Light X 22.5__

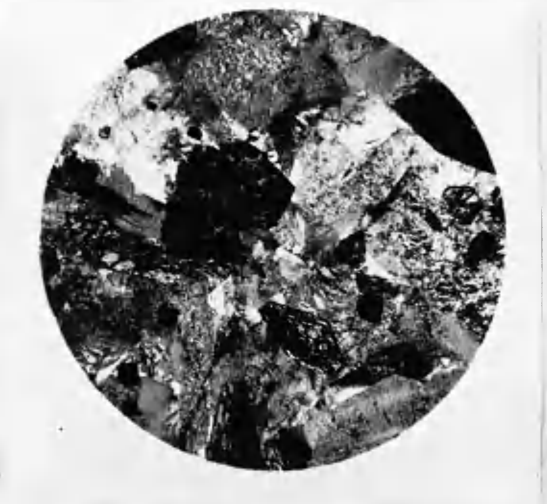
(15) __Talaidh tholeiite__: Elongated augite showing cervicorn structure and slender laths of plagioclase.

__Ordinary Light X 40.0__

PLATE I

1

2



3

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PLATE II

1

2

3

4

PLATE III

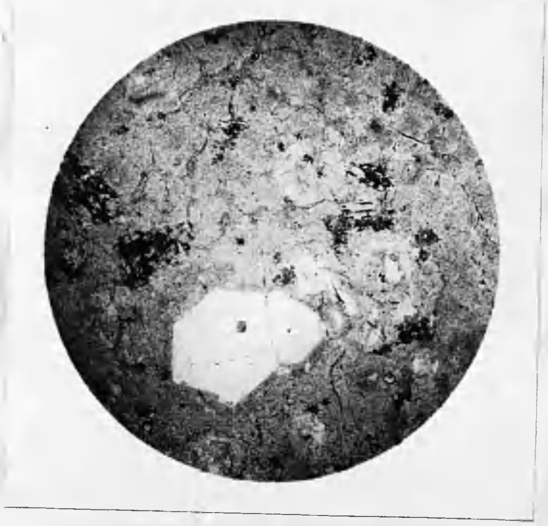

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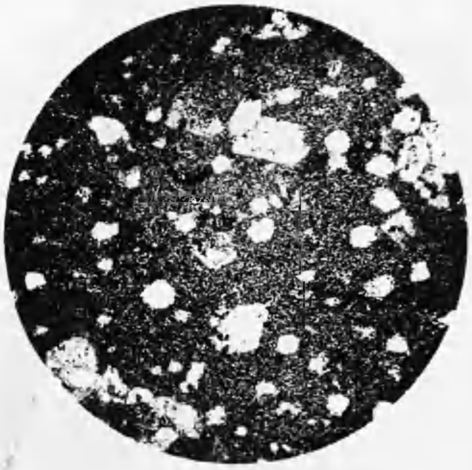
PLATE IV



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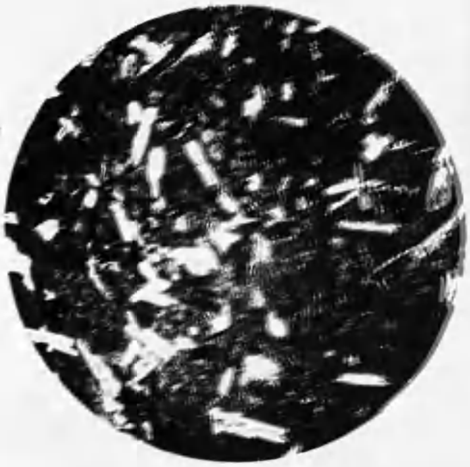

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