Chapter 9 The petrography of the minor intrusions

History of research

The intrusive nature of the numerous basaltic sheets which occur within the Jurassic rocks wherever they are exposed beneath the lava plateau of Skye was first conclusively demonstrated by Macculloch (1819). Geikie (1897, p. 305) remarked that the east coast of the island, especially the stretch from Loch Sligachan to Rubha Hunish 'has been classic ground for this part of volcanic geology since it supplied the materials for Macculloch's descriptions and diagrams'. The sills of Trotternish have nevertheless not received from petrographers the attention that might have beeen expected.

Geikie identified the rocks of the sills as 'somewhat largely crystalline ophitic dolerites, gabbros or diabases' and stated that they exhibit a persistent uniformity of composition and structure characteristic of sills and dykes. He added that the sills probably continue north of Skye beneath the sea, for at least twelve miles, since sills of the same type form the Shiant Isles, where on Garbh Eilean the great northern cliff exhibits a single sheet over 500 ft thick. Judd (1885) visited the Shiant Isles and found that in addition to ophitic dolerite and gabbro, an ultrabasic type which he named dunite was present. Geikie was unable to find this rock in situ but remarked that it probably occurs at the base of some of the sills, where it has segregated from the rest of the mass. Notwithstanding his earlier statement, Geikie was impressed with the considerable variety in texture displayed by the Shiant sills (Geikie 1897, p. 309).

Modem petrographical study of the sills may be said to have begun with F. Walker's (1930) investigation of the Shiant Isles and since this and subsequent work offers strong support for Geikie's contention that the system of sills here is, or was, continuous with that of Trotternish, this work is germane to the present account. Walker found, at the base of the Garbh Eilean sill, a layer of picrite with 50–75 per cent olivine, which gives place to dolerite rich in olivine 15 ft above the beach; this in turn is transitional into crinanite at 45 ft above the beach. The sill is evidently an upper leaf of the system, for a lower leaf appears beneath the ledge of Whitbian strata on which it rests. The separation of the picrite was ascribed by Walker to gravitational differentiation by sinking of the olivine crystals. In addition to the picrite-crinanite series, he also recognized pegmatitic and syenitic segregations. Subsequently Walker (1931) investigated the small islands between the Shiants and Trotternish, Fladda-chuain, Gaeilavore, Gearran, An Bord, the three Skerries and Trodday, all of which lie within the area shown on the one-inch Rubha Hunish (90) Sheet. All expose alkali olivinedolerites and related rocks. Finally he investigated the north Trotternish sills (Walker 1932) demonstrating the existence of picritic types W. of Kilmaluag Bay, at Druim na Slochd, at Creag na-h-Eiginn and in the cliff at Meall Tuath. In all these cases, dolerite overlies picritic dolerite or picrite. Gravitational differentiation was advocated for some of them but intrusion of viscous picrite, crowded with olivine crystals was also envisaged (Walker 1932, p. 252) to account for the exposures W. of Kilmaluag Bay.

Interest in the Shiant sills has been revived by H. I. Dreyer (1953) and his associates. A new traverse of the difficult face of Garbh Eilean has revealed an abrupt contact between picrite and picrodolerite, defined by a thin layer with very small olivine granules, a little interstitial plagioclase and no clinopyroxene. The picrodolerite passes gradually upwards into crinanite. Detailed studies of the olivines (Johnston, 1953) and of the clinopyroxenes (Murray 1954) from the rocks on this traverse have yielded very interesting results; the olivines develop highly fayalitic outer zones in the upper part of the sill, while a limited upward enrichment in iron is displayed by the pyroxenes.

Harker's (1904) memoir contains descriptions of a few of the dykes within the present area but as the primary survey of the Portree (80) and Rubha Hunish (90) sheets had not been made, his account is necessarily incomplete.

Petrography of the sills

This account is concerned solely with the sills intruded into the Jurassic sediments, except for three inclined sheets exposed in Oisgill Bay, which penetrate the lavas, but which are believed to be connected with the sills exposed nearby in the sediments. As already noted, Harker's 'Great Group of Sills' (Harker 1904, pp. 235–54) are now considered to be the central columnar portions of lavas.

The sills in the Jurassic sediments, although they occupy various strati-graphical horizons from the Middle Lias to the Kimineridgian, are linked together and were most probably produced by a single pulse of magma, or a series of pulses close together in time, since (except at Oisgill Bay) clear evidence of chilled internal contacts have not been discovered. The variants may well have developed from a single magma, within the spaces now occupied by the sills.

Although the sills with their boldly columnar outcrops present an appearance of uniformity, detailed examination reveals considerable textural and mineralogical variation. The following types will be recognized for purposes of petrographical description: (1) normal olivine-dolerite, (2) marginal tachylitic and basaltic modifications, (3) picrodolerite, (4) crinanitic and teschenitic variants, (5) pegmatic dolerite.

Olivine-dolerite

The constituent minerals are forsteritic olivine, diopsidic augite, moderately calcic plagioclase, titanomagnetite and very small amounts of zeolites, particularly analcime and thomsonite. The rock in hand-specimen is dark grey, with the grain-size usually just sufficient to reveal to the naked eye that rounded olivines and tabular feldspars are present in a "doleritic" texture. Weathering imparts a dull reddish-brown or dirty grey skin.

The olivine is rounded to subautomorphic but it never shows sharply-developed crystal faces. It ranges from about 0.2 to 2.0 mm in diameter; occasionally a tabular tendency, parallel to (010) can be detected. In thin section it is invariably colourless in all the dolerites investigated. Yellowish-brown fayalitic varieties similar to those in the upper part of the Garbh Eilean sill, which were first noticed by Walker (1930, p. 366); commented on by Tilley in the discussion on this paper, and fully investigated by Johnston (1953), who found that they range up to Fa_{95} have not been discovered in any of the Trotternish rocks. Refractive index measurements indicate a range of composition from Fa_{18} to Fa_{24}, with some indication of very thin outer zones a little richer in iron orthosilicate. Most olivines enclose one or two tiny magnetite octahedra.

The olivine has nowhere been found to enclose feldspar as at Garbh Eilean (Johnston, 1953); its crystallization here seems to have been completed before that of feldspar began.

The plagioclase is tabular parallel to (010) but shows no preferred orientation. The mesh of thin platy crystals imparts the characteristic doleritic texture to the rock. The maximum length of the feldspar is about 2.0 mm in the coarsest varieties of the normal olivine-dolerite; but the range of sizes is considerable, and not every thin section shows an average length of feldspars over 0.5 mm (the lower limit for dolerite sensu stricto adopted here). Albite and Carlsbad seem to be the dominant, though not the only twin laws. The maximum anorthite content recorded here is An_{76} (from refractive index and Albite-Carlsbad extinction measurements; this may be compared with An_{80} in the Shiant Sills). Normal composition zoning without reversals is the rule, and compositions down to An_{32} have been found. The mean feldspar composition cannot be estimated from microscopic observation but the normative figure derived from a chemical analysis (p. 148) is $Or_7Ab_{37}An_{56}$.

No orthopyroxene and no evidence of pigeonitic clinopyroxene (of low 2V) has been found in these rocks. The pyroxene is augite, preserving a characteristic pale biscuit colour in every thin section, and forming xenomorphic crystals commonly up to 4 mm x 2.5 mm, but sometimes exceeding over 10 mm in length. In composition it is a diopsidic augite, and though Murray's analyses of pyroxenes with similar optical properties in the Shiant crinanite showed 124 to 1.33 per cent of TiO_2 no distinct purple colour such as is found in the pyroxenes of some alkali olivine-dolerites was noted.

The titanomagnetite is automorphic or hypautomorphic, but it is a later mineral which sometimes had wrapped itself around the feldspars. There is some reason to believe that it may have developed its crystal faces by replacement of adjacent minerals, and the possibility that the opaque octahedra in the olivines are really of later crystallization than the olivines is worthy of consideration. A little apatite occurs.

Zeolites, though occasionally present, are minor constituents only of the normal dolerites. Pale brown or colourless analcime, and fibroradiate thomsonite are sometimes found in interstitial positions.

Excellent examples of the normal dolerites in the Geological Survey collection come from near the LochMealt waterfall (S33486) [NG 5092 6532], (S33487) [NG 5091 6532], (S33488) [NG 5091 6532], (S33489) [NG 5091 6532], (S33490) [NG 5091 6532], (S33491) [NG 5091 6532], (S8020) [NO 153 856], from east of Dun Raisaburgh (S30799) [NG 5123 6385]; ½ mile W. of Kilt Rock (S31326) [NG 4993 6656]; Meall Brataig (near Kilmaluag) (S31327) [NG 4455 7491], Lon Ostatoin (S31330) [NG 4078 7269], Druim na Slochd near Flodigarry (S38021) [NG 4635 7211]-(S38022) [NG 4635 7211]. The northernmost inclined sheet at Oisgill Bay, 55 ft thick, is olivine-dolerite in its centre (S38070) [NG 1354 4971], (S38073) [NG 1356 4952] but the later intrusion into it, only 4 ft thick, has crystallized as olivine-phyric basalt (S38072) [NG 1355 4961].

Alteration in these rocks is usually confined to partial conversion of olivine into chlorite or bowlingite. It is interesting to note that although on the average the dimensions of the olivines in the rocks of the sills are similar to those of the phenocrysts of this mineral in the olivine-basalts of the lava-pile (see p. 105), the plagioclase and the augites are decidedly coarser in the sills. The exception to this rule is provided by the Vaternish-type lavas where both these minerals exceed in average dimensions their counterparts in the sills (p. 111).

Marginal types. In spite of the excellence of the exposures of the sills in N. Trotternish, fresh material at or near their contacts with the enclosing rocks is not easy to obtain. At Oisgill Bay, the 3-inch chilled rock at the base of the northern inclined sheet (S38068) [NG 1354 4972] contains a few chlorite pseudomorphs after olivine of 0.5 mm diameter, labradorites of 0.1 mm, and tiny clinopyroxene granules in a groundmass of glass devitrified to a green mineraloid; chabazite and thomsonite occupy cavities. The adjacent lava (S38067) [NG 1353 4975] has been extensively altered to green nontronitic material. In the tachylite at the top of this sheet, the black glass remains unaltered (S38079) [NG 1343 4931]. In the central later intrusion (S38071) [NG 1355 4961]–(S38072) [NG 1355 4961] glass rich in opaque granules occurs interstitially. At the contact of the lower sill on the south side of the Bay with the '*Estheria*' Shales, a selvedge of opaque glass 0.2 mm thick is found; zeolites have been introduced into the shale, and the adjacent margin of the dolerite gives the impression of containing an abnormal amount of magnetite in tiny granules, as well as small altered olivines and labradorites. These marginal rocks are interesting as showing that the presence of intersertal glass is not an adequate criterion for the identification of a rock as a tholeiite; they are contact rocks of typical alkali dolerites.

In the case of the thicker sills, the rock may remain holocrystalline right up to the contact. Slices across the top contact of the lower sill at Rubha Hunish (S38028) [NG 411 764], (S38029) [NG 411 764], (S38030) [NG 4115 7645] against shale, show a progressive reduction in average length of labradorites from 0.5 mm at 20 ft below the top (S38027) [NG 411 764] to 0.3 mm 5 ft below and, about 0.2 mm in contact with the shale, which has been brecciated by the magma. The shale is hornfelsed, with the development of fine-grained biotite and tiny, parallel-extinguishing needles, probably of sillimanite. The pyroxene in the sill ceases to be ophitic 5 ft from the contact.

At the Loch Mealt waterfall, the lowest specimen (S33483) [NG 5092 6532] is porphyritic, with stellate clusters of bytownite crystals and with pseudomorphs after olivine in a groundmass of 0.1 mm labradorites, intergranular clinopyroxene and titanomagnetite. The grain-size gradually increases above this (S33484) [NG 5092 6532]–(S33485) [NG 5092 6532].

The implication of these observations is that olivine and calcic plagioclase were already present as crystals when the magma was intruded. No olivine, however, as coarse as that in the central parts of the dolerite and picrodolerite has been found in the marginal rocks, so that it appears that olivine continued to separate after intrusion.

Picrodolerite

The sills exhibit regions of profound enrichment in olivine, where the rock-type approaches an ultrabasic composition. Walker (1932) has used the terms picrite-dolerite for those rocks from the North Skye sills with 20–50 per cent olivine, and picrite for those with 50–70 per cent. It might be objected that the original picrite of Tschermak (1866) was an olivine-teschenite, in which the calcium and aluminium are mainly combined in analcime, whereas the present rocks always contain an appreciable feldspar content. However, picrite is a term well established in Scottish petrography for the olivine-rich differentiates of alkali dolerites. Few of the slices in the Geological Survey collection show as much as 50 per cent olivine, and it is considered that the term picrodolerite, recently applied by Dreyer (1953) to the rocks above the

picrite on Garbh Eilean, adequately covers most if not all the olivine-enriched rocks of Trotternish.

The Meall Tuath cliff at Rubha Hunish has already been mentioned as exhibiting a picritic layer, with dolerite below and above. This has been investigated in more detail by collecting at 10-ft vertical intervals up the chimney which transects the cliff, starting from the lowest exposure above the scree and continuing, with a 30-ft break, to the cliff top. Unfortunately the bottom contact of the upper sill is not exposed but the lowest specimen is believed to be within 20 ft of the base. The results of modal analyses of the suite (S46734) [NG 4116 7628], (S46735) [NG 4116 7628], (S46736) [NG 4116 7628], (S46737) [NG 4116 7627], (S46738) [NG 4116 7627], (S46739) [NG 4116 7627], (S46740) [NG 4116 7626], (S46741) [NG 4116 7626], (S46742) [NG 4116 7626], (S46743) [NG 4117 7625], (S46744) [NG 4117 7625], (S46745) [NG 4117 7625], (S46746) [NG 4117 7624], (S46747) [NG 4117 7624], (S46748) [NG 4117 7624], (S46749) [NG 4117 7623], (S46750) [NG 4117 7623], (S46751) [NG 4117 7623], (S46752) [NG 4117 7622], (S46753) [NG 4117 7622] are summarized in Figure 15, and compared with rock densities and determinations of MgO and CaO which serve to confirm the general picture derived from the modes. The lowest rocks are normal olivine-dolerites, but from 20 ft up the exposed section, the olivine-content shows a progressive though apparently non-linear increase up to a maximum at 40 to 100 ft, above which it falls off, declining to zero at 160 ft, not less than 120 ft below the top of the sill, the roof of which has been eroded off. The picrodolerite in the enriched region characteristically shows an abundance of rounded or subangular olivines, the largest crystals reaching 4.5 mm long but generally lying within the range of 0.5–3.0 mm. Although several crystals may be in juxtaposition, they do not form interlocked aggregates. The maximum size of the olivines of the picrodolerite is decidedly greater than those of the underlying dolerite, which hardly exceed 1.0 mm. In composition, as determined from refractive index measurements, the olivines are magnesian, Fa_{17} to Fa_{23} and showing little obvious zoning; it will be noted that their composition is close to that in the Garbh Eilean picrite as determined by Johnston (1953); whereas a wide range of zoning was found in the picrodolerite there. The plagioclase in the basal dolerite at Meall Tuath and in the picrodolerite is identical in size, not exceeding 0.5 mm; the composition range is An_{72} to An_{28} but the bulk is in the labradorite category. Pale brown augite ophitically encloses the plagioclase but seldom mantles the olivine. Titanomagnetite is present, and small amounts of zeolites and chlorite.

As the olivine dies out above the picrodolerite level, a significant change in the texture as well as the composition of the rock occurs. The feldspar becomes coarser, the maximum length of the crystals increasing to 1.0 mm. The augite not only becomes more abundant, but over a restricted range represented by the specimens from 150 to 160 ft (S46749) [NG 4117 7623]-(S46750) [NG 4117 7623], shows evidence that it began to crystallize before the feldspar, in that the larger crystals are free from included plagioclase. A later generation, now intersertal to the feldspar mesh, also occurs. Still higher in the intrusion, the coarse ophitic habit of the augite is resumed; but fresh olivine continues to be totally lacking. Some of the chlorite recorded in the modes at the three highest levels sampled (S46751) [NG 4117 7623], (S46752) [NG 4117 7622], (S46753) [NG 4117 7622] is in the form of pseudo-morphs which may represent former olivines, but even so, the amount of olivine originally present was insignificant compared with that in the 'enriched' layer. It would be notably less than in the 'normal' dolerites.

The upper sill at Rubha Hunish thus shows three zones, transitional into one another: (1) normal olivine-dolerite at the bottom, probably 40 ft thick; (2) picrodolerite, 120 ft thick if the dividing line is placed at 20 per cent olivine; (3) non-olivine bearing dolerite, succeeded upward by dolerite with only insignificant amounts of olivine (now pseudomorphed in chlorite), at least 140 ft thick.

Discussion of the place and mechanism of olivine concentration will be deferred to the next chapter.

Other examples of sliced picrodolerites come from N. of Kilmuir Church Yard (S31331) [NG 4006 7225]; Carn Mor Quarry, Duntulm (S32268) [NG 406 730].

Crinanitic and teschenitic dolerites

Another cause of variation in the texture and composition of the sill rocks is the substantial fluctuation in the content of zeolites, especially analcime and thomsonite. Zeolites are normally present in amounts of 2–3 per cent in the olivine-dolerite and picrodolerites; but when this amount is substantially exceeded, the rocks pass into categories to which the terms crinanite and teschenite have been applied elsewhere in Scotland.

Crinanite was defined by Flett (1909) as a rock transitional between camptonite and dolerite rich in analcime. In an extended definition (Flett in Cunningham Craig and others 1911, pp. 42–3) he stated:

'The crinanites… are dark-coloured fine-grained basic rocks… consisting mainly of olivine, augite and plagioclase felspar, with a considerable amount of analcite and zeolites. Olivine is abundant in small grains… The augite is always purple… but the depth of colour varies in different crystals… The augite has a marked dispersion of one of the optic axes and shows hour-glass and zonal structures… The felspar… belongs mostly to labradorite, though the outer zones are more rich in soda… The iron oxides form irregular plates often fringed with scales of dark brown biotite. Most of these rocks have very perfect ophitic structure… Perfectly transparent analcite is not uncommon, but often this mineral is turbid and granular with weak double refraction. The radiate zeolite appears to be mostly natrolite… The crinanites [occur] as narrow vertical dykes… '

Although the original definition was extended by G. W. Tyrrell (1928) to cover the much coarser rocks of the four large sills in south-central Arran, it does not appear that the zeolite-bearing rocks of North Skye can properly be described as crinanites within its strict terms; they are not only coarser than the type rocks, but they are not dyke rocks, their pyroxenes are not appreciably purple and they do not carry biotite.

It is therefore proposed to describe as crinanitic dolerites those rocks in the Trotternish sills which contain over 3 per cent zeolites occurring in an intersertal relationship with feldspar, or filling subvesicular spaces. Good examples come from the lower sill at Rubha Hunish (S38026) [NG 411 764], (S38027) [NG 411 764], (S38028) [NG 411 764], (S38029) [NG 411 764] where the analcite surrounds and encloses automorphic pyroxene and plagioclase, without attacking the latter. In such a case the impression is gained that analcite, with associated thomsonite, are the last minerals of the pyrogenic sequence. Other examples come from 1200 yd S. of Kilmuir School (S31328) [NG 3881 6791], from ½ mile N. of Duntulm Castle (S31334) [NG 4110 7513], from Mingay Island (S31346) [NG 2236 5766] and from localities near Loch Fada (S31463) [NG 4906 4927]–(S31464) [NG 4900 4941]. There appears to be no regularity in the development of this variant of the olivinedolerite.

The same is true of the teschenitic variety. This is distinguished from the crinanitic type by the fact, well brought out in Walker's (1923) definition, that the plagioclase is partly or wholly replaced by analcime. This criterion has been accepted very generally in British petrographic nomenclature. The analcime, sometimes accompanied by other zeolites, here shows evidence of a hydrothermal role. Patches of teschenitic dolerite occur in the North Skye sills, for example on Ben Volovaig (S33616) [NG 4355 7607] whence came Walker's analysed sample (p. 147); on Eilean Trodday ((S31332) [NG 4416 7920], (S37738) [NG 4446 7844]); on Ascrib Island (S31337) [NG 3000 6357]; S. of Loch Fada (S31466) [NG 4934 4753] and at the head of Lon Druiseach (S31467) [NG 4921 4668]. It is difficult to distinguish any factor which has controlled the distribution of these patches. On Eilean Mhuire, in the Shiant Isles, an irregular mass of teschenite in the upper sill passes into syenite according to Walker (1930), but this rock type is not represented in the Geological Survey collection from Trottemish.

Pegmatitic dolerite

In the small islands of the North Minch, Walker (1931) identified bands of coarse gabbroid material traversing the normal dolerite, showing unchilled margins and interlocking junctions with the normal rock. Similar bands have been found 500 yd N.N.E. of Flora Macdonald's grave (S32704) [NG 4013 7231]; on Eilean Trodday (S31703) [NS 8694 9374] and 60 yd N. of Kilt Rock, near the base of the lower sill (S37736) [NG 5077 6644]. The feldspars, which reach 2 mm long, are somewhat less calcic than in the dolerite, $An._4$ being the most basic recorded. Remarkable skeletal or dendritic forms are assumed by the titanomagnetite, which reaches similar dimensions. Olivine is rare or absent, though bowlingite pseudomorphs may sometimes be found (S37786) [NN 1272 7958]. Augite is generally pale brown, and may present crystal faces to the feldspar; it commonly exceeds 4 mm. In some cases a faint greenish tint can be distinguished near the margins. A little bright green amphibole occurs (S32704) [NG 4013 7231], (S32711) [NG 4352 7590]. Zeolites, especially thomsonite, are invariably present in quantity. Stilbite and analcime have also been identified. The pegmatitic dolerite is associated with teschenitic dolerite on Ben Volovaig (S32711) [NG 4352 7590]; but the augite is less uniform in colour, exhibiting purple and green tints as well as the usual pale brown. The two rock types may be regarded as having been influenced by the concentrated hydrothermal fluids collected towards the end of the crystallization-history of the

sills.

(Table 10) **Analyses of dolerites and related rocks**

	N	0	P	Q	R	S	T	U
SiO_2	40.47	40.62	45.07	46.97	47.51	47.83	43.49	50.04
Al_2O_3	5.96	8.93	14.43	15.00	17.28	15.31	14.57	14.27
Fe_2O_3	2.10	0.57	0.80	1.71	3.56	1.15	5.62	3.76
FeO	12.32	12.61	10.69	8.94	5.77	9.22	7.40	6.33
MgO	29.32	26.31	14.61	10.52	5.98	6.60	5.32	5.99
CaO	4.91	5.64	9.74	10.70	11.47	12.38	11.61	12.11
Na_2O	1.18	1.32	1.75	2.18	2.60	2.53	2.92	3.41
K_2O	0.40	0.13	0.34	0.63	0.79	0.40	0.92	0.83
H20+	1.12	2.19	1.05	0.38	1.40	1.28	3.58	0.79
H20–	0.59	0.61	0.35	0.63	1.30	0.28	1.39	0.40
TiO_2	1.50	0.82	0.83	1.59	1.80	2.86	2.95	1.89
P_2O_5	0.26	0.15	0.10	0.12	0.12	0.16	0.40	0.24
MnO	0.23	0.39	0.33	0.37	0.13	0.36	0.12	0.28
BaO	—	—	0.01	—	—	—	—	—
CoO NiO	—	0.03	0.02	—	—	0.02	—	—
CO_2	—	0.03	0.02	—	—	0.05	—	—
Cl	—	0.01	-	—	—	0.01	—	—
	100.36	100.36	100.14	99.72	99.71	100.44	100.29	100.34

N. Picrite, top of cliff W. of Camas Mor; analyst N. Sahlbom in Walker 1932, p. 247.

O. Picrite, S. face of Garbh Eilean, Shiant Is., by the shingle beach; analyst E. G. Radley in Walker 1930, pp. 371–2.

P. Olivine-dolerite (picrodolerite of present account), Garbh Eilean 30 ft above the beach; analyst E. G. Radley in Walker 1930, pp. 371–2.

Q. Olivine-dolerite ("normal dolerite"), just S. of mid-point of S.W. shore. Fladda-chuain, analyst N. Sahlbom in Walker 1931, p. 757.

R. Olivine-dolerite ("normal dolerite"), Loch Mealt near Waterfall, 80 ft above lower contact; analyst, N. Sahlbom in Walker 1932, p. 245.

S. Crinanite, Garbh Eilean, 125 ft above the beach; analyst, E. G. Radley, in Walker 1930, pp. 371–2.

T. Teschenite, Ben Volovaig, half way up slope; analyst, N. Sahlbom in Walker 1932, p. 249.

U. Pegmatitic dolerite, Fladda-chuain, N. end; analyst N. Sahlbom in Walker 1931, p. 760.

Chemical composition

All the variants described are adequately represented by chemical analyses published by F. Walker (1931) and it has not been considered necessary to undertake further rock analyses apart from the magnesia and lime determinations for the 20 rocks of the Meall Tuath suite (Figure 15). Those for rocks from the Rubha Hunish (90) Sheet are reproduced in (Table 10), with the three main types from Shiant for comparison. The picrites and picrodolerite show, as would be expected, high MgO and FeO contents, and a low Fe_2O_3/Fe0 ratio. These are considered to be olivine cumulates, with interstitial dolerite. The teschenitic and pegmatitic types show much higher Fe_2O_3/FeO ratios, and also display distinct enrichment in Na_2O and a slight enrichment in K_2O as compared with the normal and crinanitic dolerites. Combined water is very high in the teschenitic variant, where, according to Walker, 12 per cent zeolites (including analcime) are present. The apatite content of this rock is higher than normal, but fluorine was unfortunately not determined in the

analysis; that concentrated volatiles influenced this type is supported by the chemical and modal data.

(Table 11) Norms and modes of dolerites and related rocks

Norms	N	O	P	Q	R	S	T	U
or	2.2	0.6	1.7	3.3	4.5	2.2	5.6	5.0
ab	4.7	3.3	14.7	17.8	22.0	21.0	19.2	28.8
an	10.0	20.8	30.6	29.8	33.4	29.5	23.9	20.9
ne	2.8	4.1	—	—	—	—	2.7	-
di	9.9	5.7	13.5	18.2	18.5	25.4	24.7	29.6
by		—	0.8	5.9	7.8	6.2	—	7.6
of	62.3	61.5	33.9	17.8	22	7.1	4.1	3.3
it	29	1.5	1.5	3.0	3.5	5.5	5.6	3.7
mt	3.0	0.6	1.2	2.6	5.1	1.9	8.1	5.3
op	0.7	0.3	0.3	0.3	0.3	0.3	1.0	0.4
Normative Or			4	6	7	4		9
Plagioclase Ab			31	35	37	40		53
An			65	59	56	56		38
Modes								
Olivine	66	59*	31*	18	9½	12*	7½	—
Augite	14	10	17	23	23½	24	22	27½
Plagioclase	17½	26	50	51½	60½	60	46	52½
Titanomagnetite	2½	2	2	6½	5	3	11½	8
Zeolites-	—	3	—	1	1½	1	12	12
Apatite-	—	—	—	—	—	—	—	—

* It is not certain that these correspond with the analysed specimens though they are from the same localities.

Petrography of the dykes

General. Of the very numerous dykes exposed in the area of the Portree and Rubha Hunish (90) sheets, a total of 177 have been sliced. Although this number cannot be regarded as a true sample, the distribution of rock-types, summarized in (Table 12), perhaps gives some indication of their relative importance. The types are listed in the order in which they are to be described.

(Table 12) The dykes of north Skye

Rock-Type	On One-inch map	No. of Slices
Normal olivine-dolerite and basalt	KT)	21
Normal crinanitic variants	Kc	43
Picritic dolerite [Picrite on map]	fU°	7
Mugearite, including feldspar-phyric types	XM	12
Variolite	vK	6
Leidleite	pL	1
Trachyte	OT	1
Feldspar-phyric dolerite and basalt, including crinanitic variants [Dolerite, basalt or Tholeite (un- classed)]	KD	32
Allivalite, olivine-eucrite [E'gabbroic (unclassed)]	UA, E■	15
Tholeiitic dolerite and basalt	KT	29

As already noted in the account of field relations, many of the dykes are of compositions similar to the lavas exposed in the same part of the island. This applies to some of the olivine-dolerites and basalts, which include olivine-phyric types; to the mugearites and the trachytes, and to a few of the feldspar-phyric dolerites and basalts, in which the feldspar phenocrysts are no more calcic than labradorite. On the other hand, the bulk of the feldspar-phyric dykes carry calcic bytownite or anorthite phenocrysts, and these rock types are not known to be represented among the lavas; the 'big-feldspar' mugearite lavas contain phenocrysts of labradorite composition. No lavas corresponding to the allivalites or olivine-eucrites are known, and this fact makes it difficult to believe that these curious lenticular dykes or pods acted as volcanic vents. The sliced rocks from North Skye include no lavas as olivine-rich as the picritic dykes, though one lava described by D. Almond (1964) from Strathaird compares with them. These dykes may well represent injections of olivine-cumulus from the sill system. The tholeiitic types, which carry little or no olivine and contain an intersertal mesostasis that may, at an earlier stage, have been glass, are likewise not represented among the lavas save by the pillow-lava of Creag Mor (p. 102). It is very noticeable that not a single quartz-dolerite has been found in North Skye, and the supposed tholeiites fail to reveal any examples comparable with the silica-rich Talaidh and Brunton types of Mull (Bailey and others 1924, pp. 301, 372). The situation in Skye generally is that rock-types referable to the tholeiitic lineage are very much rarer than in Mull, if indeed, they exist at all in significant quantities.

Normal olivine-dolerite and basalt

It has already been noted that the lavas include a class of dolerites (with the average length of the feldspar tablets greater than 0.5 mm) as well as basalts, but that there is no evidence of major differences in composition between the two types. In the case of the dykes, rocks which are texturally dolerites are somewhat commoner than basalts, but both occur in the suite and the artificial nature of the distinction is again evident.

Another comparative point of some interest is that whereas ophitic crystallization of the augite is very widespread both in the lavas and the sills, in the dykes the intergranular texture is commoner. Here small crystals of clinopyroxene sometimes showing crystal faces, nestle in the interstices of the mesh of feldspars. Good examples include (S31453) [NG 4632 3943], (S32714) [NG 2949 6514], (S33844) [NG 2506 3661], (S33858) [NG 2433 4777], while ophitic types are represented by (S33961) [NG 3655 5536].

The olivines in these dykes are usually rounded, as in the lavas and sills, though occasionally tabular, automorphic forms appear (e.g. (S31965) [NG 4684 5859], where the olivine seems to enclose some feldspar). For the most part, the olivines appear to have begun to crystallize before the magma was injected into the fissures; this is borne out by the presence of olivine phenocrysts in tachylite glass at the margins of the dykes (e.g. (S31430) [NG 4402 5929], (S33958) [NG 3655 5536]). Generally the olivines do not enclose any other mineral except titanomagnetite. The size range is up to 1.25 mm diameter, and forsteritic compositions, similar to those in the lavas are characteristic.

The feldspar mesh is made up of zoned crystals in which the bulk composition lies within the labradorite range. Occasionally the centres are more calcic and usually there are thin marginal zones of andesine or even oligoclase.

The clinopyroxene is usually pale-coloured in thin section, not colourless when compared with olivine, yet with no well defined tint beyond a vague grey or pale brown in most cases. A few examples, however, show definite purple colouration and faint pleochroism e.g. (S31974) [NG 4545 5628], (S22874) [NX 42 49]. In no case has orthopyroxene, or pyroxene with a low optic axial angle, been found in these rocks. Diopsidic augites occur in every case investigated.

The crystallization in the normal types is completed by the titanomagnetite, often automorphic or skeletal in outline, and no mesostasis is present. However, some glass usually occurs close to the contact with the country rock.

Crinanitic variants

In the crinanitic variants, zeolites are present in addition to the minerals described above, but the pyrogenic constituents continue to appear in much the same proportions. True crinanites, dyke rocks corresponding with the definition of Flett cited on p. 146 do occur, but they are rare. Examples include (S31417) [NG 3910 6079], (S31429) [NG 4378 5894], (S31592) [NG 2439 4695], (S33841) [NG 2534 4241]. Two rocks from Geo Mor (S33846) [NG 2020 3932] are coarser than normal, but otherwise of crinanite compositions; they contain olivines up to 1.5 mm long, the labradorite (An_{67} maximum) forms a mesh of crystals 1–1.5 mm long; the ophitic augite is a definite purple colour by transmitted light and varies up to 2.5 mm diameter; titanomagnetites are 0.4 mm on the average and a few per cent analcime is present. Most of the dykes classed as crinanitic, however, fail to meet Flett's definition in that the augite is intergranular rather than ophitic, and in many cases it is not purple in colour. Zeolites, including analcime, thomsonite and chabazite are present in vesicles or in spaces in the mesh.

Some of the dykes in this subclass closely resemble the alkali-basalt lavas in that rounded, or in some cases automorphic olivine phenocrysts are present e.g. (S33956) [NG 3671 5726], (S33959) [NG 3653 5548], (S31592) [NG 2439 4695], (S32710) [NG 4089 7352], (S33836) [NG 2679 4246], (S36209) [NG 1672 5446]. These range in size between 0.5 and 2.5 mm, and may be enclosed in a basaltic or doleritic matrix. It is not difficult to believe that dykes of this sort acted as feeders for the olivine-phyric alkali basalts which form the predominant lithology in North Skye. The dyke in Gob na Hoe (S36210) [NG 1901 5406], (S36211) [NG 1901 5406], (S36212) [NG 1901 5406] forms a striking example. Well formed olivines up to 2.5 mm long are enclosed in a mesh of 0.5 mm labradorites, with purple intergranular and subophitic augite, automorphic titanomagnetites of 04 mm, and a little analcime.

Other members carry only very small olivine crystals, though often in some abundance (e.g. (S31969) [NG 3864 5580], (S31872) [NS 2289 6473], (S32709) [NG 4062 7577], (S32944) [NG 2833 4053], (S33835) [NG 2684 4250] and these are not readily correlated with the plateau lavas.

At the margins of the crinanitic dykes, chilling has caused glass to form. This may be vesicular, with minerals such as thomsonite, analchne, chabazite and chlorite in the vesicles (e.g. (S31347) [NG 2181 5980] from Rodmor Peninsula). Extreme zeolitic alteration is not particularly common in the dykes, though in a rock from Allt Dearg (S33992) [NG 3858 4828] the feldspars have been almost totally replaced.

Picritic dolerites-picrites

A few olivine-rich dykes of ultrabasic aspect have been found. Both in mineralogy and texture they are virtually identical to the picrite dolerite layers in the Trotternish sills. The olivines range up to 5 mm diameter; typically they are well rounded and a representative example from Breabost Burn, E.N.E. of Dun Flashader (S33981) [NG 3628 5365] revealed a composition as indicated by refractive index measurements, of Fa_{13} the most magnesian olivine recorded in the area. The matrix of the rock consists of small labradorite crystals not more calcic than those in the normal dolerites; subophitic pale greyish or brown augite and hypautomorphic titanomagnetite. Zeolites, including especially thomsonite are present in some instances (S33908) [NT 770 542], (S33971) [NG 3696 5352]. In two cases, a dyke from the summit of Ben Geary (S31339) [NG 2475 6137], and another from Allt Yelkie (S31414) [NG 3842 6056] the proportion of olivine considerably exceeds 50 per cent, and since zeolites are present the rocks are true picrite in accordance with the original definition of the term. In both rocks some brown chrome-spinel is present. The feldspar in these rocks shows zonal ranges of $An_{68–60}$ and $An_{70–40}$ respectively, (the lower estimates being the less satisfactory), and has been attacked by zeolitic alteration. In the field, the picrites and picritic dolerites are recognizable by the abundance of yellowish olivine.

Mugearite

In appearance, the mugearite dykes, like the lavas of this composition, are recognizable to the experienced observer by their black colour, very fine grain, their platy fracture (in the dykes it is usually parallel to the walls) and their tendency to form a thin brown or reddish brown crust upon weathering. Under the microscope, they are hardly distinguishable from the lavas. The chief constituents are oligoclase (or more probably potash oligoclase and anorthoclase—see p. 164), tiny augite granules, microphenocrysts of olivine more fayalitic than in the other dyke rocks, and an abundance of tiny octahedra of titanomagnetite. The feldspars range from 0.04 mm (S37732) [NG 3856 3606] to 0.4 mm (S31403) [NG 3051 4144], the average seldom exceeding 0.2 mm long. In most of the sliced rocks, secondary alteration, especially

chloritization of olivine, zeolitization of feldspar and introduction of analcime and chabazite into gas cavities has occurred, giving the impression that the dykes have been more subjected to the movement of hot waters than the centres of the exposed lavas such as those of Hartaval and the Roineval area. The freshest example is from a dyke, the centre one of three exposed in Dubh Allt, a stream crossing the Portree-Sligachan road near Beinn na Greine (S38005) [NG 4690 4155]. Here the olivines are less than 0.1 mm diameter, and there are a few labradorite phenocrysts up to 0.5 mm long. A lava exposed a little above the dykes (S38007) [NG 4660 4166] is very similar though a little coarser and though the junction is not seen, it is permissible to think that the dykes might have been the sources of the flows. Other examples of mugearites come from Voaker Burn (S31398) [NG 3648 3999], the shore of Loch Caroy (S31403) [NG 3051 4144], from N.E. of the road bridge over Vidigill Burn (S34181) [NG 3899 3652], the Tungadal River (S34186) [NG 4239 3669], from Allt an Lon Ghuirm, S.E. of Edinbain (S36229) [NG 3590 4928] and from a stream 640 yd E.N.E. of Garadubh (S37753) [NG 4776 3674], (S37755) [NG 4785 3667].

None of our sliced specimens is a big-feldspar mugearite, comparable with the Roineval lavas (p. 120) and it is not certain that dykes of this remarkable rock type have been located. Small phenocrysts of composition respectively An_n (S31394) [NG 3716 3942] and An_n (S37792) [NM 9597 8000] have been found in two dykes.

Probably the best-known example of a mugearite dyke in North Skye is that of Am Bile, exposed 11 miles E.N.E. of Portree. J. W. Judd and G. A. J. Cole (1883) described the two-inch glassy selvedges of this dyke, and cited the following analysis by Hodgkinson: SiO_2, 5029; Al_2O_3, 17.33; Fe_2O_3, 11.14; MnO, 0.66; CaO, 6.17; MgO, 2.62; Na_2O, 4.24; K_2O, 2.40; Loss on ignition, 327; Total, 100.72. Harker (1904, pp. 331–2) gave a petrographical description of the mugearite, which in the centre is coarser than that of Druim na Criche (S9373) [NG 5040 4457], (S9374) [NG 5040 4457],(S9375) [NG 5040 4457.

Variolite

A small but well defined group of dykes shows characteristics that may be regarded as consistent with the usage of the term variolite as adopted by Harker (1904, p. 347) and the authors of the Mull Memoir (Bailey and others 1924, pp. 150–1) though it should be noted that in Mull these rocks characteristically form the carapaces of pillow lavas. In the field, the dykes are pale grey or bluish-grey, fine-grained, often containing vesicles which may be empty, or filled with zeolites or a black mineraloid. Under the microscope they are found to be dominated by stellate groups or radiating sheaves of fine acicular or platy feldspars, the composition of which, according to their optical properties lies between An_{is}, and soda anorthoclase. Pyroxenes also occur in the form of thin prisms with an acicular tendency; they are, without exception, augites but their exact position with respect to the iron end of the series has not been determined. Acicular amphiboles also occur in some cases, pale-brown or green (S37724) [NG 3919 6003], (S37751) [NG 5089 4509]. Brown biotite also occurs in tiny flakes and minute octahedral or rods of titanomagnetite and accessory apatite complete the pyrogenic assemblage. A variable amount of material which was formerly glass but is now represented by fine devitrification products, may form a background to the rock (S37729) [NG 4144 3848]. Analcime and chlorite both commonly occur as late or secondary minerals (S31431) [NG 5011 5787]. Good examples of variolite dykes come from the S. end of Creag Langan (S31431) [NG 5011 5787], the Snizort River, 660 yd W.S.W. of Uigshader (S31445) [NG 4245 4616] and 1 mile S. of the trigonometric point on Sithean Bhealaich Chumhaing.

Leidleite

A single example of a rock comparable with the stony type of leidleite of the Mull Memoir (Bailey and others 1924, pp. 281–2) found during the field survey was identified by Mr. E. H. Francis. The rock has a pale bluish tint, is fine-grained and is riddled with vesicles most of which are empty, though a few have white mineral linings. In thin section it shows acicular yellow-brown amphiboles, 0.1–0.2 mm long set in a matrix of ill-defined feldspar of feathery rather than tabular form, though in places stellate groupings can be seen. The feldspar is an untwinned alkali type, perhaps anorthoclase. No glass is present. Some vesicles are rimmed with alkali feldspar. The single example (S31747) [NG 4995 4251] comes from the Tungadal River.

Trachyte

Trachyte dykes are poorly represented in the collection from the present area, but as noted above, Harker (1904, p. 58) has already described the Drynoch group in Bracadale Burn. There is little to add; the rocks are very pale grey in the field, and carry sparse visible phenocrysts of augite and biotite. One example, collected 450 yd N.W. of the bridge in Glen Vidigill (S31388) [NG 3795 3643] contains a little olivine, and some clinopyroxene; it represents a type transitional between mugearite and trachyte comparable with the lava of Analysis IX, p. 121. The exact nature of the alkali feldspar which forms the bulk of the rock in these dykes requires refined study of fresh material; probably it is anorthoclase or sanidine. One specimen contains corroded xenocrysts of albite. Apatite needles, seldom seen in the basic dykes, are noticeable in these.

Feldspar-phyric dolerite and basalt

As (Table 12) shows, feldspar-phyric dolerite and basalt dykes form an important element in the swarm and are treated separately because they present a petrogenetic problem, in carrying abundant phenocrysts of bytownite or anorthite, that does not apply to any of the lavas save the big-feldspar mugearites. Most of the present group of dykes have no counterpart among the lavas, though a few, notably (S33834) [NG 2694 4259] from the eastern base of Knock Vatten, (S31421) [NG 3810 5844] from 275 yd N. of the ruins of Caisteal Disdein and (S33859) [NG 2766 4593] from a quarry S.E. of Fairfield Cottage contain labradorite phenocrysts and could have been the feeders of feldspar-olivine-phyric basalts such as those listed on p. 115. For the rest, however, the phenocrysts are very calcic and the zoning within them shows a marked break, the outermost zones corresponding with the labradorite found as small crystals in the matrix.

(Table 13) Analyses and norms of allivalite and eucrite

	V	XII	Y	Z
SiO_2	47.33	44.95	48.28	47.28
Al_2O_3	20.08	24.02	20.38	21.11
Fe_2O_3	0.55	0.93	1.78	3.52
FeO	3.24	4.07	6.70	3.91
MgO	12.53	9.43	7.93	8.06
CaO	14.47	13.70	11.80	13.42
Na_2O	1.34	1.21	1.75	1.52
K_2O	0.07	0.11	014	0.29
H_2O+	0.21	1.27	0.76	0.53
H_2O-	0.14	0.48	0.09	0.13
TiO_2	015	013	0.23	0.28
P_2O_5	tr	0.02	0.02	tr
MnO	0.08	0.08	0.28	0.15
CO_2	—	tr	0.03	—
S	—	0.01	—	—
Cr_2O_3	0.18	0.05	—	—
NiO	—	0.01	—	—
BaO	—	0.01	—	—
SrO	—	0.02	—	—
Li_2O	—	nt. fd.	—	—
FeS_2	—	—	0.04	—
	100.37	100.50	100.21	100.20
Norms	V	XII	Y	Z
Or	0.56	0.56	0.56	1.67
ab	1.32	9.96	14.67	12.58
an	48.93	59.77	47.54	50.04
ne	—	—	—	—

	wo	9.55		3.48		4.52		6.96	
di	en	7.26	18.09	2.50	6.64	2.80	18.77	5.20	13.32
	fs	1.28		0.66		1.45		1.06	
hy	en	—		1.80	2.46	12.60	19.46	9.70	12.08
	fs	—		0.66		6.86		2.38	
ol	fo	16.70	19.96	13.44	17.52	3.08	5.12	3.64	4.66
	fa	3.26		4.08		2.04		1.02	
	mt	0.79		1.39		2.55		510	
	it	—		0.24		0.53		0.61	
	ap	—		0.04		0.04		—	
	cr	—		0.06		—		—	
	ca	—		—		0.07		—	
	py	—		.002		0.04		—	
Plagioclase		$Or_iAb_{18}An_{81}$		$Or_1Ab_{14}An_{85}$		$Or_1Ab_{23}An_{76}$		$Or_2Ab_{20}An_{78}$	

Key to table 13

V. Allivalite from Unit 10 of the Layered Series, Hallival, Rhum; Analyst, G. M. Brown 1957, p. 47.

XII. Allivalite, Broisgillmore Burn, ½-mile S.S.W. of summit of Am Bidean, Skye; Analysts W. F. Waters and K.L.H. Murray, Geological Survey Lab. No. 1576, 1950. Guppy and Sabine 1956, p. 24.

Y Gabbro-variant of Great Eucrite Ring-dyke, Centre 3. Ardnamurchan W. side of Creag an Airgid, 1¼ miles S. 40° E. of Achnaha; Analyst E. G. Radley, Geological Survey Lab. No. 736 in Richey and Thomas 1930, p. 85.

Z Olivine-gabbro (Eucrite). Major intrusion. Coir' a'Mhadaidh, Cuillins, Skye. Analyst, W. Pollard in Harker 1904, p. 103.

The phenocrysts tend towards a certain constancy of size, as if they had in some way been graded; few of the bytownite-anorthites are less than 2 mm or more than 5 mm long. Their calcic compositions are sufficiently evident from measurement of maximum extinction angles in the 'symmetrical' zones but they show complexity of twinning and parallel growth, where aggregated, so that the use of the more accurate Albite-Carlsbad method is fraught with uncertainty. Refractive index measurements of ten representative examples covering all possible varieties of matrix gave the following figures for maximum anorthitecontent : An_{70} (S30790) [NG 4194 6370], An_{84} (S31348) [NG 2154 6024], An_{90} (S31351) [NG 2636 5740], An_{90}(S31976) [NG 4596 5493], An_{92} (S32716) [NG 2868 6558], An_{87} (S32934) [NG 3075 4506], An_{77} (S33849) [NG 1925 3929], An_{80} (S33981) [NG 3628 5365], An_{93} (S33986) [NG 3999 5249], An_{88} (S36237) [NG 3800 5104]. Estimates of the break in the zoning have been attempted in a number of cases, these gave results as follows: An_{77}/An_{57} (S33849) [NG 1925 3929]; An_{93}/An_{78} (S33986) [NG 3999 5249]; An_{75}/An_{65} (S34002) [NG 4056 4991], the stroke representing the range of composition apparently missing.

Olivine is usually present in these dykes as phenocrysts or early crystals, but in size it is invariably inferior to the feldspars. In only one case does the olivine reach 1 mm diameter (S32717) [NG 2309 6482].

A variety of matrices are displayed. Of the 32 rocks sliced, half are classified as dolerites, half as basalts. In only one case (S33990) [NG 3862 4861] is there clear evidence of a second generation of olivine crystallization, but labradorite, locally crystallized, is invariably present. As in the other dykes, the augite is generally very pale in colour, though purple tints were noticed in a few cases (S31975) [NG 4549 5630], (S30790) [NG 4194 6370]. The Intergranular habit is commoner than the ophitic, only seven out of 32 rocks showing the latter in well-developed form. Titanomagnetite is invariably present.

Crinanitic types with up to 10 per cent zeolites are included in this class, 12 rocks falling into this group. Chabazite, analcime, thomsonite and stilbite were noticed; one rock (S31417) [NG 3910 6079] shows a very spectacular development of thomsonite.

Allivalite, olivine-eucrite, gabbro

Perhaps the most interesting dykes of North Skye are the coarse, phanerocrystalline intrusions which occupy a series of linear broad lenses or pods, trending N.N.W. (p. 136). In these the texture is not doleritic but gabbroid, made up of xenomorphic interlocked crystals of calcic plagioclase, olivine, clinopyroxene and titanomagnetite. The rocks are classified as allivalite when the anorthite-content of the plagioclase exceeds 80 per cent; olivine-eucrite when it is in the range $An_{70–80}$ and gabbro when it is less than 70 per cent, in accordance (as far as allivalite is concerned) with the proposals of G. M. Brown (1957, p. 12), in his recent work on the type allivalites of Rhum, and as far as eucrite is concerned with those of W. J. Wadsworth (1961, p. 28).

Most of the dykes sampled belong to the allivalites and contain calcic bytownite or anorthite as their main constituent. As representative of them, a rock from the centre of the lens exposed in Broisgillmore Burn, ½ mile S.S.W. of the summit of Am Bidean (S37870) [NG 3430 4105] has been analyzed (Table 13). The rock is grey, gabbroid in appearance, and is composed of plagioclase crystals exhibiting mutual boundaries, the composition as estimated from refractive index determinations being An_{90}, and as calculated from the rock analysis An_{85}. Rounded fresh olivines with intermediate refractive index 1.710 (corresponding with 27 per cent fayalite) are enclosed by ramifying pale green salitic clinopyroxenes with $\beta = 1.703$ and moderate optic axial angle. A few magnetite crystals are present, but these are not common. Among late-stage effects, chlorite-bowlingite veinlets cut the ferromagnesian minerals, and there is some alteration of the feldspar to a member of the thomsonite family having intermediate index 1.544. Another sliced rock from the left bank of the burn is similar (S31410) [NG 3430 4105]; extensive zeolitization and serpentinization is seen in places (S31411) [NG 3430 4105]. Towards the margins of the lens the rock begins to assume a porphyritic aspect; this is due to the fact that while the coarse minerals described above continue to be present they are now enclosed in a doleritic matrix with labradorite and ophitic augite (S31412) [NG 3430 4105]. This observation is believed to be of some petrogenetic significance (p. 170). The lens as at present exposed is intrusive into 'big-feldspar' mugearite, with bytownite phenocrysts in a fluxion groundmass of alkali feldspar (S31413) [NG 3430 4105].

The analysis of the rock from the centre of the lens shows that the rock is somewhat more feldspathic than allivalites from the type locality analysed by G. M. Brown (1957) but the feldspar composition leaves no doubt as to the correctness of the classification. Olivine greatly predominates over pyroxene; whereas in the eucrites cited in (Table 13) the reverse situation obtains, and the feldspar is a little less calcic.

A rock closely similar to the analysed specimen comes from 1560 yd N.N.W. of the Manse at Bracadale. The feldspar composition in An_{84}; the plates, which range up to 4 mm across, enclose crystallographically oriented inclusions, apparently of glass. The olivine carries 26 per cent fayalite and zeolites are again present, especially thomsonite. In a rock from the dyke forming the waterfall in Voaker Burn (S31402) [NG 3471 3924] the feldspar again shows inclusions, and is zoned An_{80} to An_{70}. The very pale green augite contains rod-like inclusions, probably of pigeonite. In this rock, a second, smaller generation of feldspars occurs. Another allivalite is exposed on the shore 300 yd north of the U.F. Manse at Dunvegan (S31591) [NG 2510 4683]. In the allivalite exposed 400 yd N. of Fairfield Cottage the plagioclase (An_{86}) greatly predominates, but there is more olivine than augite; zeolites are absent. Another excellent example, with anorthite (An_{90}) crystals 4 mm across comes from 1000 yd S.W. of Beinn a'Chleirich (S32933) [NG 3278 4450].

From the S.E. point of Ardroag (S32945) [NG 2769 4271] comes a dyke rock which in places exhibits gabbroic texture, but in others is doleritic, the maximum anorthitecontent of the feldspar is 75 per cent. The dyke 260 yd E.S.E. of Edinbain Hotel (S33985) [NG 3474 5076] again shows a mixed texture, and the feldspar suggests a eucritic rather than allivalitic composition; there are also thin, sharp zones of sodic plagioclase around the larger crystals. The rock from what may be a plug at Creag Bhreac, 800 yd E. of the Beinn na Cloiche is on the allivalite/ecurite boundary and again shows the admixture of large interfering plagioclases with small tabular crystals.

Summarizing, it appears that with small variations in the composition of the plagioclase which forms 60–70 per cent of these rocks, both allivalites and olivineeucrites are present. Olivine is normally twice as abundant as clinopyroxene. Some of the rocks are gabbroid and phanerocrystalline; others contain an admixed doleritic mesh.

Tholeiite

About one-third of the doleritic or basaltic dykes examined have proved to have two properties in common; a paucity or total absence of olivine, and the presence in the interstices of the labradorite mesh of patches of glass, or much more frequently, of chlorite or an ill-defined green mineraloid that may represent the devitrification products of glats. Although quartz is rare (in fact, only slice S33979, from 400 yd S.S.E. of Dun Flashader contains free quartz) and none of the patches show alkali feldspar, the rocks resemble closely many that have previously been classified as tholeiites in Scotland. This appears to be consistent with Rosenbusch's (1887) definition of tholeiite. As Holmes (1929) remarks, the essential features are the basaltic composition of the crystalline framework, the development of intersertal texture, and in the case of unqualified tholeiite, freedom or near freedom from olivine. Nevertheless, it must not be supposed that such rock necessarily derives from what is now accepted among petrologists as tholeiitic magma (vide Tilley 1952). As already noted, intrusions which manifestly belong to the alkali-basalt suite may be poor in olivine (p. 145) and may contain intersertal glass near their contacts with country rocks.

One feature of the rocks classified in North Skye as tholeiites which demands that a cautious view be taken of their origin, is the total absence from them of orthorhombic pyroxene or of pigeonite. A repeated search for these minerals has only served to reveal that all the pyroxenes investigated are, as in the "normal" basaltic rocks, diopsidic augites.

Dealing first with those dykes that carry a few per cent of olivine, it is possible to see in these comparisons with the Salen type of the Mull Memoir (Bailey and others 1924, p. 285). A good example comes from Gab na Hoe (S36213) [NG 1904 5409]–(S36214) [NG 1905 5411], where a few olivines of 0.2 mm, not constituting more than 3 per cent of the rock, occur within a labradorite mesh of tablets 0.7 mm long, with inter-granular pale augite, titanomagnetite and intersertal patches of dark glass. Other examples include a specimen from 700 yd W. of Dun Borrafiach (S31340) [NG 2289 6372]; and from the Hamra River, Glendale (S32916) [NG 1563 9309], (S33855) [NG 2280 4462], (S33857) [NG 1970 4656].

Probably of greater importance, both numerically and from a genetic point of view, are the olivine-free dykes that approximate to the Acklington type of Holmes (1929, p. 28). In an example from Allt Dearg (S33989) [NG 3862 4861], thin 0.3 mm long labradorites form stellate groupings; there are intergranular colourless to very pale purple augites and smaller titanomagnetites; and about 20 per cent of the rock consists of fine-grained chlorite in intersertal relation to the feldspars. A similar rock, from the east side of Ard Beag (S31344) [NG 2176 6120] is composed of labradorite, zoned from An_{70} to An_{30} averaging 0.5 mm, pale augite in granules of 0.25 mm diameter, some showing a tendency to grow round the feldspar; titanomagnetite moulded on the feldspar and dusty glass mixed with dull olive-green chlorite of low birefringence. A basaltic version of this rock is found in a dyke on the shore 910 yd S.E. of Ullinish Lodge; and there are numerous other examples (S31436) [NG 4191 4473], (S32483) [NG 2442 5476], (S32715) [NG 2863 6546], (S32935) [NG 2985 3925], (S33838) [NG 2664 4224], (S33970) [NG 3490 5383], (S37733) [NG 3936 3632]. A single example carries augite phenocrysts (S32872) [NG 3741 6582].

Porphyritic tholeiites

Dykes containing calcic plagioclase phenocrysts up to 5 mm long set in a matrix similar to the tholeiites described above are known at a number of localities. The phenocrysts are similar in appearance, shape and composition to those described in the dykes related to the alkali basaltic suite (p. 160). Determinations gave An_{92} (S30784) [NG 3761 6349]; An_{85} (S31433) [NG 4451 4451]; An_{92} (S32712) [NG 3009 6313] while the range of zoning in the phenocrysts in (S31973) [NG 4373 5546] is from An_{88} to An_{60}.

The matrix in some of these rocks corresponds with the Salen type (S30784) [NG 3761 6349], (S31343) [NG 2181 6118], (S31433) [NG 4451 4451], (S31963) [NG 4290 5831], (S31973) [NG 4373 5546], (S31978) [NG 4101 5273], (S33984) [NG 3471 5078], others might be regarded as porphyritic Acklington types (e.g. (S32712) [NG 3009 6313], (S33028) [NG 5078 6590], (S33839) [NG 2521 4434]. It is, of course, well known that bytownite-anorthite occurs as phenocrysts in the Mull tholeiites, as well as in many of the dykes that swing south-eastward across southern Scotland and northern England. The significance of these phenocrysts is discussed below (p. 164).

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TABLE X

ANALYSES OF DOLERITES AND RELATED ROCKS

	N	O	P	Q	R	S	T	U
SiO_2	40·47	40·62	45·07	46·97	47·51	47·83	43·49	50·04
Al_2O_3	5·96	8·93	14·43	15·00	17·28	15·31	14·57	14·27
Fe_2O_3	2·10	0·57	0·80	1·71	3·56	1·15	5·62	3·76
FeO	12·32	12·61	10·69	8·94	5·77	9·22	7·40	6·33
MgO	29·32	26·31	14·61	10·52	5·98	6·60	5·32	5·99
CaO	4·91	5·64	9·74	10·70	11·47	12·38	11·61	12·11
Na_2O	1·18	1·32	1·75	2·18	2·60	2·53	2·92	3·41
K_2O	0·40	0·13	0·34	0·63	0·79	0·40	0·92	0·83
H_2O+	1·12	2·19	1·05	0·38	1·40	1·28	3·58	0·79
H_2O-	0·59	0·61	0·35	0·63	1·30	0·28	1·39	0·40
TiO_2	1·50	0·82	0·83	1·59	1·80	2·86	2·95	1·89
P_2O_5	0·26	0·15	0·10	0·12	0·12	0·16	0·40	0·24
MnO	0·23	0·39	0·33	0·37	0·13	0·36	0·12	0·28
BaO	—	—	0·01	—	—	—	—	—
CoO NiO	—	0·03	0·02	—	—	0·02	—	—
CO_2	—	0·03	0·02	—	—	0·05	—	—
Cl	—	0·01	—	—	—	0·01	—	—
	100·36	100·36	100·14	99·72	99·71	100·44	100·29	100·34

N. Picrite, top of cliff W. of Camas Mor; analyst N. Sahlbom *in* Walker 1932, p. 247.

O. Picrite, S. face of Garbh Eilean, Shiant Is., by the shingle beach; analyst E. G. Radley *in* Walker 1930, pp. 371-2.

P. Olivine-dolerite (picrodolerite of present account), Garbh Eilean 30 ft above the beach; analyst E. G. Radley *in* Walker 1930, pp. 371-2.

Q. Olivine-dolerite (" normal dolerite "), just S. of mid-point of S.W. shore. Fladda-chuain, analyst N. Sahlbom *in* Walker 1931, p. 757.

R. Olivine-dolerite (" normal dolerite "), Loch Mealt near Waterfall, 80 ft above lower contact; analyst, N. Sahlbom *in* Walker 1932, p. 245.

S. Crinanite, Garbh Eilean, 125 ft above the beach; analyst, E. G. Radley, *in* Walker 1930, pp. 371-2.

T. Teschenite, Ben Volovaig, half way up slope; analyst, N. Sahlbom *in* Walker 1932, p. 249.

U. Pegmatitic dolerite, Fladda-chuain, N. end; analyst N. Sahlbom *in* Walker 1931, p. 760.

(Table 10) Analyses of dolerites and related rocks.

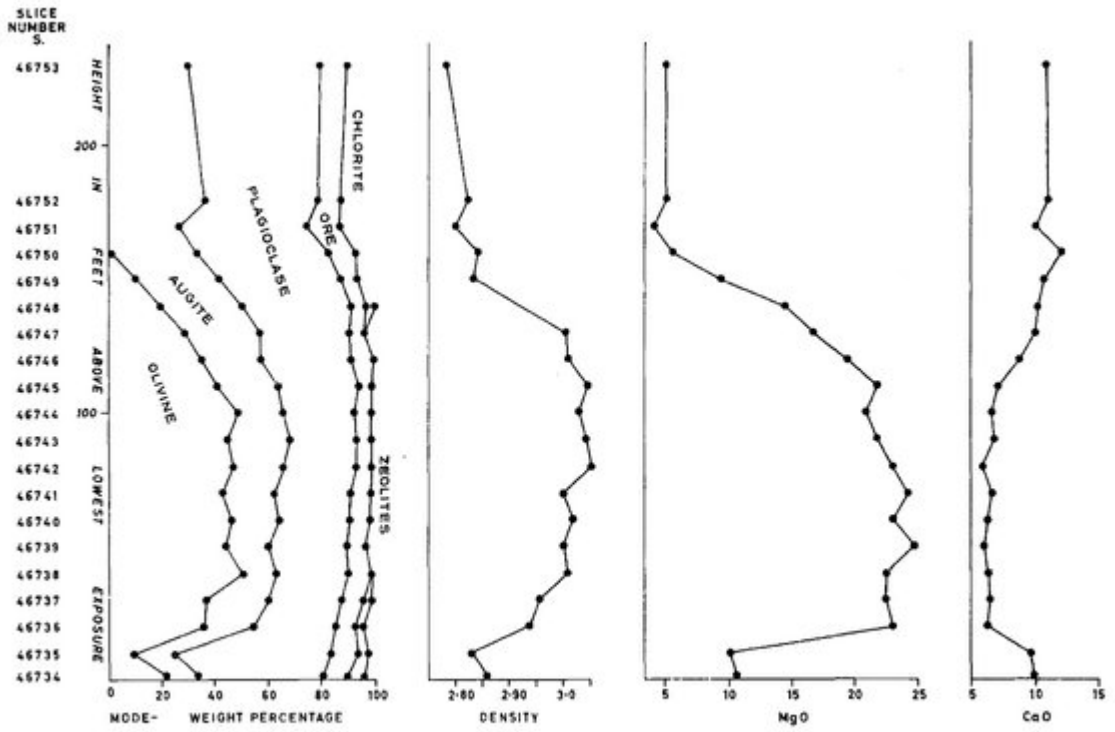

FIG. 15. *Modes of a suite of specimens collected at intervals in the central chimney cutting the Meall Tuath upper sill, Rubha Hunish. Density determinations and estimates of magnesia and lime are given for comparison. Densities by G. Wilson, chemical determinations by R. Lambert, Durham University Geology Department*, 1962

(Figure 15) Modes of a suite of specimens collected at intervals in the central chimney cutting the Meall Tuath upper sill, Rubha Hunish. Density determinations and estimates of magnesia and lime are given for comparison. Densities by G. Wilson, chemical determinations by R. Lambert, Durham University Geology Department, 1962.

TABLE XI

NORMS AND MODES OF DOLERITES AND RELATED ROCKS

Norms	N	O	P	Q	R	S	T	U
or	2·2	0·6	1·7	3·3	4·5	2·2	5·6	5·0
ab	4·7	3·3	14·7	17·8	22·0	21·0	19·2	28·8
an	10·0	20·8	30·6	29·8	33·4	29·5	23·9	20·9
ne	2·8	4·1	—	—	—	—	2·7	—
di	9·9	5·7	13·5	18·2	18·5	25·4	24·7	29·6
hy	—	—	0·8	5·9	7·8	6·2	—	7·6
ol	62·3	61·5	33·9	17·8	2·2	7·1	4·1	3·3
il	2·9	1·5	1·5	3·0	3·5	5·5	5·6	3·7
mt	3·0	0·6	1·2	2·6	5·1	1·9	8·1	5·3
op	0·7	0·3	0·3	0·3	0·3	0·3	1·0	0·4
Normative Or			4	6	7	4		9
Plagioclase Ab			31	35	37	40		53
An			65	59	56	56		38
Modes								
Olivine	66	59*	31*	18	9½	12*	7½	—
Augite	14	10	17	23	23½	24	22	27½
Plagioclase	17½	26	50	51½	60½	60	46	52½
Titanomagnetite	2½	2	2	6½	5	3	11½	8
Zeolites	—	3	—	1	1½	1	12	12
Apatite	—	—	—	—	—	—	1	—

* It is not certain that these correspond with the analysed specimens though they are from the same localities.

(Table 11) Norms and modes of dolerites and related rocks./p>.

TABLE XII

The Dykes of North Skye

Rock-Type	*On One-inch map*	*No. of Slices*
Normal olivine-dolerite and basalt	K^D	21
Normal crinanitic variants	K^C	43
Picritic dolerite [Picrite on map]	fU°	7
Mugearite, including feldspar-phyric types	X^M	12
Variolite	vK	6
Leidleite	P^L	1
Trachyte	O^T	1
Feldspar-phyric dolerite and basalt, including crinanitic variants [Dolerite, basalt or Tholeite (unclassed)]	K^D	32
Allivalite, olivine-eucrite [E′gabbroic (unclassed)]	U^A, E′	15
Tholeiitic dolerite and basalt	K^T	29
Tholeiitic feldspar-phyric dolerite and basalt	K^T	13

(Table 12) The dykes of North Skye./p>.

TABLE XIII

Analyses and Norms of Allivalite and Eucrite

	V	XII	Y	Z
SiO_2	47·33	44·95	48·28	47·28
Al_2O_3	20·08	24·02	20·38	21·11
Fe_2O_3	0·55	0·93	1·78	3·52
FeO	3·24	4·07	6·70	3·91
MgO	12·53	9·43	7·93	8·06
CaO	14·47	13·70	11·80	13·42
Na_2O	1·34	1·21	1·75	1·52
K_2O	0·07	0·11	0·14	0·29
H_2O+	0·21	1·27	0·76	0·53
H_2O-	0·14	0·48	0·09	0·13
TiO_2	0·15	0·13	0·23	0·28
P_2O_5	tr	0·02	0·02	tr
MnO	0·08	0·08	0·28	0·15
CO_2	—	tr	0·03	—
S	—	0·01	—	—
Cr_2O_3	0·18	0·05	—	—
NiO	—	0·01	—	—
BaO	—	0·01	—	—
SrO	—	0·02	—	—
Li_2O	—	nt. fd.	—	—
FeS_2	—	—	0·04	—
	100·37	100·50	100·21	100·20

Norms

	or	0·56		0·56		0·56		1·67	
	ab	11·32		9·96		14·67		12·58	
	an	48·93		59·77		47·54		50·04	
	ne	—		—		—		—	
di	wo	9·55	18·09	3·48	6·64	4·52	8·77	6·96	13·32
di	en	7·26		2·50		2·80		5·20	
di	fs	1·28		0·66		1·45		1·06	
hy	en	—		1·80	2·46	12·60	19·46	9·70	12·08
hy	fs	—		0·66		6·86		2·38	
ol	fo	16·70	19·96	13·44	17·52	3·08	5·12	3·64	4·66
ol	fa	3·26		4·08		2·04		1·02	
	mt	0·79		1·39		2·55		5·10	
	il	—		0·24		0·53		0·61	
	ap	—		0·04		0·04		—	
	cr	—		0·06		—		—	
	ca	—		—		0·07		—	
	py	—		·002		0·04		—	

Plagioclase $Or_1Ab_{19}An_{81}$ $Or_1Ab_{14}An_{85}$ $Or_1Ab_{23}An_{76}$ $OR_2Ab_{20}An_{78}$

(Table 13) Analyses and norms of allivalite and eucrite.