Chapter 7 Petrography of the volcanic rocks

History of research

The Earliest investigator of the lava-field of Skye, John Macculloch (1816, 1817, 1819) had none of the benefits of microscopical petrography, and it was not until the time of Zirkel in 1870 that modern techniques were first applied to the basalts. Meanwhile Archibald Geikie, early in his career, had interested himself in the time-relations of the Scottish trap-rocks (1861, 1867). In 1883 J. W. Judd entered the field with descriptions of a number of occurrences of basaltic glass, in collaboration with G. A. J. Cole. This was followed by a series of papers from Judd, mainly concerned with the broader aspects of the history of the Tertiary volcanoes, and suggesting that the basalt plateaux were formed of lavas emitted at central vents. In 1886 he suggested that the term basalt should be applied only to such rocks as contain some remains of a vitreous groundmass, and that dolerite should be used for holocrystalline basic rocks 'in which the felspar appears in section as an entangled mass of lath-shaped crystals, while the augite and olivine occur either in definite crystals or rounded grains'.

In 1886 Sir Archibald Geikie strongly contested Judd's views on central eruption and advocated quiet emission of the plateau lavas from fissures, a conception which he further developed in his 'Ancient Volcanoes' (1897). This work contains petrographical descriptions of the plateau lavas (Vol. II, pp. 183–4) contributed by F. H. Hatch, W. W. Watts and A. Harker. Geikie recognized five types of lava on the basis of field occurrence: (1) Thick massive prismatic or rudely jointed sheets, including true superficial layers which show the characteristic slaggy or vesicular bands at their upper or lower surfaces; (2) Prismatic or columnar sheets of which he remarks : 'It is not always possible to be certain that columnar sheets which appear to be regularly intercalated among the undoubted lavas . . . may not be really intrusive'; (3) Slaggy or amygdaloidal lavas without any regular jointed structure; (4) Banded or stratiform lavas, owing their layering to regular textural changes, or to bands of vesicles; (5) Lavas showing flow structure, generally of rare occurrence. The first description of the tuff and agglomerate of Portree Harbour was given by Geikie (1897, pp. 284–6) and he also noted the red partings between some of the lavas (p. 254). His main conclusion (p. 255) was that the plateau lavas show no thickening towards a centre.

The primary survey of one-inch sheets 70 and 71 by Alfred Harker formed the basis of his great memoir, published in 1904. The southern part of the lava field, together with a number of relics involved in the Cuillins centres, comes into these sheets, and Harker has remained the main authority on the petrography of the Skye lavas. Like Geikie, he was impressed by the contrast between the unjointed amygdaloidal layers, and the columnar sheets, and rightly remarked (Harker 1904, p. 29) that the latter 'form all the salient features of the plateau country'. Unlike Geikie, however, he confidently reached the conclusion that the prismatic-jointed layers were all dolerite sills, of later date than the lavas. This, as already noted (p. 80), has not been supported by later authors, and Harker's description of the petrography and chemistry of the basalts (pp. 29–50), thus requires to be read in conjunction with his account of the 'Great Group' of basic sills (pp. 235–253). Harker coined the name mugearite for the trachy-basaltic sheets of Druim na Criche and Roineval which he regarded as portions of composite sills, the upper member of which was misleadingly described as olivine-dolerite crowded with large porphyritic feldspars. Kennedy (1931) has subsequently brought forward evidence to show that these are composite lava-flows. These bodies lie near the southern margin of the area of one-inch Sheet 80, with which we are here concerned.

G. V. Wilson's reports on the primary survey of one-inch sheets 80 and 90 (Wilson 1935, p. 70; 1936, p. 83; 1937, p. 78) leave no doubt as to the opinion of the surveyors on the question of the extrusive nature of the hard, prismatic layers. The flows are stated to be 'characterized by highly decomposed and slaggy tops and bottoms, with hard black central portions. Occasional thin interbedded layers of red bole, shale and coaly matter also occur, but as yet no intrusive sills have been noted within the lava sequence', (Wilson 1935, p. 70). The primary survey also indicated the extent of the tuff first noted by Geikie, and this is described as a palagonite tuff, containing bombs which consist mainly of devitrified glass with numerous crystals of olivine and feldspar, while in the case of the smaller fragments the matrix is still clear, yellow glass (Wilson 1937, p. 78). The tuff which lies between the Jurassic sedimentary rocks and the basal lava of the Tertiary volcanic suite, is interpreted as indicating that volcanic activity commenced with an explosive phase which ejected a great quantity of glassy materials. Trachytes were first noted from the northern part of the island in 1935 associated with mugearites and big-feldspar basalts.

A general description of the lava plateaux with some support for Judd's conception, has been given by Richey (1948, p. 37 et. seq.), and the olivine-basalts, mugearites, feldspar-phyric mugearitic basalts and trachytes have been mentioned in an excursion guide (Wager and others, 1948, p. 8). New analyses of Skye mugearites and trachyte have been included in a petrological study by I. D. Muir and C. E. Tilley (1961) and of basalt in a paper by Tilley and Muir (1962).

The magnetic properties of the lavas (p. 85) have been determined by M. A. Khan (1960). Before concluding this review mention must also be made of the many contributions to the mineralogy of Skye by M. F. Heddle, brought together by Goodchild in a posthumous memoir (1901) which includes analyses of most of the zeolites for which The Storr and other localities are famous, as well as of other species. Interest in these minerals has recently been revived by J. M. Sweet (1959, 1960, 1961).

It is also important to recall that petrographical investigation in other Tertiary centres, especially in Mull (Bailey and others, 1924), in Ardnamurchan (Richey and Thomas, 1930) and in Antrim (Tomkeieff 1940, Patterson 1955 A, B) has thrown much light on the petrography and chemistry of the lavas which compose the Tertiary plateaux. The petrological discussions which have accompanied and followed these publications will be referred to in a later chapter.

Palagonite tuffs

Field relations. The tuff is associated with carbonaceous sediments of Tertiary age, and underlies the base of the lava sequence. It has been found on the east coast at Camastianavaig, at Camas Ban (Harker 1904, p. 23 figured a section from this locality), and at Red Cliff on the north side of Portree Harbour, whence it is seen at intervals in the cliff section for over 5 miles. About half a mile north of Prince Charles's Cave the outcrop swings inland and the bed forms a capping to the cliffs over a considerable area. It is present at Lon Coire na h-Airidh and farther north has been found on the coast between Staffin and Flodigarry. In Vaternish it has been noted in the vicinity of Halistra and Stein, and along the foot of the Sgurr a'Bhagh landslip on the shore of Loch Bay (Wilson 1937, p. 78).

The deposit, which is visibly fragmental, weathers brown and contains rounded bombs of glassy lava, as well as scattered crystals of olivine and feldspar. It has been found to contain fragments of fossil wood on the coast between Ard Beag and Bay (Wilson 1936, p. 82). At many places, lenticular cakes of lava with pipe amygdales occur in it; there are also lenticular dolerite bodies, some of which are probably intrusive. The suggestion has been made (Wilson 1937, p. 78) that the deposit was laid down in water.

Petrography. The tuff from the excellent exposures at Creag Mor, west of Beal Point (S37871) [NG 508 448]<ref>Five figure numbers in brackets refer to the Scottish Sliced Rock Collection of the Geological Survey and Museum unless otherwise stated. Numbers prefixed by 'Durham' relate to specimens in the collection of the Department of Geology of Durham University.</ref> is a dark brown crystal-vitric variety containing conspicuous amygdales or pockets filled with hard white opaline silica. The constituents include crystals of labradorite of approximate composition An_{70} and beautiful automorphic olivines, some complete, some in fractured condition, with a composition, ascertained by refractive index measurements, corresponding to the range Fa_{16}–Fa_{19}. These are set in a matrix of glass fragments, which display a zonal arrangement within individual fragments. The inner zone is clear yellow glass with refractive index ranging up to 1.595. Having regard to the refractive index measurements of natural basaltic glasses recorded by Tilley (1922), which show a range from 1.586 to 1.649 (excluding glasses with mugearitic affinites), there is little reason to doubt that this is a true basaltic glass or sideromelane. An analysis of the yellow glass is given below (p. 97). The yellow inner zone is separated from the next zone by a region, up to 0.1 mm wide, full of dusty opaque particles. Then follows a narrow green zone, succeeded by clear brown isotropic glass in which the range of refractive index is from 1.545 down to 1.480. This has a fringe showing partial devitrification to 'palagonite'. The zones may enclose olivine or feldspar crystals at any point, and do not in any way conform to the positions of the crystals. Gas cavities occur only in the outer brown zone. Between the glass fragments, white-reflecting isotropic silica with refractive index in the range 1.520–1.525 occurs, probably opal mixed with a little chalcedony. An essentially similar specimen (S31751) [NG 4990 4455] was obtained from the path side, ¼ mile E.S.E. of Torvaig; here the olivines range up to 2.5 mm across, while the labradorites are no more than 0.6

mm long. Some of the olivines are automorphic, but others have a remarkably corroded appearance in thin section. It is of this specimen that G. V. Wilson (1937, p. 78) remarked 'On closer examination the clear yellow glass is seen to pass outwards through a deep greenish layer into an olive-green layer and finally into an angular, fragmental material in which the interstices are often filled with analcite and opal. It is stated that the appearance of the junction of the glassy and fragmentary types leaves no doubt that the latter was formed in situ from the former'. The presence of devitrified fringes round the fragments is again a conspicuous feature. In material from the cliffs 600 yds N. of Rudha na h'Airde Glaise (S37967) [NG 509 458] labradorite laths up to 1.25 mm long and small clinopyroxenes are set in quite isotropic pale yellowish-green fragments with refractive index 1.584–1.596, having devitrified margins; the glass turns dark brown, and is of markedly lower refringence, as the margins are approached. In this rock carbonate with ω = 1.681 (slightly ferriferous dolomite) occurs between the fragments.

At Craig Ulatota, the upper 15 ft of the Tertiary sandstone can be seen. This is a pale brown rock (S37956) [NG 514 476] containing angular quartz and alkali-feldspar grains of about 0.15 mm, with a sprinkling of grains of partly oxidized chloritic material perhaps heralding the onset of explosive volcanism. Some 82 ft above the base of the tuff, which here encloses impersistent flows of microporphyritic olivine-basalt (S31938) [NM 7894 6305] and hyalopilitic basalt containing olivines up to 3.0 mm diameter and Y-terminated labradorites, there occurs a bed of grey and red ashy tuff (S37959) [NG 514 476], (S37961) [NG 514 476] in which glass shards are conspicuous under the microscope. Plant remains occur in this bed, and adventitious quartz-grains, well rounded, are also seen.

From a stream section near Gesto House (S31385) [NG 3572 3676] comes a vitric tuff containing isotropic brown glass lapilli in a dark, streaky glass matrix.

The tuff exposed at Camas Ban resembles that of Creag Mor except that devitrification has proceeded further, and the matrix contains dolomite and chabazite, but no opal (S37923) [NG 4916 4236]. A volcanic bomb from this locality (S37924) [NG 4916 4236] proves to be a porphyritic tholeiite containing glomeroporphyritic labradorite, in a groundmass of small labradorites and granular purple augites set in glass carrying plates or rods of iron-titanum oxides. Devitrification of the glass had produced a green mineraloid resembling the 'palagonite' of the tuff.

Chemical Composition of the Sideromelane and Palagonite. The yellow glass with refractive index 1.595 was separated from the Creag Mor rock (S37871) [NG 508 448] by Miss H. A. H. Macdonald and analysed with the result given in (Table 1), analysis I. The X-ray photograph of the concentrate (X2012) showed only a little impurity, probably feldspar. The norm calculated from the analysis ((Table 2), p. 99) indicates a composition approaching oversaturated basalt.

The product of devitrification of the sideromelane contains a fibrous mineral in which the fibres display moderate birefringence, up to 0.015, negative elongation and variable refractive index, in the range 1.51 to 1.54. In transmitted light this material is pale to deep brown. Separations were made from.a specimen from Camas Ban (S40387); Durham 2495) showing, in thin section, glass lapilli preserved in fibrous and radiating 'palagonite'. Gravity methods produced a concentrate containing 89 per cent grains of brown glass in various stages of devitrification; and 11 per cent colourless isotropic grains. Brown and colourless fractions were separated magnetically. The refractive index of the brown fraction was found by Dr. Sabine to lie in the range 1.516–1.531; while the colourless grains show 1.476 and below. Both fractions were analysed ((Table 1), columns II, III).

The most noteworthy feature is the high Na_2O figure in both analyses II. and III; the increase in total alkalis as compared with basaltic glass (column A) is threefold.

(Table 1) Analyses of palagonite, glass and tuff

	I	II	III	A	IV
SiO_2	51.5	56.0+	43.3+	37.8	33.24
Al_2O_3	15.6	15.8	11.5	13.7	21.53
Total Fe as Fe_2O_3	10.6	1.5	14.7	12.3	3.23
MgO	5.7	1.0	21	1.9	0.72
CaO	10.4	2.2	1.6	1.6	2.36

Na_2O	3.2	6.2	8.2	3.8	013
K_2O	0.6	2.2	0.8	3.4	0.07
Ignition loss	0.7	14.3	16.4	23.0	35.69
TiO_2	1.7	0.8	1.4	—	2.73
P_2O_5	—	—	—	—	0.25
MnO	tr.	tr.	tr.	2.5	0.09
Cl	—	—	—	—	tr.
S	—	—	—	—	Nil.
Cr_2O_3	—	—	—	—	tr.
BaO	—	—	—	—	010
Li_2O	—	—	—	—	tr.
	100.0	100.0	100.0	100.0	(S10014)
	I	II	III	A	IV
FeO	8.9	tr.	P4	—	—
H_2O below 105°	0.3	5.0	7.3	—	24.65
CO_2	—	—	—	—	0.22
C	—	—	—	—	0.60
+ by difference					

I Yellow glass separated from 'palagonite' tuff, n = 1.595, Creag Mor, Skye

II Colourless glass from 'palagonite' tuff, n = 1.476 Camas Ban

III Brown partly devitrified glass from 'palagonite' tuff, Camas Ban

A Palagonite, 2,350 fathoms Pacific Ocean, lat. 13° 28' S. long. 149° 30' W. (Peacock, 1930).

IV Interbasaltic deposit, 10 in thick, in Tertiary lavas, Stream 1500 yd S.E. of Blackhill (Edinbain), Skye.

Analysts: I-III, A. D. Wilson (semi-micro methods), Geological Survey and Museum, Lab. Nos. 1740 (1958), 1712, 1713 (1956); A. Sipocz, recalculated by Peacock; IV, G. A. Sergeant, Geological Survey and Museum, Lab. No. 1086 (1943); Guppy and Sabine 1956, p. 28.

The proper use of von Walterstansen's term 'palagonite' was discussed and clarified in a series of papers by M. A. Peacock (1926, 1928, 1930), who advocated the restriction of the term to the gel-like or obscurely fibrous products of the hydration of sideromelane at low or moderate temperatures. He added 'It occurs typically in dominantly vitreous basaltic tuffs formed under conditions of drastic cooling and subsequent prolonged saturation with water or water vapour' (1930 p. 177). So far the term may aptly be applied to the present material. However, Peacock claimed that palagonite has substantially the composition of basalt to which 20 or 30 per cent water has been added. This is clearly not so in the present case, where there are losses in MgO and CaO, and great gains in Na_2O. The palagonite of Skye is most closely comparable with the skin of sideromelane fragments dredged by the 'Challenger' expedition from the Pacific (Peacock 1930, p. 175; Table 1, Column A) which is believed to have acquired alkalis from the sea-water.

It appears, therefore, that the change from sideromelane to palagonite, illustrated in the Skye basalt tuff, is accompanied by hydration, loss of lime and magnesia, and substantial gain of soda. Apparently the process may proceed to a stage where iron also is lost. Whether these changes are due to the eruption of glass fragments into sea-water or whether they also demand the intervention of hot circulating fluids, is less clear.

A thin layer of tuff collected by D. A. Haldane from a horizon between lavas near Edinbain (S33954) [NG 3524 4916]–(S33955) [NG 3524 4916] shows another variety of palagonite. The rock is made up of subspheroidal bodies of 0.02–0.25 mm diameter, probably the remains of glass lapilli, set with angular plagioclase crystals in a streaky matrix of dark brown and reddish brown glass. There has been extensive divitrification, indicated by optical activity suggesting an incipient fibrous structure. An analysis (Table 1), column IV shows that in this case, there has been loss of Na_2O, as well as of MgO and CaO as compared with average plateau basalt. In these respects the rock is comparable with the palagonite tuff of Iceland (Peacock, 1926, p. 66) rather than that of Portree. The high alumina, however, suggests that contemporaneous subaerial weathering may also have had some influence on this rock, as in the case of the interbasaltic horizons in Antrim (Eyler 1952).

Tholeiitic pillow lavas

Field Relations. At Creag Mor, west of Beal Point, the upper part of the 'Palagonite' tuff, totalling about 60 ft, is seen. About half-way up the section, ashy shales, overlain by 4 ft of yellowish-brown, bedded tuff, is succeeded by lavas having well-developed pillow structure. The surfaces of the pillows are ropy and pipe amygdales occur in the pillows. What appears to be a second horizon of pillow lavas overlies yellow tuff some 12 ft higher in the section.

Petrography and Chemistry. The unaltered sideromelane glass in the palagonite tuff makes it possible to obtain some detailed information of the nature of the earliest magma of the North Skye volcano. Investigation of the pillow lavas, which were undoubtedly contemporaneous with the early explosive phase, also suggests that magma of a type more saturated with silica than that responsible for the great pile of plateau lavas was available at an early stage.

The rock of the pillow lava (S37872) [NG 508 448], (S38092) [NG 507 448] is a micro-porphyritic tholeiitic basalt. The phenocrysts, up to 1 mm long are of fresh clear plagioclase of composition An_{65}; these tend to occur in groups in which the crystals are separated by black glass. The groundmass consists of plagioclase laths of about 0.1 mm long, not fluxionally arranged, with elongate and dendritic, faintly purple clinopyroxene between them; many of these are obviously incompletely crystallized. Rounded areas of a brown mineraloid may represent former olivines, but this is uncertain. Very dark glass is abundant between the ribs of the dendritic pyroxenes and elsewhere. Rims of the glass, enclosing tiny acicular pyroxenes, surround amygdales which have been filled with carbonate having

ω = 1.662 (ankeritic calcite) and with chlorite.

An analysis of this rock is given in (Table 2), column V; in column VA the analysis is recalculated free of calcite, but neglecting the very small quantities of ferrous iron and magnesium in the ankeritic calcite. The results suggests an affinity with the non-porphyritic Central type of basalt, as developed in Mull (Bailey and others 1924, pp. 14, 17) or the Causeway type of Tomkeieff (1940, 1948) than with the Plateau Basalts. The absence of olivine from the norm is, for example, noteworthy. At the same time, it is not desired to lay great stress on this occurrence, having regard to its insignificant proportions compared with the main lava series, and the altered state of the rock.

(Table 2) Analyses and norms of sideromelane, pillow lava and tholeiitic basalts

Analysis	I	V	VA	B	C
SiO_2	52.0	42.30	47.6	47.35	49.76
Al_2O_3	15.6	14.24	15.8	13.90	14.42
Fe_2O_3	0.7	3.87	4.3	5.87	3.95
FeO	8.9	5.49	6.2	8.96	7.77
MgO	5.7	4.42	5.0	5.97	5.30
CaO	10.4	16.76	12.5	10.65	10.22
Na_2O	3.2	2.40	2.7	2.73	2.49
K_2O	0.6	0.27	0.3	0.54	1.83
H_2O+	0.9	1.22	1.3	1.16	1.03
H_2O-	0.3	1.69	1.9	1.04	2.04
TiO_2	1.7	1.57	1.8	1.75	0.94
P_2O_5	—	0.18	0.2	0.24	0.21
CO_2	—	5.07	—	0.32	0.06
S	—	0.09	—	0.23	—
FeS*2*	—	-	—	—	0.04
Cr_2O_3	—	0.04	—	—	—
BaO	—	0.07	—	—	0.04

MnO		tr.		0.24		0.3		0.23		0.20	
		100.0		99.92		99.9		100.94		100.30	
	Norm	I		V		VA		B		C	
Q		—		1.92		2.1		1.08		0.48	
or		3.3		1.67		1.9		2.78		10.56	
ab		27.3		20.44		23.1		23.06		20.96	
an		26.4		26.97		30.5		24.19		22.80	
di	wo	10.6		9.741		11.21		10.671		11.14	
di	en	5.4	20.9	6.60	18.72	7.5	21.4	6.50	20.73	6.10	21.86
di	fs	4.9		2.38		2.7		3.56		4.62	
hy	en	8.8	17.0	4.50	6.35	5.1	7.2	8.40	13.02	7.20	12.48
hy	of	8.2		1.85		2.1		4.62		5.28	
mt		0.9		5.57		6.3		8.58		5.80	
ii		3.2		3.04		3.4		3.34		1.67	
ap		—		0.34		0.4		0.34		0.34	
ca		—		11.50		—		0.70		0.10	
py		—		0.30		0.3		0.73		—	
rest		1.2		3.02		3.4		2.20		3.15	
Feldspar		$Or_6,Ab_{48}An_{46}$		$Or_3Ab_{42}An_{55}$				$Or_6A13_{46}An_{48}$		$Or_{19}Ab_{39}An_{42}$	

I Sideromelane from 'Palagonite' Tuff, Camas Ban, Skye

V Pillow lava, Creag Mor, Skye

VA Pillow lava, Creag Mor, Skye, analysis recalculated free of calcite

B Type Salen tholeiite

C Type Staffa basalt

Analysts: I. A. D. Wilson, Geological Survey Lab. No. 1740 (1958)

V. A. D. Wilson and P. Coombs, Lab. No. 1645 (1954) Guppy and Sabine 1956, p. 28

B.F.R. Ennos, Lab. No. 407 Bailey and others 1924 p.17

E. G. Radley, Lab. No. 669 Bailey and others 1924 p.17

Main Lava Series

Lava types. A total of 396 thin sections of lavas from the main lava series of Northern Skye have been examined in connexion with the present investigations.<ref>A. preliminary naming of those cut in London (approximately half of the total number) was carried out by Dr. J. Phemister. Part of the remainder were examined by Mr. E. H. Francis in 1950, but the whole series was reinvestigated to provide symbols for the maps and for the present account.</ref> Six lava types are recognized for descriptive purposes, and in the table below these are briefly defined, with the appropriate symbols. The number of slices in each category is shown and in view of the fact that many serial collections of lava-successions were made during the field survey, and during a visit in 1950, these give a rough impression of the relative abundance of the different types, but probably erring on the low side in the case of the Hebridean type (1).

The Hebridean lava type of (Table 3) corresponds with the 'Plateau Type of Basalt' of the Mull Memoir (Bailey and others 1924, p. 136). The Mull term has not been used here, to avoid confusion with the 'Plateau magma-type' of Bailey and others (1924, p. 14) which involves concepts going far beyond the definition of lavas, and because it is linked to a style of vulcanism not necessarily justified by the evidence in North Skye (p. 160) Tomkeieff's (1948) more non-committal term is thus adopted, but (without prefix) it is restricted here to the finer-grained rocks which fall within the textural category of basalt. Coarser lavas, of similar composition, where the feldspars average over 0.5 mm in length, which would be dolerites on the basis of their textures, have been assigned to the new Vaternish Hebridean type. All the types listed in (Table 3) are recognizable in the field.

Field Structure. The complete lithological sequence within a single lava-flow of any of the types listed above, appears from the field evidence to be as follows:

4. Bole or fossil soil, produced by weathering of the exposed surface of the flow; generally red owing to ferric oxide concentration.

3. Upper amygdaloidal layer, representing the upper crust or carapace of the flow in which crystallization commenced during the movement of the flow. May be brecciated ; and is generally rich in ovoid gas cavities now filled with zeolites, chlorite, carbonates or, in the case of trachyte flows, agate. The rock is generally of a chilled type, and has often been altered as a result of the passage of fluids (especially water vapour) from the still-liquid magma, and possibly from atmospheric sources, through it.

2. Central massive layer, which may or may not exhibit vertical prismatic jointing. Generally made of lava reasonably free from secondary hydrous minerals, this layer was formed when the central layer of magma came to rest and crystallized. Usually contains few gas cavities.

1. Lower amygdaloidal layer, composed of chilled lava which encloses many gas cavities, including pipe amygdales which, from their inclination, may have formed when the central magma layer was still moving. The lava here tends to contain more hydroxyl-bearing minerals than the central massive layer. Usually very much thinner than the upper amygdaloidal layer.

The complete four-fold arrangement is not shown by every lava-flow. Some have only poorly-developed central layers, while in other cases the upper and lower carapaces can hardly be distinguished from the massive or prismatic centre. The hole is not invariably present, indicating that at some times during the vulcanicity, flows followed one another in sufficiently rapid succession to prohibit inter-flow weathering. Nevertheless boles are very common in the North Skye sections and their presence demonstrates the extrusive origin of the doleritic Vaternish types, among others.

(Table 3) Lava types in Northern Skye

	Symbol 1" map	Slices
1. Hebridean Type of olivine-phyric olivine-basalt, with ophitic or intergranular augite which may be yellow, pale brown, purple, faintly green or colourless in thin section. Composition of the feldspar in the range An55 to An70. Mesostasis of zeolites, especially analcime, thomsonite, chabazite, generally present. Feldspars not exceeding 0.5 mm average length.	B^{He}	214
2. Vaternish Hebridean Type olivine-phyric olivine-dolerite, composition similar to Hebridean type but plagioclases average over 065 mm long.	B^{V}	42

3. **Feldspar-phyric olivine-basalt**, olivine and labradorite phenocrysts generally of microporphyritic dimensions, (i.e. less than 2 mm), in a groundmass of composition similar to the Hebridean type.	fB	44
4. Mugearite, dark grey, platy weathering trachybasalt, composed of olivine, oligoclase, orthoclase, clinopyroxene and iron-titanium oxides, normally exhibiting trachytic texture.	W^M	69
5. Big-feldspar mugearite, macroporphyritic mugearite basalt, with large phenocrysts of labradorite-bytownite in a mugearite groundmass.	fW^M	23
6. **Trachyte**, pale grey or white trachyte containing a few alkali-feldspar and ferromagnesian phenocrysts in a groundmass of alkali feldspar laths; shows trachytic texture.	T	14

Detailed investigation of the boundaries between massive central layers and upper and lower carapaces has made it clear that the central layer is not a later intrusion. Chilled contacts are not found, nor has any sign of transgression been discovered. It is easily possible to demonstrate the petrographical identity of the rocks in all three layers, allowing for the alteration which has occurred in the amygdaloidal carapaces. Nevertheless, once the solid carapaces have formed the environment of a central layer is not unlike that of a shallow intrusive sill. It appears probable that in the case of the Vaternish type flows the carapaces were sufficiently impervious to conserve enough of the volatiles in the central portion to permit coarse crystallization to ensue ; the feldspars in this type are as coarse or coarser than those in the thick sills intruded into the Jurassic sediments. The Vaternish type flows are nevertheless quite definitely extrusive, and exhibit the characteristic four-fold layering. This can be seen very well in the cliffs of Tianavaig Bay. Conservation of volatiles is also indicated by the presence of pegmatitoid segregations (see p. 112) in the Vaternish type flows. The suggested picture of the consolidation of a typical lava is, then, that a solid crust formed at the top and bottom surfaces of the flow as it moved, and that in some cases there was a considerable time-interval before the centre consolidated. If the centre solidified as a whole, prismatic jointing was produced as in a sill. Subaerial weathering, if sufficiently prolonged, produced a laterite-like soil on the top surface of the crust. Tropical conditions are not necessarily implied, since the internal heat of the cooling flow would contribute to the efficiency of the weathering process. While recent and present-clay parallels for this process are easy to find in regions of current basaltic vulcanism, it may be noted that in Skye ropy (pahoehoe) or blocky (aa-aa) surfaces of lavas are seldom if ever to be observed. Presumably these are transient features, readily destroyed by weathering or concealed by later flows.

Petrography and chemistry of a stratified lava. To investigate the relations between the various layers listed above, the second lava flow of the main series exposed at Creag Mor was chosen. The section is as follows:

	feet
4. Red bole	1½–2
3. Purple amygdaloidal basalt	8
2. Massive basalt, columnar jointed	50
1. Amygdaloidal basalt, resting on bole above 1st lava	½–1

The rock of the massive layer (S37873) [NG 508 448] is a microporphyritic olivine-basalt of Hebridean type, containing hypautomorphic or rounded olivines up to 1.5 mm diameter, set in a groundmass of plagioclase laths averaging 0.3 mm long. There are a few larger plagioclases which might be regarded as microphenocrysts, and in these conspicuous zoning, with cores having a maximum anorthite-content of 70 per cent, is displayed. The range in the typical groundmass plagioclase is approximately An_{62} to An_{66}. Augite, pale mauve under the microscope, encloses the feldspars in ophitic clots up to 1.5 mm in diameter. There are also small olivines, possibly of a second generation, and automorphic titanomagnetites of 0.05–0.15 mm in the groundmass. A little pale green chlorite is present, and olive-green bowlingite seams some of the olivine phenocrysts. Interstitial thomsonite and analcime are present, but in small amounts only. An analysis of this rock is given in column VI, (Table 4).

Relics of a comparable texture are preserved in the overlying amygdaloidal rock (S37874) [NG 508 448]. Pseudomorphs in a highly magnesian chlorite (having $\gamma = 1.54+$) after olivine are of the same dimensions as the olivine phenocrysts in the massive layer. The groundmass plagioclases again average 0.3 mm long, but they have been extensively attacked by chlorite. The interstices between the feldspars are filled with dark, iron-rich glass, with in places, skeletal, slag-like clinopyroxenes. It is noteworthy that no titanomagnetite crystals are to be found; their constituents are presumably in the glass and the implication is that they crystallize late in the magma. Numerous gas-cavities occur, lined with stilbite, chabazite, analcime and fibrous ?laumontite, as well as with chlorite. A channel sample was cut in order to determine the average composition of this rock, which is given in column VII, (Table 4).

In the bole (S37875) [NG 508 448] relics of the texture of the amygdaloid can be seen in patches, surrounded by dense red iron oxide. There are also a few rounded grains of fresh calcic plagioclase, microcline, quartz and clinopyroxene which must be regarded as detrital. A small area in the slice shows basalt of finer grain-size than the average for the flow, but with better-crystallized clinopyroxene than in the upper amygdaloid. Irregular cracks in the bole have been infilled with a mosaic of fine-grained quartz. The composition of an average sample is given in column VIII, (Table 4).

(Table 4) Analysis of Hebridean basalt, amygdaloid and bole

	VI	VII	VIII	D	E
SiO_2	45.99	42.40	34.27	46.12	44.15
Al_2O_3	14.65	14.66	19.72	15.46	15.49
Fe_2O_3	223	8.82	18.55	3.85	7.57
FeO	9.80	4.92	0.82	6.51	2.57
MgO	9.46	8.33	5.05	10.12	6.36
CaO	8.68	8.40	648	10.66	9.08
Na_2O	2.83	2.60	1.70	1.48	2.01
K_2O	0.46	0.30	0.32	0.65	0.31
$H_2O > 105°$	2.34	3.68	6.31	2.38	5.80
$H_2O > 105°$	1.38	3.76	3.51	1.01	4.90
TiO_2	1.90	2.09	2.71	1.37	P35
P_2O_5	0.20	0.21	020	0.06	0.08
MnO	0.19	0.15	0.20	0.21	0.20
CO_2	tr.	tr.	0.01	—	—
S	0.02	0.01	tr.	tr.	—
Cr_2O_3	0.05	0.03	0.03	—	—
NiO	0.01	0.01	0.02	—	—
BaO	0.01	0.01	0.01	—	—
SrO+	0.03	0.03	0.07	—	—
Li_2O	nt. fd.	nt. fd.	nt. fd.	—	—
	100.23	100.41	99.98	99.88	99.87

+ Spectrographic determinations.

VI Massive centre of 2nd Lava, Creag Mor, of Beal Point, Rubha na h'Airde Glaise, Skye.

VII Upper Amygdaloid of 2nd Lava, same locality.

VIII Bole above 2nd Lava, same locality.

D Middle part of lava flow, Island Magee, Antrim.

E Vesicular, zeolitic, upper part of lava flow, Island Magee, Antrim.

Analysts: VI, VII, VIII, W. F. Waters and K. L. H. Murray, Geological Survey Lab. Nos. 1577, 1578, 1579, (1951), Guppy and Sabine 1956, pp. 27, 28. D, E, W. H. and F. Herdsman in Tomkeieff, 1934, p. 502.

The principal chemical differences between the centre and the upper carapace are (i) a major increase in ferric at the expense of ferrous iron in the latter; (ii) a sharp rise in water-content; (iii) an appreciable decrease of lime and silica and small decreases in alkali-content. A comparison of the middle and the amygdaloidal top of a Hebridean-type lava described by Tomkeieff (columns D, E in (Table 4)), shows differences of the same type and order, except that soda is higher in the amygdaloid here. In both instances alumina remains constant. The strongly oxidized state of the iron suggests either the influence of atmospheric oxygen, or the initial presence of iron-bearing minerals which were more susceptible to the effects of later weathering than those in the massive centres.

The conversion of amygdaloid into bole is accompanied by a further sharp rise in ferric oxide, and the elimination of most of the remaining ferrous oxide. Following the pattern of lateritic weathering, alumina rises at the expense of lime, magnesia and silica, notwithstanding the presence of free silica in the bole. In some cases the texture of the lava can be discerned in the bole (for example (S37919) [NG 4952 5399], (S37920) [NG 4952 5400], Storr; (S37877) [NG 4836 5496], (S37878) [NG 4834 5496], (S37879) [NG 4833 5495], Hartaval; (S37946) [NG 4868 4415], (S37947) [NG 4868 4417] Vaternish type, R. Chracaig); but in other cases the texture is totally destroyed (for example (S37880) [NG 4506 6904], (S37885) [NG 4505 6906], Quirang; (S39100) [NM 9508 7992], (S39101) [NM 9470 8026], mugearite, Hartaval).

At one time it was supposed that a mineral species called plinthite existed in certain boles (Thomson 1836; Heddle 1882, 1883). Re-examination of some of the material by J. M. Sweet (1960) shows it to consist of mixtures of zeolites and haematite; but the type specimen is a montmorillonitic clay with haematite and a little analcime.

Petrography of Hebridean type olivine-basalts

The rocks of the Hebridean type olivine-basalts include green to black trappides from the central portions of the flows, and pale grey, purple or greenish amygdaloids from the upper and lower carapaces. In the trappides, small amygdales are seldom entirely absent, but usually they do not constitute an important part of the rock. In most cases the texture of the central portion shows a considerable measure of consistency, but in a few instances, coarse segregations, to which the term pegmatitoid (Lacroix 1928, Dunham 1933) is applicable, can be found. These are taken to represent pockets where accumulated volatiles slowed down the rate of crystallization. In shape they are often irregular but there is a tendency to form flat-lying schlieren. In the trappides the olivine phenocrysts, which are a universal feature of the type, can in some cases be seen with the naked eye.

The amygdales contain zeolites, chlorite and green mineraloids of the kind that petrographers at one time called viridite, and which would come within Peacock's (1930) definition of chlorophaeite, though not necessarily exhibiting the colour-change on exposure associated with that material in some dolerites. These late minerals and mineraloids are discussed in a separate section below.

There is little doubt that the amygdaloids are very much more susceptible to alteration by superficial weathering than the trappides ; indeed this is the reason for the step-featuring which is such a characteristic part of the scenery in the lava country. Thus the mineral composition of the amygdaloids may well differ at surface from that to be found underground. In the absence of specimens from borings, however, it is not possible to ascertain this directly.

From microscopical evidence, the Hebridean type lavas are to be classed as olivine-phyric, olivine-basalts, generally carrying a mesostasis of zeolites. The essential pyrogenic minerals are olivine, clinopyroxene, plagioclase and titanomagnetite ; each species will be considered in turn.

Olivine is present as phenocrysts in all the lavas of this type. Previous descriptions of the Plateau type lavas, other than that in the Ardnamurchan Memoir (Richey and Thomas 1930, p. 114) appear to lay insufficient stress upon

the existence of what is plainly an early generation of this mineral. In the hand specimen the olivine is yellowish-green to green, but in thin section it appears colourless. The crystals may have well-developed automorphic faces ((S31302) [NG 2531 6147], (S31313) [NG 2366 6033], (S31345) [NG 2618 6230], (S31408) [NG 3495 4119], (S31420) [NG 3761 5866], (S31595) [NG 2305 4812]) or the habit may be tabular or platy ((S36194) [NG 1646 5624], (S36206) [NG 1570 5459], (S37914) [NG 4954 5397]). Far more commonly, however, the olivine phenocrysts show rounded outlines, and this may be regarded as the normal case. In diameter they range from 0.25 mm up to 3.5 mm, but a scatter-diagram based on measurements on all the available slices shows a strong maximum for the range 0.5–1.0 mm and a subsidiary peak at 2.0 mm. These olivines are classed as phenocrysts because they fail to enclose either plagioclase or pyroxene crystals. They do, however, enclose tiny automorphic crystals of titano-magnetite, even when perfectly fresh, and it appears necessary to assume that at least some of the iron-titanium oxide crystallized early, unless the oxides were introduced by replacement, which appears unlikely.

There can be little doubt that this generation of olivine had already crystallized before the basalt magma was extruded, and that the rounding of the crystals is due to abrasion while they were being carried in suspension. There is however, in many of the basalts, though not in all, evidence of a second generation of olivine crystals, rarely exceeding 01 mm in diameter. These can be seen to enclose feldspars and they are often enclosed in clinopyroxene plates. The aggregate quantity of olivine of the second generation is usually less thin that of the porphyritic kind; for example in a Hebridean basalt from Score Horan (S37987) [NG 2858 5891] olivine phenocrysts make up 17½ per cent by weight of the rock, while second generation olivine amounts to less than 10 per cent. However, there are exceptional cases where the latter exceeds the former; another lava from Score Horan (S37990) [NG 2850 5887] contains 6 per cent phenocrysts, and 21 per cent second generation olivine.

Estimates of the composition of the olivines have been made by the immersion technique of refractive index measurement. This method is regarded as preferable to the measurement of apparent optic axial angle by means of the universal stage, as advocated by Tomkeieff (1939) and used in recent investigations of olivine in the Shiant Islands Sill by R. Johnston (1953). As will be evident from the table given by the former author (Tomkeieff 1939, p. 235), in the highly magnesian olivines a variation of 1° in 2H corresponds to 11, 7 and 5 per cent of fayalite in the range from 0 to 23 per cent Fa. As the apparent optic axial angle is not directly observable in this range (see for example the strictures of Hess (1949) on indirect measurement of 2H, which accord with our experience) this can only be an inaccurate procedure for the determination of magnesian olivines. On the other hand, according to recent refractive index data (Deer and Wager 1939; Winchell 1951), a range of 0.002 in β (the accepted limit of error in immersion measurement) corresponds to less than 2 per cent fayalite content. The procedure adopted here was to use bromoform concentrates of the ferromagnesian minerals from the lavas investigated. In all but a few cases, the olivine grains were readily distinguishable from the coloured clinopyroxenes. Determinations of β on oriented grains, and of the maximum and minimum refractive indices on some hundreds of grains in each powder then indicated the range of olivine composition present. That a range exists is shown by the results given in (Table 5): It arises from two causes: (1) zoning; (2) differences in composition between first and second generation crystals. Observation on sections showing an optic axis normal to the section seldom reveal much evidence of zoning in the Hebridean basalts (though this is very evident in the mugearites) and it is considered that cause (2) is the more significant. The olivines of the Skye Hebridean basalts shown an extreme range from Fa_{13} to Fa_{30}, but the average composition is in the vicinity of Fa_{20}.

In the trappide centres, much of the olivine is fresh, but it is seldom completely unaltered. Various alteration products occur. Highly birefringent green bowlingite may form fringes and fill cracks traversing the mineral (S31311) [NG 2419 6077], (S33824) [NG 2222 4172], (S33872) [NG 2316 4380]. Occasionally olivine is rimmed with golden-yellow xylotile (S37914) [NG 4954 5397]. Reddish-brown iddingsite occurs in a similar way, and may result from the oxidation of bowlingite (S31383) [NG 3139 3616], (S31457) [NG 4732 4383], (S31461) [NG 4776 4624], (S32465) [NG 2452 5578]. Complete or partial replacement of olivine by iron oxides, probably a mixture of magnetite and haematite, is occasionally seen (S31425) [NG 4309 5912], (S33806) [NG 2445 4236]. Carbonates, including calcite (S31304) [NG 2482 6130] may also pseudomorph the olivine but this is far less common in these rocks than in many older lavas. Probably the most widespread type of alteration of olivine is to a low-birefringence magnesian chlorite (S37884) [NG 4506 6905], (S37889)

[NG 4503 6909] and in some cases the chlorite has brown margins, as if representing a thin outer zone in the olivine where the iron-content was greater (S37885) [NG 4505 6906]. In the amygdaloids, olivine has usually been completely altered, either to chlorite, or to a dirty green mineraloid (S37980) [NG 2859 5894].

The plagioclase occurs as a mesh or network of slender laths ranging up to 0–5 mm long. In a few cases, they are arranged in a fluxion texture (S37970) [NG 509 458], (S38006) [NG 4680 4165]) but this is unusual and it appears likely that the magma was stationary before much feldspar crystallized. In composition the plagioclase lies within the labradorite range and the crystals usually show distinct zoning. The estimates of composition given in (Table 5) are based on refractive index measurements in powders from the light fractions in bromoform. In the other slices examined, observations of extinction angles and other optical properties suggest a similar range, with occasionally an outer zone more sodic than those in (Table 5). Except where they have been attacked by zeolites, which embay the margins and penetrate along cleavages and twin planes (S36194) [NG 1646 5624], (S36195) [NG 1645 5619], (S36196) [NG 1762 5682], (S36197) [NG 1747 5673], (S36225) [NG 3687 4902] the feldspars are fresh and clear in the trappide centres. Albitization is extremely rare and was proved in a single instance only (S31460) [NG 4211 4960].

The pyroxenes all belong to the augite group as restricted by Hess (1949); all show extinction angles in the range 40–45°, and repeated observations failed to reveal a single instance of a pyroxene with optic axial less than 40°. The clinopyroxene from lava 12 of The Storr sequence (Table 5) (S37909) [NG 4944 5388] was found to have 2V = 52°, β = 1.700; corresponding with a sub-calcic augite. This may be compared with the properties of a purple pyroxene separated from a pegmatitoid patch in lava 4 of the same sequence (S37901) [NG 4960 5370], which showed 2V = 50°, β = 1.706, possibly nearer the augite-ferroaugite boundary (see Hess 1949) than the previous example. Owing, however, to the effect of Ti and Al upon their optical properties, it is not proposed here to attempt a closer definition of the composition of the pyroxenes of the basalts.

(Table 5) Minerals in lavas exposed at The Storr and Rubha na h-Airde Glaise. (One-inch Sheet 80, six-inch Sheet Skye 18 N.W.)

Lava No.	Slice No.	Symbol 1" map	Olivine % Fa	Plagioclase % An	Ol	Py	Mode Pl	Wt % Mt	Ch	Z
S										
24	(S37922) [NG 4956 5405]	Wm	32–35	32–20	2	23	48	25	1	-
23	(S37921) [NG 4952 5400]	oB	24–30	55–30						
22	(S37919) [NG 4952 5399]	oB	19–20	54–48						
21	(S37918) [NG 4952 5399]	oB	19–24	68–57						
20	(S37917) [NG 4953 5398]	oB	18	69–55						
19	(S37916) [NG 4953 5398]	oB	18	66–52						
17	(S37915) [NG 4954 5397]	oB	25	64–57						

16	(S37914) [NG 4954 5397]	oB	18							
15	(S37913) [NG 4955 5396]	Bc		70–62						
14	(S37912) [NG 4955 5396]	Bc	20	70–						
13	(S37911) [NG 4940 5392]	oB		66–						
12	(S37909) [NG 4944 5388]	oB		65–55	5	28	43	7	16	1
11	(S37908) [NG 4946 5386]	oB	13–20	66–	24					
10	(S37907) [NG 4948 5384]	fB		68–58	1	17	27	8	37	10
9	(S37906) [NG 4950 5382]	oB	18–20	70–58	16	31	35	15	2	—
8	(S37905) [NG 4952 5380]	oB	16–20	66–	23	29	33	10	3	2
7	(S37904) [NG 4954 5378]	oB	19	70–55	13	25	44	11	1	6
6	(S37903) [NG 4956 5376]	oB	18–20	67–60	19	25	36	9	11	—
5	(S37902) [NG 4958 5373]	fB	19–25	75–65						
4	(S37900) [NG 4962 5367]	oB	19–20	67–	14					
3	(S37899) [NG 4964 5364]	oB+	19–26	45–20	14					
2	(S37898) [NG 4966 5362]	oB	20–25	65–	19	25	40	9	6	—
1	(S37896) [NG 4970 5355]	oB	21–25	68–	5	23	53	6	13	—
R										
6	(S37975) [NG 509 458]	oB	24	56–	17	32	34	6	—	11

5	(S37974) [NG 509 458]	oB	18–24	64–	14	24	48	10	—	4
4	(S37973) [NG 509 458]	oB	17–		18	24	39	11	—	8
3	(S37970) [NG 509 458]	oB	18–21	60–	15	20	48	14	—	3
1	(S37968) [NG 509 458]	oB	18	55–	20	19	50	5	—	6

R = Cliff section ■ mile N. of Rudha na h'Airde Glaise.

S = Storr; nos. 1–13 in cliff S. of Coire Faoin; nos. 14–24 in southermost gully on main east face.

Under mode the symbols used are as follows (figures in brackets assumed densities): Ol–olivine (3.3); Py–pyroxene (3.3); Pl–plagioclase (2.7); Mt–titanomagnetite (5.0); Ch–chlorite (2.6); Z–zeolites (2.1).

In colour the clinopyroxenes show considerable variation. Of 155 slices examined for the purpose, 64 showed augite of a definite purple or mauve tint (of the shade usually supposed to denote the presence of Ti); 59 were in shades of brown, pale brown and yellow; 7 were distinctly green, while to our eye, 25 were colourless. Thus it is certainly not true to say that purple augite is characteristic of the Hebridean lava type; nor is there any correlation between this colour in pyroxene and the presence or absence of an abundant zeolitic mesostasis in the rock.

In habit the clinopyroxenes also vary considerably. A well defined ophitic habit, whereby a single crystal of augite envelops many feldspar laths in diverse orientations, was noted in exactly half of the 214 slices examined. Of the remainder, 31 were intersertal or subophitic, and 71 intergranular. The ophitic crystals commonly reach 2.5–3.0 mm in diameter; granules, on the other hand, nestling in clots between the feldspar laths, rarely exceed 0.25 mm diameter.

The opaque minerals have already been mentioned as occurring as tiny euhedra included in the olivine phenocrysts. These rarely exceed 0.05 mm in width. Opaque minerals also form elongate plates and hypautomorphic grains intergrown with the feldspar and pyroxene, usually somewhat larger than the inclusions in the olivine, but rarely exceeding 0.25 mm in their greatest dimension. A polished section of the analysed rock (S37873) [NG 508 448] on examination at high magnification showed that the opaque constituent is silver-grey in reflected light and homogeneous. It proved to be completely isotropic and is distinctly magnetic. It is therefore identified as titanomagnetite<ref>In the sense in which this term is used by Chevalier, Bolfa and Mathieu 1955).</ref>, for, having regard to the TiO_2 content of the rock (p. 110) it is very probable that it carried $FeTiO_3$ in solution, and that the rate of cooling has been such as to inhibit unmixing. Another example (S37877) [NG 4836 5496], from Bealach Hartaval, showed similar homogeneity. However, the coarser magnetite from a pegmatitoid in lava no. 4 of The Storr sequence (S37901) [NG 4960 5370] proved to contain lamellae of exsolved anisotropic ilmenite, a further illustration of the slow rate of cooling in these coarse segregations.

It remains to consider the mesostasis of the Hebridean type lavas. Examples of rocks entirely composed of the pyrogenic minerals listed above are very rare, though occasionally an example can be found where the only other constituent is chlorite, in very small amount (S37898) [NG 4966 5362], (S37928) [NG 4923 4232]. The normal situation is, however, that pockets of zeolites and of chlorite occur in the angular spaces between the feldspar laths. Among the zeolites, the commonest are analcime, thomsonite and chabazite. Analcime forms clear and cloudy pools which may be completely isotropic, or which may exhibit feeble birefringence. The refractive index is close to 1.490 and faujasite and levynite may also be present; indeed on chemical grounds these calcic zeolites would be expected rather than analcime. Distinction from chabazite is also difficult unless the rhombohedral cleavage or crystal outline of this mineral can be seen (S37885) [NG 4505 6906], (S37891) [NG 4501 6912]. Thomsonite forms groups of fibres showing characteristic Y-elongation. In a pegmatitoid from Quirang (S37882) [NG 4506 6904] the phyllosilicate gryolite was identified; this occurs with zeolites at other localities described below and it may be a more frequent constituent of the mesostasis than has been supposed. The chlorites vary considerably in colour from bright green in thin section to nearly colourless. Magnesian types with positive elongation, birefringence of 0.005 or less, and refractive index 1.60–1.61 are commonest e.g. (S37896) [NG 4970 5355], but occasionally examples with higher birefringence can be found e.g. (S37903) [NG 4956 5376].

The pegmatitoids (S37582) [NS 387 760], (S37901) [NG 4960 5370], (S37910) [NG 4942 5390] associated with the Hebridean type lavas differ from the lavas both in composition and texture. The most striking feature is the total absence of olivine, showing that these patches formed when the physicochemical conditions for the separation (probably the necessary high temperature) no longer existed. The pyrogenic minerals are clinopyroxene (as indicated above, probably somewhat more ferriferous than the augite of the lavas), plagioclase which may be as sodic as oligoclase, magnetite with ilmenite lamellae, and abundant analcime, thomsonite, chlorite and other hydroxyl-bearing minerals. Pyroxene and plagioclase may reach 5 or even 10 mm long.

Composition of the Hebridean type lavas. Few of the Hebridean-type lavas are free from zeolites and chlorite and the centre of the 2nd lava of Creag Mor (S37873) [NG 508 448], a chemical analysis of which has already been cited (p. 103), is representative of the type. In (Table 6) this is compared with other Skye olivine-basalts, and C.I.P.W. norms are given. It is interesting to note that the normative feldspar (An_{52}) is decidedly more sodic than the range of composition deduced from optical measurements (An_{62-70}), showing that the Na/Ca ratio is higher in the zeolites (chiefly analcime and thomsonite) than in the plagioclase.

The mode of the rock, measured by means of a count of 4100 points, gave the following results in volume per cent; Plagioclase, 43; Zeolites and Chlorite, 10; Pyroxene, 28; Olivine, 12; Titanomagnetite, 7. The result shows a poor correspondence with the norm, but measurement of a second section gave almost identical figures, and measurement by a second observer provided further confirmation. The discrepancy, a tendency to obtain low results in the mode for light minerals, high results for the dark, is considered to be due to the overlap effect in this fine-grained rock, where the feldspars average only 0.3 mm long (see for example Chayes, 1956), causing pyroxenes to overlie feldspar within the thickness of the slide. The modal figures given in

The plagioclase occurs as a mesh or network of slender laths ranging up to 0–5 mm long. In a few cases, they are arranged in a fluxion texture (S37970) [NG 509 458], (S38006) [NG 4680 4165]) but this is unusual and it appears likely that the magma was stationary before much feldspar crystallized. In composition the plagioclase lies within the labradorite range and the crystals usually show distinct zoning. The estimates of composition given in (Table 5) are based on refractive index measurements in powders from the light fractions in bromoform. In the other slices examined, observations of extinction angles and other optical properties suggest a similar range, with occasionally an outer zone more sodic than those in (Table 5). Except where they have been attacked by zeolites, which embay the margins and penetrate along cleavages and twin planes (S36194) [NG 1646 5624], (S36195) [NG 1645 5619], (S36196) [NG 1762 5682], (S36197) [NG 1747 5673], (S36225) [NG 3687 4902] the feldspars are fresh and clear in the trappide centres. Albitization is extremely rare and was proved in a single instance only (S31460) [NG 4211 4960].

must therefore be treated with caution; it seems certain that they have no more than a general comparative value, though it is believed that the estimates of olivine-content can be relied upon.

An attempt to find a rock free from hydroxyl-bearing minerals for the purpose of investigation being carried on by Professor C. E. Tilley showed how difficult this is to achieve. However, one such rock was discovered, and the analysis (Muir and Tilley 1962, p. 212) and the norm are quoted in Column IX, (Table 6). The rock (S43948) [NG 4666 4621] contains tabular, slightly corroded olivines up to 1 mm long, set in a basaltic framework of 0.3 mm plagioclase, intergranular and subophitic pale augite, and titanomagnetite.

These figures raise the question of consistency within individual lava flows. Tomkeieff (1934) has demonstrated a measure of gravitative differentiation within a basalt probably allied to the present suite at Island Magee. No comparable case has been found during the present survey, but in several instances pairs of specimens from different parts of the same flow gave closely similar modal analyses. For example, two specimens from the lowest exposed lava, 50 ft thick, at

Maoladh Mor, Quirang, showed:

		ol	py	pl	mt	ch
(S37781) [NN 0948 7578]	18 ft above base	24	28	38	8	2
(S37780) [NN 0953 7561]	near base	24	28	37	10	1

(Table 6) Analyses and norms of Hebridean Type Basalts. Skye

Analysis		VI		IX		F		G		H	
SiO_2		45.99		46.12		46.61		46.38		45.68	
Al_2O_3		14.65		13.94		15.22		16.77		14.66	
Fe_2O_3		2.23		1.95		3.49		3.22		2.88	
FeO		9.80		10.46		7.71		8.03		9.67	
MgO		9.46		11.08		8.66		8.83		9.82	
CaO		8.68		9.05		10.08		10.68		9.37	
Na_2O		2.83		3.11		2.43		1.94		2.14	
K_2O		0.46		0.57		0.67		0.10		0.19	
H_2O+		2.34		1.49		2.07		2.46		3.43	
$H_2O–$		1.38		0.40		1.10		0.37		0.36	
TiO_2		1.90		1.81		1.81		1.04		1.65	
P_2O_5		0.20		0.23		0.10		0.08		0.07	
MnO		0.19		0.18		0.13		0.24		0.22	
CO_2		tr.		—		tr.		nil		nil	
S		0.02		—		—		—		—	
Cr_2O_3		0.05		—		tr.		—		—	
NiO		0.01		—		tr.		—		—	
BaO		0.01		—		—		—		—	
SrO		0.03		—		—		—		—	
		100.23		100.39		100.08		100.14		100.14	
	Specific Gravity					2.87		2.84		2.97	
	Norm										
or		2.8		3.3		3.9		0.6		1.1	
ab		23.6		21.0		20.4		16.2		17.7	
an		28.8		22.4		28.6		37.0		30.1	
ne		-		2.8		-		-		-	
di	wo	6.8		9.3		8.6		6.4		6.6	
di	en	4.1	13.3	5.7	18.0	5.7	16.5	4.0	12.4	4.1	12.8
di	fs	2.4		3.0		2.2		2.0		2.1	
hy	en	3.1	5.0			6.9	9.7	11.8	17.6	10.2	15.7
hy	of	1.9				2–8		5.8		5.5	
ol	fo	11.5	18.6	15.4	24.3	6.2	0.89	4.3	6.8	7.1	11.2
ol	fa	7.1		8.9		2.7		2.5		4.1	
mt		3.3		2.9		5.1		4.6		4.2	
it		3.5		3.5		3.5		2.0		3.2	
ap		0.3		0.3		0.3		0.3		0.2	
Feldspar		$Or_5Ab_{43}An_{32}$		$Or_7Ab_{45}An_{54}$		$Or_7Ab_{39}An_{34}$		$Or_1Ab_{30}An_{69}$		$Or_2Ab_{36}An_{62}$	

Key To (Table 6)

VI Olivine-basalt, Creag Mor, cliff W. of Beal Point, Rubha na h'Airde Glaise, Skye. Analysts: W. F. Waters and K. L. H. Murray, Geological Survey Lab. No. 1577 (1950), Guppy and Sabine 1956, p. 27.

IX Olivine-basalt, quarry on W. side of road near Achtalean, 2¼ miles N.N.W. of Portree, Skye; Geological Survey slice (S43948) [NG 4666 4621]. Analyst: J. H. Scoon (1960). Muir and Tilley 1962, p. 212.

F Olivine-basalt, near bridge over Allt Fionnfhiachd, Drynoch Skye. Analyst: W. Pollard (1899). Quoted from Harker (1904, p. 31).

G Fine-grained basalt, 100 yd N.W. of Loch Cuil na Breig, Skye. Analyst: W. H. Herdsman. Quoted from King (1953, p. 365).

H Basalt with ophitic texture, 50 yd W. of Strollamus Quarry, Skye. Analyst: W. H. Herdsman. Quoted from King (1953, p. 365).

In spite of the consistencies shown by the analyses of the Hebridean 'plateau' lavas, there is a good deal of variation in their olivine-content, as might be expected from the presence of a pre-extrusion generation of this mineral. This is illustrated by the modal measurements in (Table 5), and also by the results for lavas from the well-exposed cliff section at Biod a'Ghoill, Score Horan, Vaternish ((Table 7), p. 112).

Petrography of Vaternish Hebridean type lavas

In texture the rocks of Vaternish type are olivine-dolerites containing, by definition, plagioclase which exceeds 0.5 mm in average length. The olivine again occurs in two generations e.g. (S36199) [NG 1705 5657] but its porphyritic character is less obvious since the size of the crystals remains the same as in the Hebridean type, while the later feldspars reach lengths comparable with those of the olivines. Measurements on the 42 available slices showed that the range of size, 0.1 to 3.5 mm, is identical with that of the Hebridean type, while there is again a distinct maximum for the range 0.5 to 1.0 mm. The few measurements made suggest that the composition-range is also similar and again in these rocks, there is little obvious evidence of zoning in the olivines.

The clinopyroxenes are again augites, with optic axial angles exceeding 40°. The faintly green pyroxene, for example, in the lava exposed at the foot of the main cliff at The Storr (S37912) [NG 4955 5396] has refractive index $\beta = 1.699$, and $2V = 46½$. No pigeonite was found in the Vaternish type lavas. An ophitic habit is more widespread in this type but it is by no means universal. Altogether 27 examples examined were ophitic, 6 subophitic or intersertal, and 8 intergranular. In colour there was a more marked tendency towards purple tints in the augite, over half the examples studied showing this characteristic while only two were green and two brown.

The range of plagioclase composition is An_{55} to An_n, but the larger part of each of the zoned crystals generally corresponds with the more calcic range of the labradorite division. In a few cases, cores of bytownite have been noticed e.g. (S31381) [NG 3159 3631]. In size, the tabular crystals range up to over 3 mm across e.g. (S38011) [NG 4609 4175] in this group but the normal average is between 0.5 and 1.5 mm. The feldspars, as in the finer-grained basalts, form a mesh, the interstices of which are partly filled with granular ophitic augite, and partly with zeolites and chlorite. The attack upon the feldspar by zeolites, particularly members of the analcime group, is more obvious in these coarse rocks than in the Hebridean basalts e.g. (S32477) [NG 2463 5436], (S32482) [NG 2538 5311], (S32489) [NG 2675 5185], though it is seldom as severe as in some of the intrusive teschenitic dolerites described in Chapter 8.

The zeolites in the mesostasis include, besides analcime, well-developed thomsonite (S31406) [NG 3191 3890], (S32917) [NG 3429 4456], and chabazite (S37904) [NG 4954 5378].

Notwithstanding the slower rate of cooling which the coarser texture of the Vaternish type lavas may be taken to indicate, the opaque constituent is again homogeneous titanomagnetite in the typical example examined in polished section (S37912) [NG 4955 5396], showing no sign, even at high magnification, of unmixing. The titanomagnetite crystals share in general the coarser texture of the rock as a whole, and occasionally reach as much as 0.5 min across (S31399) [NG

3432 3977].

Pegmatitoid segregations are, as might be expected, well developed in the Vaternish lavas. A good example can be seen at the top of the prominent feature which encircles Ben Tianavaig, S. E. of Portree. The feature is formed by a Vatemish type basalt (S37930) [NG 510 413] in which horizontally disposed, coarse segregations occur near the top of the hard portion (S37931) [NG 510 413]. The feldspar in these is conspicuously albitized; the brown augite and titanomagnetite are both coarse, and much analcite and thomsonite are present. In another example, from Quirang (S37887) [NG 4504 6907], the feldspar is oligoclase but it appears to have crystallized as such. Apatite is seen in this rock. Zeolitization of the plagioclase is a normal feature of these rocks e.g. (S38002) [NG 4704 4139].

In addition to zeolites, chlorite is widespread as a late hydroxyl-bearing mineral. In a single instance (S30683) [NG 4089 6411] a little green amphibole has been detected, but this serves to emphasise that for the most part the conditions during the later stages were not suitable for the formation of minerals of this group; probably the pressure was too low.

(Table 7) Minerals in lavas exposed at Biod a'Ghoill, Score Horan, Vaternish

					Mode, Wt per cent			
Lava No.	Thickness Feet	Slice No.	Symbol one-inch map	ol	py	pl	mt	ch
14		(S37993) [NG 2800 5735]	Wm	15	13	53	19	—
13		(S37992) [NG 2835 5877]	oB	20				
12		(S37991) [NG 2841 5884]	oB	13				
11		(S37990) [NG 2850 5887]	oB	26				
9	25	(S37987) [NG 2858 5891]	oB	28				
8	28	(S37986) [NG 2858 5891]	oB	13				
7	36	(S37985) [NG 2858 5892]	oB	19				
6	25	(S37984) [NG 2858 5892]	oB	13	35	38	4	10
5	44	(S37983) [NG 2859 5892]	fB	11	29	44	13	3
4	24	(S37982) [NG 2859 5893]	oB	33				
2	56	(S37979) [NG 2859 5894]	oB	17				

No new chemical analysis of a rock of the Vaternish type has been made but we would regard both the analysed rocks of the 'Great Group of Dolerite Sills' (8057, 7854) cited by Harker (1904, p. 248) as members of this group. The general similarity of these analyses with those of the Hebridean type is at once apparent, though the alkalis in the Broc-bheinn rock (Na_2O 3.58 ; K_2O 1.19) are somewhat higher than normal.

There is, however, little justification for any suggestion that lavas of the Vaternish type crystallized from basaltic magma significantly different in composition from that producing the Hebridean-type lava. The coarser texture is, we suggest, due to a more effectively sealed outer carapace during crystallization. The division between the types is admittedly an arbitrary one, useful for the identification of mapping horizons, and valuable when a distinction is to be drawn between extrusive basalt and dolerite ; but without fundamental significance.

Zeolites associated with the Hebridean and Vaternish Hebridean type basalts. Northern Skye has long been renowned among mineralogists for the beauty and variety of the zeolites and associated minerals to be found in cavities in the lavas. During the second half of last century M. F. Heddle published chemical analyses of nearly all the species found here, and these were collected together in the posthumous volume edited by Goodchild (Heddle 1901).

In connection with the present work, small collections of these zeolites in the possession of the Geological Survey and the Durham University Geology Department (prefix D) have been investigated by optical, and in some cases X-ray methods, with the results summarized below.

Analcime occurs in trapezohedral crystals up to 2 cm in diameter at The Storr, in cavities exposed on the main cliff face in a Vaternish-type lava. The optical properties are anomalous (D. 2417), though a normal X-ray powder pattern has been obtained. The refractive index is 1.481 but in birefringent areas the high index is 1.491. In a vesicle in lava no. 8 of The Storr sequence (S37905) [NG 4952 5380] the analcime, with refractive index close to 1.493, show polysynthetic twinning and is appreciably birefringent. Complex twinning is also seen in a specimen from Quirang with typical analcime morphology, and n = 1.489–1.491. The difficulty of distinguishing birefringent analcime, which appears to be common in these lavas, from faujasite and chabazite has already been mentioned. The new mineral wairikite (Steiner 1955) may be present (it is stated to show polysynthetic twinning) but the whole group of minerals appears to require further investigation.

Chabazite forms clusters of rhombohedra up to 5 mm on the side. A specimen from The Storr (D. 2413A) gave refractive indices, α = 1.485, γ = 1.490. A cavity from the amygdaloid overlying the 4th lava of the Quirang section (S37886) [NG 4504 6907] proved to be lined with chabazite showing α= 1.490, γ = 1.494. According to the data summarized by Winchell (1951, p. 334) these chabazites lie near the calcic end of the series. Variable optic sign and optic axial angle is a characteristic feature. Rhombohedral cleavage is noticeable in thin section, and provides a means of distinguishing the mineral from analcime.

Thomsonite forms white or bluish compact fibrous masses in many specimens. An example from The Storr (D. 2413) showed Y-elongation, parallel extinction, positive optic sign, α = 1.521, β = 1.526, γ = P531. Another (2416) showed α = 1.517, β = 1.522, γ = 1.526. Heddle (1901, p. 110) gave the following analysis of a specimen from The Storr: SiO_2 39.02; Al_2O_3 28.13; Fe2O 33.28; CaO 10.73; K_2O 1.01; Na_2O 3.71; H_2O 13.99; Total 99.87. He also quoted several analyses of a variety called faroelite, the composition of a Storr specimen being: SiO_2 41.32; Al_2O_3 28.44; CaO 11.54; Na_2O 5.77; H_2O 13.26; Total 100.33.

Stilbite occurs as white or cream-coloured radiating bundles. At The Storr (D. 2413) the mineral has negative sign, low 2V, α = 1.493, γ = 1.509; X∧C = 9°. The birefringence is unusually high, but similar properties were shown by another specimen (2415). In a third (2419C), α = 1.495, γ = 1.504, X∧C = 4°. In the basalts the mineral appears to be found chiefly in large cavities, rarely in the mesostasis of the rock, but as mentioned below, extensive replacement of the feldspar of a trachyte by stilbite has been found.

Laumontite occurs both at the Quirang and The Storr as delicate fibres which prove under the microscope to be very elongated plates showing 'hour-glass' type twinning. The optical properties of a Quirang specimen are: optically negative, 2V = 25°; ce = 1.514, y = 1.525, Z∧C = 19–23°. Heddle (1901, p. 91) gave two analyses of laumontite from Storr, one of which showed SiO_2 51.98; $A1_2O_3$ 20.34; Fe_2O_3 0.59; CaO 11.55; H_2O 15.78; Total 100.24. This, he stated, came from a vein 1½ in in thickness.

Mesolite from The Storr (2420) forms fine white hair-like fibres (Heddle described them as 'plumose tufts'). They have birefringence not above 0.001, refractive index close to 1–505. Heddle (1901, p. 108) analysed a specimen from this locality: SiO_2 56.72; $A1_2O_3$ 26.70; CaO 8.90; Na_2O 5.40; H_2O 12.92; Total 100–63.

Levynite, in colourless platy crystals, uniaxial negative with (.0 = 1.502, e = 1.498 occurs at The Storr (D.2419 B). Heddle (1901, p. 96) gave an analysis from the Quirang: SiO_2 43.13; Al_2O_3 21.77; FeO 1.38; CaO 9.25; K_2O 0.95; Na_2O 3.44; H_2O 20.20; Total 100.12.

Apophyllite $KCa_4 FSi_4O_{10}.8H_2O$, though not a zeolite is intimately associated with analcime, chabazite, thomsonite and laumontite at Quirang. The crystals are cubes with pearly lustre, and show penetration-twinning. Under the microscope many crystals are isotropic but a few show ultrablue or low-order grey interference colours. The refractive index is 1.539. A specimen from The Storr (2419A) with thomsonite showed n = 1.540. Heddle analysed a specimen from The Storr; SiO_2 51.2; Fe_2O_3 1.09; FeO 1.09; MnO 0.05; CaO 23.13; K_2O 5.49; Na_2O 0.37; H_2O 17.02; F 0.7; Total 99.89. The occurrence of this mineral is particularly interesting as revealing the availability of fluorine in hydrothermal fluids associated with the basalts.

Gyrolite $H_2Ca_2SiO_3.H_2O$, a phyllosilicate, occurs in white or bluish-white radiating groups of plates at the Quirang, The Storr and elsewhere. A specimen from The Storr (2420) is almost uniaxial, negative, with ω = 1.540. Anderson (1851) gave the following composition for a specimen from Storr: SiO_2 50.70; Al_2O_3 1.48; MgO 0.18; CaO 32.24; H_2O 14.18; Total 99–78.

Other minerals found in the cavities include calcite with ω = 1.660; a platy mineral, biaxial negative with low 2V, α = 1.495, γ = 1.512, inclined extinction 10°, possibly epistilbite (Quirang); and, according to Heddle, scolecite, but this has not so far been found in the collections investigated.

Heddle's doubtful species uigite has been reinvestigated by J. M. Sweet (1959) and found to be a variety of thomsonite. She has also described (Sweet 1961) hydrated calcium silicates including tobermorite, xonotlite and a new member of the tobermorite group, from a quarry on the Staffin road, ½ mile N. of Portree. The new mineral has the composition: SiO_2 41.8; Al_2O_3 5.6; Fe_2O_3 0.3; MgO 3.2; CaO 33.6; Na_2O 0.6; K_2O 0.1; $H_2O + CO_2$ 15.2. It has been named tacharanite. Saponite is associated in the same paragenesis.

With regard to the order of crystallization, there is evidence in many cases that the zeolites crystallized later than chlorite; for example in the Vaternish type lava at The Storr (S37912) [NG 4955 5396] rouleaux of chlorite have been broken up and enclosed in analcime and thomsonite; in many basalts e.g. (S37911) [NG 4940 5392] chlorite forms the initial lining of cavities, which have a later filling of fresh zeolites (levynite in (S37911) [NG 4940 5392]). Feldspars protruding into cavities in pegmatitoids (S37910) [NG 4942 5390] have been coated with chlorite before crystallization of analcime and thomsonite commenced. In another case (S37930) [NG 510 413]–(S37931) [NG 510 413] there may have been an alternation of feldspar and zeolite formation, for the cores of zoned oligoclase crystals have been extensively replaced by analcime and chlorite, while albite outer zones are clear and unaffected. Mesolite is later than analcime and thomsonite in this rock. In crystal-lined cavities, analcime or thomsonite tend to be early minerals, chabazite, stilbite, laumontite and levynite later, and mesolite latest of all.

The time of crystallization of the zeolites poses an interesting question. Their interstitial position in the solid basalts suggests that they filled an open mesh of pyrogenic minerals not long after these crystallized. It is, however, clear that zeolites migrated widely in the lava-pile; for example a red bole (S37921) [NG 4952 5400] at The Storr contains fresh stilbite and analcime which must have been introduced after the weathering process; while examples can be found in the cliffs N.E. of Portree of veinlets of zeolites which cut through more than one lava flow. Empty vesicles in the lavas are uncommon, though partly-filled examples, some of which may show the level of a standing liquid at the time of mineralization, are occasionally found (D. 2450). Against this it may be recalled that modern lavas, for example in Iceland and Hawaii, show empty vesicles. The process of movement of hot waters through the lava-pile must be conceived as long-continued.

Petrography of feldspar-phyric olivine-basalt

The feldspar-phyric basalt group is also to be regarded as a variant of the Hebridean type, to which it is evidently closely related. It differs from the Hebridean type only in containing small phenocrysts of plagioclase, probably the result of pre-extrusion crystallization of this mineral. The phenocrysts are normally within the microporphyritic range, i.e. up to 2 mm long, (e.g. (S31315) [NG 2359 6022], (S31389) [NG 3629 3859], (S31423) [NG 3996 5743], (S37902) [NG 4958 5373]) but a few examples have been found with phenocrysts up to 3 or rarely 5 mm long (e.g. (S32305) [NM 5357 6177], (S32467) [NG 2453 5567], (S32830) [HU 419 252], (S37907) [NG 4948 5384]). It should be noted that the 'big-feldspar' rocks which are common between Bracadale and Mugeary, have a trachybasaltic groundmass, and are not included in the present group. In composition the plagioclase is usually a basic labradorite, occasionally with bytownite inner zones ((S32932) [NG 3390 4628], (S33995) [NG 3631 4820]), but it is not as a rule markedly out of phase with the groundmass plagioclase. The phenocrysts are seldom automorphic or complete; they appear to have been broken up during transport in the magma.

The plagioclase of the groundmass ranges up to 0.2 mm long and has a composition only slightly more sodic than that of the phenocrysts. The texture is identical with that of the Hebridean basalts, save that in a rock from the second flow below the summit of Healaval Bheag (S38095) [NG 2241 4212] it has an orthophyric rather than basaltic appearance. Olivine phenocrysts ranging up to 3.0 mm diameter, in shape automorphic or rounded, are present as in the Hebridean lavas; usually they are more abundant than feldspar phenocrysts. A second generation can often be distinguished.

There seems to be a greater tendency for the augite in the feldspar-phyric basalts to be intergranular rather than ophitic; 20 examples were found to belong to the former category, while only 6 were found to be ophitic. It is not, however, certain that these figures are significant. In a single instance, augite, as well as feldspar, was found to be porphyritic (S32932) [NG 3390 4628]. Well-formed phenocrysts of about 2 mm long occur in this rock, and there is also a second generation of clinopyroxene granules of about 0.05 mm.

Titanomagnetite is present, commonly within the size-range 0.01–0.05 mm. A mesostasis variously of chabazite (S31315) [NG 2359 6022], analcime (S31352) [NG 2665 5510] and fibrous zeolites (S32467) [NG 2453 5567] is found to occur.

No analysis of a member of this group has been made, but it is perhaps appropriate to comment that it is doubtful whether the proportion of feldspar phenocrysts is sufficient, in any of the North Skye examples, to produce a rock as aluminous as the Porphyritic Central Type of Mull (Bailey and others 1924, analyses p. 24, petrography p. 148). Nor are the olivine phenocrysts noticeably less abundant than in the Hebridean or Plateau type, as they are in Mull; for example the feldspar-phyric basalt exposed in The Storr (S37902) [NG 4958 5373] contains 15 per cent by weight of olivine, and 15 per cent labradorite phenocrysts. It is nevertheless interesting to notice that an occasional Mull example shows porphyritic augite, as seen in (S32932) [NG 3390 4628].

Petrography of mugearite

In the field the mugearites are fine-grained, dark grey or black trappides, usually showing closely-spaced platy jointing parallel to the bedding. Weathering gives rise to an orange or brown-coloured crust a few mm thick. In this section we are concerned with the non-feldspar-phyric type, which occurs at the summit of the Beinn Edra, Ramascaig and Beinn Totaig groups, and which forms an important element in the Bracadale and Osdale groups (p. 81).

The type-locality for mugearite, Druim na Criche, lies within the Portree (80) Sheet, on the S.W. side of the headwaters of the Glenmore River, 1½ miles due S. of the crofter hamlet of Mugeary. Harker (1904, p. 246 et. seq.) defined the rock as follows :

'a dark, finely-crystalline rock, without phenocrysts . the exposed outcrops with their yellowish-brown tint and highly fissile character look… like trachyte… chemical analysis shows,… as compared with average rocks of like silica percentage…

low magnesia and lime and high alkalis, including potash as well as soda… rather (a) high amount of phosphoric acid. The chief mineralogical peculiarities… which result from its peculiar chemical composition and go to characterise it as a special rock-type are two :

Firstly, the feldspar is not labradorite but oligoclase, with subordinate orthoclase; and, secondly, the ordinary bisilicate minerals are very poorly represented, augite being typically quite subordinate to olivine . . . and iron ore. Among minor points… may be noted the unusual richness in apatite.'

The type rock ((S8732); analysis 'K', (Table 8)) forms the lower part of what Harker regarded as a composite sill; but Kennedy (1931) has given strong reasons, including the presence of a slaggy layer at the base of the mugearite, for regarding the Druim na Criche occurrence as extrusive. The upper part of the composite flow, as it is now considered to be, is discussed below, for it consists of big-feldspar mugearite.

Reviews of the application of the term mugearite have been written by A. G. MacGregor (1928), A. K. Wells (1954) and F. Walker (1952). According to the latter's re-definition, mugearite is 'a fine-grained aphyric or microphyric rock rich in oligoclase, fissile, and brightly coloured on outcrop, and with well-marked trachytic feldspar laths… less abundant major constituents are orthoclase, olivine and iron ore. Augite is subordinate in amount, biotite and brown hornblende generally present and apatite an abundant accessory. The general aspect is trachytic.'

The recent investigations of I. D. Muir and C. E. Tilley (1961) have provided the important information that the feldspar in the mugearites is potash oligoclase and lime anorthoclase; orthoclase sensu stricto is not present. Further, their studies and the present work have shown that the olivine is decidedly richer in the fayalite molecule than is the case in the normal basalts. It is suggested that both features, which are characteristic of the mineralogy of these rocks, could with advantage be incorporated in a modern definition.

Mugearite lavas, besides forming a capping on the great lava escarpment of The Storr, Hartaval and Beinn Edra, are exposed in numerous places in the country between Mugeary and Edinbain. At many points slaggy tops and bottoms can be seen. Boles have been developed on mugearites at The Storr, and at Bealach Hartaval; at the latter locality 160 ft of massive mugearite, with closely-spaced vertical joints, rests on bole overlying a Vaternish type basalt (S38099) [NG 4793 5569] and is overlain by 20 ft of amygdaloidal mugearite capped by a well-developed red bole (S39101) [NM 9470 8026]. There is no doubt as to the extrusive nature of these rocks.

Olivine forms microphenocrysts generally not over 0.7 mm in diameter, rounded in form, and in some cases showing some intergrowth with feldspar. Measurements of refractive indices show a range in composition in rocks assigned to this group from Fa_{32} (Storr; (S37922)) to Fa_{60} (Bracadale; (S37938) [NG 3620 3918]). According to Muir and Tilley (1961, p. 195) the olivine in the type mugearite of Druim na Criche shows a range of composition from Fa_{37} to Fa_{58}; in a mugearite-basalt from the Rha River it is $Fa_{40–51}$ while in a rock from Totardor which is transitional between the mugearites and the trachytes, the advancing iron-enrichment is shown by olivine compositions of $Fa_{66–71}$: Zoning is plainly seen when a section with an emergent optic axis is examined. In the mugearite from Hartaval analysed for the present account, the olivine in a bromoform concentrate varied little from Fa" and the mineral forms 5 per cent by weight of the rock. In The Storr mugearite (S37922) [NG 4956 5405] it amounts to no more than 2 per cent, but in other mugearites olivine is more abundant; in the type rock (S8732) [NG 437 366]; (S39015) [NM 9490 8300] it is over 10 per cent.

Alkali-feldspar, previously assumed to be a mixture of oligoclase and orthoclase (though the latter mineral could not satisfactorily be distinguished under the microscope) has now been shown by Muir and Tilley (1961) to be potash oligoclase, showing albite twinning, which grades outward into apparently untwinned anorthoclase. From the Druim na Criche rock they separated three fractions which proved to have the following respective compositions: $Or_{14}Ab_{65}An_{21}$; $Or_{20}Ab_{67}An_{13}$; $Or_{25}Ab_{64}An_{11}$. The characteristic fluxion texture is formed of a mass of subparallel elongate crystals of these feldspars, varying up to about 0.25 mm long. Occasionally a few scattered phenocrysts are present, and these tend to be more calcic than the groundmass; for example, those in the Hartaval rock approximate to An_{50}. It is interesting to note that Muir and Tilley (1961, p. 198) find that the central portions of the plagioclase phenocrysts approach as closely to the high structural state as does any natural occurring plagioclase.

Clinopyroxene can be distinguished in many mugearites, though not in all e.g. (S31397) [NG 3626 3933]. When present it occurs in small granules, generally yellowish-brown (S31391) [NG 3842 3806], (S31396) [NG 3566 3888], (S31436) [NG 4191 4473] but occasionally purple (S32487) [NG 2710 5160]. Ophitic augite, though not typical, has been noted in a number of instances (S31750) [NG 454 498], (S32496) [NG 2786 4993], (S32925) [NG 3566 4330]. A microlithic habit is also occasionally seen (S34176) [NG 3522 4920]. Analyses of separated pyroxenes from the Druim na Criche and Rha River rocks published by Muir and Tilley (1961, p. 196) show that these are calcic augites, not greatly different from those normally found in the alkali olivine-basalts; but in the Totardor mugearite-trachyte, the composition has entered the ferroaugite field. Nevertheless, iron-enrichment is not as striking (on present evidence) in the clinoporoxenes as in the olivines of the mugearites.

(Table 8) Analyses of mugearites and trachyte

Analysis	J	X	K	L	XI
SiO_2	47.51	48.12	49.68	58.64	66.13
Al_2O_3	16.99	16.30	16.99	16.38	16.03
Fe_2O_3	3.31	4.90	3.45	3.05	3.17
FeO	10.60	9.11	8.99	4.91	0.70
MgO	4.23	3.80	2.79	1.06	0.84
CaO	6.48	5.97	5.46	2.90	1.45
Na_2O	5.01	5.69	5.78	6.07	5.34
K_2O	0.70	0.74	1.90	3.49	4.82
H_2O+	1.24	1.01	1.77	0.55	0.36
H_2O-	0.55	0.77	0.34	0.99	0.43
TiO_2	2.85	2.74	2.13	0.89	0.61
P_2O_5	0.53	0.56	0.48	0.66	0.08
MnO	0.20	0.20	0.27	0.18	0.10
CO_2	—	—	—	—	—
F	—	—	0.23	—	—
S	—	tr	—	—	—
Cr_2O_3	—	tr	—	—	—
NiO	—	tr	—	—	—
BaO	—	0.02	0.12	0.13	—
SrO	—	0.05*	—	—	—
Cl	—	—	0.02	—	—
	100.20	99.98	100.40	99.90	99.77

* spectrographical determination.

Specific Gravity

	Norm	J		X		K		L		XI	
	Q	—		—		—		2.16		12.12	
	or	3.89		3.89		11.12		20.94		28.73	
	ab	38.25		42.97		38.90		51.35		45.06	
	an	21.96		17.24		14.46		6.95		5.28	
	ne	2.27		2.56		5.61		—		—	
di	wo	2.90	5.76	3.71	7.33	3.25	7.53	1.39	2.85	0.12	0.22
di	en	1.35		1.90		1.30		0.40		0.09	
di	fs	1.51		1.72		1.98		1.06		0.01	
	en	—		—		—		2.20	6.56	2.01	2.26
hy	of	—		3.99		—		4.36		0.25	

Ol	fo	6.47	14.88	5.32	10.52	3.99	10.67	—	—
Ol	fa	8.41		5.20		6.68		—	—
ac		—				—		—	3.20
mt		4.87		7.10		4.98		4.41	1.37
it		5.32		5.17		4.10		1.67	0–67
ap		1.34		1.34		1.34		1.68	—
fl		—		—		0.35		—	—
Normative feldspar	or	6		6		18		27	37
	ab	60		67		60		64	57
	an	34		27		22		9	6

Key to (Table 8)

J. Mugearite-basalt, Rha River above Uig, Skye. Analyst: J. H. Scoon in I. D. Muir and C. E. Tilley (1961, pp. 190–1).

X. Mugearite, top of eastern main scarp, Bealach Hartaval, Skye; from hard centre of a flow 180 ft thick. Analysts: W. F. Waters and K. L. H. Murray, Geological Survey Lab. No. 1580 (1951). Sum. Prog. Geol. Surv. for 1951 (1953), p. 63.

K. Mugearite from the type locality. Analyst: J. H. Scoon in Muir and Tilley (1961) pp. 190–1.

L. Mugearite-trachyte, Totardor, Skye. Analyst: J. H. Scoon in Muir and Tilley (1961, pp. 190–1).

XI. Trachyte, Ros a'Mheallain 1½ miles N.E. of Bracadale, Skye. Analyst: J. H. Scoon (1949); analysis communicated by Professor C. E. Tilley.

Titanomagnetite is very abundant, considerably more so than in any of the basalts; indeed the abundance of opaque granules is one of the most striking features of the group. Often they are no more than 0.01 mm diameter, but occasionally they range up to 0.1 mm. A polished section of the analysed rock (S37876) [NG 4824 5492] reveals complete homogeneity in the silver-grey granules, all of which appear perfectly isotropic. The ore fraction separated from the Druim na Criche rock proved to have the composition: magnetite 37.5, ulvospinel 42.8, ilmenite 19.7 (Muir and Tilley 1961, p. 197) as at Hartaval in homogeneous solid solution. The opaque granules are appreciably magnetic.

Apatite can be distinguished in many slices. Zeolites and chlorite occur in small vesicles and chloritic alteration of the olivine is common To account for the undersaturated C.I.P.W. norm obtained by recalculation of the analysis of the Hartaval mugearite it must be supposed that zeolites are present, though they are not seen in the slices ((S39100) [NM 9508 7992], (S37976) [NG 5052 4468]).

Composition of Mugearite. Harker's description of the type mugearite of Druim na Criche, near Mugeary, was accompanied by an analysis by W. Pollard (Harker 1904, p. 263) which showed 1.47 per cent P_2O_5 (S8732). A new analysis by J. H. Scoon of a rock from the same locality, though unfortunately not of a duplicate of the same rock, is recorded by Muir and Tilley (1961, Table 4, column 1). The two rocks appear identical under the microscope, but there are major differences in the estimates, not only of P_2O_5, but also of Al_2O_3, Fe_2O_3 and FeO. For this reason, the older analysis is not reproduced here. In (Table 8), a new analysis of mugearite from Hartaval is compared with the results for Druim na Criche, Rha River and Totardor cited by Muir and Tilley. Compared with the Hebridean basalts, all these rocks are much richer in alkalis, and somewhat poorer in lime and magnesia, as would be expected from their mineralogy. The River Rha rock may be regarded as intermediate between olivine-basalt and mugearite. A number of similar basalts are represented in the Geological Survey collection, their principal characteristics being the presence of feldspar less calcic than labradorite, and the presence of olivine richer in fayalite than in the normal basalts ((S37899) [NG 4964 5364], (S37921) [NG 4952 5400], (S37940) [NG 402 342], (S37993) [NG 2800 5735]). Transition from mugearite towards trachyte is illustrated by the Totardor rock (S37938) [NG 3620 3918]<ref>Tilley and Muir have recently proposed the name benmoreite for this rock; Geol. Fiiren: Stockholm Forhand, 1964, 85, 439.</ref>.

Owing to the fine grain-size of the mugearites, micrometric analysis fails to yield satisfactory results. It may, however, be of some interest to mention that titanomagnetite reaches as much as 16 per cent by volume in some of these rocks.

Petrography of big-feldspar mugearite and mugearite-basalt

The mugearite and mugearite-basalt are striking in appearance, with glassy yellowish or white plagioclase in a dense, dark grey groundmass. The upper part of the composite sheet at Druim na Criche was described by Harker (1904 p. 262) as porphyritic olivine-dolerite, with medium labradorites up to one-inch long in a fine-grained groundmass containing feldspar, olivine, augite, magnetite and apatite. The groundmass feldspar, on the basis of extinction angles, was identified as labradorite in this rock, but in a similar rock from Talisker was stated to contain more acid feldspar. Harker moreover noted the unusual richness of the rock in alkalis, and Kennedy (1931) subsequently showed that if allowances are made for the phenocrysts, the groundmass of the Druim na Criche upper member differs very little in chemical composition from the associated mugearite. Wager (1956) has suggested that if 50 per cent labradorite is added to the Druim na Criche mugearite analysis, the resulting composition is near that of the big feldspar rock as regards albite and "iron" ratios. The relevant analyses are reproduced in (Table 9).

Additional material has been collected from Druim na Criche and also from Roineval, another locality mentioned by Harker in connection with composite porphyritic dolerite—mugearite sheets. The Druim na Criche rock (S33016) [HU 464 578] has phenocrysts of labradorite near An., as stated by Harker; they are almost lacking in zoning. The groundmass feldspar certainly also contains some labradorite but zoning to andesine or even oligoclase is present. The other constituents are pseudomorphs after olivine in a green mineraloid, subophitic clots of grey augite, titanomagnetite of about 0.1 mm and some chlorite. With feldspars reaching 0.4 mm., the texture of the groundmass here is appreciably coarser than that of the underlying mugearite (S38015) [NG 4339 3683] where the feldspars do not exceed 0.2 mm long.

In the Roineval rock (S37943) [NG 402 342]–(S37944) [NG 402 342] the phenocrysts again reach as much as 2.5 cm in width, but here the composition is An_{55} and the phenocrysts are surrounded by a thin outer zone of oligoclase. There is a marked contrast in this rock between the bulk composition of the phenocrysts and that of the ground-mass feldspar, which consists of fluxion oligoclase of composition near An_{20} probably with anorthoclase. Small broken and altered olivines, tiny augite granules and abundant titanomagnetite granules again complete the assemblage, with the addition (S37944) [NG 402 342] of a little brown hornblende. This rock is properly classified as a porphyritic mugearite, and it is clear that the Druim na Criche rock is a porphyritic mugearite-basalt, not a dolerite.

The big-feldspar rocks form conspicuous parts of the lava succession in the country from Mugeary through Edinbain to Beinn Bhreac, and all the remaining 21 sliced examples prove to have mugearite groundmasses. At Ros a'Mheallain, the hill is capped by big-feldspar mugearite which rests, not on mugearite, but on slaggy trachyte (S37936) [NG 3749 4038]. Evidently the big-feldspar rock occurs independently of the composite flows. The rock here (S37937) [NG 3744 4042] carries labradorite phenocrysts with cores of bytownite, An_{74}, in a groundmass largely of oligoclase, with olivine, subophitic augite and titanomagnetite. Similar contrasts in composition between phenocrysts and groundmass feldspar are shown in other sliced rocks (S31283) [NG 3798 4068], (S31395) [NG 3559 3878], (S31960) [NG 4791 5548], (S32502) [NG 2836 4957], (S32504) [NG 3141 4529], (S33871) [NG 2057 4387], (S36224) [NG 3560 4721] though cores more calcic than labradorite in the phenocrysts are relatively uncommon (S36232) [NG 3538 4877], (S36233) [NG 3529 4865], (S36234) [NG 3521 4858]. All the evidence points to the incorporation of xenocrysts of plagioclase in magma of mugearite composition as the chief factor in producing these striking rocks.

The presence of slaggy tops on rocks of this group e.g. (S38044) [NG 3496 3885] leaves no doubt as to their extrusive origin. In the example cited, the phenocrysts have been severely attacked by analcime.

Composition of Big-feldspar Mugearites. No new analysis has been made, but the analysis from Druim na Criche is reproduced from Harker in (Table 9). If it is compared with the underlying non-porphyritic mugearite (Table 8), K and with the 'Porphyritic Central' type of Mull (Bailey and others 1924, p. 22) this brings out the significantly higher alkali percentages in the mugearitic rocks. A recalculation of the Druim na Criche analysis, subtracting 33 per cent labradorite of composition An_{60} is given; although this corresponds roughly with the amount of phenocrysts present, the result suggests that the groundmass of this rock is not identical with the underlying mugearite, but has more calcic plagioclase, a fact already established by petrographical examination. Kennedy's (1931) calculation, in which 33 per cent feldspar of composition An_{75} is added to the non-porphyritic mugearite analysis (Table 9), column MK gives better agreement, but corresponds less well with the observed mineralogy.

(Table 9) Analysis of porphyritic mugearite

	M	MK	MD	PC
SiO_2	50.33	49.26	48.5	50
Al_2O_3	19.97	21.42	15.2	18
Fe_2O_3	2.81	4.06	4.2	9
FeO	6.23	4.78	9.4	
MgO	3.24	2.02	4.8	5
CaO	8.03	8.60	6.0	10
Na_2O	4.30	4.40	4.1	2.5
K_2O	1.19	1.40	1.8	0.4
H_2O+	0.99	1.07	1.5	
H_2O-	0.87	0.72	1.3	
TiO_2	1.81	122	2.7	
P_2O_5	0.17	0.98	0.3	
MnO	0.17	0.19	0.2	
BaO	0.06	—		
S	nt. fd.			
	100.17			

M. "Porphyritic olivine-dolerite", Druim na Criche, 5 miles S.S.W. of Portree, Skye; Analyst: W. Pollard (Harker 1904, p. 263).

MK. Calculated composition of a rock consisting of one-third labradorite (Ab_2 An_3) phenocrysts in a groundmass of mugearitic composition (Kennedy 1931, p. 177).

MD. Composition of porphyritic rock of M with one third labradorite of composition An_{60}, subtracted.

PC. Porphyritic Central Magma-type of Mull for appropriate silica percentage (Bailey and others 1924, p. 22).

Petrography of trachyte

The trachyte lavas, which occur chiefly in the central and southern regions of One-inch Sheet 80, vary in colour from cream to pale grey. Their slaggy tops and bases tend to assume a purple tint. The rocks exposed by the roadside at Ros a'Mheallain, 2 miles N.E. of Bracadale ((S37868) [NG 3739 4039]; analysis XI, (Table 8)) shows small scattered biotite and feldspar phenocrysts in a stoney groundmass. The biotite, which is pleochroic X yellow < Z deep brown, has $\gamma = 1.630$, presumably lies midway between the magnesium and iron ends of this complex series. The feldspar phenocrysts, where unaltered, are apparently of orthoclase, but they have been extensively converted to stilbite, with perceptible inclined extinction, negative $2V = 30°$, $\alpha = 1.491$, $\gamma = 1.500$, in the Geological Survey specimens. A little chabazite is associated with the stilbite, and some mesolite occurs in cavities. Rounded crystals of a dark green clinopyroxene with high refringence (satisfactory determinations were not obtained) suggest hedenbergite rather than ferroaugite (S37934) [NG 3757 4030]. A nearly colourless acicular amphibole, with $Z \wedge C = 22°$, $\gamma = 1.645$ also occurs in small amount. The main constituent of the rock, enclosing all the others so far mentioned, is alkali-feldspar in laths of about 0.1 mm long, arranged in a trachytic texture. These show more or less parallel extinction. The analytical data show that albiteoligoclase, An_{10} is the main constituent but the problem of potassium substitution in the molecule again arises here, for separate albite and orthoclase in the groundmass are not distinguishable. Scattered granules of titanomagnetite are present, but they are far less abundant than in the mugearite or the benmoreite. In types transitional to mugearite the proportion of the opaque constituent increases rapidly, and is accompanied by a darkening of the colour of the rock (S32921) [NG 3509 4440], (S36240) [NG 3065 5045], (S38046) [NG 3486 3932]-(S38047) [NG 3476 3944].

The slaggy trachyte (S37936) [NG 3749 4038] seen above the mugearite which rests on the main trachyte at Ros a'Mheallain contains a well-crystallized zeolite of orthorhombic aspect in cavities. This is identified as heulandite; it is optically positive, has high 2V, $\gamma = 1.508$; X inclined at 6° to one strong cleavage.

In addition to zeolites, agate occurs as an amygdale filling in the trachytes (S38047) [NG 3476 3944]. The appearance of quartz in the norm at the trachyte end of the series presented in (Table 8) shows that an oversaturated condition is finally attained in these rocks. Fluorine continues to be available, for apatite can be identified in some examples e.g. (S31409) [NG 3719 4189].

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TABLE I

ANALYSES OF PALAGONITE, GLASS AND TUFF

	I	II	III	A	IV
SiO_2	51·5	56·0+	43·3+	37·8	33·24
Al_2O_3	15·6	15·8	11·5	13·7	21·53
Total Fe as Fe_2O_3	10·6	1·5	14·7	12·3	3·23
MgO	5·7	1·0	2·1	1·9	0·72
CaO	10·4	2·2	1·6	1·6	2·36
Na_2O	3·2	6·2	8·2	3·8	0·13
K_2O	0·6	2·2	0·8	3·4	0·07
Ignition loss	0·7	14·3	16·4	23·0	35·69
TiO_2	1·7	0·8	1·4	—	2·73
P_2O_5	—	—	—	—	0·25
MnO	tr.	tr.	tr.	2·5	0·09
Cl	—	—	—	—	tr.
S	—	—	—	—	Nil.
Cr_2O_3	—	—	—	—	tr.
BaO	—	—	—	—	0·10
Li_2O	—	—	—	—	tr.
	100·0	100·0	100·0	100·0	100·14

	I	II	III	A	IV
FeO	8·9	tr.	1·4	—	—
H_2O below 105°	0·3	5·0	7·3	—	24·65
CO_2	—	—	—	—	0·22
C	—	—	—	—	0·60

+ by difference

I Yellow glass separated from 'palagonite' tuff, n= 1·595, Creag Mor, Skye

II Colourless glass from 'palagonite' tuff, n = 1·476 Camas Ban

III Brown partly devitrified glass from 'palagonite' tuff, Camas Ban

A Palagonite, 2,350 fathoms Pacific Ocean, lat. 13° 28′ S. long. 149° 30′ W. (Peacock, 1930).

IV Interbasaltic deposit, 10 in thick, in Tertiary lavas, Stream 1500 yd S.E. of Blackhill (Edinbain), Skye.

Analysts: I-III, A. D. Wilson (semi-micro methods), Geological Survey and Museum, Lab. Nos. 1740 (1958), 1712, 1713 (1956); A. Sipöcz, recalculated by Peacock; IV, G. A. Sergeant, Geological Survey and Museum, Lab. No. 1086 (1943); Guppy and Sabine 1956, p. 28.

(Table 1) Analyses of palagonite, glass and tuff.

TABLE II

Analyses and Norms of Sideromelane, Pillow Lava and Tholeiitic Basalts

Analysis	I		V		VA		B		C	
SiO_2	52·0		42·30		47·6		47·35		49·76	
Al_2O_3	15·6		14·24		15·8		13·90		14·42	
Fe_2O_3	0·7		3·87		4·3		5·87		3·95	
FeO	8·9		5·49		6·2		8·96		7·77	
MgO	5·7		4·42		5·0		5·97		5·30	
CaO	10·4		16·76		12·5		10·65		10·22	
Na_2O	3·2		2·40		2·7		2·73		2·49	
K_2O	0·6		0·27		0·3		0·54		1·83	
H_2O+	0·9		1·22		1·3		1·16		1·03	
H_2O-	0·3		1·69		1·9		1·04		2·04	
TiO_2	1·7		1·57		1·8		1·75		0·94	
P_2O_5	—		0·18		0·2		0·24		0·21	
CO_2	—		5·07		—		0·32		0·06	
S	—		0·09		—		0·23		—	
FeS_2	—		—		—		—		0·04	
Cr_2O_3	—		0·04		—		—		—	
BaO	—		0·07		—		—		0·04	
MnO	tr.		0·24		0·3		0·23		0·20	
	100·0		99·92		99·9		100·94		100·30	
Norm										
Q	—		1·92		2·1		1·08		0·48	
or	3·3		1·67		1·9		2·78		10·56	
ab	27·3		20·44		23·1		23·06		20·96	
an	26·4		26·97		30·5		24·19		22·80	
di- wo	10·6		9·74		11·2		10·67		11·14	
di- en	5·4	20·9	6·60	18·72	7·5	21·4	6·50	20·73	6·10	21·86
di- fs	4·9		2·38		2·7		3·56		4·62	
hy- en	8·8	17·0	4·50	6·35	5·1	7·2	8·40	13·02	7·20	12·48
hy- of	8·2		1·85		2·1		4·62		5·28	
mt	0·9		5·57		6·3		8·58		5·80	
il	3·2		3·04		3·4		3·34		1·67	
ap	—		0·34		0·4		0·34		0·34	
ca	—		11·50		—		0·70		0·10	
py	—		0·30		0·3		0·73		—	
rest	1·2		3·02		3·4		2·20		3·15	
Feldspar	$Or_6Ab_{48}An_{46}$		$Or_3Ab_{42}An_{55}$				$Or_6Ab_{46}An_{48}$		$Or_{19}Ab_{39}An_{42}$	

I Sideromelane from 'Palagonite' Tuff, Camas Ban, Skye
V Pillow lava, Creag Mor, Skye
VA —do—, analysis recalculated free of calcite
B Type Salen tholeiite
C Type Staffa basalt

Analysts: I. A. D. Wilson, Geological Survey Lab. No. 1740 (1958)
V. A. D. Wilson and P. Coombs, Lab. No. 1645 (1954) Guppy and Sabine 1956, p. 28
B. F. R. Ennos, Lab. No. 407 } Bailey and others
C. E. G. Radley, Lab. No. 669 } 1924, p. 17.

(Table 2) Analyses and norms of sidermelane, pillow lava and tholeiitic basalts.

TABLE III

Lava Types in Northern Skye	Symbol One-inch map	Slices
1. *Hebridean Type of olivine-phyric olivine-basalt*, with ophitic or intergranular augite which may be yellow, pale brown, purple, faintly green or colourless in thin section. Composition of the feldspar in the range An_{55} to An_{70}. Mesostasis of zeolites, especially analcime, thomsonite, chabazite, generally present. Feldspars not exceeding 0·5 mm average length.	B^{He}	214
2. *Vaternish Hebridean Type olivine-phyric olivine-dolerite*, composition similar to Hebridean type but plagioclases average over 0·5 mm long.	B^{V}	42
3. *Feldspar-phyric olivine-basalt*, olivine and labradorite phenocrysts generally of microporphyritic dimensions, (i.e. less than 2 mm), in a groundmass of composition similar to the Hebridean type.	fB	44
4. *Mugearite*, dark grey, platy weathering trachybasalt, composed of olivine, oligoclase, orthoclase, clinopyroxene and iron-titanium oxides, normally exhibiting trachytic texture.	W^{M}	69
5. *Big-feldspar mugearite*, macroporphyritic mugearite basalt, with large phenocrysts of labradorite—bytownite in a mugearite groundmass.	fW^{M}	23
6. *Trachyte*, pale grey or white trachyte containing a few alkali-feldspar and ferromagnesian phenocrysts in a groundmass of alkali feldspar laths; shows trachytic texture.	T	14

(Table 3) Lava types in Northern Skye.

TABLE IV

ANALYSIS OF HEBRIDEAN BASALT, AMYGDALOID AND BOLE

	VI	VII	VIII	D	E
SiO_2	45·99	42·40	34·27	46·12	44·15
Al_2O_3	14·65	14·66	19·72	15·46	15·49
Fe_2O_3	2·23	8·82	18·55	3·85	7·57
FeO	9·80	4·92	0·82	6·51	2·57
MgO	9·46	8·33	5·05	10·12	6·36
CaO	8·68	8·40	6·48	10·66	9·08
Na_2O	2·83	2·60	1·70	1·48	2·01
K_2O	0·46	0·30	0·32	0·65	0·31
$H_2O > 105°$	2·34	3·68	6·31	2·38	5·80
$H_2O > 105°$	1·38	3·76	3·51	1·01	4·90
TiO_2	1·90	2·09	2·71	1·37	1·35
P_2O_5	0·20	0·21	0·20	0·06	0·08
MnO	0·19	0·15	0·20	0·21	0·20
CO_2	tr.	tr.	0·01	—	—
S	0·02	0·01	tr.	tr.	—
Cr_2O_3	0·05	0·03	0·03	—	—
NiO	0·01	0·01	0·02	—	—
BaO	0·01	0·01	0·01	—	—
SrO^+	0·03	0·03	0·07	—	—
Li_2O	nt. fd.	nt. fd.	nt. fd.	—	—
	100·23	100·41	99·98	99·88	99·87

+ Spectrographic determinations.

VI Massive centre of 2nd Lava, Creag Mor, of Beal Point, Rubha na h'Airde Glaise, Skye.
VII Upper Amygdaloid of 2nd Lava, same locality.
VIII Bole above 2nd Lava, same locality.
D Middle part of lava flow, Island Magee, Antrim.
E Vesicular, zeolitic, upper part of lava flow, Island Magee, Antrim.

Analysts: VI, VII, VIII, W. F. Waters and K. L. H. Murray, Geological Survey Lab. Nos. 1577, 1578, 1579, (1951), Guppy and Sabine 1956, pp. 27, 28. D, E, W. H. and F. Herdsman *in* Tomkeieff, 1934, p. 502.

(Table 4) Analysis of Hebridean basalt, amygdaloid and bole.

TABLE V

MINERALS IN LAVAS EXPOSED AT THE STORR AND RUBHA NA H-AIRDE GLAISE
(One-inch Sheet 80, six-inch Sheet Skye 18 N.W.)

Lava No.	Slice No.	Symbol One-inch map	Olivine % Fa	Plagio-clase % An	Mode, Wt % Ol	Py	Pl	Mt	Ch	Z
S										
24	37922	WM	32–35	32–20	2	23	48	25	1	—
23	37921	oB	24–30	55–30						
22	37919	oB	19–20	54–48						
21	37918	oB	19–24	68–57						
20	37917	oB	18	69–55						
19	37916	oB	18	66–52						
17	37915	oB	25	64–57						
16	37914	oB	18							
15	37913	Bc		70–62						
14	37912	Bc	20	70–						
13	37911	oB		66–						
12	37909	oB		65–55	5	28	43	7	16	1
11	37908	oB	13–20	66–	24					
10	37907	fB		68–58	1	17	27	8	37	10
9	37906	oB	18–20	70–58	16	31	35	15	2	—
8	37905	oB	16–20	66–	23	29	33	10	3	2
7	37904	oB	19	70–55	13	25	44	11	1	6
6	37903	oB	18–20	67–60	19	25	36	9	11	—
5	37902	fB	19–25	75–65						
4	37900	oB	19–20	67–	14					
3	37899	oB+	19–26	45–20	14					
2	37898	oB	20–25	65–	19	25	40	9	6	—
1	37896	oB	21–25	68–	5	23	53	6	13	—
R										
6	37975	oB	24	56–	17	32	34	6	—	11
5	37974	oB	18–24	64–	14	24	48	10	—	4
4	37973	oB	17–		18	24	39	11	—	8
3	37970	oB	18–21	60–	15	20	48	14	—	3
1	37968	oB	18	55–	20	19	50	5	—	6

R = Cliff section ¼ mile N. of Rudha na h'Airde Glaise.
S = Storr; nos. 1-13 in cliff S. of Coire Faoin; nos. 14-24 in southermost gully on main east face.

Under mode the symbols used are as follows (figures in brackets assumed densities): Ol–olivine (3·3); Py–pyroxene (3·3); Pl–plagioclase (2·7); Mt–titanomagnetite (5·0); Ch–chlorite (2·6); Z–zeolites (2·1).

(Table 5) Minerals in lavas exposed at the Storr and Rubha na h-Airde Glaice (One-inch Sheet 80, six-inch Sheet Skye 18 N.W.). .

TABLE VI

ANALYSES AND NORMS OF HEBRIDEAN TYPE BASALTS, SKYE

Analysis

	VI	IX	F	G	H
SiO_2	45·99	46·12	46·61	46·38	45·68
A_2l_2O	14·65	13·94	15·22	16·77	14·66
Fe_2O_3	2·23	1·95	3·49	3·22	2·88
FeO	9·80	10·46	7·71	8·03	9·67
MgO	9·46	11·08	8·66	8·83	9·82
CaO	8·68	9·05	10·08	10·68	9·37
Na_2O	2·83	3·11	2·43	1·94	2·14
K_2O	0·46	0·57	0·67	0·10	0·19
H_2O+	2·34	1·49	2·07	2·46	3·43
H_2O-	1·38	0·40	1·10	0·37	0·36
TiO_2	1·90	1·81	1·81	1·04	1·65
P_2O_5	0·20	0·23	0·10	0·08	0·07
MnO	0·19	0·18	0·13	0·24	0·22
CO_2	tr.	—	tr.	nil	nil
S	0·02	—	—	—	—
Cr_2O_3	0·05	—	tr.	—	—
NiO	0·01	—	tr.	—	—
BaO	0·01	—	—	—	—
SrO	0·03	—	—	—	—
	100·23	100·39	100·08	100·14	100·14
Specific Gravity			2·87	2·84	2·97

Norm

		VI		IX		F		G		H	
or		2·8		3·3		3·9		0·6		1·1	
ab		23·6		21·0		20·4		16·2		17·7	
an		28·8		22·4		28·6		37·0		30·1	
ne		—		2·8		—		—		—	
di	wo	6·8	13·3	9·3	18·0	8·6	16·5	6·4	12·4	6·6	12·8
	en	4·1		5·7		5·7		4·0		4·1	
	fs	2·4		3·0		2·2		2·0		2·1	
hy	en	3·1	5·0	—		6·9	9·7	11·8	17·6	10·2	15·7
	of	1·9				2·8		5·8		5·5	
ol	fo	11·5	18·6	15·4	24·3	6·2	·89	4·3	6·8	7·1	11·2
	fa	7·1		8·9		2·7		2·5		4·1	
mt		3·3		2·9		5·1		4·6		4·2	
il		3·5		3·5		3·5		2·0		3·2	
ap		0·3		0·3		0·3		0·3		0·2	
Feldspar		$Or_5Ab_{43}An_{52}$		$Or_7Ab_{45}An_{48}$		$Or_7Ab_{39}An_{54}$		$Or_1Ab_{30}An_{69}$		$Or_2Ab_{36}An_{62}$	

KEY TO TABLE VI

VI Olivine-basalt, Creag Mor, cliff W. of Beal Point, Rubha na h'Airde Glaise, Skye. Analysts: W. F. Waters and K. L. H. Murray, Geological Survey Lab. No. 1577 (1950), Guppy and Sabine 1956, p. 27.

(Table 6) Analyses and norms of Hebridean type basalts, Skye.

TABLE VII

MINERALS IN LAVAS EXPOSED AT BIOD A'GHOILL, SCORE HORAN, VATERNISH

Lava No.	Thickness Ft.	Slice No.	Symbol one-inch map	ol	Mode, Wt per cent py	pl	mt	ch
14		37993	W^M	15	13	53	19	—
13		37992	oB	20				
12		37991	oB	13				
11		37990	oB	26				
9	25	37987	oB	28				
8	28	37986	oB	13				
7	36	37985	oB	19				
6	25	37984	oB	13	35	38	4	10
5	44	37983	fB	11	29	44	13	3
4	24	37982	oB	33				
2	56	37979	oB	17				

(Table 7) Minerals in lavas exposed at Biod a'Ghoill, Score Horan, Vaternish.

TABLE VIII

ANALYSES OF MUGEARITES AND TRACHYTE

Analysis	J	X	K	L	XI
SiO_2	47·51	48·12	49·68	58·64	66·13
Al_2O_3	16·99	16·30	16·99	16·38	16·03
Fe_2O_3	3·31	4·90	3·45	3·05	3·17
FeO	10·60	9·11	8·99	4·91	0·70
MgO	4·23	3·80	2·79	1·06	0·84
CaO	6·48	5·97	5·46	2·90	1·45
Na_2O	5·01	5·69	5·78	6·07	5·34
K_2O	0·70	0·74	1·90	3·49	4·82
H_2O+	1·24	1·01	1·77	0·55	0·36
H_2O-	0·55	0·77	0·34	0·99	0·43
TiO_2	2·85	2·74	2·13	0·89	0·61
P_2O_5	0·53	0·56	0·48	0·66	0·08
MnO	0·20	0·20	0·27	0·18	0·10
CO_2	—	—	—	—	—
F	—	—	0·23	—	—
S	—	tr	—	—	—
Cr_2O_3	—	tr	—	—	—
NiO	—	tr	—	—	—
BaO	—	0·02	0·12	0·13	—
SrO	—	0·05*	—	—	—
Cl	—	—	0·02	—	—
	100·20	99·98	100·40	99·90	99·77

* spectrographical determination.

Specific Gravity

Norm	J	X	K	L	XI
Q	—	—	—	2·16	12·12
or	3·89	3·89	11·12	20·94	28·73
ab	38·25	42·97	38·90	51·35	45·06
an	21·96	17·24	14·46	6·95	5·28
ne	2·27	2·56	5·61	—	—
di wo	2·90	3·71	3·25	1·39	0·12
di en	1·35 (wo+en+fs 5·76)	1·90 (7·33)	1·30 (7·53)	0·40 (2·85)	0·09 (0·22)
di fs	1·51	1·72	1·98	1·06	0·01
hy en	—	—	—	2·20	2·01
hy of	—	—	—	4·36 (6·56)	0·25 (2·26)
Ol fo	6·47	5·32	3·99	—	—
Ol fa	8·41 (14·88)	5·20 (10·52)	6·68 (10·67)	—	—
ac	—	—	—	—	3·20
mt	4·87	7·10	4·98	4·41	1·37
il	5·32	5·17	4·10	1·67	0·67
ap	1·34	1·34	1·34	1·68	—
fl	—	—	0·35	—	—

Normative feldspar	J	X	K	L	XI
or	6	6	18	27	37
ab	60	67	60	64	57
an	34	27	22	9	6

(Table 8) Analyses of mugearites and trachyte.

TABLE IX

Analysis of Porphyritic Mugearite

	M	MK	MD	PC
SiO_2	50·33	49·26	48·5	50
Al_2O_3	19·97	21·42	15·2	18
Fe_2O_3	2·81	4·06	4·2	} 9
FeO	6·23	4·78	9·4	
MgO	3·24	2·02	4·8	5
CaO	8·03	8·60	6·0	10
Na_2O	4·30	4·40	4·1	2·5
K_2O	1·19	1·40	1·8	0·4
H_2O+	0·99	1·07	1·5	
H_2O-	0·87	0·72	1·3	
TiO_2	1·81	1·22	2·7	
P_2O_5	0·17	0·98	0·3	
MnO	0·17	0·19	0·2	
BaO	0·06	—		
S	nt. fd.			
	100·17			

(Table 9) Analysis of porphyritic mugearite.