Chapter 10 Igneous petrology

The initial eruption in North Skye

The evidence from North Skye shows that volcanic activity began with an explosive phase, during which crystals of magnesian olivine and labradorite were erupted with liquid magma which froze to glass. In view of the association of plant-bearing sediments and of pillow lavas with the crystal-vitric tuffs, the last named probably accumulated in water. Bombs of hyaline porphyritic basalt were thrown out at the same time. A central type of eruption is perhaps suggested, but the location of the vent is unknown; it might be concealed beneath the lavas between the Portree coast and the Halistra district in Vaternish. There is no evidence to suggest that what later became the main centre in the Cuillins was active and this stage is not known to be recorded in that area.

From the limited evidence afforded by the unaltered glass in the tuff (p. 95) and the recalculated analysis of the pillow lava (p. 99) it is suggested that the initial magma may have been more closely allied to the tholeiite lineage than to that of the subsequent alkali olivine-basalts. This view is based on (i) the higher silica-contents of these rocks (52.0; 47.6) than that of average Hebridean basalt (45.9); (ii) the absence of olivine from the C.I.P.W. norms, (iii) the lower alkali/ silica ratio as compared with the Hebridean series. Soda, for example, reaches 5 per cent for a silica-content of 52 according to the plots both of the Mull authors (Bailey and others 1924, p. 26) and that of L. R. Wager (1956, p. 230), whereas it is only 3.2 per cent in the sideromelane of the 'palagonite' tuff. It is nevertheless recognized that in rocks which have been subjected to alteration, as these have, the evidence is not decisive.

The alkaline olivine-basalt suite

General: The great pile of lavas which overlies the tuffs represents, in the main, the quiet outpouring of magma, with very little explosive activity. The lava plateaux so produced consist predominantly of olivine-basalts, but in the region between Greshornish and Mugeary, mugearites and trachytes are frequently interbedded with the basalts, while in Trotternish a few mugearites are also found. It must be emphasized that the olivine-basalts do not disappear even where mugearites become commonest, but alternate with them. The argument has already been advanced that the confinement of dykes of these less usual rock-types to the regions in which lavas of the same composition are found suggests that the lavas were erupted from fissures. There is also ample similar evidence provided by the dykes of olivine-phyric basalts similar or identical to the typical basaltic lavas, though this evidence does not extend to the most impressive of the dykes, those now filled with allivalite. The exact role of the Cuillins centre while the basalts were being erupted, if indeed it existed at this stage, is unknown. The lavas do not appear to thicken towards it, and only the rhyolites of Fionn Choire and Bruach na Firthe, south of the present area, appear to be definitely related to it. According to Harker (1904, p. 57) the stratigraphical position of these is in the midst of the basalt series, but their distribution is extremely local. The major intrusions of peridotite, gabbro and granite now exposed in the Cuillins centre are certainly later than the lava pile, but it is nevertheless possible that the main magma chambers were associated with the centre, and that the dykes were fed from there.

The suite 'Plateau' or Hebridean basalt-mugearite-trachyte was considered by the authors of the Mull Memoir to form a related series and there are strong geographical and chemical reasons for this view. The chemical evidence shows that transitions exist between members of the suite, though this is not as complete as might be desired. It is conveniently summarized for Skye and for the whole Hebridean lava region on a variation diagram, in which the oxides (recalculated to eliminate water) are plotted against the 'differentiation index' of Thornton and Tuttle (1960). This index is the sum of quartz, orthoclase, albite and nepheline of the C.I.P.W. norm and since it represents crystallization from the petrogenic residual system SiO_2–$NaAlSiO_4$–$KAlSiO_4$, its magnitude increases with advancing differentiation. In the variation diagram no attempt has been made to smooth the curves; the lines join points in order of rising index values. The impression is thus conveyed of the progressive fall of MgO, FeO and CaO as the SiO_2, NaO_2 and K_2O rise, while demonstrating at the same time that considerable deviations from any possible average curve exist. While it cannot be denied, in the light of the international comparative studies of the results of rock analysis, that analytical errors may contribute to the irregularity

of the curves, it is certain from the mineralogy of the rocks concerned that substantial variation in the oxides corresponding with any given index value exists. This is well illustrated by the cluster of basalts lying between index values 24 and 30. The same is evident from Wager's plots of albite ratios and normative plagioclase compositions against iron ratios (Wager 1956, p. 229).

The average Hebridean basalt lies in the region between index values 24 and 30, and it is significant that the normal olivine-dolerite of the Trotternish sills also falls here.

In (Figure 16) the normative compositions of the feldspars of those rocks in which normative nepheline does not appear are plotted in relation to the orthoclase-albite-anorthite triangle, to show the general trend of variation from the cluster of basalts on the calcic side of the centre of the plagioclase series, towards anorthoclase and sanidine in the mugearites and trachytes<ref>Three rocks, nos. 22, 24, 25, showing normative nepheline have also been plotted.</ref> (see also Muir and Tilley 1961, p. 201).

Causes of Variation. The physical chemistry of crystallizing silicate melts of basaltic composition, as revealed by experimental investigation of relevant systems, is such that the composition of the solid phases which separate differ to a marked extent from that of the liquid at all stages except the very latest. Ideally, therefore, the crystallization of basaltic magma is a fractional process, with the compositions of the crystals and the liquid changing progressively as the temperature falls. Providing, however, that fluid and crystals remain together until crystallization is complete, the composition of the rock produced will be the same as that of the parent magma; but it is unlikely that this ideal situation is ever attained, though under some circumstances it may be closely approached.

If, during the crystallization process, liquid and solid phases become separated, differentiated products will result. The earliest crystals to separate in quantity are magnesian olivines, which at normal pressure begin to crystallize at 1890°C. (Bowen and Schairer, 1935). Very calcic plagioclase follows below 1600°. The evidence from the layered series in Rhum, most recently described by G. M. Brown (1957) indicates that forsteritic olivine and bytownite-anorthite are denser than the basaltic magma, and under quiet conditions these minerals may settle to the bottom of a magma-chamber, producing 'cumulus' (Wager, Brown and Wadsworth, 1960). Meanwhile the liquid above will produce minerals less rich in MgO, FeO, CaO when it crystallizes. This mechanism for producing differentiated types has been familiar since the time of Harker (1908); it has been elaborated by many field and laboratory studies since then, too numerous to mention here.

It should further be noted that a sudden change of temperature and pressure such as might take place when a magma is ejected from a subterranean chamber and extruded at the surface, must necessarily affect the compositions of the crystals able to separate.

It is clear that the Trotternish and Shiant sills offer good examples of the concentration of early-separated olivine to form picrite and picrodolerite, both by the phenomenon of sinking under the influence of gravity, and the activity of currents in the magma. It also seems probable that olivine cumulus may be carried in suspension by magma moving under pressure towards a point of escape, thus giving rise to picritic dykes and to basalts abnormally rich in this mineral. It is suggested that the two factors which contributed most to the considerable variation in olivine-content displayed by the Hebridean-type lavas were this one, and the factor of the stage at which eruption took place in relation to temperature change accompanying it.

(Figure 17) illustrates the chemistry of the accumulative rocks formed by the separation of olivine. These lie to the left of the line for D = 16.5, and in this area the curves for magnesia and ferrous oxide rise steeply, while ferric oxide, lime and alumina fall. Some of the variation in the olivine-basalt field is also doubtless due to removal of olivine at an early stage.

A rough test of the efficiency of crystallization differentiation to produce mugearite and trachyte from magma corresponding to average Hebridean-type basalt may be made by means of the graphical method known as the subtraction diagram. (Table 14) gives average figures for the three rock-types, calculated from the analyses used in constructing (Figure 17).

(Table 14) Average Hebridean basalt, mugearite and trachyte

	Basalt	Mugearite	Trachyte
SiO_2	47.2	51.2	63.9
Al_2O_3	15.5	17.6	16.3
Fe_2O_3	32	4.9	2.9
FeO	9.9	7.5	2.4
MgO	9.0	2.8	0.9
CaO	9.4	4.9	1.5
Na_2O	2.7	6.4	6.4
K_2O	0.5	1.7	4.8
TiO_2	2.2	2.3	0.6
P_2O_5	0.2	0.5	0.3
MnO	0.2	0.2	—

(Table 15) gives the compositions and C.I.P.W. norms of the differentiate which must be removed from average basalt to yield average mugearite (1); from average basalt to yield average trachyte (2); and from average mugearite to yield average trachyte (3), together with the percentage-weight of differentiate to be removed<ref>The silica percentage is taken at the point where K_2O reaches the zero line in each case. In the addition calculations, the percentage at the point where MgO reaches zero is taken in the first, and where TiO_2 reaches zero in the second.</ref>. It is immediately apparent that the fractions removed to form both mugearite and trachyte would be rocks such as are found as major intrusives in the Hebridean province-the first would be a eucrite, the second a gabbro-the fraction to give the transition mugearite to trachyte is not at all a likely composition and may be discarded.

One other possibility is perhaps worth considering. This is the addition, for example by assimilation, of foreign material to the magma. This can be examined by means of addition diagrams. The results for basalt to mugearite, and for mugearite to trachyte are given in (Table 16), together with norms.

Table 15 calculated compostions of subtracted differentiates

Composition	(1) Basalt to Mugearite	(2) Basalt to Trachyte	(3) Mugearite to Trachyte
SiO_2	45.5	45.3	44.6
Al_2O_3	14.6	15.4	18.3
Fe_2O_3	2–4	3.2	6.0
FeO	109	10.7	10.2
MgO	11.6	9.9	3.8
CaO	11.3	10–3	6.6
Na_2O	1.2	2.3	6.4
K_2O	—	—	—
TiO_2	2.2	2.5	3.2
P_2O_5	0.1	0.2	0.2
MnO	0.2	0.2	0.2
Percentage Removed	70	89	66

	Norm	(1) Basalt to Mugearite	(2) Basalt to Trachyte	(3) Mugearite to Trachyte
ab		10.0	19.4	34.1
an		34.5	31.8	21.1
ne		—	—	10.8
	wo	8.7	7.8	3.5
di	en	5.4	4.7	1.7
	fs	2.8	2.6	1.7
hy	en	11.6	4.4	5.5
	of	5.8	2.4	5.6

ol	fo	8.4	11.0	8.8
	fa	4.7	6–3	6.1
mt		3.5	4.6	1.3
it		4.3	4.7	
ap		0.3	0.3	
	Normative Feldspar	An78	An62	

(Table 16) Calculated assimilation by mugearite and trachyte

Composition	Basalt to Mugearite	Mugearite to Trachyte	Syenite, Eilean Mhuire Shiant
SiO_2	53.0	68.7	
Al_2O_5	18.5	15.6	
Fe_2O_3	5.7	2.2	
FeO	6.5	0.5	
MgO	—	02	
CaO	2.9	02	
Na_2O	8.1	6.4	
K_2O	2.2	5.9	
TiO_2	2.3	—	
P_2O_5	0.6	02	
MnO	0.2	—	
Percentage Added	69	73	

	Norm			
	Q	—	10.0	—
	or	12.8	35.0	25.6
	ab	51.8	47.7	49.8
	an	7.5	—	—
	ne	91	—	4.0
	ac	—	5.6	54
	wo	1.5	0.1	
di	en	—	0.05	6.2
	fs	1.7	0.05	
ol	fo	—	0.3	—
	fa	1.6	0.4	—
	mt	8.4	0.5	4.6
	it	1.3	-	0.9
	ap	1.3	0.3	1.0

Neither result is encouraging, though the material to be added to mugearite to produce trachyte is a possible rock composition, that of a quartz-syenite. It is not greatly different from an acid segregation found within the 60-ft thick syenite forming a centre to the Upper Dolerite of Eilean Mhuire, in the Shiant Islands (Walker 1930, p. 383 et. seq.), the origin of which is attributed to auto-intrusion of residual magma. It might thus be claimed that it is just possible for large bodies of rock of the required composition to exist, but it remains doubtful whether such large volumes could possibly be assimilated.

On the whole, therefore, the calculations support the view that mugearite and trachyte could be produced from basaltic magma by normal processes of fractional crystallization and separation of solid phases. It is suggested that mugearite is perhaps not an intermediate stage in the generation of trachyte ; and it seems right to conclude that the acquisition of foreign material by the magma is a less attractive hypothesis than crystallization differentiation.

The average composition upon which the calculations discussed above have been based must nevertheless be viewed with some suspicion, for few of the analyses upon which they are based are of rocks in which the pyrogenic minerals are completely fresh. Tilley and Muir (1962) have pointed out that fresh basalts derived from the Hebridean magma type

should not show significant amounts of hypersthene in the norm, and they cite the olivine-basalt of Achtalean ((Table 6), No. IX) as an example. The fact that hypersthene appears in the norms of nearly all the analyses used to derive the figures for average basalt in (Table 14) is the result of hydration and oxidation of olivine accompanied by selective leaching. While it must be agreed that the average lacks the validity of that obtained from the fresher alkali basalts of Hawaii, it is hardly to be expected that, if a suitable number of fresh basalts from the Hebrides can be found and analysed, the conclusions stated above about the relative importance of fractional crystallization and assimilation will be materially altered.

Role of Volatiles. So far no attention has been paid to the roles of the volatile and gas phases in the differentiation of the alkaline basaltic magmas. Yet sills, lavas and dykes alike reveal that water vapour, fluorine, carbon dioxide and other volatile phases were active, at least during the later stages of crystallization of each rock mass. To them the special crinanitic and teschenitic types in the sills are to be attributed, but these are only concentrated manifestations of processes from which few of the igneous rocks entirely escaped. To the fluids concentrated as crystallization proceeded are to be ascribed the zeolites and chlorite which occupy interstitial spaces in the feldspar mesh, which have in some cases partially replaced the feldspars and other minerals, and which have filled the amygdales. Combined water, held in these OH-bearing minerals, is not an accident but a characteristic constituent of the North Skye igneous rocks; and its effect was felt in many cases before the completion of the main crystallization of the rocks, as well as at later stages.

In a contribution which may well prove to be of fundamental importance for petrology, Osborn (1959) has shown, on the basis of a consideration of equilibria in the system FeO-Fe_2O_3-SiO_2 that crystallization may follow very different paths according to whether (i) the total composition of the system remains constant, or (ii) the partial pressure of oxygen is maintained at a constant level. He extends these considerations to the system embracing MgO, and to natural basalts and their associates, and suggests that alternative (i) leads to enrichment of iron in the liquid during fractional crystallization, such as Wager and Deer (1939) proved for the Skaergaard intrusion. Alternative (ii) can only be sustained if there is evolution and loss of gas, leading to decreasing iron oxide content and increasing silica in the liquid. In (Figure 18) the trend of the Iron oxide/iron oxide plus magnesia ratio is plotted against SiO_2 percentage to ascertain the relationship of the present alkaline basaltic series to Osborn's alternative paths. It emerges that it occupies a position intermediate between the closed system with extreme fractionation as represented by Skaergaard, the new figures for liquid compositions given by Wager (1960) being employed here, and the lava series from the Cascade Mountains cited by Osborn as characteristic of orogenic conditions, and approaching the open system situation. From olivine-basalt to mugearite, there is a sharp rise in the iron ratio with little change in silica, as in the main part of Skaergaard and in Nockolds's (1954) average tholeiites. But thereafter the curve for the Hebrides flattens off towards benmoreite and trachyte, suggesting that in the formation of these the conditions more nearly approached the situation where partial pressure of oxygen remained constant.

Allivalitic and feldspar-phyric rocks

It remains finally to consider the origin of the highly calcic plagioclase phenocrysts in certain of the dykes, and since the composition of the feldspar involved is the same, the remarkable allivalitic dykes of North Skye.

Dealing with the latter first, it is very improbable in the light of experimental studies that liquids of allivalite composition had a separate magmatic existence; certainly no satisfactory means is known by which such liquids could have been separated from basaltic magma. But, as already noted, the accumulation of very basic feldspars, separating as early crystal phases, is well authenticated from the allivalites of Rhum. Brown (1957) attributed the layered series to bottom accumulation of crystals, perhaps associated with sorting by currents and with occasional release of volatiles.

It is here suggested that the allivalite dykes represent portions of a bytownite-anorthite cumulus (as in Rhum but with less abundant olivine, clinopyroxene and titanomagnetite) which became mobilised and squeezed into dyke fissures. The mush of large feldspars appears to have been lubricated by basaltic liquid as attested by the presence of a little inter-crystal dolerite or basalt in some dykes (p. 156).

It is also tempting to ascribe the anorthite phenocrysts in the feldsparphyric dykes to the break-up of cumulates of feldspar by intruding magmas of various compositions. It must be admitted, however, that the phenocrysts could have

crystallized from the dyke magmas before intrusion. For example, magma of the average Hebridean-type composition corresponds in available Na_2O and CaO content to plagioclase of composition An_{58} but the corresponding solidus position is An_{85} and this will therefore be the anorthite-content of the first-formed crystals. The very calcic plagioclases could have crystallized from the dyke magmas in at least some cases; but if they did, the striking break in zoning which they often show must be attributed to the change of temperature upon intrusions into the dyke fissure. It is appropriate to add that the phenocrysts of the big-feldspar mugearite lavas (An_{66}) would also represent the appropriate composition to be expected when average mugearite magma began to crystallize.

There is no evidence that cumulates rich in calcic plagioclase were ever re-fused in the present area. Had this occured, magmas capable of producing high-alumina basalts in the sense of Kuno (1960) would have resulted. But as Kuno's fig. 10 shows, such rocks are not known from the Brito-Arctic region except in the chilled margin of the Skaergaard intrusion, East Greenland. During the present investigation, no aphyric high-alumina rocks have been disclosed.

Summary

It is possible that tholeiitic magma was available at the beginning of volcanic activity in North Skye, and again when the late dykes were intruded. But the igneous events recorded in this part of the Island are mainly concerned with the extrusion and intrusion of alkaline basaltic magma, and with its differentiation during crystallization, to yield ultrabasics (picrite, allivalite) and the mugearitetrachyte series. It is possible that the escape of a gas phase may have exerted a decisive influence in the formation of the latter series.

No inference as to the ultimate primary magma — if there was a single one — seems appropriate from this limited study.

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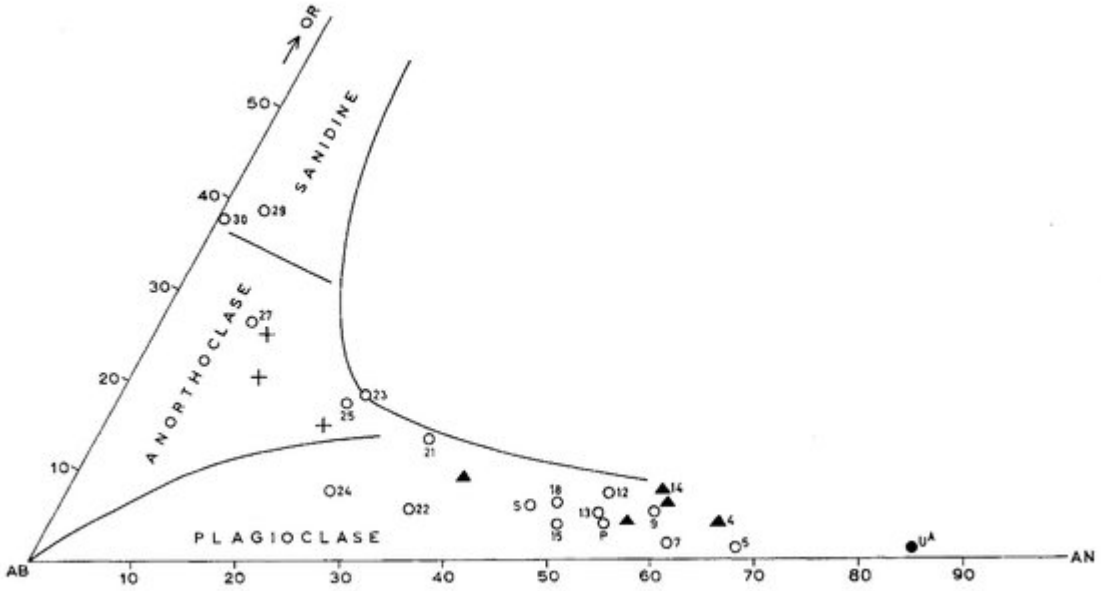

FIG. 16. *Plot of compositions of normative feldspars in Hebridean lavas and sills.*
Circles lavas; triangles, sills; black circle, dyke; crosses, feldspars from Druim na Criche mugearite, analysed by Muir and Tilley 1961. *P, tholeiitic pillow lava; S, normative feldspar in glass from palagonite tuff. Numbers correspond with those for Fig* .17. *U^A, allivalite dyke*

(Figure 16) Plot of compositions of normative feldspars in Hebridean lavas and sills. Circles lavas; triangles, sills; black circle, dyke; crosses, feldspars from Druim na Criche mugearite, analysed by Muir and Tilley 1961. P, tholeiitic pillow lava; S, normative feldspar in glass from palagonite tug. Numbers correspond with those for Fig 17. U^A, allivalite dyke. List of chemical analyses used in Figs. 16 & 17. 1. Picrite, base of cliff S. of Garbh Eilean, Shiant; Walker 1930, p. 371. 2. Picrite, top of cliff W. of Camas Mor, Skye; Walker 1932, p. 246. 3. Picrite-basalt, An Camach, Strathaird, Skye; Almond 1964. 4. Olivine-dolerite, 30 ft above beach, S. face of Garbh Eilean, Shiant; Walker 1930, p. 371. 5. Fine-grained basalt, 100 yd N.W. of Loch Cuil na Creig, Skye; King 1953, p. 365 6. Olivine-basalt, scarp E. of Dunmull Toberdornan Townland, 3 miles S.E. of Portrush, Northern Ireland; Patterson 1955, p. 103. 7. Ophitic basalt, 50 yd W. of Strollamus Quarry, Skye; King 1953, p. 365. 8. Olivine-basalt, scarp S. of County Road, Ballykeel Townland, 1¾ miles E.S.E. Portrush, N. Ireland; Patterson 1955, p. 103. 9. Basalt, E. side Rubha Dearg, 1 mile W. of Loch Aline, Morven; Bailey and others 1924, p. 15. 10. Olivine-dolerite, summit of Ben Lee N.W. of Loch Sligachan; Harker 1904, p. 248. 11. Olivine-basalt, flow 1, Ben Meabost, Skye; Almond 1960. 12. Olivine-basalt, near bridge over Allt Fionnfhiachd, Drynoch, Skye; Harker 1904, p. 31. 13. Olivine-basalt, Creag Mor, Skye; (p. 103). 14. Olivine-dolerite, Loch Mealt, near Waterfall, Skye; Walker 1932, p. 247. 15. Basalt, ■ mile N.N.E. Pennycross House, Mull; Bailey and others 1924, p. 15 16. Basalt, cliff 200 yd W. of Loch Eilean, Morven; Bailey and others 1924, p. 15. 17. Olivine-basalt, Achtalean 2¼ miles N.N.W. of Portree, Skye; Tilley and Muir 1962, p. 212. 18. Basalt, Orval, Rhum; Harker 1908, p. 57. 19. Olivine-dolerite, 500 yd N.

of Tam, Broc-bheinn, 4 miles N.N.W. of Sligachan, Skye; Harker 1904, p. 248. 20. Trachybasalt, An Carnach, Strathaird, Skye; Almond 1960. 21. Dolerite-mugearite, S. of Fionn-Chro, Rhum; Harker 1908, p. 130. 22. Mugearite-basalt, River Rha, above Uig, Skye; Muir and Tilley 1961, p. 190. 23. Doleritic mugearite, Eilean a'Bhaird, Canna; Harker 1908, p. 130. 24. Mugearite, cap of Hartaval, Skye; (p. 118). 25. Mugearite, Druim na Criche, near Mugeary, Skye; Muir and Tilley 1961, p. 190. 26. Mugearite (Benmoreite), 290 yd E. of Kinloch Hotel, Mull; Bailey and others 1924 p. 27. 27. Mugearite-trachyte (Benmorerite), Totardor, Skye; Muir and Tilley 1961, p. 190. 28. Trachyte, Ardnachross Vent, ¼ mile W. Rubha an t-Sean-Chaisteil, Mull; Bailey and others 1924, p. 27. 29. Trachyte, Ros a'Mheallain, Skye; (p. 118). 30. Trachyte, Vent, Braigh a'Choir' Mhoir, W. of Salen, Mull ; Bailey and others 1924, p. 27.

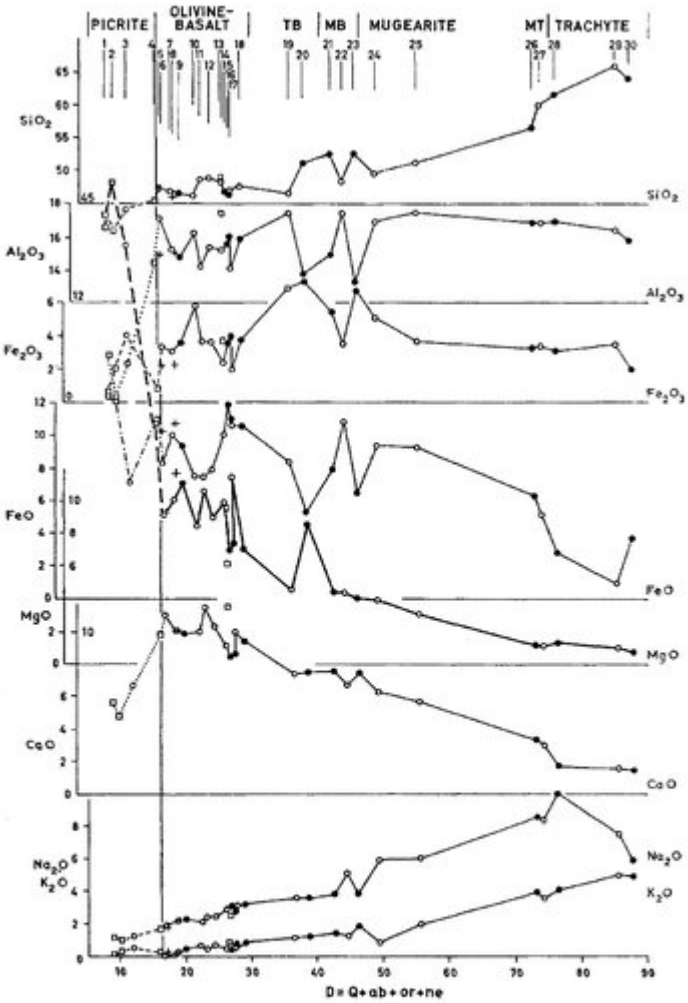

Fig. 17. *Variation diagram for the Alkaline Olivine-basalt lavas and minor intrusions. Black spots, Skye lavas; open circles, other Hebridean lavas; crosses, Antrim plateau basalts; open squares, North Skye and Shiant sills; TB trachybasalt MB mugearite-basalt; MT mugearite-trachyte. Picrite and picrite-basalt fall in a field limited by the line for D = 16·5 and are considered to be accumulative rocks*

(Figure 17) Variation diagram for the Alkaline Olivine-basalt lavas and minor intrusions. Black spots, Skye lavas; open circles, other Hebridean lavas; crosses, Antrim plateau basalts; open squares, North Skye and Shiant sills; TB trachybasalt MB mugearite-basalt; MT mugearite-trachyte. Picrite and picrite-basalt fall in a field limited by the line for D = 16–5 and are considered to be accumulative rocks. List of chemical analyses used in Figs. 16 & 17. 1. Picrite, base of cliff S. of Garbh Eilean, Shiant; Walker 1930, p. 371. 2. Picrite, top of cliff W. of Camas Mor, Skye; Walker 1932, p. 246. 3. Picrite-basalt, An Camach, Strathaird, Skye; Almond 1964. 4. Olivine-dolerite, 30 ft above beach, S. face of Garbh Eilean, Shiant; Walker 1930, p. 371. 5. Fine-grained basalt, 100 yd N.W. of Loch Cuil na Creig, Skye; King 1953, p. 365 6. Olivine-basalt, scarp E. of Dunmull Toberdornan Townland, 3 miles S.E. of Portrush, Northern Ireland; Patterson 1955, p. 103. 7. Ophitic basalt, 50 yd W. of Strollamus Quarry, Skye; King 1953, p. 365. 8. Olivine-basalt, scarp S. of County Road, Ballykeel Townland, 1¾ miles E.S.E. Portrush, N. Ireland; Patterson 1955, p. 103. 9. Basalt, E. side Rubha Dearg, 1 mile W. of Loch Aline, Morven; Bailey and others 1924, p. 15. 10. Olivine-dolerite, summit of Ben Lee N.W. of Loch Sligachan; Harker 1904, p. 248. 11. Olivine-basalt, flow 1, Ben Meabost, Skye; Almond 1960. 12. Olivine-basalt, near

bridge over Allt Fionnfhiachd, Drynoch, Skye; Harker 1904, p. 31. 13. Olivine-basalt, Creag Mor, Skye; (p. 103). 14. Olivine-dolerite, Loch Mealt, near Waterfall, Skye; Walker 1932, p. 247. 15. Basalt, ■ mile N.N.E. Pennycross House, Mull; Bailey and others 1924, p. 15 16. Basalt, cliff 200 yd W. of Loch Eilean, Morven; Bailey and others 1924, p. 15. 17. Olivine-basalt, Achtalean 2¼ miles N.N.W. of Portree, Skye; Tilley and Muir 1962, p. 212. 18. Basalt, Orval, Rhum; Harker 1908, p. 57. 19. Olivine-dolerite, 500 yd N. of Tam, Broc-bheinn, 4 miles N.N.W. of Sligachan, Skye; Harker 1904, p. 248. 20. Trachybasalt, An Carnach, Strathaird, Skye; Almond 1960. 21. Dolerite-mugearite, S. of Fionn-Chro, Rhum; Harker 1908, p. 130. 22. Mugearite-basalt, River Rha, above Uig, Skye; Muir and Tilley 1961, p. 190. 23. Doleritic mugearite, Eilean a'Bhaird, Canna; Harker 1908, p. 130. 24. Mugearite, cap of Hartaval, Skye; (p. 118). 25. Mugearite, Druim na Criche, near Mugeary, Skye; Muir and Tilley 1961, p. 190. 26. Mugearite (Benmoreite), 290 yd E. of Kinloch Hotel, Mull; Bailey and others 1924 p. 27. 27. Mugearite-trachyte (Benmorerite), Totardor, Skye; Muir and Tilley 1961, p. 190. 28. Trachyte, Ardnachross Vent, ¼ mile W. Rubha an t-Sean-Chaisteil, Mull; Bailey and others 1924, p. 27. 29. Trachyte, Ros a'Mheallain, Skye; (p. 118). 30. Trachyte, Vent, Braigh a'Choir' Mhoir, W. of Salen, Mull ; Bailey and others 1924, p. 27.

TABLE XIV

Average Hebridean Basalt, Mugearite and Trachyte

	Basalt	*Mugearite*	*Trachyte*
SiO_2	47·2	51·2	63·9
Al_2O_3	15·5	17·6	16·3
Fe_2O_3	3·2	4·9	2·9
FeO	9·9	7·5	2·4
MgO	9·0	2·8	0·9
CaO	9·4	4·9	1·5
Na_2O	2·7	6·4	6·4
K_2O	0·5	1·7	4·8
TiO_2	2·2	2·3	0·6
P_2O_5	0·2	0·5	0·3
MnO	0·2	0·2	—

(Table 14) Average Hebridean basalt, mugearite and trachyte.

TABLE XV

CALCULATED COMPOSITIONS OF SUBTRACTED DIFFERENTIATES

Composition	(1) *Basalt to Mugearite*	(2) *Basalt to Trachyte*	(3) *Mugearite to Trachyte*
SiO_2	45·5	45·3	44·6
Al_2O_3	14·6	15·4	18·3
Fe_2O_3	2·4	3·2	6·0
FeO	10·9	10·7	10·2
MgO	11·6	9·9	3·8
CaO	11·3	10·3	6·6
Na_2O	1·2	2·3	6·4
K_2O	—	—	—
TiO_2	2·2	2·5	3·2
P_2O_5	0·1	0·2	0·2
MnO	0·2	0·2	0·2
Percentage Removed	70	89	66
Norm			
ab	10·0	19·4	34·1
an	34·5	31·8	21·1
ne	—	—	10·8
di wo	8·7	7·8	3·5
di en	5·4	4·7	1·7
di fs	2·8	2·6	1·7
hy en	11·6	4·4	5·5
hy of	5·8	2·4	5·6
ol fo	8·4	11·0	8·8
ol fa	4·7	6·3	6·1
mt	3·5	4·6	1·3
il	4·3	4·7	
ap	0·3	0·3	
Normative Feldspar	An_{78}	An_{62}	

(Table 15) Calculated compositions of subtracted differentiates.

TABLE XVI

Calculated Assimilation by Mugearite and Trachyte

Composition	*Basalt to Mugearite*	*Mugearite to Trachyte*	*Syenite, Eilean Mhuire Shiant*
SiO_2	53·0	68·7	
Al_2O_3	18·5	15·6	
Fe_2O_3	5·7	2·2	
FeO	6·5	0·5	
MgO	—	0·2	
CaO	2·9	0·2	
Na_2O	8·1	6·4	
K_2O	2·2	5·9	
TiO_2	2·3	—	
P_2O_5	0·6	0·2	
MnO	0·2	—	
Percentage Added	69	73	
Norm			
Q	—	10·0	—
or	12·8	35·0	25·6
ab	51·8	47·7	49·8
an	7·5	—	—
ne	9·1	—	4·0
ac	—	5·6	5·1
di wo	1·5	0·1	6·2
di en	—	0·05	
di fs	1·7	0·05	
ol fo	—	0·3	—
ol fa	1·6	0·4	—
mt	8·4	0·5	4·6
il	[illegible]·3	—	0·9
ap	1·3	0·3	1·0

(Table 16) Calculated assimilation by mugearite and trachyte.

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
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	5·7	5·7	4·0	4·1
di fs	2·4	3·0	2·2	2·0	2·1
di	13·3	18·0	16·5	12·4	12·8
hy en	3·1	—	6·9	11·8	10·2
hy of	1·9		2·8	5·8	5·5
hy	5·0		9·7	17·6	15·7
ol fo	11·5	15·4	6·2	4·3	7·1
ol fa	7·1	8·9	2·7	2·5	4·1
ol	18·6	24·3	·89	6·8	11·2
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	$Or_2Ab_{43}An_{55}$	$Or_1Ab_{45}An_{45}$	$Or_2Ab_{32}An_{64}$	$Or_1Ab_{30}An_{69}$	$Or_2Ab_{36}An_{62}$

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.

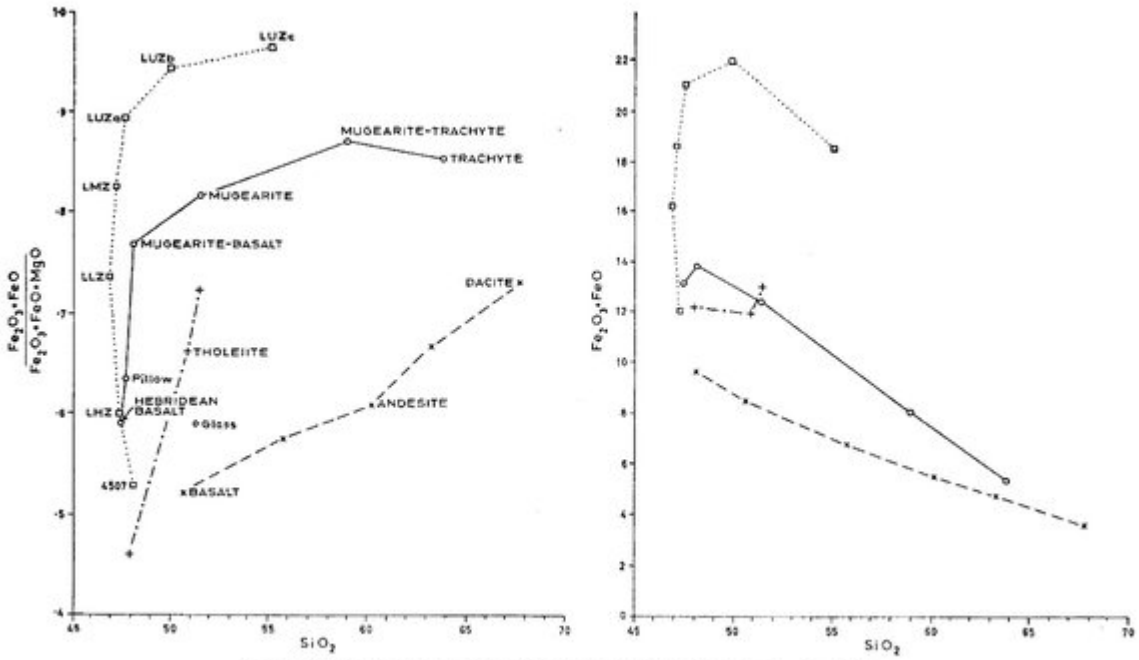

FIG. 18. *Plots of iron-oxide-magnesia ratio and iron oxide-content against silica. Dotted line, Skaergaard liquids (Wager 1960); full line, Hebridean alkaline olivine-basalt suite; dot-dash, average tholeiites (Nockolds 1954); dashes, Cascade volcanics (Osborn 1959)*

(Figure 18) Plots of iron-oxide-magnesia ratio and iron oxide-content against silica. Dotted line, Skaergaard liquids (Wager 1960); full line, Hebridean alkaline olivine-basalt suite; dot-dash, average tholeiites (Nockolds 1954); dashes, Cascade volcanics (Osborn 1959).