THE IGNEOUS ROCKS OF THE LAMLASH REGION.

T H E S I S

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Science

by

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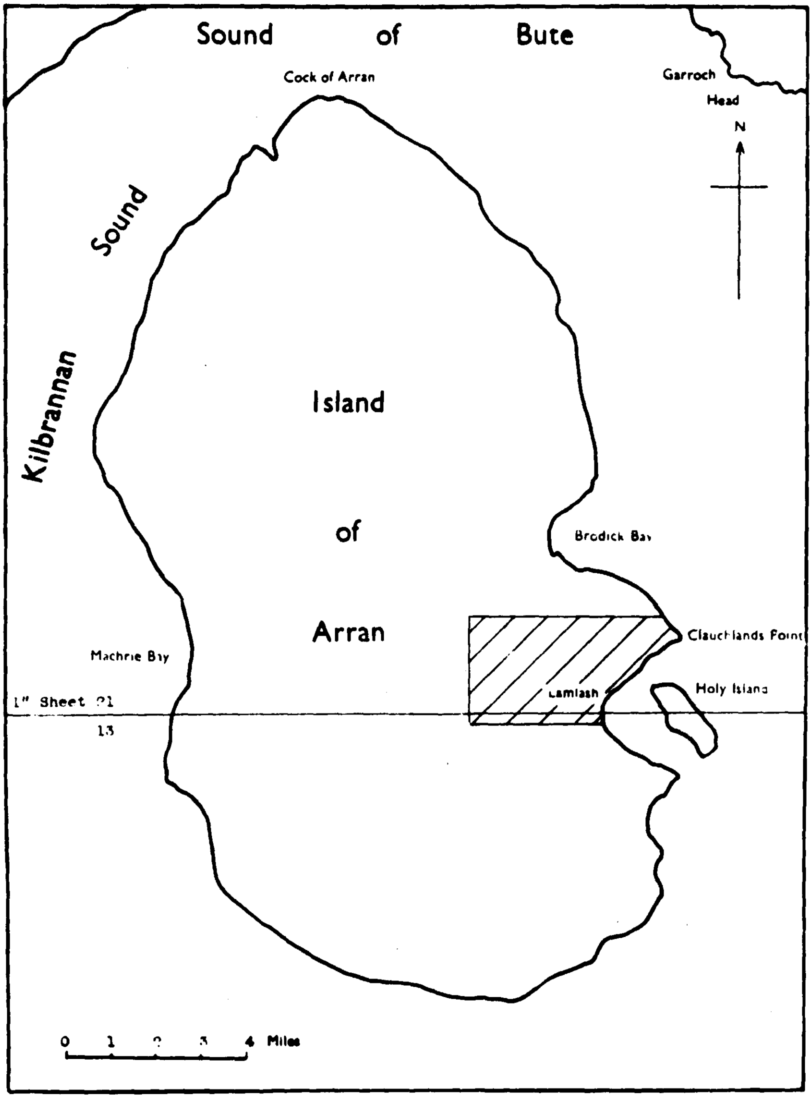

Fig. 1. Index map of the Lamlash region.

I. INTRODUCTION.

The Tertiary igneous rocks of Arran with its diversity of rock types and good exposures has provided subject matter for many papers. The present study centres around Lamlash and was undertaken initially with a view to the remapping of the boundaries of the principal igneous masses. For this account the results of the investigation are presented, especial stress being given to the composite sheet constituting The Sheans, of which the problem of the mode of emplacement of the acid veins receives particular attention.

(i) Location and Previous Literature. The region covering an area about 10.7 square miles is as shown in the index map Fig. 1. It comprises parts of six-inch Ordnance Survey Sheets, Buteshire CCXLIX and CCL. Briefly stated, it occurs within the geographical limits of the Monamore burn in the south, Tounie burn in the west, the steep southern slope of Glen Dubh in the north, and the Lamlash coastline in the east. Previous literature concerning the region is scanty but, as regards the Clauchland crinanite, brief accounts have appeared from time to time (Zirkel, 1871; Allport, 1874; Harker, 1903; Gregory and Tyrrell, 1924, and Tyrrell, 1928). Harker (1903) while describing the Tertiary igneous rocks of Arran referred to the acid veins of The Sheans as segregations of the basic rock. In 1910 the Geological Survey map of the island was first/

first published, which fixed the boundaries of the outcrops as they stand to-day, although at the time of publication they were meant to represent dolerites and diabases. This terminology was revised in the later editions of the maps (1947, 1948). In their short paper, Gregory and Tyrrell (1924) gave a section of the composite dyke near the eighth milestone on the Ross road. Subsequent work on the island included the publication of the Arran Memoir (Tyrrell, 1928) which dealt briefly with certain parts of the region, but under the limitations of a volume of its kind, coupled with the poorly exposed nature of the outcrops, The Ross, Cnoc Dubh and The Sheans could not have received fuller treatment.

(ii) Country Rocks. The country rocks into which the igneous rocks were emplaced consist of Permian and Triassic sandstones (Gregory, 1915; Tyrrell, 1928). They are moderately coarse sandstones interstratified with occasional lenticles of conglomerate, as seen along the foreshore of Lamlash bay, along the headwaters of the Benlister and Lag a' Bheith burns and on the southern slope of The Ross. The general dip of the sandstones is south-south-east, usually with low angles around 12°, and rising occasionally at the margins of intrusive masses to steep to an almost vertical dip as at Clauchlands Point.

Despite the massive nature of the igneous rocks, the extent of metamorphism on the associated sandstones is slight.

Where/

Where the direct contact between the sandstone and the igneous rock is exposed as at Claughlands Point, it is sharp and the effect of metamorphism does not extend beyond five or six feet from the contact. The sandstones at the contact show some alternating dark and light coloured bands arranged roughly parallel to the walls of the contact. In thin sections, the dark coloured bands are seen to result from higher concentration of chlorite from the ferromagnesian minerals originally contained in sandstones rather than from the adjacent igneous rock. The light coloured bands consist of quartz exhibiting undulose extinction.

II. IGNEOUS ROCKS.

About one-third of the area under investigation consists of igneous rocks of basic, sub-basic and acid composition. Of these the basic rocks consisting of crinanites and olivine dolerites make up almost the entire igneous mass. They form the impressive hills of Cnoc Dubh and The Ross on one side, and the Clauchlands on the other. They are referred to in the Arran Memoir (Tyrrell, 1928) under the local place names as the Monamore and Clauchland crinanites. The sub-basic and acid rocks of essentially quartz dolerite-tholeiite-craignurite-felsite group occur as isolated outcrops, representing eroded remnants of composite sheets or dykes.

These igneous rocks are all emplaced in Permian and Triassic sandstones and are thus referable to the Tertiary age

of/

of the igneous activity. The absence of Kainozoic sediments render it difficult to assign to each of the different intrusions a particular time within the Tertiary period. However, by a study of their mutual intersections their respective age can be established quite clearly. Broadly speaking, the earliest manifestations of the igneous activity were marked by the emplacement of the large sheeted bodies of the crinanites and olivine dolerites, viz., the Monamore and Clauchland crinanites. These were followed by the less basic suite, the quartz dolerite-tholeiites, and contemporaneously the felsites which often form composite bodies, as in the Ross road quarry, Monamore burn, and The Sheans. These rocks invariably cut the crinanites and the olivine dolerites, wherever these are also associated. During the final phase of igneous activity, numerous basic dykes of basalt and tholeiite were formed which, in the majority of cases, are found to cut the earlier basic as well as the later sub-basic and acid rocks.

The different igneous rocks are treated under the following three main headings:-

A. Crinanites and allied Olivine dolerites.

B. Composite Intrusions.

C. Dykes.

A. Crinanites and allied Olivine dolerites.

The term 'crinanite' was first introduced by Flett (1911, p.117) for certain analcite-bearing olivine dolerite dykes of the/

the Loch Crinan area, Argyllshire, the rock being considered to represent the hypabyssal equivalent of the plateau basalt of the Mull authors (Bailey and others, 1924). Tyrrell (1923; 1928) regards some of the coarse analcite-rich facies as teschenite, but since the richness or poverity of analcite is local and appears to be of no special significance as pointed out by Walker (1926, p.346), all such related rock types are here treated under the heading of crinanite. Where analcite is absent, but the characteristic titanaugite is still retained, the rocks are described as olivine dolerite allied to crinanite.

The major parts of the two crinanite outcrops, Monamore and Clauchland occur in the area under investigation. They form thick massive sheets, which have a general south-south-easterly dip, showing a gradual thinning in the direction from west to north-north-west. It is therefore concluded that the source from which these crinanites and olivine dolerites were derived must lie somewhere in a south-easterly direction, probably in the region beneath the Firth of Clyde.

(i) Field Relations.

(a) Monamore Crinanite.

The Monamore crinanite is represented on the One-inch Geological Survey Map of Arran, 1947, as extending from Squiler (1332 feet, O.D.) in the south, across The Ross (989 feet, O.D.) to Cnoc Dubh (1003 feet, O.D.) in the north. Close inspection of/

of the outcrops show the Monamore crinanite to dip in a general south-south-easterly direction at angles of 12^{o} to 15^{o}, conforming with the general direction and dip of the sandstones. The heights of Cnoc Dubh and The Ross being almost the same, and moreover the dip of the crinanite mass being south-south-easterly, it is evident that the whole mass is actually two separate sheets. The northern slope of The Ross, overlooking the Benlister burn shows clearly the sandstone intercalation separating The Ross and the Cnoc Dubh sheets. Furthermore, the extreme southerly exposure of the Cnoc Dubh crinanite seen in the Benlister burn is found to disappear beneath the sandstones. It is thus inferred that the Monamore crinanite consists of two or three separate sheets injected at different horizons in the Permian and Triassic sandstones. The first of these forms The Ross, the second Cnoc Dubh, and the third occurring outside the area under investigation forms Sguiler (Fig. 2).

The average width of the outcrops is half a mile, and its total area is over three-quarters of a square mile.

The Ross Crinanite. This rock mass which forms The Ross and extends across the Monamore burn, occupies an area about a quarter of a square mile. The western boundary of the outcrop representing the lower contact of the sheet, forms a low escarpment running north to south, west of the cairn of Ross. Here the escarpment shows a most striking penetration and veining by/

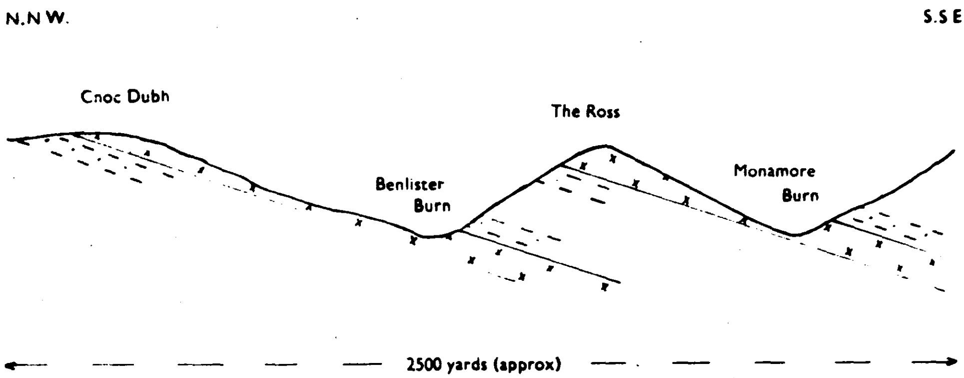

Fig. 2. Section of the Monamore crinanite, showing the disposition of The Ross and Cnoc Dubh Sheets.

by basalt which becomes tachylytic along the margins against the crinanite. At the extremities of the escarpment, the crinanite is invested with conspicuously white lenticular quartzitic sandstone inclusions, disposed parallel to the base of the sheet. The widths of the sandstone inclusions range between three and ten inches, but their lengths where exposed can be traced to over five feet. Veins of basalt with prominent tachylytic margins are invariably present between the crinanite and the sandstone inclusions.

The escarpment face overlooking the Benlister burn is formed by the crinanite underlain by sandstone disposed conformably and dipping south-easterly. This escarpment forms the northern boundary of the outcrop. The southern boundary which is seen in the steep escarpment overlooking the Ross road and again in the Monamore burn is clearly defined. As in the north, this southern escarpment shows the sandstone underlying the crinanite and conformably dipping in a south-easterly direction. An intercalation of well stratified conglomeratic sandstone is here exposed (Fig. 3). It thins out to the east and consequently shows the crinanite sheet to fray out at its western extremity. The eastern limit depicting the upper contact of the sheet can only be approximately fixed. It runs along near the base of the gentle south-easterly slope of The Ross near Ross cottage, and thence into the Monamore burn.

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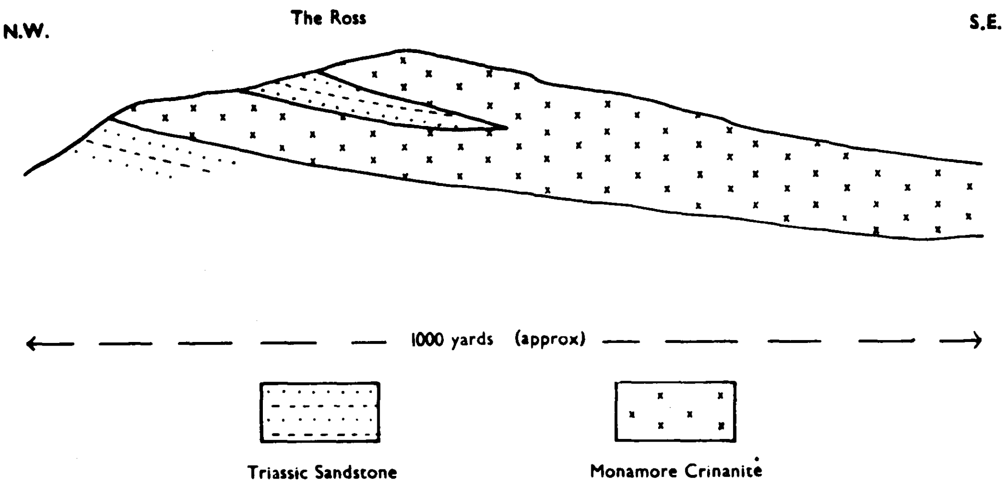

Fig. 3. Section across The Ross, showing intercalation of sandstone within The Ross sheet.

In the Monamore burn an interesting section of The Ross crinanite is exposed (Fig.4(a)). The lower contact seen in the section a quarter of a mile west of Mill dam, shows the crinanite resting on a thin sheet of quartz felsite. The contact between the quartz felsite and the crinanite is poorly exposed. Downstream, a composite sheet consisting of quartz felsite flanked by craignuritic basalt rather than a single sheet of quartz felsite, as shown in the Arran Memoir (Tyrrell, 1928, p.115), is emplaced within the crinanite. Still farther downstream the upper contact of the crinanite occurs adjacent to the Mill dam, but is not clearly defined. Here hard baked conglomerate and quartzitic sandstones, obviously formed as a result of the crinanite emplacement terminate the section.

The crest of The Ross, which marks the erosion surface of the crinanite shows a coarse massive rock, characterised by regular divisional planes, inclined in the same direction as the sheet. Slightly towards the interior from the point in the escarpment overlooking the top of the wood in the Monamore burn, and again 150 yards due east from this point, pockets of light coloured pegmatitic rock, averaging eight inches in diameter can be observed. These pockets contain titanaugite crystals which may reach lengths of three inches. Towards the centre of the pegmatitic pockets, drusy cavities are/

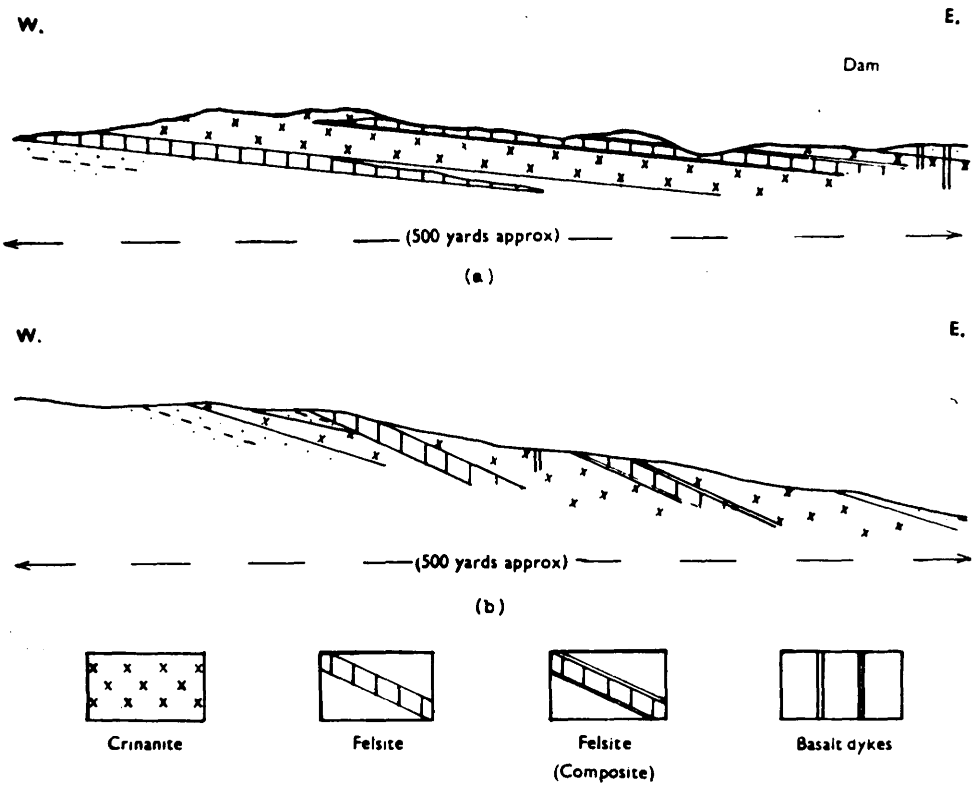

Fig. 4. Section along (a) the Monamore burn west of Mill Dam, and along (b) the Benlister burn, 300 yards west of Benlister cottage.

are marked by projections of euhedral cryśtals of zeolites or are lined by them in a botryoidal pattern. Associated with these pegmatitic pockets there also occur leucocratic veins and lenses of similar material often also containing elongated drusy cavities. The contacts of all such leucocratic facies with the normal rock, although apparently sharp, are actually transitional.

Cnoc Dubh Crinanite. The Cnoc Dubh mass is less regular than The Ross. Part of it is exposed along the bed of the Benlister burn, while the rest occur as three irregular outcrops farther to the north. In the Benlister burn a similar section as in the Monamore burn is seen (Fig. 4(b)). The upper contact of the Cnoc Dubh sheet occurs 100 yards west of Benlister cottage. Here the crinanite dips in the usual south-easterly direction, while the baked sandstones show a local dip to west-north-west. Proceeding upstream a composite dyke consisting of quartz felsite centre and craignuritic basalt margins is emplaced in the crinanite. It has a steep inclination downstream. Another quartz felsite dyke disposed parallel to the composite dyke outcrops farther upstream. Although the eastern margin of this dyke is in contact with the crinanite, the western margin shows a greyish coloured sandstone intercalation. The lower contact conforms to the dip of the sandstones.

Immediately/

Immediately north of the Benlister burn and overlooking it, is part of the escarpment of the easterly isolated outcrop which again displays parallely disposed lenticular inclusions of sandstone similar to those of The Ross. Intervening basalt with tachylytic selvages against both the sandstone and the crinanite are invariably present. At Cnoc Dubh, the most northerly outcrop, the crinanite is coarse and gabbroic with minor development of pegmatitic pockets and leucocratic veins on the gently inclined south-eastern slope.

(b) Clauchland Crinanite.

The Clauchland crinanite (Tyrrell, 1928, p.116) extends mainly eastwards from the fourth milestone on the Brodick-Lamlash road towards Clauchlands Point, a distance of 2½ miles. The average width of the outcrop is three-eighths of a mile and its total area is about a square mile. The whole mass forms a thick almost continuous sheet, thinning out gradually in the direction from west to north-north-west. The dip of the sheeted mass agrees with the sandstones, which is mainly 12^{o} to the south-east, but on approaching Clauchlands Point the direction of dip gradually changes to a southerly and ultimately to a south-south-westerly direction, with the angle progressively increasing until it becomes almost vertical at the Point.

The northern limit of the sheet representing the lower contact is for the most part clearly defined, being marked by a/

a west to east escarpment. Along this escarpment the sandstones appear to dip beneath and conformably to the igneous mass which shows irregularities only where it enters the sea near Clauchlands Point. Here the mass forms a steep or almost vertical contact with the sediments which dip at angles 40^{o} to 50^{o} to the south-south-west. At Clauchlands Point, the shore section reveals the entire thickness of the crinanite sheet, which is estimated at 600 feet. The margins of the crinanite against the sandstones are fine grained, changing rapidly into a coarse grained type within about four feet from the contact. Still farther inwards relatively light coloured pegmatitic facies exist, similar to those occurring on The Ross.

Along the upper or southern contact, the sheet appears everywhere to plunge beneath the sandstones at a steeper angle than the dip in the sandstones. This is well seen in the eastern headwater of the Blairmore burn and again in the small burn running alongside Dunan Mor. A little to the north of the same locality an outcrop of massive sandstone almost isolated from the rest, occurs in the midst of the igneous mass. Tracing the crinanite westwards into the region east of the Brodick-Lamlash road the outcrop disappears, but immediately reappears west of the road. Here the outcrop of the crinanite is invaded by thin irregular sheets of quartz basalt, emplaced horizontally into the crinanite and displaying tachylytic selvages at the margins.

The/

The crinanite is relatively fine grained at this locality and is at times indistinguishable from the quartz basalt emplaced in it. Nevertheless, here too may be seen occasional leucocratic pockets and streaks. The extreme western end of the Clauchland crinanite, outcropping in the headwaters of the Lag a' Bheith burn, shows the crinanite to fray out into three separate thin sheets. These sheets are highly transgressive and dip north-west, while the sandstones dip in the opposite direction. In the central part of the crinanite mass on the top of Clauchlands, the rock exhibits identical features to those of the interior of the mass along the Clauchland shore section. Veining by tachylytes are prominent locally.

(ii) Petrography.

In hand specimen the normal crinanite is a medium to coarse grained rock of dark greyish-green colour. Lustrous titanaugite crystals are conspicuous, displaying ophitic intergrowths with the felspars. Olivine grains are sometimes identifiable in the fresh specimens. The average specific gravity of five specimens is 2.93. Thin sections of the crinanites collected from various localities show that, despite the extensive outcrop the mineral composition is uniform. It (Plate IX, Fig 1) consists mainly of olivine, titanaugite, plagioclase felspar and iron ore, along with analcite, zeolites/

zeolites, and accessories biotite and apatite.

Olivine occurs as anhedral crystals, embedded in ophitically intergrown titanaugite plates and felspar laths. Some of the crystals are circular, while others are slightly elongated (average length 0.75 mm.) with pyramidal terminations. Serpentinisation is pronounced especially in the case of the Monamore crinanite. The serpentinisation results in pseudomorphs or interlacing networks in partially altered olivine. Elsewhere serpentine occurs in irregular patches. The serpentine is essentially of two types. The first with pale green colour and with comparatively weak birefringence is distinguished as chrysotile, while the second with yellowish-brown colour, strong pleochroism and stronger birefringence as bowlingite. The titanaugite is characteristically lilac coloured, but the intensity of the colour varies irregularly within the crystal. Pleochroism is prominent especially in the deeper coloured areas, from dark to pale violet. The mineral is optically positive, and $Z \wedge c$ is 49°. Refractive indices for α and γ are respectively 1.727 and 1.702, and the birefringence 0.025 (D.74). The plagioclase felspar, roughly three times as long as it is broad has an average length of about 1 mm. It is polysynthetically twinned on the albite law. Maximum extinction angle in zone normal to 010 is 31°, and refractive index for γ = 1.565, indicating the felspar composition as labradorite $Ab_{65}An_{45}$.

Iron/

Iron ore is abundant, and judging from its prominent skeletal habit and light coloured leucoxene alterations is ilmenite. It is found commonly in association with olivine and titanaugite. Pyrite in highly irregular forms and showing a golden yellow colour in reflected light is not uncommon. Analcite occurs in the interstices. It is dusty and brownish coloured in ordinary light. Although generally isotropic a few show anomalous polarisation colours. Strongly refrigent zeolites are quite commonly associated with analcite. Biotite is an abundant accessory. It is commonly developed in the interspaces between or around the fingers of the skeletal iron ore or is sometimes contained in it. It is flaky in habit and possesses a foxy red or reddish-brown colour. Individual crystals occurring independently of the iron ore, are prism shaped and are appreciably light coloured, indicating the richness in colour of the biotite associated with the ilmenite to have been acquired by reaction with the ore (Hall, 1941, p.21). Apatite is common. It is seen as elongated narrow prisms and hexagonal basal sections, and also as acicular needles. It is mainly embedded in the interstitial analcite, with the crystal ends not uncommonly extending into the felspar laths.

<u>Pegmatitic Pockets and associated leucocratic Veins.</u>

Under the microscope serpentinised olivine is occasionally present. The titanaugite although comparatively reduced in amount, still retains its ophitic relationship with the felspar as well as its rich lilac colour. In places where the peripheries are in contact with analcite it is rendered grass green and feebly pleochroic. The labradorite felspar which is primarily responsible for the leucocratic colour, forms 60 to 65 per cent. of the rock. Where titanaugite plates are absent the labradorite plates are diversely arranged. The labradorite felspars have suffered widespread analcitisation and zeolitisation along the cleavages and margins, such that the boundaries of the laths are rendered indefinite. Ilmenite is fairly abundant and forms ragged and skeletal crystals. Analcite and zeolites constitute a much larger proportion here than in the normal rock. Analcite is essentially confined to the interstices between the labradorite laths. It invariably replaces the felspar but is in turn replaced by zeolites. The zeolites occur in diverse habits. Some occur as anhedral plates with prominent cleavages, others as narrow radiating prisms, and the remainder form fibrous radiating aggregates. Extinction is straight, but the birefrigence is found to vary. One with third order interference colours and relatively higher relief than the other is identified as thomsonite, while another with lower relief, low order grey interference colours and positive elongation as natrolite.

The bulk composition of the Clauchland crinanite quoted/

quoted from the Arran Memoir is given in Table I, (A). It is compared with two other chemical analyses from the West of Scotland, the later crinanite dyke from Whiting Bay, Arran, (B), and the computed average composition by Tyrrell of the eight analyses, representing the Kainozoic plateau basalt magma given in the Mull Memoir, (C). Except for the minor discrepancies, all the analyses tabulated are closely comparable. Hence it is inferred that the crinanite suite of the area corresponds to the plateau basalt of the West of Scotland.

The normative and modal compositions of the Clauchland crinanite are given in Table I (b). The modal composition determined from specimen (D. 74) collected from the same locality as the analysed rock shows a close agreement with the normative composition, despite the fact that the mode and the norm specimens were not one and the same. If, however, the comparison can be considered justifiable, it appears that the excess of the anorthite molecule in the felspar of the norm is represented in modal pyroxene, while some normative iron ore also probably enters into the pyroxene.

The analyses of the leucocratic vein associated with the pegmatitic pockets from the Clauchlands Point, also quoted from the Arran Memoir is included in Table I, (D).

On/

TABLE I.

	A.	B.	C.	D.
SiO_2	44.68	43.95	45.8	46.50
Al_2O_3	16.37	17.60	15.0	22.86
Fe_2O_3	4.31	1.43	3.8	3.30
FeO	8.11	11.89	9.5	4.63
MgO	6.59	6.95	8.2	2.52
CaO	8.70	8.54	9.4	9.50
Na_2O	3.28	3.66	2.5	4.53
K_2O	.21	.35	.5	.39
H_2O + 105	1.69	.82	1.8	3.25
H_2O - 105	2.99	.94	.9	.80
CO_2	.06	-	-	-
TiO_2	2.51	3.42	2.4	1.30
P_2O_5	.15	.11	.3	.26
MnO	.32	.10	.3	tr.
BaO	.02	-	-	-
	100.04	99.76	100.3	99.84

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

B. (26383). Crinanite, dyke on shore near Schoolhouse, Whiting Bay, Arran. Quoted from Arran Memoir, 1928, p.121. Analyst: W.H.Herdsman.

C. Average plateau basalt type of the Kainozoic igneous suite in the West of Scotland, computed by Tyrrell from the analyses given in 'The Tertiary and Post-Tertiary Geology of Mull, etc.', 'Mull Memoir, 1924, p.15. Quoted from Arran Memoir, 1928, p.121.

D. White aplitic vein in Clauchland crinanite, shore, three-sixteenths of a mile N. 9 W. of Clauchlands Point, Arran. Quoted from Arran Memoir, 1928, p. 121. Analyst: W.H.Herdsman.

Table I(b)/

TABLE I (b)

CLAUCHLAND CRINANITE.

Normative composition.

Orthoclase		1.11
Albite		27.77
Anorthite		29.19
Diopside	$CaSiO_3$ - 5.45 $MgSiO_3$ - 3.50 $FeSiO_3$ - 1.58	10.53
Hypersthene	$MgSiO_3$ - 3.40 $FeSiO_3$ - 1.58	4.98
Olivine	Mg_2SiO_4 - 6.72 Fe_2SiO_4 - 3.47	10.19
Magnetite		6.26
Ilmenite		4.71
Apatite		.34
Water		4.68
		99.76

Modal Composition.

Felspar	52.9
Titanaugite	18.8
Olivine	13.4
Iron Ore	3.0
Analcite, zeolites etc	11.9
	100.0

On comparison with the normal crinanite (A), the vein is slightly more acidic, as seen by the slight increase in alkalies and corresponding lower values for total FeO and MgO. These differences correspond to the increased proportion of the leucrocratic minerals, felspar, analcite and zeolites and the corresponding decrease in pyroxene, olivine and iron ore in the vein.

Walker and Poldervaart (1947, p.662) plotted the three variables FeO, Na_2O + K_2O and MgO of all the available chemical analyses of olivine-free dolerites and their pegmatitic variants from different parts of the world on to a triangular diagram, which is here reproduced in Fig. 5(a). The corners of the triangle represent 100 per cent. of each of the three variables. The arrowhead representing the pegmatitic point of each of the normal dolerite indicates the trend and also the extreme limit of variation. For comparison the writer has plotted the leucocratic vein and the normal crinanite on to the same diagram. The variation represented by the pegmatitic rock follows the calc-alkaline trend. This tendency is illustrated more especially by Fig. 5(b), where the Clauchland crinanite and its variation trend is plotted for comparison with the line of descent of the calc-alkaline suite, as represented by Daly average basalt, andesite, dacite and rhyolite.

(iii) Genesis/

(iii) Genesis of the Pegmatitic Pockets and associated Veins.

Any account of the petrogenesis of the crinanite will have to explain the occurrence of the pegmatitic pockets and associated leucocratic veins, even though these form an insignificant proportion of the whole mass. A brief survey of some of the literature dealing with similar leucrocratic facies, reveals the fact that such rocks are found in every doleritic suite whether olivine-bearing (Bailey and others, 1924, p.140; Thomas and others, 1930, p.114), or otherwise (Tomkeieff, 1929, p.102; Walker and Poldervaart, 1949, p.662). Wherever such pegmatitic facies have been studied, it appears that the enclosing dolerite is otherwise undifferentiated. Poldervaart (1944, p.106) suggests that in the absence of such pegmatitic facies the normal dolerite becomes more highly fractionated in the direction of iron rich varients.

Tomkeieff (1929, p.117) when dealing with the pegmatitic bands and schlieren in the olivine-free dolerite of the Whin sill, attributed their formation to segregation of 'wet fractions' within the body of the magma, the relatively high proportions of volatiles reducing viscosity, and thereby promoting the development of a coarser type of crystallisation. Subsequent workers have supported this hypothesis, and the present writer believes the pegmatitic facies in the crinanites to have originated in like manner, since the mineralogy (analcite and zeolites/

zeolites) and the presence of drusy cavities are in keeping with their hydrous paragenesis. Tomkeieff also regarded the coarser facies as the heteromorphic variety of the normal rock resulting from liquid fractionation due to partial liquid immiscibility. The variation in composition not only of the dolerite pegmatite of the Whin sill but also of other similar dolerite pegmatites have been pointed out by Walker and Poldervaart (Fig. 5(a)). Likewise, the present writer has shown the variation in composition of the pegmatitic facies from the enclosing crinanite. If, however, the formation of the pegmatitic facies and the attendant change in composition be attributed to partial liquid immiscibility, the chief objections would appear to be on theoretical grounds. Experimental evidence on silicate melts of compositions within the range shown by the common igneous rocks suggests that liquid immiscibility cannot occur (Bowen, 1928, pp. 8-19; King, personal communication).

Bailey and others (1924, p. 138) after a detailed petrographic study, were of the opinion that the pegmatitic rocks in plateau basalts in Mull were the result of crystallisation differentiation. Walker and Poldervaart (1949, p. 662) after a study of similar coarse facies in the Karroo dolerites and also of the chemical analyses of such varients and the enclosing dolerites from various parts of the world, arrived/

arrived at a similar conclusion. The latter authors supported their arguments by means of the triangular variation diagram as shown by the author in Fig. 5(a). With the evidence of variation in composition always forthcoming, they inferred that the pegmatitic facies cited could only represent late stage crystallisation differentiates. On Walker and Poldervaart's view, the variation in composition of the pegmatitic facies in the present area would suffice to regard them also as late stage differentiates of the normal crinanite.

However, if one assumes crystallisation differentiation alone responsible for their formation, the difficulty at once would be to explain why only localised areas should be affected when the rest of the normal rock, exhibiting a typical ophitic texture, remains uniform in composition throughout its entire mass.

It is generally accepted that with the release of pressure volatiles tend to separate within the body of the magma (Fenner, 1926, p.696). Since the pegmatitic facies contain drusy cavities, it seems reasonably certain that separation of volatiles also served as a focal point for the segregation of certain other constituents of the magma, more especially alkalies and alumina. This segregation would be assisted by crystallisation and thus give rise to relatively acid rich pegmatitic facies. Continued movement during consolidation would/

would explain the drawn out and vein-like character of some of the leucocratic bodies. The author believes that only in this way could the localised differentiation be accounted for satisfactorily.

Thus the crinanite suite of rocks with an almost constant quantitative mineralogical composition throughout its mass, present but little evidence of variation. The only evidence of minor differentiation in composition appears in the pegmatitic pockets and vein-like bodies which are restricted and which are considered to result from local concentration of volatiles due to release of pressure. The undoubted primary nature of the crinanite magma is seen in the close similarity in chemical composition with the primary basalt magma of the West of Scotland (average of eight analyses of the olivine plateau basalt magma from the West of Scotland). This magma corresponds to the olivine basalt magma of Kennedy (1933).

B. Composite Intrusions.

Composite Intrusions are of considerable interest, and although much work has been done since Bunsen's proposal of the two magma hypothesis in 1851, the source of the magmas and their mechanism of emplacement remain problems on which agreement among petrologists is still to come.

The Mull authors (Bailey and others, 1924, p. 32) defined composite/

composite intrusions as those wherein interior contacts between the associated rocks of contrasted composition are lacking. When contacts are present, the intrusions are classed as multiple. Daly (1933, p.79) and Tyrrell (1940, p.31), make no mention of interior chilled contacts, but on the other hand consider composite intrusions as formed by successive injections of chemically differing melts into the same fissure which widens to receive them. The terminology adopted here is in accordance with that of Daly and Tyrrell.

From observations in Skye, Harker (1904, pp.201-203) directed attention to the variations in the intimacy of the relations between the basic and acid members and established the usual time sequence of injection as from basic to acid, the general pattern being basic flanking the acid interior. Subsequent researches (Bailey and others, 1924; Thomas and Richey, 1930) have confirmed these observations as applicable to the occurrences in Mull and Ardnamurchan.

In the following section, three composite intrusions occurring in the region are described and discussed.

(a) The Ross Road Composite Dyke,
(b) The Monamore Composite Sheet,
(c) The Sheans Composite Sheet.

(a) The Ross Road Composite ~~Sheet~~ Dyke.

(i) Field Relations.

On either side of the eighth milestone on the Ross Road are/

are two abandoned roadside quarries. The one nearer Lamlash shows both a composite and a multiple dyke (Fig. 6). This quarry is about 50 feet in length and 14 feet in height. It has a layer of boulder clay on top, and debris of well stratified sandstones and highly angular quartz felsite fragments at the base. The dykes striking N.N.W. to S.S.E. form part of the main Arran dyke swarm.

The composite dyke is of symmetrical type, with central acid member flanked by basic. This symmetry in arrangement modifies Gregory and Tyrrell's section (1924, p.420) where a further acid member was shown to occur between the basic rock and the sandstones on the north-eastern side of the intrusion. According to the writer's observation, this acid rock was not observed, but instead two minor dykelets of the central acid rock were found invading both the flanking basic margins toward the base of the section as shown in the figure.

The flanking basic rock has an average width of 4 feet. It shows smooth surfaces due to prominent spheroidal weathering. The margins toward the sandstones for about two or three inches from the contact show a relative diminution in grain size though not becoming glassy, while the sandstones for about five inches in width are thermally metamorphosed to quartzite. Against the acid rock there is no such diminution in grain size, but there is, however, a marked alteration. Thin/

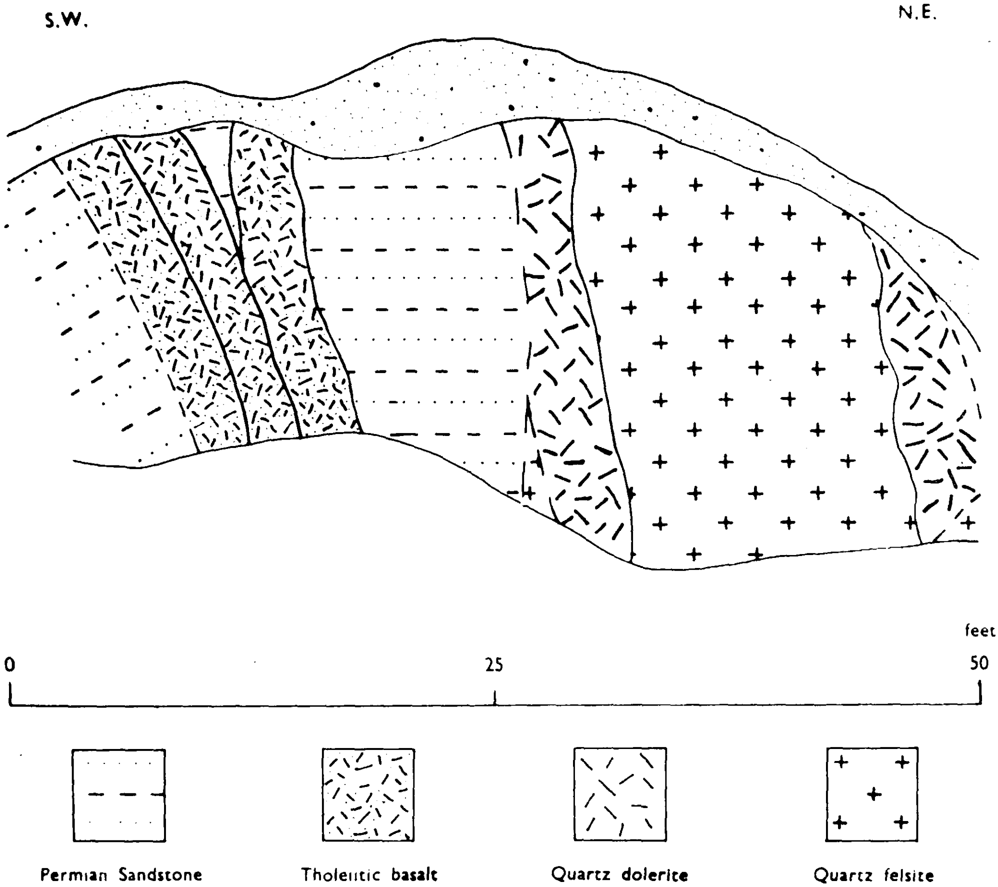

Fig. 6. Section in Lower Quarry near 8th M.S. on the Ross Road, Monamore Glen.

Thin sections cut from both the basic flanks show them to be petrographically identical and hence it is inferred that they originally formed a single dyke unit.

The acid member contrasts well from the basic member in being much lighter in colour and having highly angular surfaces. It has a width of 13 feet indicating a considerably greater volume of the acid than of the basic rock. Its contacts with the basic flanks are well defined. The margins for about an inch in width are characterised by alternating dark and light coloured flow bands, disposed parallel to the walls of the contact. On the whole, this narrow marginal zone is appreciably darker in colour than the corresponding central acid portions further away from the contact.

(ii) <u>Petrography</u>.

<u>Basic Rock</u> (Quartz dolerite). In hand specimen the quartz dolerite is a fine to medium grained rock of dark grey to deep green colour. Under the microscope the rock is much altered. It consists of altered pyroxenes, plagioclase felspar, some olivine and iron ore, together with abundant secondary minerals, chlorite, fibrous amphibole and iron ore, which render optical determination impossible. Rarely, where unaltered cores exist, a pale brown colour is discernible. The plagioclase felspars on the other hand are relatively less altered. They form moderately stout laths averaging 0.5 mm. in length and displaying/

displaying a sub-ophitic relationship with the altered pyroxenes. The laths show lamellar twinning and compositional zoning. The maximum symmetrical extinction angle at the core is about 33^{o}, while the margins have extinction angles around 19^{o}. Apart from the usual alteration to calcite, saussuritisation of the felspars is quite common. Iron rich olivine occurs sparsely as rounded microphenocrysts. They are completely altered to dark greenish-brown bowlingite with much disengaged iron ore. Iron ore in irregular and ragged crystals is mainly magnetite. Few are granular and these are sometimes arranged along the elongation of the original pyroxene crystals.

The mesostasis has a very fine micro- or cryptocrystalline texture. Adjacent and enclosed laths of the larger felspars show marked albitisation and irregular borders suggestive of corrosion. The iron ore is markedly skeletal and sub-variolitic in habit. Here and there are minute grains of epidote and a little biotite. The mesostasis therefore displays distinctly acidic characters, which are emphasised by the reaction relations displayed towards the earlier formed crystals. In places material similar to the general mesostasis forms more extensive irregular patches. Such finer grained portions of the rock are also amygdaloidal. The amygdules which are roughly circular and averaging about a millimetre in diameter contain coarsely crystalline aggregates of feathery and plumose quartz and calcite/

calcite (Plate VI, Fig. 1), occasionally lined on the outside of the walls by plagioclase felspar laths. Where quartz and calcite are absent, chlorite completely occupies the amygdules. Associated with the amygdules are still finer felted patches with minute microlites and skeletal iron ore and exhibiting sharp contacts with the enclosing rock. They appear more in the nature of thoroughly digested xenoliths, thus confirming Harker's (1904, p. 185) observation of the frequent association of amygdules with xenoliths.

Apart from alterations, chloritisation and carbonatisation just described, the quartz dolerite shows no other noteworthy modifications towards the contact with the central acid member.

Acid Rock (quartz felsite). In hand specimen the quartz felsite is a fine grained, buff to flesh coloured rock, with numerous megascopic crystals of quartz and felspar, the latter often in clusters and associated with greenish clots of chlorite. These megascopic constituents are equally distributed throughout the entire width of the quartz felsite. Under the microscope it is a micro- to cryptocrystalline rock, consisting of conspicuous quartz crystals and felspar aggregates with chlorite set in a brown turbid felsitic base with microlites together with abundant vermicular quartz. The phenocrystic quartz occur as rounded or oval shaped crystals, sometimes with pyramidal terminations. They show embayed borders, and also irregular outlines/

outlines resulting from the growth of matrix quartz in optical continuity with the phenocrysts. Following the inner side of the borders and conforming to the faces of the quartz crystals or its embayed outlines are dust-like inclusions of iron ore (Plate VI, Fig. 2). Similar dust-like inclusions lining the borders of sodic felspars in the composite dyke of Iceland have been interpreted by Guppy and Hawkes (1925, p. 329) as due to incipient melting. The writer believes the iron ore inclusions lining the borders of the quartz crystals are also due to a similar origin, indicating the extreme limit of resorption of the phenocrystic quartz reached by the enveloping magma. The felspars are invariably replaced by kaolinitic material and sometimes by sericite. Occasionally they may be replaced by quartz, the fabric at times resembling micrographic intergrowths. Despite the modified condition, traces of polysynthetic albite and pericline twinning persist. The maximum symmetrical extinction angle is near 20^{o}, while its index of refraction is about equal to quartz, indicating the composition of the felspar as basic oligoclase or acid andesine. Some of the crystals which show no definite twinning show a patchy uneven extinction, suggestive of cryptoperthite. Ferromagnesian minerals are represented by the unusual abundant presence of chlorite, associated with calcite. The accessory minerals are zircon, epidote, pyrite and apatite.

Thin sections from near the contact with the basic flanks/

flanks show the prominent development of flow structure similar to that seen in rhyolites (Plate VI, Fig. 3). The flow is sinuous, primarily due to the interference occasioned by large embayed quartz crystals, around which the flow lines wind or between which they thread their way. These features apart from showing that the acid rock post-dated the basic, also indicate that the quartz crystals themselves were already in existence while flow movement was in progress. The dark coloured flow bands, equally distinctive under the microscope, are due to much chloritic and liminotic material. Moreover, minute microlites that behave indifferently to the flow banding and hence are distinguished as products of devitrification are sporadically developed.

A thin section of the specimen of the same quartz felsite from Dr. Tyrrell's collection (L. 14) shows embayed quartz crystals surrounded by feathery spherulites of quartz-alkali felspar intergrowths (Plate VI, Fig. 4). In the groundmass similar feathery spherulites are common and are found replacing the smaller quartz grains. As such these spherulites are clearly due to devitrification. Also present in the groundmass are minute acicular crystals of strongly pleochroic hornblende, with low extinction angles.

Thus the quartz felsite with the absence of fresh ferromagnesian minerals and its unusual amount of chlorite associated/

associated with calcite contained throughout its entire width, proves conclusively to the contaminated nature of the felsitic magma, even prior to its emplacement.

(b) The Monamore Composite Sheet.

(i) Field Relations.

The Monamore composite intrusion is exposed along the bed of the Monamore burn south of the seventh mile on the Ross road. It is difficult to decide whether the intrusion is a sill or a dyke, since it is emplaced not into a sedimentary formation, but into the crinanite sheet. However, the distribution of exposures suggests a coincidence between the inclination of the composite mass and that of the crinanite sheet (Fig. 4).

Like most composite intrusions, the Monamore sheet is of symmetrical type, with acid quartz felsite flanked on either side by basic craignuritic basalt. Although the actual thicknesses of the contrasted members are indeterminate, the volume of the acid nevertheless exceeds that of the basic, the latter merely representing fringes to the acid centre. The contacts between the basic and the acid rocks are everywhere transitional, with the colour becoming progressively darker from the acid rock towards the outer basic fringe. The contacts of the marginal craignuritic basalt with the crinanite are not exposed. At the dam the quartz felsite show here and there the/

the development of pitchstone facies such as are commonly seen in the felsites of the composite dykes along the Tomore shore, Arran.

(ii) Petrography.

Basic Rock (Craignuritic basalt). In hand specimen the basic rock is of a fine grained, dark grey to green colour, and none of its constituents are megascopic. Examination of thin section (Y. 50) shows a prominent acicular development of the pyroxenes and felspars, with skeletal iron ore and abundant cryptocrystalline mesostasis. In this respect the texture especially towards the acid margins differs but little from the craignuritic textures described by the Mull authors (Bailey and others, 1924, p. 225). The acicular felspars show ill defined margins and bifid terminations. They are commonly replaced by calcite and chlorite. The acicular augite, sometimes reaching lengths of 1.5 to 2 mm. and invariably chloritised, has skeletal iron ore fringing the lengths of the crystals. The augite crystals are commonly grouped in a roughly stellate fashion, or form 'sheaf-like' bundles co-operating with the felspars to give rise to a sub-variolitic structure. Skeletal iron ore besides fringing the augite is scattered all over the rock. Sometimes the skeletal iron ore shows a radial arrangement from different centres or from a felspar neucleus; features that are similar to the types often described/

described from variolites. The groundmass which is of devitrified glass, consists of turbid material frequently encroaching on the margins of the acicular crystals. Here and there irregular quartzo-felspathic areas invested with abundant needles of apatite and a little biotite occur. 'Ultra-blue' chlorite and calcite are irregularly distributed.

Towards the outer margins away from the acid rock the stellate and sheaf-like groupings persist, but there is a relative increase in the proportion of crystallisation, thus approaching the tholeiites of the Talaidh type described later (p. 88).

Acid Rock (Quartz felsite). The acid rock is similar to the quartz felsite of the composite dyke just described. It shows the usual preintrusive contamination with basic materials.

The description of the composite dyke in the Benlister burn is unnecessary since the only difference from the Monamore composite sheet is its dyke form rather than a gently inclined sheet.

(c) The Sheans Composite Sheet.

(i) Field Relations.

The Sheans consists of three low rocky hills rising abruptly to a height of 50 feet above the edge of the plateau to the south and south-east of Glen Dubh and attain an altitude of 1224 feet above sea level. The three hills are aligned north/

north-north-west to south-south-east. A deep peat filled depression separates the southern and central hills, while a shallower depression occurs between the central and northern hills. The southernmost and largest hill slopes towards the plateau, by way of a gently inclined low ridge. The northern and north-eastern faces of the hills form steep rocky scarps, characterised by columnar structure (Plates I and II).

The Sheans composite mass, which makes up the three hills, represents relics of an original sheeted igneous mass of basalt and dolerite, dipping generally to the south-east at angles of 12° to 15°. The sheet is emplaced at a lower horizon than that of the Cnoc Dubh sheet of the Monamore crinanite (Fig.7). The top of the sheet is everywhere an erosion surface, the overlying rocks having been completely removed. The lower contact with the underlying baked sandstones is located in the northern scarp of the northern hill overlooking Glen Dubh. At this point it is clear that the sheet is gently inclined south-eastwards. Elsewhere, although the course of the junction can only be ascertained within rather wide limits, it can nevertheless be inferred that similar relationships exist between the sandstones and the sheet. The maximum thickness of the sheet as is now exposed is estimated at 50 feet. The extent of the sheet is limited, being confined almost to The Sheans themselves, with the exception/

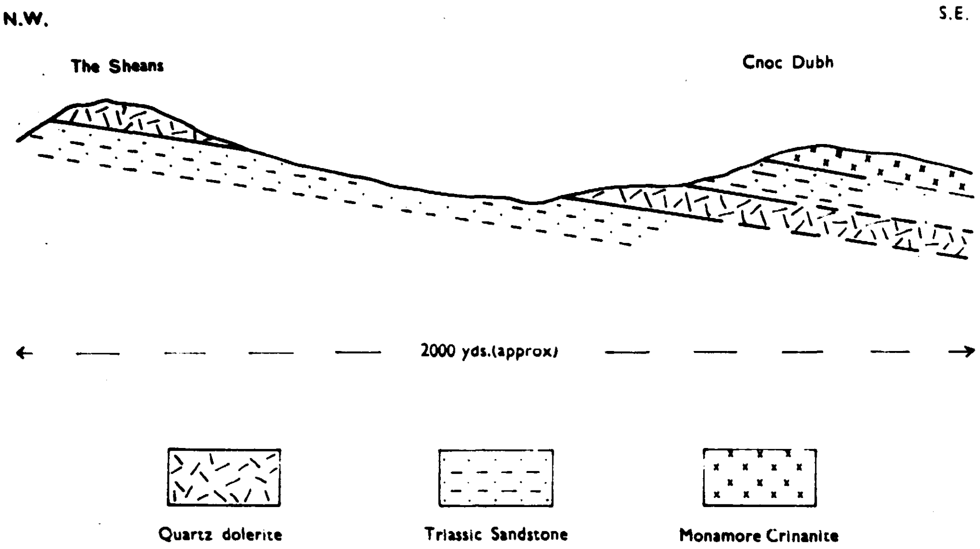

Fig. 7. Diagrammatic cross-section, illustrating the relationship of The Sheans composite sheet to the Cnoc Dubh sheet of the Monamore crinanite.

exception of three small isolated outcrops occurring to the west of Cnoc Dubh (Fig. 8(a)).

<u>Components of the Sheet</u>. Although mapped as quartz dolerite in the Survey map (1947), the different rock components constituting The Sheans vary widely in compositional and textural characteristics. The rocks, in so far as have been preserved, consist of quartz basalt of basic craignuritic affinities, overlain conformably by a thin sheet about 5 feet in thickness of porphyritic dolerite. Both these rocks are traversed by ramifying acid veins, but the porphyritic dolerite is more intensely veined than the basalt.

The main exposure of the porphyritic dolerite is on the summit of the southern hill. It is conspicuous by its porphyritic texture and freshness as compared to the other rocks comprising the sheet. Towards the margins with the underlying quartz basalt the rock shows an accentuation of its porphyritic texture, as a result of the matrix becoming more fine grained. This fine grained texture must be regarded as resulting from chilling during emplacement of the dolerite, rather than by contact with the basalt, since the latter, as will be seen, is of later age although appearances suggest otherwise. The only contact in situ with the underlying quartz basalt is near the top of the western slope of the southern hill. Elsewhere, examples of the contact are seen in the boulders/

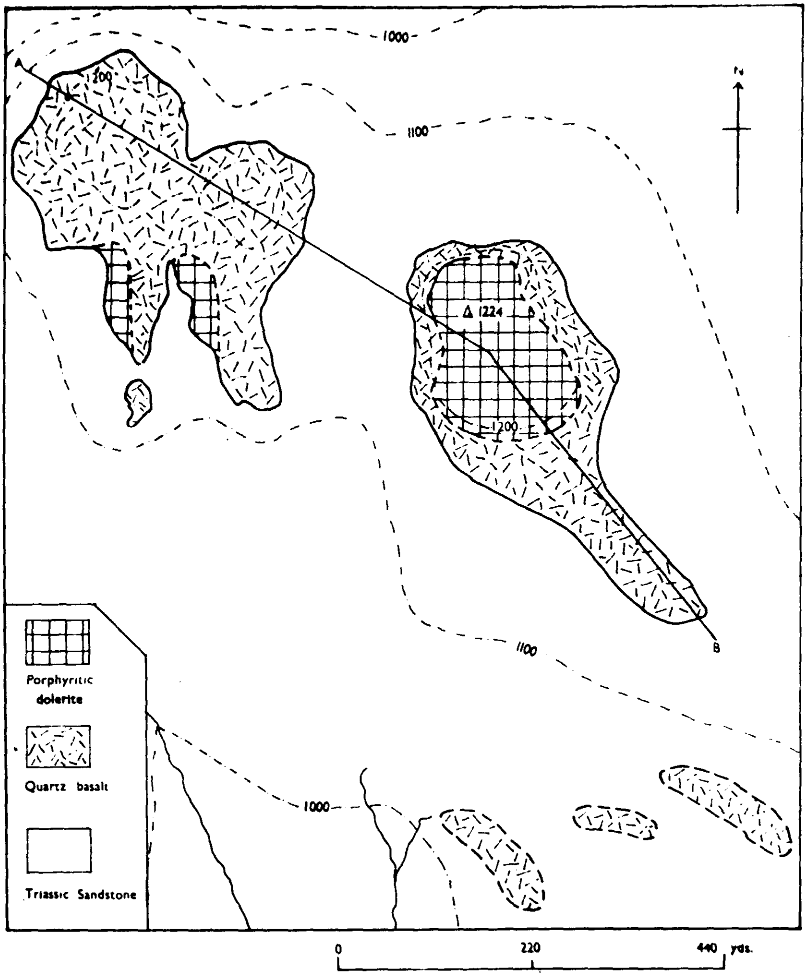

Fig. 8 (a). Geological Map of The Sheans.

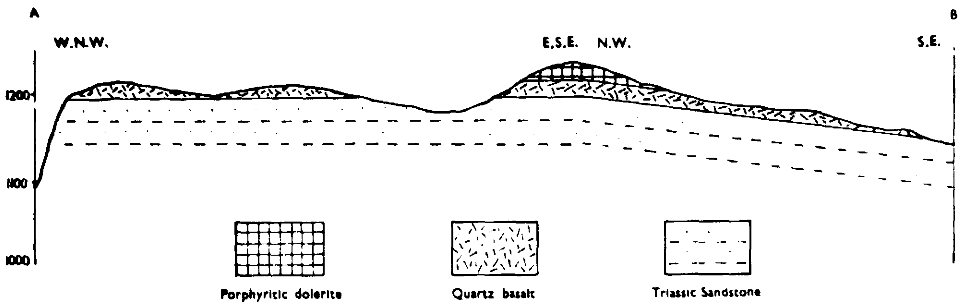

Fig. 8 (b). Cross-section of The Sheans along line indicated on the map.

boulders scattered on the north-eastern slope of the three hills. Detailed examination of the contacts show that the precise junction, although sharp, possesses no tachylytic selvages.

The quartz basalt of craignuritic affinities as is now preserved is the most abundant rock of The Sheans. It is found in all the three hills as well as in the scattered outcrops west of Cnoc Dubh. Compared to the porphyritic dolerite it is for the most part uniform-looking, except where inclusions of an extremely fine textured basalt and/or coarse porphyritic dolerite are encountered. These inclusions show all gradations in colour from dark grey to colours approaching that of the host rock. They show prominent rounded borders and embayed outlines. In the small isolated outcrops uniform-looking basalt passes locally into areas containing large closely spaced felspars and having the appearance of a normal porphyritic rock. These areas, however, are readily distinguishable from the overlying porphyritic dolerite, as they are much finer grained than even the finer chilled margins of the porphyritic dolerite. Moreover, they are also relatively lighter in colour. Furthermore, in thin section (Y.83) the contained felspars are found to be xenocrysts, some of which were probably derived from the porphyritic dolerite itself.

The acid member of the sheet as it now exists is seen only as ramifying veins. By the intensity of the veining of porphyritic/

porphyritic dolerite as compared to the underlying quartz basalt, and since the base of the sheet is found to lie on sandstones (p.34), the continuous mass of acid rock if ever present must have overlain the dolerite. While it is possible that the sequence was then repeated at higher levels in inverse order, the sheet obviously possesses a more complex character than the usual symmetrical type of composite body. Mention must, however, be made in this connection regarding the three small outcrops marked as felsites on the Survey map (1947). The first is mapped as occurring on the east side of the base of the southernmost hill, the second immediately adjoining the extreme easterly outcrop of part of the Cnoc Dubh crinanite mass, and the third on the top of Meall Buidhe, east of Cnoc Dubh. Careful search of the above mentioned localities showed instead of felsite, fragments and boulder outcrops of weathered whitish-coloured sandstones.

(ii) Petrography.

Porphyritic dolerite. (Plate VII, Fig. 1). In hand specimen the porphyritic dolerite is a fine to medium grained rock of light to dark grey colour. The plagioclase felspar phenocrysts average 3 x 2 mm. in size, while pyroxene is occasionally identified. Specific gravity of the rock is 2.83. Under the microscope the phenocrysts are confined entirely to the plagioclase felspar. The matrix which is microcrystalline and texturally/

texturally sub-ophitic, consists essentially of less calcic plagioclase, pyroxene and iron ore. The plagioclase felspar phenocrysts comprise 55 per cent. by volume of the rock. They are tabular or rectangular in shape with fretted edges. Twinning is invariably present, Carlsbad twinning being as common as broad lamellar albite twinning. Maximum symmetrical extinction angle in zone normal to 010 is 40°. A series of 2V determinations gave values ranging from (-)79° to (-)86°, indicating the compositional range of the felspar from $Ab_{25}An_{75}$ to $Ab_{17}An_{83}$. Refractive index for γ is 1.573. The felspar is thus distinguished as bytownite. Traces of zoning, although not conspicuous, are present. In the groundmass the plagioclase felspar commonly in laths, shows albite twinning. Maximum symmetrical extinction angle is 29°, while 2V = (+)75°, suggests the felspar as labradorite of approximate composition $Ab_{42}An_{58}$. Both monoclinic and rhomic pyroxenes are present, but the former is the commoner of the two. The monoclinic pyroxene appears more commonly in equidimensional plates intergrown with felspar laths, while the rhomic pyroxene appears to be columnar in habit. 2V determined on a number of crystals gave a constant value of (+)52°, indicating the monoclinic pyroxene as one of the clinoenstatite/diopside series, probably with 80 per cent. of the diopside molecule (Winchell, 1933, p.223). Refractive indices for α and γ, are 1.670 and 1.713

respectively/

respectively. The rhomic pyroxene with straight extinction is optically negative. 2V approximately 68°, corresponds to about 36 per cent. of $FeSiO_3$ (Winchell, 1933, p.218). Pleochroism is present, with X = yellowish-green, Y = pale green, and Z = greenish-brown. Iron ore is granular while apatite occurs sparingly.

The finer grained equivalent, (Plate VII, Fig.2) the porphyritic basalt, contains the bytownite phenocrysts as abundantly and of the same size as those in the dolerite (see Table II(c)). The crystals show fretted edges suggestive of minor corrosion, and also frequently contain islets of groundmass material. The matrix consists of a felted aggregate of minute felspar laths, pyroxene grains and iron ore. Occasionally the felspars and the pyroxenes are intergrown in a manner resembling 'sheaf-like' bundles. The pyroxenes are altered to patches of penninite, distinguished by its characteristic 'ultra-blue' interference colours.

Thin sections of the contacts with the underlying craignuritic basalt show sharp as well as gradational contacts. As in the field, the sharp contacts are defined not by tachyltic selvages of either of the rocks but by tectural differences. In cases of sharp contacts indications of reaction between the dolerite and the craignuritic basalt are insignificant. Nevertheless, in one section (D.44) a bytownite phenocryst in/

in the dolerite, although sharply truncated by the basalt shows slight albitisation and indications of corrosion at the contact. This feature also clearly establishes that the porphyritic dolerite was of an earlier age than the craignuritic basalt. As regards gradational contacts, the junction is marked by a zone of prominently developed cervicorn and spherulitic structures (Plate VII, Fig. 3). The former is seen in the curious branching of the augite in 'antler-like' fashion, identical with those described and figured by the Mull authors (Bailey and others, 1924, p. 302), while the latter consists of radially arranged augite and felspar intergrowths. The bytownite felspar phenocrysts towards these transitional zones are occasionally rendered very irregular and reduced in size as a result of encroachment by these secondary structures.

Towards the margins of the acid veins, neither the porphyritic dolerite nor its finer equivalent show evidence of strain. Sometimes there appears to be no appreciable modification or reaction effected by the acid veins during the latter's emplacement, while at other times the reactions are quite significant. The bytownite phenocrysts, which in the areas more remote from the veins show inconspicuous zoning are here very highly albitised. The albitisation, which progressively increases in intensity towards the vein walls, is characterised by/

by irregular anastomising strings of more sodic felspar traversing the central more calcic core, reminiscent of the albitisation features seen in the spilitic rocks (Bailey and Grabham, 1909, p. 250). Although the sodic strings are clear, the host felspars are either rendered turbid or else are saussuritised. Several of the felspars show replacement by chlorite along their margins and cleavages, particularly so at the immediate margins with the veins. The pyroxenes are altered to chlorite and epidote. Free quartz occurs prominently towards the contacts, but is rarely seen further away from the veins (R. 9). It forms small irregular grains scattered sporadically, or forms roughly circular granular aggregates, in which are sometimes seen acicular needles of apatite. None of the specimens in the writer's collection showed the presence of micropegmatite, but this may perhaps have been due to its being masked by kaolinitic material, which is so abundantly developed along the margins with the vein material. Some of the margins are represented by an almost opaque mass of dirty brown colour.

The bulk composition of the porphyritic dolerite (R. 10), and its finer grained equivalent (R. 9) are given in Table II. The fresh sample of porphyritic dolerite was obtained from the centre of a mass encircled by acid veins, while the sample of the fine grained equivalent was taken from the immediate/

immediate margin with the vein. For comparison, the analyses of the olivine gabbro from Skye (A), and three others from Mull, representing the olivine gabbro (B), and basalts (C) and (D) have been reproduced. Comparing the porphyritic dolerite of The Sheans to the olivine gabbros of Skye and Mull, The Sheans dolerite is poorer in magnesia than the Skye gabbro, and poorer in total iron calculated as FeO and total alkalies than the Mull gabbro or to the basalts. Comparing the fine grained basalt of The Sheans (R. 9) with the other basalts of Mull (C) and (D), the total iron of The Sheans is lower than in (C), but higher than in (D). On the other hand, magnesia is higher than in both the Mull basalts, while the total alkalies are correspondingly less.

Comparing the rocks of The Sheans (R. 10) and (R. 9), the two compositions are almost identical with each other, except for discrepancies in the proportions of silica, alkalies and the femic constituents. If the silica and the total alkalies are considered the dolerite is relatively more basic, whereas if the femics are considered, it is more acid. In view of the differences in the location of the samples in respect of the acid veins, it seems possible that the higher femics in the finer grained rock may be related to the displacement of the constituents during the emplacement of the acid veins. (See later p. 69).

However/

TABLE II.

	No. R. 10	A	B	No. R. 9.	C	D
SiO_2	47.69	47.28	48.34	48.87	48.51	47.49
Al_2O_3	21.92	21.11	20.10	19.72	19.44	21.46
Fe_2O_3	1.28	3.52	1.97	.52	5.66	1.72
FeO	5.63	3.91	6.62	7.19	4.00	4.80
Total iron as FeO	(6.91)	(7.43)	(8.59)	(7.71)	(9.66)	(6.52)
MgO	5.94	8.06	5.49	6.04	5.12	4.59
CaO	13.03	13.42	13.16	11.28	12.03	13.24
Na_2O	1.63	1.52	1.66	1.76	2.53	2.17
K_2O	.07	.29	.98	.15	.25	.42
H_2O + 105	1.82	.53	.44	2.73	.48	2.54
H_2O - 105	.48	.13	.02	.87	.04	.17
CO_2	...	...	.11	...	.09	.08
TiO_2	.44	.28	.95	.46	1.46	.93
P_2O_5	.05	tr.	.04	.05	.16	.43
MnO	.14	.15	.32	.13	.23	.15
BaO	...	...	.10	...	...	...
	100.12	100.20	100.30	99.78	100.04	100.23
Sp. Gr.	2.85	2.90	2.93	2.83	2.93	2.82

No. R. 10 Porphyritic dolerite, from the top of the extreme southern hill of The Sheans about a mile and a half west of the Brodick-Lamlash road, Arran. Analyst: W. H. Herdsman.

A. (8194, Lab. No. 19). Major Intrusion, Cullins. Coir 'a 'Mhadaidh Skye. Olivine gabbro. Quoted from 'Tertiary Igneous Rocks of Skye', 1904, p. 103. Analyst: W. Pollard.

B. (14846, Lab. No. 373). Major Intrusion, Beinn na Duatharach; $\frac{5}{8}$ mile N. N. W. of summit of B. na Duatharach, Mull. Olivine gabbro. Quoted from Mull Memoir, 1924, p. 24. Analyst: E. G. Radley.

No. R. 9. Porphyritic basalt, from the top of the extreme face of the middle hill of The Sheans, about a mile and a half west of the Brodick-Lamlash road, Arran. Analyst: W. H. Herdsman.

C. (18472, Lab. No. 447). Pillow-lava. $\frac{1}{4}$ mile slightly east of S. of cairn on Cruach Choireadail, Mull, Basalt, Porphyritic Central type. Quoted from Mull Memoir, 1924, p. 24. Analyst: E. G. Radley.

TABLE II (b)

PORPHYRITIC DOLERITE (R. 10).

Normative Composition.

Orthoclase			.56
Albite			13.62
Anorthite			52.26
Diopside	$CaSiO_3$	5.34	10.39
	$MgSiO_3$	3.20	
	$FeSiO_3$	1.85	
Hypersthene	$MgSiO_3$	10.90	17.50
	$FeSiO_3$	6.60	
Olivine	Mg_2SiO_4	.42	.83
	Fe_2SiO_4	.41	
Magnetite			1.86
Ilmenite			.76
Water			2.30
			100.08

Modal Composition.

Felspar of Phenocrysts	53.5
Felspar of Matrix	5.9
Pyroxene	26.7
Magnetite	2.0
Mesostasis	11.9
	100.0

****

D. (18471, Lab. No. 446). Lava. $\frac{3}{8}$ mile N.E. of cairn on Cruach Doire nan Guilean, west side of the little lochan, Mull. Basalt, Porphyritic Central type. Quoted from Mull Memoir, 1924, p. 24. Analyst: E. G. Radley.

TABLE II (c).

PORPHYRITIC BASALT (R. 9).

Normative Composition.

Quartz			1.86
Orthoclase			.56
Albite			14.67
Anorthite			45.59
Diopside	$CaSiO_3$	4.29	8.44
	$MgSiO_3$	2.30	
	$FeSiO_3$	1.85	
Hypersthene	$MgSiO_3$	12.80	23.23
	$FeSiO_3$	10.45	
Magnetite			.70
Ilmenite			.91
Water			3.60
			100.56

Modal Composition.

Felspar of Phenocrysts	59.9
Felspar of Matrix	40.1
	100.0

****

However, a general comparison of the tabulated rock analyses shows that they are all closely comparable to one another. The notable high lime and alumina content of the analyses are due to the presence of calcic plagioclase felspar phenocrysts, which are characteristic of the rocks of the Porphyritic Central Magma Type as a whole. (Bailey and others, 1924). Thus it is a justifiable inference that the porphyritic dolerite of The Sheans corresponds to the rocks of the Porphyritic Central Magma Type of Mull.

The normative and modal compositions of the porphyritic dolerite given in Table II(b) are closely comparable. The slight excess of the felspars in the norm may be assigned to the mesostasis of the mode.

Quartz basalt of basic craignuritic affinity. (Plate VII, Fig.4). The apparently xenolith- and xenocryst-free rock is a uniform grey coloured basalt. It is medium to fine grained, and none of its constituents are megascopic. Under the microscope the texture is micro- to cryptocrystalline. Mineralogically it consists of plagioclase felspar, pyroxene, amphibole and iron ore and accessories apatite and biotite, together with a felspathic-rich mesostasis in which are occasionally seen exceedingly fine micropegmatitic intergrowths (R.13). The plagioclase, commonly in laths are minutely irregular. They show/

show slight marginal zoning and albite twinning. Maximum extinction angle is 28°. The laths are frequently replaced by calcite, which is an unusually abundant constituent of the rock. The pyroxene seldom fresh, occurs as narrow prisms and irregular grains. It is invariably altered to chlorite with much disengaged iron ore lining the fringes of the crystals. These secondary alterations are in turn replaced by calcite. Here and there the pyroxene shows alterations to fibrous uralite. The amphibole occurs commonly as minute euhedral prisms, exhibiting an oblique extinction and strong yellowish-green pleochroism. Iron ore is in irregular grains and strings.

Thin sections of this rock, which appears quite homogeneous in hand specimens, are invariably found to contain both xenoliths and xenocrysts. The xenoliths consist of coarse dolerite and fine textured basalt which vary from ghost-like relics, recognisable only by the small irregular patches containing abundant fine granular and iron ore dust to obvious less modified ones as can be seen in the field.

The coarse dolerite xenoliths correspond in character to the overlying porphyritic dolerite, providing further evidence for the prior emplacement of the dolerite. Whereas the/

the larger xenoliths of dolerite show only a marginal modification, the smaller ones are totally altered. In such cases the phenocryst felspars are strongly albitised, albitic rims and anastomising strings occurring. Some of the felspars are saussuritised, while others are kaolinised. Pyroxenes are commonly altered to chlorite and occasionally at the margins to uralite. Epidote and chlorite are abundantly developed throughout the altered xenoliths. Biotite occurs sparingly. Mechanical disintegration of the margins of the xenoliths can also be observed, as seen by the 'strewing' of the highly altered felspar phenocrysts all along the borders. Apart from the presence of these felspars the effect of contamination on the host rock is less evident as appears to be commonly the case (Nockolds, 1933, p. 561). The boundary zone contains abundant turbid and limonitic material.

The fine textured basalt xenoliths do not match any of the rocks in the immediate vicinity. Hence it must be presumed that the fragmentation of the rock mass of the character of the basalt must have taken place in depth. As regards the texture, several of these xenoliths show a typical variolitic texture, with the microlites of pyroxenes, felspars, and strings of iron ore arranged in spheroidal or radial aggregates/

aggregates. The spheroidal aggregates, measuring approximately half a millimetre in diameter, are usually closely packed, but may also be separated by a matrix of glass. In some of the other fine textured xenoliths of basalt the minerals form a felted aggregate instead of a variolitic texture. Where somewhat coarser than average, the minerals of the felted aggregate develop an acicular crystallisation and the resultant texture approaching that of the craignuritic type. Irrespective of the textures these xenoliths show vesicular cavities, containing granular quartz, penetrated by apatite needles along with minute amphibole prisms growing from the margins of the vesicles towards the interior - a feature referred by Nockolds (1933, p.565) as indicating preferential absorption of volatiles by the xenoliths.

Xenocrysts are of two types. The first, which are commonly present, are of dusty untwinned alkali felspar - soda orthoclase or albite. Sometimes they are so closely spaced as in the small isolated outcrops west of Cnoc Dubh, that they give rise to a typical 'xenoporphyritic' rock as defined by Tomkeieff and Marshall (1935, p.265). These felspars have rounded corners and embayed outlines. They are frequently replaced by sericite, occupying almost the entire/

entire crystal and leaving only a narrow, seldom clear rim. The second, less common, are rounded quartz crystals with green chloritic borders, a product of reaction between the sub-basic magma and the acid xenocrysts.

Thin sections of the margins of the craignuritic basalt with the acid veins show no prominent modifications. But, as discussed later, the presence of 'tongue-shaped' apophyses of the acid vein, clearly indicate some reaction having taken place.

It thus becomes evident that the craignuritic basalt with its xenoporphyritic aggregates and acid xenocrysts and basic xenoliths, affords evidence of contamination not only from contact with the dolerite, but also of contamination of a pre-intrusive nature.

The chemical composition of the uniform-looking craignuritic basalt is given in Table III. For comparison the hypersthene dolerite of the basic member of the Bennan composite sill, Arran (A) is reproduced, along with two other analyses from Mull, the Talaidh type of tholeiite (B), forming the basic member of the composite sill of Rudh 'a 'Chromain, and the basic craignurite of the cone sheet (C) from Allt an Dubh-choire. Inspection of the four analyses show that apart from the slightly smaller proportion of the total alkalies, especially of potash in The Sheans rock, all the analyses are closely similar.

TABLE III.

	No. R. 15.	A	B	C
SiO_2	54.86	54.83	53.97	55.82
Al_2O_3	14.32	14.10	14.65	11.47
Fe_2O_3	2.73	3.57	3.62	3.68
FeO	6.67	5.87	6.32	7.66
MgO	4.22	4.88	4.49	4.08
CaO	8.08	7.90	7.98	7.88
Na_2O	2.08	2.32	2.54	2.58
K_2O	.88	1.73	1.52	2.00
H_2O + 105	1.64	1.23	.94	1.88
H_2O - 105	.49	.48	1.92	.66
CO_2	2.68	1.90	.51	.08
TiO_2	1.04	.74	1.24	1.62
P_2O_5	.07	.24	.27	.23
MnO	.12	.37	.30	.40
BaO	...	...	.04	.03
	99.84	100.19	100.40	100.18
Sp. Gr.	2.78	-	2.83	2.88

No. R. 13. Quartz basalt, from near the base of the middle hill of The Sheans, about a mile and a half west of the Brodick-Lamlash road, Arran. Analyst: W. H. Herdsman.

A. (24457. Lab. No. 826). Hypersthene dolerite, basic member of Bennan composite sill, shore at foot of Struey Falls Bennan Head, Arran. Quoted from Arran Memoir, 1928, p. 204. Analyst: E. G. Radley.

B. (17170, Lab. No. 432). Basic margin, Composite Sill, Rudh 'a 'Chromain, Mull, Tholeiite, Talaidh type. Quoted from Mull Memoir, 1924, p. 17. Analyst: E. G. Radley.

C. (16800, Lab. No. 412). Cone-sheet. Allt an Dubh-choire, 1220 yards above junction with Scallastle River, Mull. Craignurite (basic). Quoted from Mull Memoir, 1924, p. 19. Analyst: E. G. Radley.

TABLE III (b)

QUARTZ BASALT (R. 13)

Normative Composition.

Quartz			19.56
Orthoclase			5.00
Albite			17.29
Anorthite			23.07
Corundum			1.53
Hypersthene	$MgSiO_3$	10.59	19.08
	$FeSiO_3$	8.58	
Magnetite			3.94
Ilmenite			1.98
Water			2.13
			99.68

****

(iii) <u>Megascopic Features of the Acid Veins</u>.

Especially prominent on the western slope of the southern hill of The Sheans are massive boulders and well exposed outcrops, which reveal an extremely intricate ramifying network of acid veins emplaced in a host of basalt and dolerite. The veins are usually conspicuous owing to their lighter colour as compared to the basic rock, but all variations in colour are seen, the darker veins becoming difficult to distinguish. On weathered surfaces the acid vein rock being more resistant than the rocks in which it occurs, stands out as prominent ridges. The same applies to the rounded host rock fragments which they invariably contain and as a result of which the veins generally assume a pitted weathered surface. In freshly broken surfaces the line of junction between fragments and matrix is often hard to distinguish, although it may be quite obvious on the original weathered surface. Owing to the extreme irregularity of the veins (Plate III), coupled sometimes with the uncertainty of the vein margins, it is impossible to state their exact widths. Very roughly, however, they may be stated as varying from microscopic dimensions to six or eight inches and in cases of irregular patches, up to about a foot in diameter.

It must be recalled that Harker (p.1) refers to these/

these acid veins as segregations. However, in view of the fact that they are found in both the porphyritic dolerite and the underlying craignuritic basalt together with the prominent reaction features as will be seen in the ensuing microscopic description, it becomes evident that the acid veins are not segregations but products of later introduced acid material. Tyrrell (1928, p. 136) concluded that the acid material represents later infillings along intervening spaces of the originally shattered basalt.

It has been pointed out (p. 34) that the rocks of The Sheans, whether basalt or dolerite, are characterised by a prominent development of columnar structure (Plates I and II). Locally, as on the western slope of the southern hill, platy structure is occasionally observed. Neither this prominent columnar structure nor the occasional platy structure show any influence in guiding the entrance of the acid vein material, nor is it in any way disturbed by the occurrence of the veins. Hence it must be inferred that the columnar jointing of the host rocks, basalt and dolerite, post-dated the vein emplacement, and that the latter occurred while the host rocks themselves were still hot or above the normal temperature.

(iv) Microscopic Features of the Acid Veins.

As in the field the microscopic features are equally intricate. Their contacts with the adjacent wall rock are both sharp and transitional. Against the fine textured basalts, especially/

especially those of the porphyritic type, the vein margins are usually sharply defined, whereas against the relatively coarser dolerite there is quite frequently a progressive acidification of the basic host.

In cases of sharp contacts there are neither chilled selvages, nor fine grained borders in the majority of cases. Some of these sharply defined contacts show little or no reaction between the margin and wall rock, but there is however an interpenetration of the two rock structures. Frequently a phenocryst of plagioclase firmly rooted in the wall rock projects into the acid vein, with the projected part showing a prominent sodic rim sometimes with a denticulate contact against the calcic core. (Plate VIII, Fig. 1). The sharp contacts are more often tortuous than regular. Fig. 9 represents part of the tortuous vein margin with 'tongue-shaped' apophyses, emplaced in porphyritic basalt and with wall rock inclusions centrally contained in the apophyses. Such 'tongue-shaped' apophyses are not altogether confined to sharp contacts. They are also equally prominent in transitional contacts whether with the craignuritic basalt or porphyritic dolerite (Plate VII, Fig. 4), (R. 3a; R. 3b).

As regards transitional contacts, it must be stated that even the sharp contacts which in the field are characteristic are/

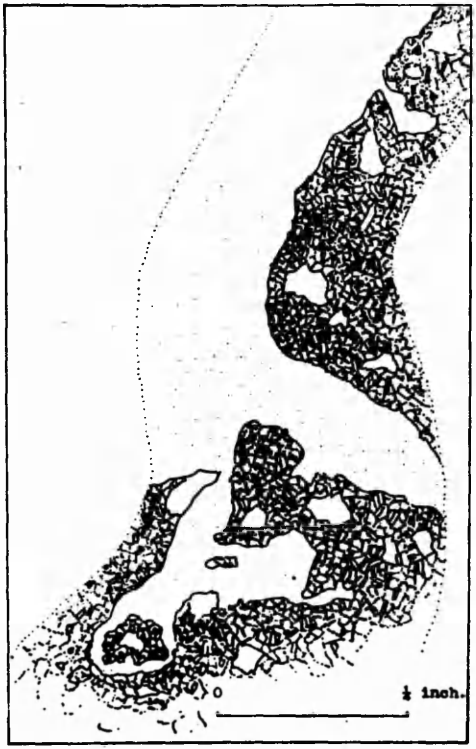

Fig. 9. Sketch of part of the junction between the porphyritic basalt and the acid vein of The Sheans (microsection D.36).

are no longer so distinctive under the microscope. The normal uncontaminated dolerite has been described as consisting of microphenocrysts of bytownite with inconspicuous zonal rims of sodic felspar set in a matrix of pyroxene, labradorite and iron ore (p.37). Within two or three millimetres of the acid veins the phenocryst of bytownite shows a progressive increase in albitisation, saussuritisation and kaolinisation. In the matrix, chlorite and epidote, sometimes with fibrous uralite, replace the pyroxene as well as the neighbouring labradorite and iron ore. Quartz shows a progressive increase towards the veins. These features of subsequent modifications of the dolerite and basalt by the acid vein have been dealt with more fully earlier. (p.40). On the acid side of the vein, the porphyritic texture gives way to xenoporphyritic texture (Tomkeieff and Marshall, 1935, p.265) with the zenocryst felspar forming the xenoporphyritic constituents. Nearer the margins with the wall rock, the zenoporphyritic felspar resembles outliers of the phenocryst felspar of the wall rock. In other cases, however, the xenocrysts of the veins are more crowded than the corresponding phenocrysts in the host rock. This would imply not only differential movement within the vein, but also the selective removal of the original matrix of the basic rock.

<u>Mineralogy and Mineral Habits</u>. The approximate mineralogical composition of the veins in the porphyritic dolerite is 68 per/

per cent. plagioclase, 9 per cent. pyroxene, 3 per cent. iron ore, 2 per cent. epidote and 18 per cent. felspathic mesostasis (R. 5) (Table IV(b)), which is actually not notably different from the enclosing porphyritic dolerite (Table II(b)). The majority of the plagioclase felspars show corroded outlines and conspicuous marginal zoning. Some even retain fringes of the original matrix. They have the same optical properties as the bytownite of the wall rock, i.e. (+) 2V ranging between 86° to 90° and R.I. $\gamma = 1.575$. They only differ from those of the wall rock by their ubiquitous albitisation, saussuritisation and kaolinisation. The albitisation is sometimes seen as regular albitic shells surrounding the calcic core. In other cases the shells make denticulate contacts with the calcic centre, while equally and commonly the original felspar is traversed by anastomising strings of felspar of more sodic composition. These albitic shells have 2V about $(+)80^{\circ}$ suggesting the composition as basic andesine, while the extreme outer fringe with straight extinction or nearly so is distinguished as albite-oligoclase. Several of the calcic cores are replaced by saussurite, while the sodic shells frequently contain prominent grains of epidote. Apart from saussuritisation, many of the bytownite felspars - especially those which are highly corroded - are replaced and obscured by abundant kaolinitic material. The pyroxene which is identical with/

with the wall rock, is a diopsidic augite. Iron ore occurs commonly in association with the pyroxenes and chloritic patches. Quartz is abundantly present in the interstices and occasionally as relatively large sized grains (0.5 mm.). Alkali felspar, mainly perthitic soda orthoclase (?) is found in the abundant mesostasis. Epidote is commonly present, not only in the saussurite of the calcic cores, as crystals in the albitic shells and as products of alterations of the pyroxenes, but also as roughly circular patches of narrow radiating crystals, the immediately surrounding matrix of the rock showing a high concentration of quartz. Chlorite, commonly the ultra-blue variety, is associated with calcite. Micropegmatite lines the margins of the felspar (Plate VIII, Figs. 3 & 4) or, where the latter is highly altered, it replaces the felspar. Apatite and zircon occur as minor accessories.

The veins in the craignuritic basalt are uniform in texture. They consist of the same minerals as their equivalents in the porphyritic dolerite, except that the xenocrysts of plagioclase felspar are never more calcic than basic andesine, while quartz and the felspathic mesostasis are comparatively more abundant. The femics are represented by uralite, epidote and chlorite. Iron ore grains are disposed along the narrow prisms of the chlorite pseudomorphs. Quartz occurs as fairly large/

TABLE IV.

	No. R. 5.	No. R. 10.	No. R. 9.
SiO_2	51.86	47.69	48.87
Al_2O_3	24.47	21.92	19.72
Fe_2O_3	1.44	1.28	.52
FeO	3.45	5.63	7.19
Total iron as FeO	(5.04)	(6.04)	(7.71)
MgO	1.74	5.94	6.04
CaO	10.69	13.03	11.28
Na_2O	2.94	1.63	1.76
K_2O	1.36	.07	.15
H_2O + 105	1.32	1.82	2.73
H_2O - 105	.18	.48	.87
CO_2	nil	nil	...
TiO_2	.44	.44	.46
P_2O_5	.05	.05	.05
MnO	tr.	.14	.13
	99.95	100.12	99.78
Sp. Gr.	2.69	2.85	2.83

No. R. 5. Acid Vein, from the top of the extreme southern hill of The Sheans about a mile and a half west of the Brodick-Lamlash road, Arran. Analyst: W. H. Herdsman.

No. R. 10. Porphyritic dolerite, from the top of the extreme southern hill of The Sheans about a mile and a half west of the Brodick-Lamlash road, Arran. Analyst: W. H. Herdsman.

No. R. 9. Porphyritic basalt, from the top of the eastern face of the middle hill of The Sheans, about a mile and a half west of the Brodick-Lamlash road, Arran. Analyst: W. H. Herdsman.

TABLE IV (b).

ACID VEIN. (R. 5)

Normative Composition.

Quartz		3.36
Orthoclase		7.78
Albite		24.10
Anorthite		50.04
Diopside	$CaSiO_3$ - 1.73; $MgSiO_3$ - .60; $FeSiO_3$ - .66	2.99
Hypersthene	$MgSiO_3$ - 3.70; $FeSiO_3$ - 3.83	7.53
Magnetite		2.09
Ilmenite		.76
Water		1.50
		100.15

Modal Composition.

Felspar	68.8
Pyroxene	8.5
Magnetite	2.8
Epidote	1.5
Quartz	2.9
Mesostasis	15.5
	100.0

****

large sized and rounded grains. Calcite is extensive and frequently replaces all the other minerals. There are also spherulites consisting of fine feathery quartz-alkali felspar intergrowths developed around a nucleus of xenocrystic felspar laths, or sometimes occurring independently of it. Occasionally the spherulites merge into fine micropegmatite.

The bulk composition of the acid vein (R. 5) is given, together with the host rock porphyritic dolerite and its finer equivalent, in Table IV. Comparison of the vein composition with that of the host rock shows only small differences. All the analyses possess a high content of alumina and lime, which is to be expected in view of the felspar xenocrysts in the vein and phenocryst in the hosts. The vein contains more silica, alumina and total alkalies, and correspondingly less total FeO, magnesia and lime. The normative and modal compositions of the vein in Table IV(b) show that the quartz and felspar taken together in the norm agree with the sum total of quartz, felspar and mesostasis in the mode, indicating that some of the normative felspar is to be assigned to the mesostasis.

(v) Mechanism of Acid Vein Emplacement.

It is generally conceded that to account for the ramifying vein network, preliminary fracturing provided the initial/

initial opening for the invading vein materials (Howe, 1924, p.612; Hurst, 1935, p.106; Sales and Meyer, 1949, p.466). Following this initial stage, emplacement of the veins can only have been attained by the following mechanisms:

(1) Purely mechanical, that is to say forcible injection of fluid granitic material accompanied either by (a) dilation of the host rocks as in the case of dyke emplacements, or by (b) simultaneous mechanical displacement of the pre-existing rocks as fragments, viz., stoping, etc. (Billings, 1935, p.140).

(2) Replacement of the host rocks adjacent to the initial fractures.

In particular cases, any one of these mechanisms may be responsible or any combination of two or more processes. The textural and structural features by which the differing modes of emplacement may be recognised were summarised by Goodspeed (1940, pp.194-195). Owing to the absence of original continuous structures in the host rocks, there are no features such as off-setting of appropriate direction and magnitude, whereby dilational and non-dilational methods of emplacement can be satisfactorily demonstrated. The only exception is in relation to the form of the veins themselves as described and discussed in the following pages.

Plates III and IV, and Figures 9, 10, 11 and 12 illustrate the typical field and microscopic characters of the acid/

acid veins. If one assumes any process of a purely mechanical nature to have operated exclusively, it must necessarily follow that the blocks and fragments of host rocks, produced originally and now isolated as a result of the ramifying vein network, possessed not only angular outlines but also sharp contacts. At present all such blocks and fragments show all gradations from sharply angular to rounded outlines with the smaller fragments which are contained in the acid veins being invariably and conspicuously rounded, while the contacts show all variations from sharp to transitional. Some of the larger blocks of host rocks are traversed by branches of the main acid veins which either display tapering or parallel walls or end abruptly in the host rocks as 'tongue-shaped' apophyses. The main acid veins are highly tortuous and irregular. They show all variations from veins with roughly parallel walls to those with indefinite margins. Their contacts when against the fine textured basalts are usually sharp, whereas those against the still finer basalt inclusions are invariably so. The latter contacts, occasionally showing undulating structures parallel to the margins of the vein walls, are strongly suggestive of flow structure. Other veins have the peculiarity of having sharp contacts on one side and transitional contacts on the immediately opposite side, or alternatively both such contacts may be seen on the same side within a apace of two to three /

three inches apart. Equally common are veins that exhibit conspicuous zonal contacts, characterised on the weathered surface by the bleached appearance and intermediate relief as between the vein and host rock. Microscopic observations of some of the sharp contacts suggest no visible reaction as having taken place between the invading vein materials and the host rocks. It is thus plainly evident from the above description as well as from those particular examples described below, that the mode of vein emplacement can on no account be attributed to any one particular mechanism.

However, in cases of relatively regular veins displaying roughly parallel walls, sharp contacts with no apparent reaction between vein and wall rock and suggestive flow structure, it appears reasonable to accept dilation of the fracture walls and subsequent injection. On the other hand, it is difficult to imagine how dilation-injection alone could explain the frequent highly irregular and tortuous forms of the veins that suddenly 'pinch' and 'swell,' even though they are characterised by sharp contacts. The difficulty would be particularly so in cases of irregular vein bodies such as depicted in Figure 10, where an elongated acid body is found emplaced in the midst of the basic host. The extremities of the acid body are characterised by acid stringers while the host rock is also contained within it as 'islets' and/

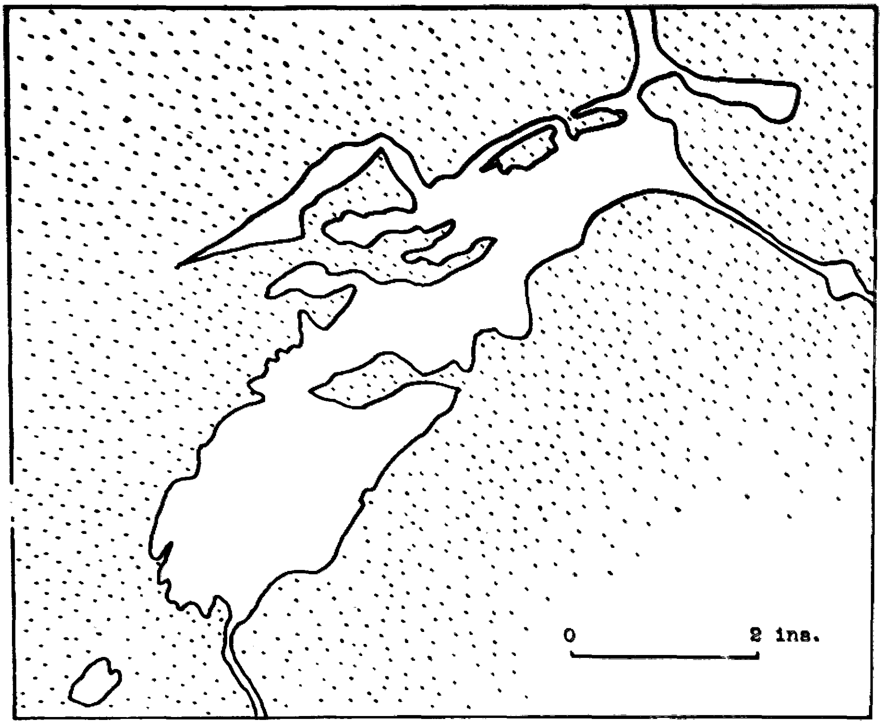

Fig. 10. Part of the highly irregular acid vein in the basic host, seen partly in top left hand corner of Plate III.

and continuous protrusions of wall rock. It is obvious that these features in no respect fit in with mechanical dilation of the fracture walls and subsequent injection for, had it been so, the acid stringers would retain the same widths as the main acid body and, likewise, the protrusions of wall rock would not have arisen. In addition, particular attention is directed to the other veins which show the following features: (a) the tortuous vein margins with commonly 'tongue-shaped' apophyses (Fig. 9); (b) the transitions of regular veins into a body with indefinite margins (Plates III and V); (c) the presence across the veins of repeated interceptions resembling 'bridge-like' septa of host rock resulting in 'lens-shaped' and circular acid bodies (Plate IV and Fig. 11); and (d) the presence of undisturbed host rock occupying the entire width of the vein (Fig. 12). The inadequacy of dilation even as a partial mechanism for veins exhibiting the above features is inconceivable. Its application in the roughly hexagonal vein pattern (Plate V) with the retention of host rock structure across the veins as well as the transitional contacts, sudden 'pinching' and 'swelling,' branching into irregular sub-veinlets and the development of acid patches is practically impossible. Furthermore, it should be noted that a consideration of the problem/

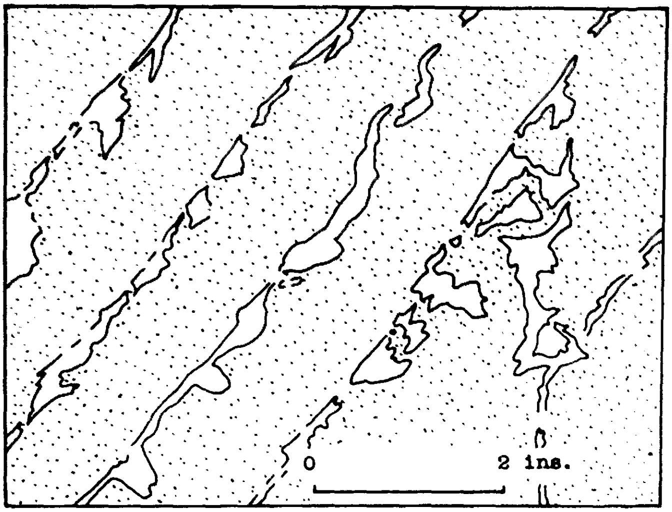

Fig. 11. Part of the acid vein system reproduced from Plate IV. The veins occurring as isolated lenses aligned along a number of parallel planes are worthy of note.

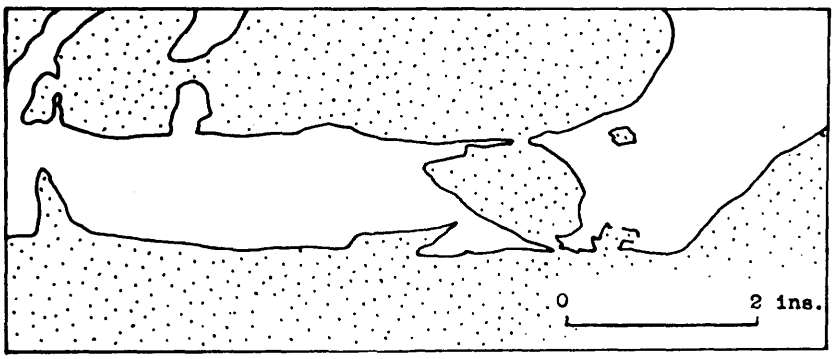

Fig. 12. An apparently regular acid vein, showing the presence of an almost isolated wall rock which occupies its entire width, and which is partly exposed at bottom of Plate III.

problem in three dimensions shows that the difficulties already indicated are likely to be still further intensified.

If some of the forms of the veins, as described and depicted above, could not have resulted from any conceivable dilation of the fracture walls accompanying the injection of the vein filling materials, it is necessary to suppose that the space now occupied by such veins were originally those of the host rocks. The latter must therefore have undergone displacement by a mechanical process of disintegration and removal, such as stoping, or alternatively by encroachment of the host rocks by processes of metasomatic replacement. There is no clearer evidence in support of a mechanical method of disintegration and removal than that provided by some of the veins emplaced in the porphyritic host rock, which show the crowding of the felspar xenocrysts as compared with the corresponding phenocrysts in the adjacent wall rock (p. 56). That the sharp contacts of some of the veins, which invariably include host rock fragments within them, might partly have resulted from this mechanism is not denied. The problem, however, arises as to what extent this mechanism was responsible for the emplacement of the present ramifying vein network. Admittedly, in localised areas, some of the veins show the above features. Elsewhere, there are evidences/

evidences showing features that are incompatible with such a mechanism. The common highly irregular and tortuous forms of the veins that suddenly 'pinch' and 'swell', together with continuous protrusions of host rocks along the margins or continuous 'bridge-like' septa of host rock which cut across the veins, must inevitably impede or completely 'dam' the passage of the disintegrated host rock fragments, thus rendering removal utterly impracticable. However, even granting that such a removal of the host rock fragments were possible, it is significant that all the veins in every case examined - especially those from the junction between the porphyritic dolerite and the craignuritic basalt - contain only inclusions of basalt in veins in basalt, and dolerite in veins in dolerite. Whereas if movement along the veins had occurred, the contained fragments would normally be expected to be more mixed in character. Frequently too, the fragments - although appearing as normal xenoliths - are too large to have been transferred along adjacent parts of a vein which may, in some cases, merge into host rock a short distance away. These seemingly displaced fragments are therefore more in the nature of undisplaced or static host rocks or 'skialiths' as termed by Goodspeed (1947, p.1251; 1948, p.67). King (1948, p.471) contends that to account for certain ramifying vein/

vein networks by disintegration and mechanical removal in the case of non-dilational veins is impossible. The author is, therefore, led to the belief that a mechanical method of stoping by itself cannot explain the ramifying vein network. It is his belief that such a mechanism can only have been effective where accompanied by dilation of the fracture walls.

Consequently, since a mechanical method of disintegration and removal is incompatible with the emplacement of some of those ramifying veins which must be also considered non-dilational in origin, it is apparent that the host rocks, which formerly occupied the area now occupied by such veins, must have therefore undergone transformations by a process of metasomatic replacement. Such transformations, affecting the host rocks in terms of ultimate crystal units, would take place along the openings provided by the initial fractures or along the margins of the infilled veins. The highly irregular and tortuous margins of the vein must be ascribed to the effects of uneven replacement. Undisputed evidence of replacement, at least on a limited scale, is shown by the retention of host rock structures across the veins (Plate V), the transitions of regular veins into a body with indefinite margins, or the numerous instances of transitional and zonal contacts. Likewise, under the microscope the included bytownite xenocrysts, which resemble outliers of the host rock, indicate selective replacement/

replacement of the matrix of the porphyritic host rock by the vein materials.

On the other hand, sharp contacts have often been used as an argument against replacement. In many cases it is reasonable to suppose that the sharp contacts were due to a mechanical method of dilation-injection accompanied by stoping, but there are also instances of sharp contacts to veins which cannot have been formed mechanically for the reasons already mentioned. That sharp contacts need not necessarily be intrusive contacts have been pointed out by many authors (Reynolds, 1936, pp. 367-407; 1947, p. 221; Goodspeed, 1937, p. 762). In particular, Webb (1946) and King (1948, p. 472) have cited examples whereby veins with parallel walls and sharp contacts can also sometimes form by replacement.

The comparison of the chemical analyses of the vein and host rocks shows that the compositions are not greatly different and for this reason the introduction of material in accounting for veins of replacement origin likewise would not require to be on a large scale. In general, it is seen that the veins are richer in silica, alkalies, and alumina, and poorer in the basic constituents as compared to the host rocks. Owing to the invariably altered character of the host rock at the immediate vicinity of the veins, the destination of the displaced constituent from areas now occupied by such veins, is not/

not clearly observed. However, it is significant to note that the comparison of the two chemical analyses of the host rocks shows that the one at the margin with the vein wall to be richer in the basic constituents than the one farther away (p. 42). The marginal host rock may, therefore, have been relatively basified.

(d) Petrogenesis.

The foregoing detailed study of the composite intrusions of the Lamlash region reveals not only the significant absence of true normal intermediate types, but also the evidence of contamination of both the contrasted types, basic and acid. In addition, there are the undoubted modifications of both types along the merging contacts, whilst the basic xenoliths demonstrate some stages in the processes of hybridization. Hybridization as such is treated in this paper as belonging to two phases, 'contact' and 'deep-seated.' The former, which is local, is referred to hybridization arising along contacts between the contrasted bodies or with the basic xenoliths, while the latter, which is more widespread, is seen in almost all the rocks.

The course of contact hybridization has been one of transfer of calcic material from the xenoliths to the acid material and the migration of alkali molecules to the basic material - a process demonstrated under the name of 'reciprocal reaction/

reaction' by Read (1924, p.440) and Thomas (1922, pp.229-60). The distribution of basic xenoliths, combined with mechanical disintegration at the edges and their subsequent enrichment in alkalies and volatiles calcite and apatite, is well characterised by the craignuritic basalt of The Sheans and likewise by the progressive acidification of the basic flanks along margins with the acid rock of the Monamore composite sheet. Such features as (i) the relatively acid rich mesostatic patches with their frequently present skeletal texture and (ii) the xenocrysts of alkali felspar and quartz, producing locally a xenoporphyritic texture, are referred to deep-seated hybridization. The first is characteristic of the craignuritic basalt of The Sheans and the basic member of the Ross road composite dyke and the second of the isolated outcrops of the craignuritic basalt of The Sheans west of Cnoc Dubh. Similar processes of deep-seated hybridization, but involving basification as opposed to acidification, are shown by the felsites in their unusually high content of ferromagnesian minerals which are seldom if ever fresh. In other words, acidification and basification are invariably found.

Hence, to account for the contrasted rock types with their acidification and basification features, one is led to fall back on Bunsen's hypothesis of two magmas, basic and acid, capable of co-existing in one or several local intercrustal magmas/

magma chambers. Although this conception of two magmas has gained general recognition in recent years, the ultimate source of the magmas is a subject which to-day is foremost in petrogenetic discussion. Harker (1909, p. 346) maintains that they are complimentary differentiates from a single parental magma; and the Mull authors (Bailey and others, 1924, p. 33) confirm the view, stating that as a result of the early extraction from the plateau magma of the basic constituents, a residual magma would reach a composition 'which would find expression as quartz dolerite with an acid mesostasis capable of mechanical separation and a separate existence as acid lavas or intrusions.'

If, as the above authors suggest, the acid rocks are residual products arising from the crystallisation differentiation of a basaltic magma, the question may at once be asked as to why the volume of the acid rock should be much in excess over the basic in these intrusions. That crystallisation differentiation, under suitable conditions, yield acid rocks from a basalt magma is not to be denied, but such a process - as pointed out by Fenner (1929), Krokstrom (1932), Holmes (1931, 1932) and Daly (1933) - can at most lead to the formation of only a small proportion of acid rock from the basic magma. Grout (1926, p. 549) states that 'as a maximum/

maximum, one-tenth of the average basalt magma may become granitic,' and no more. The high volume of the acid rock over the basic thus renders the acceptance of the theory of crystallisation differentiation exceedingly difficult.

However, granting that such a differentiation did result in a huge volume of acid rock, the difficulty again would be to explain the absence of true intermediate types, for it is most improbable that there should not be any primary rocks whatsoever of a composition truly intermediate to occupy the gap between the basic and acid rocks. Bowen's explanation (1919, p.405) for the absence of true intermediate types, namely, the high fractionation among the plagioclase felspar, is pointed out by Williams (1935, p.301) as inadequate. Moreover, he states that it is very doubtful if crystal settling would ultimately yield a rock of rhyolite composition unless the parent itself was andesitic, which is here distinctly not in evidence. Holmes (1932, pp.546-47) is likewise of the opinion that a basic magma by this process tend, at the most, to a residual magma of trachytic or synenitic composition rather than to residual acid magma. Holmes accordingly considers that to assume a single mode of origin of the acid magma to processes of crystallisation differentiation from a parent (basic) magma is to plunge oneself into difficulties. Thus, it becomes apparent/

apparent that crystallisation differentiation, under whatever condition, cannot produce the acid magma of a volume much in excess over the basic. The acid magma, like the basic, must be considered 'primary in its own right,' as suggested by Read (1943, 1948).

To explain then the primary position of the acid magma, one is forced to adopt crustal refusion of pre-existing rocks of granitic composition as postulated by Sederholm and Bachland under the respective names of "palingenesis" and "rheomorphism," a concept which has been fully discussed by Holmes (1931, 1932) in this country. According to Holmes, the initial melting of the basaltic sub-stratum would be brought about by radio-activity, the magma thus produced and subsequent uprise into the granitic crust would lead to refusion, and ultimately result in the formation of acid magma. Such a generation of magma must obviously involve some contamination of one by the other and this would lead to basification in one case and acidification in another.

C. Dykes.

The dykes of the Lamlash region form part of the main Arran dyke swarm. Continuously exposed dykes are rare. A clean washed shore, such as is provided by the Lamlash shoreline, shows the dykes to stand out as low resistant walls or shelter in narrow trenches. Inland they are mainly encountered/

encountered in the two burns, Monamore and Benlister. As regards their direction, a detailed field study shows that the great majority trend N.W. to S.E. and N.N.W. to S.S.E., that is to say, conforming with the general direction recorded for the main dyke trend of the British Tertiary province. Other trends comprising less than a quarter of the total directions recorded in order of decreasing frequency are: E. to W., W.N.W. to E.S.E., N. to S., and N.E. to S.E.. N.N.E. to S.S.W. and E.N.E. to W.S.W. trending dykes were not encountered.

The thicknesses of the dykes vary from a foot or two to about 30 feet and the average thickness is approximately 8 feet. Some of the larger and longer dykes can be traced for about 200 yards, but many of them are small and have only a short extension. Jointing has affected most of the dykes, especially along the margins of the larger dykes or throughout the entire width of the smaller ones. The centre of the larger dykes are characterised by prominent spheroidal weathering.

Although the composition of the dykes varies from extreme basic crinanites through sub-basic quartz dolerite-tholeiite to acid felsites, over three-quarters of the dykes are of basaltic composition. Dykes of true normal intermediate rock/

rock types are not found. A noteworthy feature is the way in which dykes of varying composition co-exist side by side and separated only by a thin screen of sandstone. Whereas a large number of the dykes are emplaced in sandstones, others are emplaced in crinanites or show cross-cutting relationships amongst themselves. In this way, it can be shown that some of the dykes are earlier than the main period of dyke emplacement which represented the final phase of the Tertiary igneous activity.

The dykes of the Lamlash region are treated under the following four main headings:

(i) Crinanites and allied olivine dolerites.

(ii) Quartz dolerite-tholeiites.

(iii) Dykes of intermediate composition of andesitic and craignuritic affinities.

(iv) Dykes of acid composition of craignuritic affinities.

(i) <u>Crinanites and allied olivine dolerites</u>.

Dykes of this basic group are found on the Lamlash shore, at Cordon and Innean Mor. They are all parallel to one another, striking N.W. to S.E., and maintain a uniform width of 25 feet. These dykes are emplaced in Triassic and Permian sandstones. They extend only for short distances and as such their relationships with the main crinanite sheets are nowhere seen. Nevertheless, they are cut by tholeiite dykes which develop/

develop tachylytic selvages against them and are also traversed by tachylytic veins as are invariably found in the main crinanite masses. The age of these dykes are thus regarded as contemporaneous with the main period of emplacement of the crinanite sheets.

Under the microscope, this dyke rock is more or less like the corresponding type of the crinanite sheets except that here it is much finer grained. It is non-porphyritic and ophitic in texture and consists of the minerals, olivine, titanaugite, ilmenite and some interstitial analcite, along with some secondary constituents. The olivine, commonly altered to serpentine, occurs as irregular grains. The titanaugite plates show a characteristic lilac colour and feeble pleochroism. The labradorite, ophitically intergrown with titanaugite plates, show albite and occasionally some Carlsbad twinning. Ilmenite is mainly granular with here and there some minor alterations to leucoxene. Analcite is sparingly present while biotite and apatite occur as abundant accessories.

The chemical composition and their general tendency to exhibit uniformity in mineralogy has been discussed (p.12).

(ii) Quartz dolerite-tholeiites.

These rocks of sub-basic composition constitute the commonest dyke rock here as elsewhere in the island. They occur/

occur mainly in the Monamore and Belister burns, sometimes as basic members in composite intrusions or forming multiple dykes. Whereas the main trends of these dykes are N.N.W. to S.S.E., some trend N.W. to S.E. and occasionally N. to S., as the one occurring at the junction where the main tributary meets the Lag a' Bheith burn, approximately 200 yards west of the Brodick-Lamlash road. Unlike the crinanite dykes, their thicknesses are extremely variable, being anywhere between 2 to 13 feet, with the exception of one dyke which has a width of 30 feet seen in the upper quarry near the eighth milestone on the Ross road. These dykes are invariably featured by conspicuous tachylytic selvages. As regards the age of these dykes, scarcity of critical exposures coupled with the recurrence of similar petrographic rock types at the final phase of Tertiary igneous activity, renders actual determination of the different periods of intrusions very perplexing. Broadly, however, they are referred to two phases. The first corresponds to the age of the composite intrusions as the composite dykes on the Ross road and in the Benlister burn, and the second to a much later phase, belonging to the main period of dyke activity, as illustrated in the Monamore burn, where the Monamore composite sheet emplaced in crinanite is cut by no fewer than six tholeiite dykes.

(a)/

Quartz dolerites.

(a) Non-porphyritic quartz dolerite. The quartz dolerite, which forms the basic flanks of the composite dyke at the roadside quarry near the eighth milestone on the Ross road, has been described in detail (p. 24). Elsewhere, dykes corresponding to this rock type are found cutting the crinanite in the escarpment overlooking the Benlister burn due north-east of the cairn of Ross and in the small burn, south of Creag a' Ghobair, 50 yards west of the Brodick-Lamlash road. Moreover, the numerous irregular dykelets and narrow sheets, emplaced in the crinanite in the scarp due south and west of the cairn of Ross and in the Clauchland crinanite sheet, west of the Brodick-Lamlash road, are featured by rocks of this type.

The petrography of the quartz dolerite of the composite dyke has been described (p. 26). The other dykes correspond more or less to it. However, the dyke occurring in the escarpment overlooking the Benlister burn is significant. In thin section (Y. 6), the felspars measure nearly a millimetre in length and 0.5 mm. in width. Carlsbad twinning is prominent often combined with albite twinning. Maximum symmetrical extinction angle of about 32° along with the index of refraction appreciably higher than quartz suggest the felspars as labradorite. The progressive continuous zoning is conspicuous, especially at margins which are in contact with the mesostasis. Its/

Its relations with the augite are sub-ophitic, but its margins are rather ragged as a result of encroachment by secondary alterations of the augite. The augite in anhedral plates and sub-hedral prisms is feebly coloured. $Z \wedge c = 43^{o}$. It shows marginal alterations to chlorite or to uralite. Magnetite, in sharply crystallised individuals of octahedral and squarish shapes, are scattered throughout the rock. Few of the iron ore crystals tend to associate or cling to the prisms of augite. The abundant felspathic and turbid mesostasis, which sometimes shows a patchy distribution, is charged with ill-formed feathery spherulites of alkali felspar and quartz intergrowths, little interstitial quartz and apatite needles, the latter having their extensions in the felspar laths. Sharply contrasted with the irregular patches are fine grained areas with a typical craignuritic texture that are suggestive of xenoliths which have undergone intensive reaction with the enclosing rock. Although this rock compares well with the Talaidh type of quartz dolerite, it shows many features which are incompatible with a rock of uninterrupted magmatic descent. These features may be summarised as consisting of the albitisation of the felspars labradorite, the alteration of the pyroxenes, the formation of irregular relatively acid rich patches and the mesostasis of ill-formed spherulites of alkali felspar-quartz intergrowths, features suggesting crystallisation from a contaminated/

contaminated magma.

(b) Porphyritic quartz dolerite. The typical example of this type is the 30 foot dyke exposed at the upper quarry on the Ross road. In hand specimen it is a medium to fine grained rock of dark grey colour. Felspar phenocrysts are megascopic and average 2 mm. in length. Under the microscope, the phenocrysts, highly altered and saussuritised, consist entirely of felspar as in the case of the porphyritic dolerite of The Sheans (p.37). Unlike The Sheans, this dyke rock contains acid rich mesostasis which sometimes segregate into patches. In addition, the pyroxenes are invariably altered to chlorite and the felspars show prominent progressive zoning to more sodic felspars at the margins. In a way, this type resembles the coarser equivalent of the Corrie type, described later (p. 84).

Tholeiites.

According to Holmes and Harwood (1929, p. 8), Steininger's term tholeiite was used by Rosenbusch to designate both porphyritic and non-porphyritic olivine-free, and olivine-poor plagioclase-augite rocks, possessing an intersertal texture and patchy interstices that contain glass or its devitrification products. Rocks with conspicuous olivine phenocrysts were designated as olivine tholeiite. The Mull authors/

authors (Bailey and others, 1924, p. 280) restricted its usage only to rocks of non-porphyritic character of similar composition and texture. Tyrrell (1917, p. 205; 1928, p. 240), on the other hand, used the term in a much wider sense and included in his description not only non-porphyritic and porphyritic types with glass or its devitrification products as recognised by Rosenbusch, but also types which are holocrystalline and which contain conspicuous calcic plagioclase felspar phenocrysts, approaching anorthite in composition. The terminology here is as adopted by Tyrrell. Several varieties have been described by various authors, and in the present paper they are treated under the following headings:

(a) Largs type of tholeiite.

(b) Corrie type of tholeiite.

(c) Brunton type of tholeiite.

(d) Talaidh type of tholeiite.

(e) Tholeiite with affinities to the Acklington type.

(a) Largs type of tholeiite. The Largs type of tholeiite has been described and figured by Tyrrell (1917, p. 353), and is based upon a dyke occurring on the foreshore of Largs, Ayrshire. A N-S. dyke, 3 feet wide cutting the crinanite in the Benlister burn, corresponds with the above type. Megascopically, it is a fine grained rock, conspicuously porphyritic, and is of dark grey/

grey to black colour. The porphyritic felspars average 2 x 3 mm. in size. Microscopically, the rock (Plate IX, Fig. 2) consists of glomeroporphyritic aggregates of plagioclase felspar and olivine set in a fine textured base of olivine, augite, plagioclase felspar, iron ore and abundant glassy mesostasis. The porphyritic felspars are in the form of stout rectangular crystals, commonly twinned and frequently showing slight zonal rims. The high refractive index ($\gamma = 1.58$), together with the high symmetrical extinction angle about 40°, suggest the felspars as bytownite near anorthite in composition. The crystals show frayed edges giving the appearance of corrosion. Some of the felspars contain inclusions of yellowish-green opaque matter which are sometimes arranged in a thick marginal zone that follow the cleavages of the crystals. Some show partial replacement by saussurite. The olivine occurs as rounded serpentine pseudomorphs. The serpentine, pale yellowish-green and pleochroic, is distinguished as chrysotile. In the groundmass, the olivine is again seen as granular serpentine pseudomorphs. The minute plagioclase laths, with repeated albite twinning, shows diverse orientation. The augite, approximately equal in amount to the felspars, is granular and has a pale brown colour. Iron ore grains are scattered throughout the matrix.

The 3 foot dyke, occurring in the Monamore burn, immediately/

immediately south of the lower quarry near the eighth milestone on the Ross road, is similar to the above, but shows a lesser proportion of glassy mesostasis and also the presence of abundant vesicles which contain serpentine and calcite (D.18).

The rock which forms the 3 foot dyke, emplaced in crinanite found on the foreshore about a quarter of a mile north of Clauchlands Point resembles the Largs type, except that the microphenocrysts are almost confined to olivine, and as such might be termed an olivine tholeiite. In thin section (Plate IX, Fig.3), the olivine microphenocrysts, which occur as pseudomorphs of serpentine, are in the form of 'lozenge' shaped crystals and prisms. Occasionally narrow plagioclase felspar crystals, with bifid terminations, occur as microphenocrysts. The groundmass, consisting of granular olivine augite, iron ore, and felspar laths, together with the mesostasis of glass, is similar to the Largs type.

(b) Corrie type of tholeiite. The 3 foot dyke, found on the shore 200 yards south of the mouth of the Corrygills burn, has affinities with the Corrie type of tholeiite, as defined by Tyrrell (1917, p.350) after the occurrence at Birchpoint on the foreshore of Corrie, Arran. Under the microscope (Plate IX, Fig.4) the microphenocrysts are confined to bytownite near anorthite in composition while olivine is only sporadically/

sporadically present in the groundmass. The felspar microphenocrysts commonly exhibit 'oscillatory zoning.' This type of zoning is attributed by Fenner (1926, p.700) to the influx of fresh portions of the original magma at successive intervals such that the composition of the already crystallising magma reverts again to the original. The groundmass differs from the Largs type in being almost devoid of glass. The labradorite laths, commonly sub-ophitic with the augite plates, sometimes form stout shaped crystals. The augite occurs as anhedral plates or as granular crystals. It has a light brown colour and feeble pleochroism. Iron ore which has the magnetite habit, occurring as octahedral and squarish crystals, is scattered throughout the matrix. The olivine is invariably serpentinised. The rock is also vesicular in parts. The vesicles contain serpentine together with calcite.

The dyke in the Benlister burn, 200 yards downstream from the junction with the Tounie burn, is also a Corrie type. It (D.24) differs from the above in being much finer textured and containing abundant glass. In addition, the matrix also contains abundant irregular scrappy iron ore, which sometimes occupy the vesicles and which are in turn occasionally replaced by calcite.

(c) Brunton type of tholeiite. This type of tholeiite was first described and figured by Teall (1884, pp.236-7) for the Bingfield/

Bingfield dyke occurring in the north of England. The type rock consists of narrow felspar laths which penetrate and radiate out from discrete clots of granular pyroxene embedded in a ground of abundant glass. Felspar phenocrysts are present, but are never in significant numbers. In the present area, dykes which resemble the above description are common. The dyke, found in the burn 1/3 mile west of Clauchlands farm, is the nearest approach to it. Under the microscope (Ar. 98) the rock shows characteristic stellate clusterings of irregular augite plates about 0.5 mm. in diameter with radially arranged slender plagioclase laths representing crystallisation from several augite nucleii. The augite plates are pale brown and non-pleochroic. The felspar laths, with maximum symmetrical extinction angle about 29^{o} in zone normal to 010, is labradorite. Iron ore, in small irregular grains, is evenly distributed. Here and there may be seen calcic plagioclase of microphenocrystic dimensions. The brown opaque material distinguished as glass is very subordinate, as compared to the Bingfield dyke. There also occurs sporadic grains of serpentine which probably represent original olivine.

The dyke, emplaced in crinanite and cutting the composite sheet immediately under the footbridge in the Monamore burn, and also the tholeiite dyke, forming the multiple/

multiple member with the porphyritic quartz dolerite, resemble the dyke just described, but for the presence of olivine microphenocrysts, and hence is referred to as olivine-bearing Brunton type of tholeiite. The olivine, occurring as glomeroporphyritic aggregates of serpentine pseudomorphs, are ellipsoidal and circular in shapes. Furthermore, the rock contains vesicles, the walls of which are lined by serpentine with calcite towards the centre.

The two parallel 5 foot dykes, striking N.N.W. to S.S.E. occurring on the Lamlash foreshore at Innean Mor differ from the dykes described above in containing significant amounts of plagioclase felspar microphenocrysts and thus corresponding to the anorthite-bearing Brunton type. Under the microscope (Plate X, Fig. 1) the microphenocryst felspars occur singly or as glomeroporphyritic groupings set in a ground of reasonably large sized plates (0.5 mm.) of augite, ophitically and radially intergrown by felspar laths, depicting the prominent stellate clustering characteristic of the type as a whole. The microphenocrysts felspar bytownite, near anorthite in composition, forms rectangular shaped crystals commonly with both Calsbad and albite twinning. They frequently show frayed edges, while towards the interior of the crystals, inclusions of dark opaque matter or material of the groundmass are quite often present. The augite, pale brown and non-pleochroic, shows/

shows prominent prismatic cleavages with $Z \wedge c = 42^{o}$. Scrappy and granular iron ore are scattered in the matrix, together with abundant glass.

(d) Talaidh type of tholeiite. Belonging to this type is an inclined dyke about 40 yards downstream from the confluence of the Tounie burn with the Benlister burn, while another example is seen immediately west of the lower contact of the quartz felsite sheet of the Monamore section. In addition, the irregular dykelets found in the escarpment of the crinanite, west of the cairn of Ross and at Creag a' Ghobair, show affinities with this type. Under the microscope (Plate X, Fig. 2) the rock is closely similar to the quartz dolerite. Sheaves and fan shaped cervicorn groups of slender chloritised augite fringed with grains of iron ore, together with granular and sub-ophitic plates, are present. Iron ore, besides occurring with the chloritised augite, is also seen scattered indiscriminately with skeletal or scrappy habit. There is also a patchy development of still finer mesostatic matter occasionally containing granular quartz aggregates. The rock contains much chlorite and calcite. Occurring sporadically, either individually or in clusters, are felspars of microphenocrystic dimensions. They are highly irregular in outline with some of the unusually elongated ones showing bifid and trifid terminations. Whereas some of these felspars are/

are saussuritic, others show oscillatory zoning as in the Corrie type. The abundance of chlorite and the corroded appearance of the felspar microphenocrysts suggest strongly the contaminated nature of the magma.

(e) Tholeiite with affinities to Acklington type. Two parallel dykes about two feet apart and each about three feet in width, cutting the Monamore composite sheet towards the middle of the section, show rare microphenocrystic calcic plagioclase felspar in a tholeiitic ground of granular - and sometimes columnar - augite, comparatively stout laths of felspar and scrappy iron ore along with some turbid mesostasis (D.19; G.53). The augite is pale brown to colourless with few showing straight extinction, the latter probably being the variety enstatite-augite. The labradorite laths show no special tendency to collect into stellate forms as in the Brunton type, nor sheaf-like bundles characteristic of the Talaidh type. Vesicles are present. The rock resembles the anorthite-bearing Acklington type, described and figured by Holmes and Harwood (1929, p.28).

(iii) Dykes of intermediate composition.

The dykes of this group, apart from being scantily represented, also present many difficulties in nomenclature and classification owing to the abundant glassy groundmass. They are comparatively of narrow widths, and their trend is N.W. to S.E. Being in themselves much finer grained, their tachylytic selvages are/

are not so pronounced as the quartz dolerite-tholeiite group. For purposes of description, they are arbitrarily treated in the present paper under the following headings:

(a) Rocks having affinities with augite andesite.

(b) Variolitic andesite.

(c) Tachylyte.

(d) Rocks having affinities with craignurites.

(e) Invariably xenolithic and xenocrystic hybrids.

It must be noted that this grouping cannot be taken as strict and rigid, since the rocks show all gradations from one type to another.

(a) Rocks having affinities with augite andesite. A typical representative of this rock is shown by the dyke occurring at the base of The Ross, 200 yards west of Ross cottage. In hand specimen, it is a fine grained dark grey rock differing but little from the fine grained tholeiites. Under the microscope it (G. 2) compares closely with the innimorites of Mull. It consists of glomeroporphyritic aggregates of felspars and pyroxenes set in a cryptocrystalline base of felspar microlites, iron ore, biotite, quartz and turbid mesostasis of glass. The microphenocrysts of felspar are commonly rectangular in shape, while few which are elongated have bifid terminations. They are highly zonal, sometimes with oscillatory zoning. Albite twinning is generally present. The maximum symmetrical extinction/

extinction angle on the albite twin planes is 28°, while the mean refractive index is 1.56; the composition is therefore determined as basic andesine ($Ab_{53}An_{47}$). The pyroxenes, which are pale brown to colourless, are in the form of subhedral stumpy prisms, $Z \wedge c = 42°$, which indicates common augite. The rhombic pyroxene enstatite appears also to be present as judged from the pale colour and straight extinction of certain crystals. In the groundmass the tiny laths of plagioclase are roughly parallel to each other, suggestive of flow orientation. They show the usual albite twinning and their maximum extinction angle is around 17°. The iron ore, which is skeletal and rod like, is concentrated in a manner that suggests derivation from original mafic minerals that have undergone thorough reaction. In addition, biotite which is very common in the rock is commonly found associated with these iron ores. Blebs of quartz showing undulose extinction are quite common. This particular microsection (G. 2) shows two fine textured areas exhibiting both sharp and gradational contacts with the host rock. Along the margins of the sharp contacts the felspar microlites of the enclosing rock show a tangentional arrangement, indicating undoubtedly that the fine textured areas are none other than partially digested xenoliths. The junctions of the host rock and the xenoliths are characterised by abundant skeletal iron ore and biotite which represent/

represent the products of reciprocal reaction between the host rock and the xenolith. The texture of the xenoliths is typically craignuritic.

(b) Variolitic andesite. This rock is represented by a single narrow 2 foot dyke found in the lower reaches of the Monamore water. Microscopically (Plate X, Fig. 3) the rock differs from the xenoliths contained in the craignuritic basalt of The Sheans (p. 48) in being coarser and porphyritic. The microphenocrysts are quartz and felspar with either of them occurring individually or as glomeroporphyritic aggregates. The felspars are invariably albitised and partly replaced by calcite. The quartz crystals are rounded and embayed, indicating resorption by the magma. The groundmass contains very fine microlites of augite, felspar and skeletal iron ore strings, all combining to form sheaf like bundles and roughly stellate groupings to give rise to the variolitic structure. Skeletal iron ore strings radiating out from the common centre of the type, commonly seen in variolites, are especially conspicuous. The mesostasis, consisting of brown glass, is partly replaced by calcite and chlorite. Here and there it is devitrified to feathery and turbid material, with a little quartz. Apatite needles occur as an important accessory.

(c) Tachylyte. A dyke in the Monamore burn, about a foot in width cutting the crinanite as well as the composite sheet, approximately/

approximately 100 yards farther upstream from the footbridge, corresponds to this type. Besides, as mentioned earlier, tachylytes are also encountered as irregular veins commonly seen traversing the Monamore and Clauchland crinanite sheets and dykes. Furthermore, the rapidly cooled margins of quartz dolerite-tholeiite dykes also develop tachylytic selvages (p. 78). Obviously the latter types are relatively more basic. However, microscopic examination shows that apart from the felspars being slightly more calcic in the more basic types, they are more or less similar, being essentially of almost opaque brown glass. The tachylyte, represented by the dyke (G. 39) consists of microphenocrystic plagioclase laths of approximately andesite-labradorite composition disposed in delicate orientation indicative of flow structure. Minute circular grains of quartz are haphazardly distributed. The groundmass, essentially of brown glass, is characterised by narrow bands of relatively darker and lighter colour, the latter occasionally spreading out to form patches. These lighter coloured patches on higher magnification show minute crystallites arranged in a manner somewhat resembling the variolitic structure and which must be referred to as arising from devitrification. Moreover, the groundmass is also charged with globular and reddish coloured clots which sometimes contain fibrous spherulites. This must also be attributed to devitrification.

(d)/

(d) Rocks having affinities with craignurites. Typical representatives of this type are seen as narrow and irregular dykelets emplaced in the crinanite sheets, especially in the N.-S. escarpment west of the cairn of The Ross. Equally typical is that developed along the merging contacts of the composite dyke in the Benlister burn which, again, is identical with the occurrence in the Monamore composite sheet. The petrography of this type has been described in the previous section (p. 32).

(e) Invariably xenolithic and xenocrystic hybrids. There are few dyke rocks in the area that are more or less of intermediate composition which do not conform to any of the known normal igneous rock type and as such they are treated under the name "xenolithic and xenocrystic hybrids." Such dykes are found in the headwaters of the Lag a' Bheith burn and in the Benlister burn, a little to the north of the confluence with its main tributary, the Tounie burn. Megascopically, they are medium to fine grained rocks of greenish-grey colour. Invariably they contain xenoliths, either sharply defined from the host or displaying transitional contacts. In addition, such rocks commonly exhibit in the very same dyke abrupt transitions in colour due undoubtedly to variations in composition. Microscopically, these rocks (D. 13; D. 31; D. 69) consist of altered/

altered pyroxenes, felspars, iron ore and quartz together with indeterminate turbid scanty groundmass much obscured by chlorite and calcite. The pyroxenes occur invariably as chlorite pseudomorphs associated with iron ore. Occasionally, the cores of chlorite consist of hornblende as recognised by the strong pleochroism and low extinction angle. The felspars are altered to calcite and not uncommonly replaced by chlorite along the cleavages and margins. Despite the altered condition of the felspars, it can, nevertheless, be established that the refractive index is appreciably higher than quartz showing that the composition is approximately of acid labradorite. Iron ore occurs in various shapes ranging from fairly large irregular crystals to rod-like, skeletal and scrappy habit. Moreover, in the groundmass are contained dust-like limonitic iron ore. Here and there small anhedral crystals of biotite occur, showing strong pleochroism from yellowish-brown to blood red colour, the cleavages often being obscured by chlorite or by calcite. Quartz xenocrysts, with reaction borders of fibrous spherulites, are invariably present.

The basic xenoliths, like the host rock, are highly altered. The relic structures are only represented by coarse patches of abundant chlorite, saussuritised felspars, skeletal iron ore and epidote. In some cases, where the modification is still/

still further advanced, the relic xenoliths are only depicted by dust-like and skeletal iron ore concentrations.

(iv) <u>Dykes of acid composition of craignuritic affinities</u>.

The dykes of acid composition have widths averaging 15 feet which is much greater than those of the majority of the basic dykes. These dyke rocks include ~~quartz,~~ quartz-felspar porphyry, quartz felsites, felsites and pitchstones. Since such dykes commonly occur as acid members in composite intrusions, and since independent acid dykes such as that in the Benlister burn, where the dyke of quartz-felspar porphyry is cut by tholeiite dyke, it is likely that all such acid intrusions in the present area belong to the same period as the composite bodies.

(a) <u>Quartz-felspar porphyry</u>. The only occurrence of this rock in the whole area is represented by a 30 foot dyke, striking N.N.W. to S.S.E. and extending for over 200 yards. Its main exposure is on the northern slope of The Ross, while part of it is seen in the Benlister and Tounie burns. In hand specimen, the rock is characteristically porphyritic with quartz and felspar forming the porphyritic elements. Their average lengths are 4 mm. and 5 mm. respectively. The groundmass is speckled with chloritic patches. Under the microscope the quartz crystals have pyramidal and rounded shapes and embayed margins indicative of magmatic corrosion. Frequently too, they contain inclusions/

inclusions of the groundmass. The felspars, which are roughly rectangular in shape, also show embayed outlines and inclusions, although not to the extent shown by the quartz. They are, however, much altered partly to sericite and partly to kaolinite. Occasionally, in between the alteration products faint albite twinning persists, giving a maximum symmetrical extinction angle of about 15^{o} and consequently suggesting the composition of the felspar as approximately albite-oligiclase. The groundmass, which is mainly felsitic, consists of abundant granular quartz which are sometimes moulded on little crystals of alkali felspar. Ferruginous aggregates, mainly of chlorite and sometimes with a core of hornblende, are also abundantly distributed in the matrix. Associated with the ferruginous aggregates are brownish coloured minerals which are probably altered biotite. Iron ore crystals are highly irregular and much of it is replaced by ill-formed crystals of sphene, indicating the original ore as a titanferous variety.

(b) Quartz felsite. Dykes of this rock type form the acid member of the composite dykes on the Ross road and in the Benlister burn. The latter, except for its much steeper inclination, is identical with the acid member of the Monamore composite sheet. The field relations and petrography have been considered in an earlier section (p. 28).

(c)/

(c) Felsite. These dykes are found for short distances in the Lag a' Bheith burn. However, in the Benlister burn about 200 yards north from the confluence with its main tributary the Tounie burn, a felsite dyke of 200 yards extension is found with a strike parallel to the quartz-felspar porphyry dyke. Its width is 30 feet. Microscopically, these rocks have much in common with the quartz felsites, but for the absence of the glomeroporphyritic aggregates of quartz. As usual, there are abundant chlorite patches containing skeletal iron ore, associated with ill-formed 'lozenge' shaped sphene crystals. This richness in ferromagnesian elements results from the process of basification of the magma by the dissolution of the basic xenoliths which are now seen only as dark coloured patches. Also, occurring sporadically are 'ghost-like' crystals of acid plagioclase. A little micropegmatite is not uncommonly seen (R. 65) moulded on the felspar and likewise quartz-alkali felspar spherulites in the midst of the turbid kaolinitic material. Biotite, epidote, apatite and zircon occur as accessories.

(d) Pitchstone. Although the island is reputed for the occurrence of pitchstones, they are poorly represented in the present area. They are found at two places, the first in the upper reaches of the Lag a' Bheith burn about a mile and a half west from the Brodick-Lamlash road, and the second in the lower reaches/

reaches of the Monamore water near the mill of Cnoc. Both the exposures are very poor and it is difficult to decide whether they are actually sills or dykes. In this connection, it must be noted also that the felsite of the Monamore composite sheet shows occasional pitchstone facies (p.32). In the field these glassy rocks have a colour that varies from bottle green to yellowish-brown. They differ from the tachylytes by their characteristic resinous lustre. Small crystals of quartz, rarely exceeding half a millimetre in diameter, can be megascopically identified occurring sporadically in the rock. Under the microscope (Plate X, Fig.4) the rock is porphyritic. The porphyritic crystals occuring as glomeroporphyritic aggregates include quartz, felspars, pyroxenes and a little iron ore. Quartz forms pyramidal and hexagonal crystals, with rounded corners, and embayed outlines and frequently with islets of groundmass along their edges. The felspars occur as tabular and rectangular crystals but are less corroded than the quartz. Broad lamellar albite twinning is present, often only with inconspicuous zoning. The symmetrical extinction angle is high and this, together with the comparatively high relief, as compared with the adjacent quartz, suggest the felspar as a rather calcic variety. As in the tholeiites and more or less intermediate types, oscillatory zoning is not uncommonly developed, indicative of repeated changes in composition of the magma/

magma at intervals during the crystallisation of the felspar. The main pyroxene augite builds stout stumpy crystals with their corners partly rounded. Maximum extinction angle is 43°. The rhombic pyroxene, hypersthene, is also present, and Y and Z = yellowish-green to pale green. Magnetite occurs as irregular grains. Associated with the glomeroporphyritic aggregates are the accessories zircon and apatite. The former, contained in the felspar, forms euhedral prisms which show a prominently high relief. The groundmass, mainly glass, is locally devitrified, the devitrification resulting in the development of minute crystallites which show a stellate arrangement amongst themselves or else radiate from the margins of the microphenocrysts of felspar and quartz. Where devitrification is more advanced, the groundmass is resolved into finely cryptocrystalline material, commonly with oval shaped globules of varying sizes. The smaller sized globules contain quartz, whilst the larger ones contain ill-formed plumose spherulites, sometimes with chlorite fringing the outer margins.

Petrogenesis.

The Tertiary dykes of the Lamlash region, forming part of the Arran swarm, comprise a series of widely differing compositional rock types that range from the most basic crinanites and allied olivine dolerites, through sub-basic quartz dolerite-tholeiites and more or less intermediate andesitic types, to acid quartz/

quartz-felspar porphyry, quartz felsites, felsites and pitchstones. With the exception of the crinanites, indications of contamination in greater or lesser degree are invariably present, while rocks of intermediate composition are relatively rare and present 'abnormal' characters. In these respects, therefore, the dykes present precise analogies with the larger igneous masses and composite intrusions previously described. The order of emplacement throughout the region is basic to acid, followed finally by the recurrence of basic.

As in the case of the larger bodies and composite intrusions, it is difficult to account for the rarity of intermediate rocks by a hypothesis of crystallisation differentiation from a single parent (basic) magma. Moreover, the detailed petrographic peculiarities of the hybrid rocks are especially at variance with such a view. Holmes and Harwood (1929, p.49), commenting on the variability in composition of tholeiite dykes in close proximity, came to the conclusion that they could only have arisen from hybridisation. Contamination of a basic magma by acid material, and an acid magma by basic material, resulting in acidification and basification respectively provides the only acceptable explanation, as suggested by Tomkeieff and Marshall (1935, p.283).

Hence, to explain these diverse rock types it becomes necessary to invoke two primary magmas, basic and acid. The initial/

initial melting of the basalt substratum would give rise to the basic magma corresponding to crinanite composition, since it represents the most basic and uncontaminated rock, and thus produce the earlier set of basic rocks. Subsequent uprise into the upper sialic layer would give rise to assimilation of acid material and also to an acid magma which would commonly be contaminated with partly or wholly consolidated basic material. These processes would find expression in the observed acidified basic rocks and basified acid rocks. Finally, a sub-basic residual magma was emplaced, giving rise to the extensive group of dykes of quartz dolerite and tholeiites.

III. SUMMARY AND CONCLUSIONS.

The hypabyssal rocks of the Lamlash region are found in Triassic and Permian sandstones. They consist of diverse rock types emplaced at different periods within the Tertiary era. The earliest and most basic are the crinanites, followed by the less basic suite, quartz dolerite-tholeiites and contemporaneously by acid felsites. Finally, there is the recurrence at the end of the Tertiary igneous activity of the less basic suite, quartz dolerite-tholeiites.

The/

The crinanites, referred to in the areas under the place names as the Monamore and Clauchland crinanites, form the commonest rock type. They form large sheeted bodies, the Monamore itself consisting of two separate sheets. These crinanite sheets dip in a general south-south-easterly direction and thin out to the north-west. Hence, it is inferred that the source of the crinanite magma lies somewhere in a south-south-easterly direction, in the region beneath the Firth of Clyde. Mineralogically, the crinanites present but little evidence of differentiation, the only exception being the sporadic pegmatitic pockets and associated veins which are brought about locally as a result of concentrations of volatiles arising from release of pressure on the magma during the latter's ascent. The mineralogy and chemical composition show the crinanite magma to correspond to the plateau basalt magma of the West of Scotland.

The less basic suite, quartz dolerite-tholeiite, occurs commonly in intimate relation with the acid felsite to form composite bodies. Three such intrusions occur in the present region, viz., (i) The Ross road Composite Dyke; (ii) The Monamore Composite Sheet, and (iii) The Sheans Composite Sheet.

The first two belong to the usual triple symmetrical type/

type with basic flanks and acid centre. They differ from each other in that the former shows sharply defined flow banding at the contacts between the contrasted rocks, while the latter shows transitional contacts. The Sheans composite body, as compared to the above two types, is more complex. It comprises three rock types, two basic and one acid; the acid being represented only by ramifying veins traversing both the basic rocks. Moreover, the spatial arrangement of the three rocks departs from the normal type in the sense that the earliest member, the porphyritic dolerite, rests on the later craignuritic basalt, while the still later acid member, instead of lying side by side with the craignuritic basalt as is generally the case, appears to have overlain the dolerite as judged from the intensity of the veining of the dolerite as compared to the basalt. The mechanism of acid vein emplacement is discussed and is attributed not only to mechanical dilation-injection and stoping but also to the metasomatic replacement of the host rocks.

Where fully protected from erosion, detailed field study of these composite bodies show that as in all other such bodies outside the region, the volume of the acid rock is much in excess over the basic. True intermediate types are notably absent. Furthermore, microsections show evidence of pre-intrusive hybridisation in both the basic and acid members over and above the contact modifications. Hybridisation is therefore referred

to/

to as 'contact' and 'deep-seated.'

The dykes of the region form part of the main Arran swarm. Although the majority of the dykes belong to the final phase of the Tertiary igneous activity, few are decidedly of earlier age corresponding with the main period of emplacement of the crinanites as well as with the composite bodies. Petrographically, the dyke rocks present analogous features with the crinanites and rocks of the composite intrusions. With the exception of the crinanite dykes, indications of contamination in a greater or lesser degree are invariably present while dykes of intermediate composition are relatively rare and present 'abnormal' characters.

To explain the diversity of the rock types and the rarity of true 'normal' intermediate types, two primary magmas, basic and acid, are invoked. The initial melting of the basalt substratum would give rise to basic magma, and the subsequent uprise of this magma to higher sialic level would lead to assimilation and refusion of sialic material and the ultimate generation of acid magma. This acid magma in its ascent would pick up wholly or partly consolidated basic material. In this way, it is felt that the origin of the contrasted rocks and their invariable features of contamination are more satisfactorily explained, rather than by the hypothesis of crystallisation differentiation. Finally, a sub-basic magma residual/

residual magma was emplaced, giving rise to the extensive group of dykes of quartz dolerite-tholeiite composition.

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PLATE I.

The Sheans Composite Sheet showing the columnar structure which forms the escarpment face overlooking Brodick. The base of The Sheans characterised by the columns is quartz basalt, while those to the top, seen as weathered remnants, and still displaying somewhat rude columnar structure, consist of porphyritic dolerite.

PLATE I.

PLATE II.

A closer view of the same, showing the rather perfect development of the columnar structure. The lighter irregular strings and patches are not to be confused for leucocratic acidic material. They represent mosses adhering to the surface of the rock.

PLATE II.

PLATE III.

Boulder of The Sheans Composite Sheet, showing the ramifying network of acid veins. Note the extreme irregularity of the veinlets, their variable widths, sharp as well as transitional contacts, zonal rims and along enclosed basic hosts and the irregular development of isolated patches.

PLATE III.

PLATE IV.

Boulder of The Sheans Composite Sheet. The acid veins in this case are comparatively regular as compared to the previous boulder. Note, however, that the individual acid veins consists of disconnected lenses due to truncation by continuous 'bridge-like' septa of host rock.

PLATE IV.

PLATE V.

Specimen of the porphyritic dolerite invaded by acid veins. Note the continuity of the host rock structure across the acid veins, sudden 'pinching' and 'swelling' of the veins, and the irregular development of acid patches.

PLATE V.

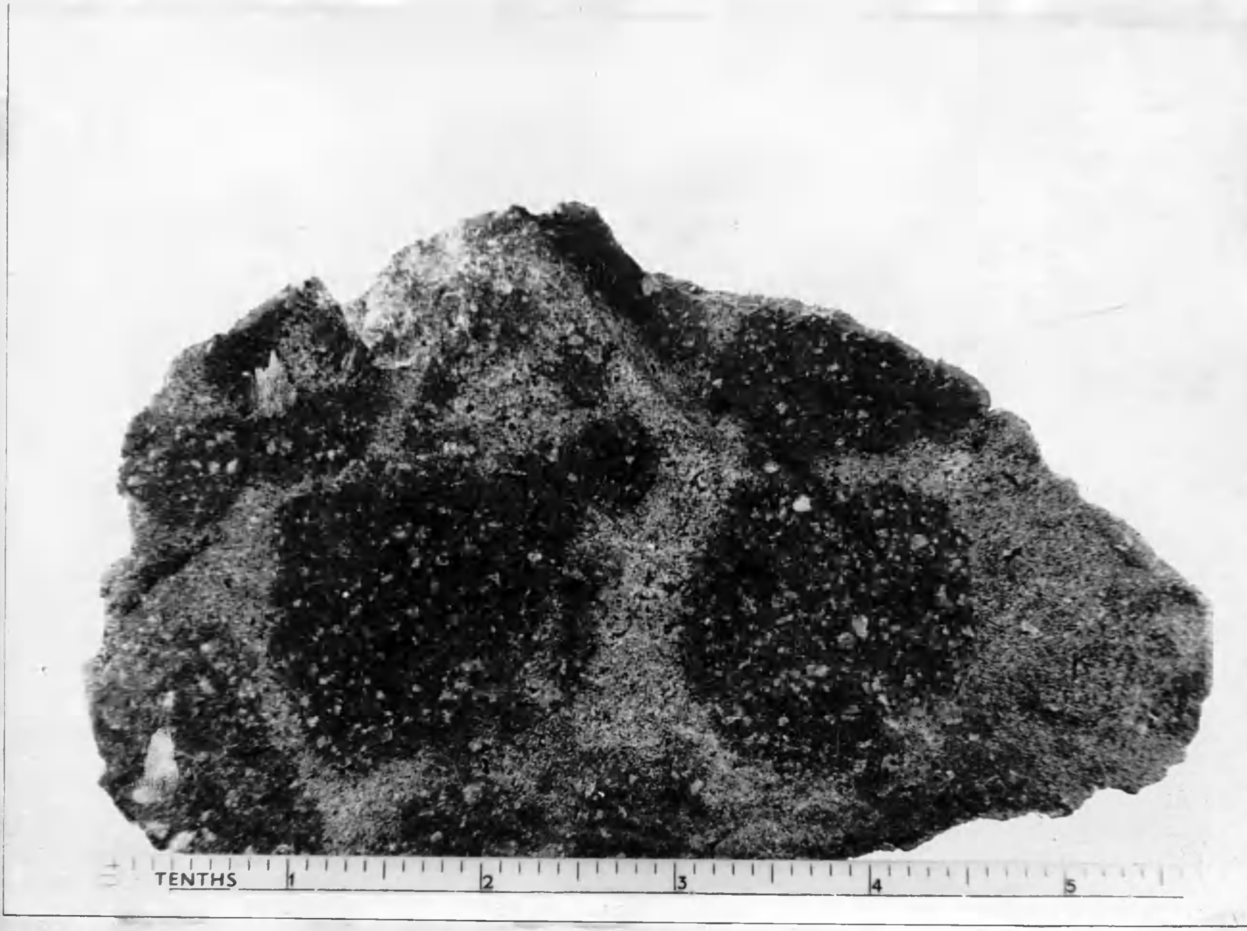

PLATE VI.

Fig. 1. Quartz dolerite, Ross Road Composite Dyke. Labradorite laths, augite granules, and skeletal iron ore. Large vesicle contains calcite and anhedral quartz crystals with chlorite towards the margins. X 20.

Fig. 2. Quartz felsite, Ross Road Composite Dyke. Glomeroporphyritic quartz aggregates with pyramidal and hexagonal cross-sections. Few of the quartz crystals are irregular, owing to the establishing optical continuity with the quartz of the groundmass. Iron ore inclusions are arranged along the borders or as parallel lines within the crystals. The groundmass consists of turbid alkali felspar and quartz. X 20.

Fig. 3. Quartz felsite, Ross Road Composite Dyke. Embayed quartz crystal with sinuous flow banding. X 20.

Fig. 4. Quartz felsite, Ross Road Composite Dyke. Glomeroporphyritic aggregates of quartz with embayed edges and fibrous spherulitic borders in a partially devitrified turbid groundmass of skeletal iron ore, minute hornblende prisms, and small quartz crystals enveloped by quartz-alkali felspar spherulites. X 20.

PLATE VI.

Fig. 1.

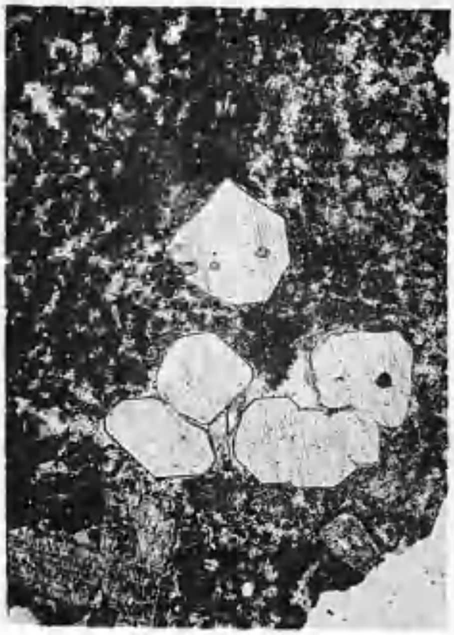

Fig. 2.

Fig. 3.

Fig. 4.

PLATE VII.

Fig. 1. Porphyritic dolerite, The Sheans Composite Sheet. Bytownite felspar phenocrysts with fretted edges, in a groundmass of small labradorite laths, platy and granular augite and euhedral iron ore. X 20.

Fig. 2. Porphyritic basalt, The Sheans Composite Sheet. Finer equivalent of above. Bytownite phenocrysts in a variolitic groundmass. X 20.

Fig. 3. Transition zone of porphyritic basalt and craignuritic quartz basalt, The Sheans Composite Sheet. Spherulitic and cervicorn growths of augite, felspar and iron ore with anhedral quartz crystals. X 20.

Fig. 4. Quartz basalt of basic craignuritic affinity, The Sheans Composite Sheet. Irregular plagioclase felspar laths, granular augite and skeletal iron ore. Towards the bottom of the picture is the tip of the 'tongue-shaped' apophyses of the acid vein. X 20.

PLATE VII.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

PLATE VIII.

Fig. 1. Sharp junction of acid vein and porphyritic basalt, The Sheans Composite Sheet. The acid vein, notably coarse as compared to the basalt, consists of innumerable wall rock inclusions notably large felspars, with prominent albitic rims. The quartz basalt is almost opaque except for the phenocrysts of bytownite firmly rooted in it and extending into the acid vein. X 20.

Fig. 2. Acid vein. The Sheans Composite Sheet. Bytownite felspar xenocrysts with albitic rims and anastomising strings. The circular patch towards the right of the picture consists of narrow radiating crystals of epidote surrounded by aggregates of anhedral quartz crystals. X 15.

Fig. 3. Acid vein, The Sheans Composite Sheet. Micropegmatite moulded on xenocrysts of plagioclase felspar laths. X 50.

Fig. 4. Acid vein, The Sheans Composite Sheet. Micropegmatite replacing xenocryst of bytownite felspar. X 50.

PLATE VIII.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

PLATE IX.

Fig. 1. Crinanite, Clauchland Crinanite Sheet from shore near Clauchlands Point. Ophitic texture. Olivine crystals, titanaugite plates, labradorite laths, skeletal ilmenite ore, with interstitial analcite and zeolite and accessory apatite. X 12.

Fig. 2. Tholeiite, Largs type, dyke in Benlister burn. Microphenocrysts of serpentinised olivine and bytownite felspar set in a groundmass of small labradorite laths, granular olivine, augite and iron ore and abundant brown glass. X 20.

Fig. 3. Olivine tholeiite, dyke in crinanite, near Clauchlands Point. 'Lozenge' shaped olivine microphenocrysts in groundmass of plagioclase laths and brown glass. X 20.

Fig. 4. Tholeiite, Corrie type, dyke in crinanite, near mouth of Corrygills burn. Bytownite microphenocryst with prominent oscillatory zoning in a groundmass of iron ore euhedra, granular augite and labradorite laths. At the bottom of the picture is a vesicle containing chloritic material which is being replaced by calcite. X 20.

PLATE IX.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

PLATE X.

Fig. 1. Tholeiite, Anorthite-bearing Brunton type, dyke on shore at Innean Mor, Lamlash. Microphenocrysts of bytownite in a groundmass of augite plates intergrown with radially arranged felspar laths, along with skeletal iron ore and subordinate brown glass. X 20.

Fig. 2. Tholeiite, Talaidh type, dyke in Benlister burn, Lamlash. Narrow felspar laths, skeletal and granular iron ore, granular augite and subordinate brown glass. X 20.

Fig. 3. Variolitic andesite, dyke, Monamore burn. Irregular quartz grains with sheaf-like aggregates of felspar, augite and iron ore in partially devitrified brown glass. X 40.

Fig. 4. Pitchstone, headwaters of Lag a' Bheith burn. Glomeroporphyritic aggregates of tabular crystals of calcic felspar, a few augite and hypersthene prisms, one or two grains of iron ore and zircon in a turbid glassy groundmass which contains abundant crystallites. X 15.

PLATE X.

Fig. 1.

Fig. 2.

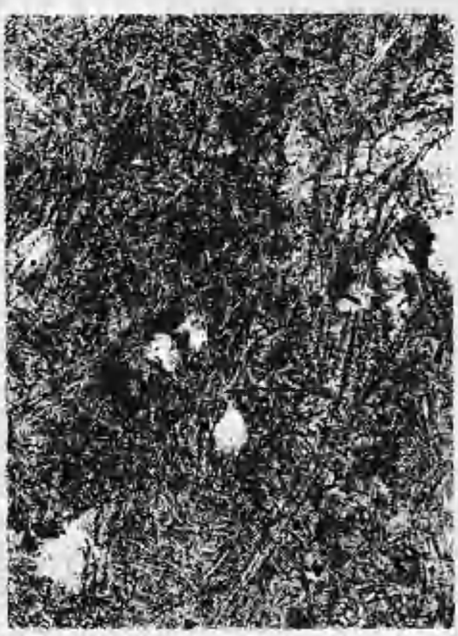

Fig. 3.

Fig. 4.

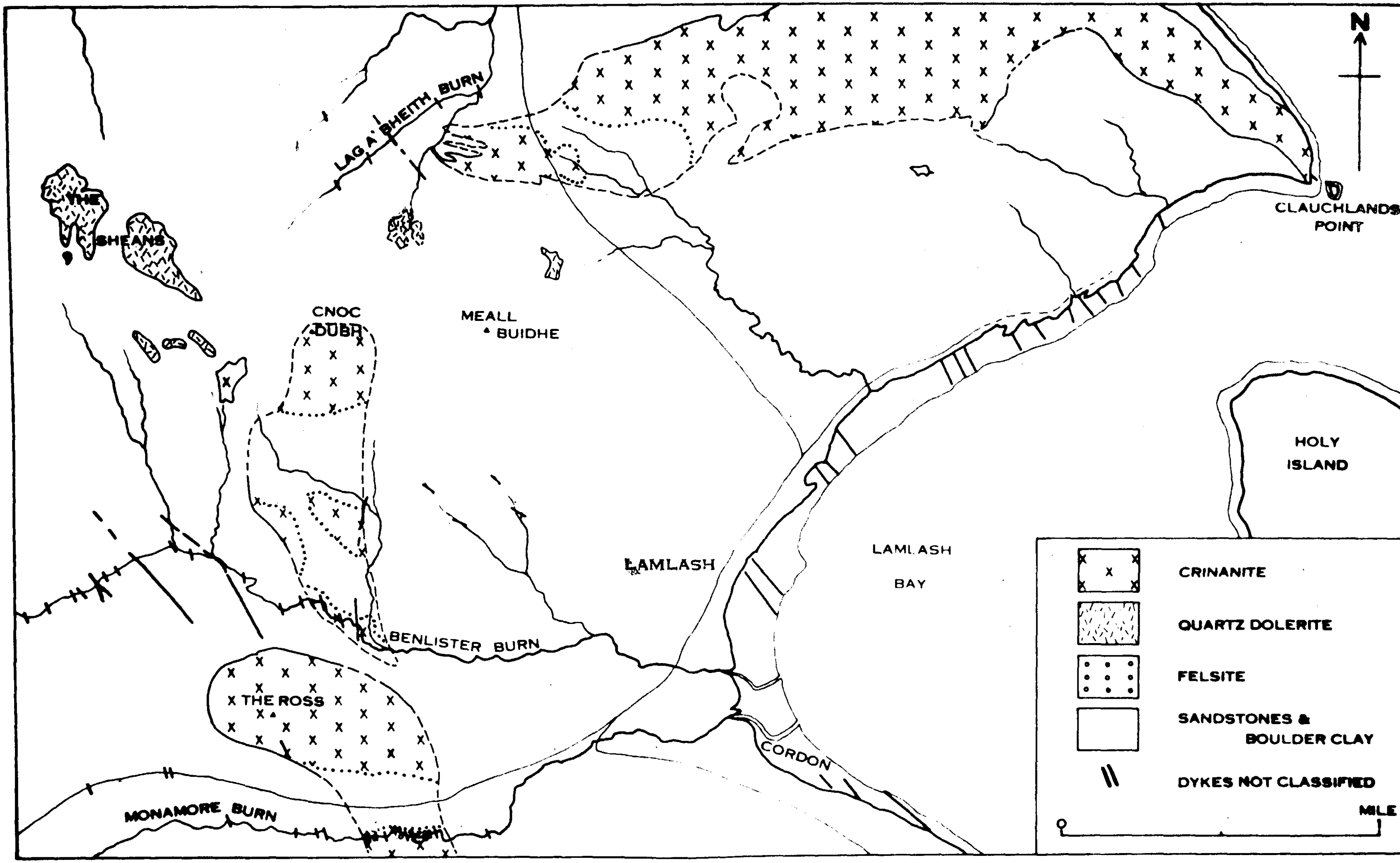

FIG. 13. GEOLOGICAL MAP OF THE LAMLASH REGION.

residual magma was emplaced, giving rise to the extensive group of dykes of quartz dolerite-tholeiite composition.

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