MINERALOGICAL MAGAZINE, DECEMBER 1969, VOL. 37, NO. 288

Cognate xenoliths in the Tertiary ultrabasic dykes of south-west Skye

FERGUS G. F. GIBB[1]
Department of Geology, University of Toronto, Toronto 5, Canada

SUMMARY. A group of ultrabasic dykes occurring in south-west Skye is typified by often abundant and diverse ultrabasic xenoliths composed of essentially the same minerals as the dykes. The xenoliths, which vary considerably in shape and size, are in sharp contact with the host rocks and exhibit no evidence of remelting by, or reaction with, the dykes. Although extensive axial concentration of olivine occurred in the dykes during intrusion, the xenoliths appear to be randomly distributed throughout all but the extreme margins of the dykes and often exhibit a preferred orientation. The orientation and distribution of the xenoliths are attributed to the suppression of rotation and axial migration of the xenoliths during the emplacement of the dykes because of the relatively high viscosity of the suspending medium.

The ultrabasic xenoliths, unlike many of those occurring in basalts, kimberlites, etc., are considered unlikely to represent primary upper mantle material and it is suggested that they were probably derived by the disintegration of layered ultrabasic rocks genetically related to the dykes and hence are of cognate origin.

AMONG the Tertiary minor intrusions of south-west Skye are at least two types of ultrabasic dykes (Drever and Johnston, 1958, 1967; Gibb, 1966). One of these—the Ben Cleat type (Gibb, 1968)—is characterized by relatively abundant ultrabasic xenoliths and it is with these xenoliths that this paper is specifically concerned.

The xenoliths range from less than ½ in. to more than 2 ft in length and may be sub-equant or elongated, angular or rounded. Many of the xenoliths are more feldspathic than the enclosing dyke rock and consequently project slightly above its weathered surface, but the majority are less feldspathic than their host and tend to produce depressions in the surface of the dyke on differential weathering.

In addition to the ultrabasic xenoliths, some of the dykes contain occasional accidental xenoliths of country rock.

Types of xenolith

All of the ultrabasic xenoliths are composed of olivine, plagioclase, and clinopyroxene, with accessory chrome spinel and magnetite, but the relative amounts of the three major constituents are very variable, and consequently quite a range of rock types is represented. Although there is a tendency for slight concentrations of similar xenoliths to occur locally within individual intrusions, the entire range of types appears to be present in most of the dykes.

Dyke 1 on Ben Cleat (Gibb, 1968, fig. 1) is a typical example of the xenolithic dykes and a quantitative study has therefore been made of the different types of xenolith occurring in it. A number of large blocks from this dyke were serially sectioned and thin

[1] Present address: Department of Geology, The University, Manchester 13.

sections of the 47 xenoliths encountered during the sectioning were prepared. This may not represent a statistically valid sample of the different types of xenolith because of the relatively small number examined, and also, since many of the xenoliths are very similar to the dyke rock, a few of them may have been missed. Nevertheless, this sample gives an adequate indication of the different types present and their relative abundances. When these xenoliths are plotted in terms of their modal mineral contents as in fig. 1 it is evident that there is a continuous range of compositions rather than a number of distinct types.

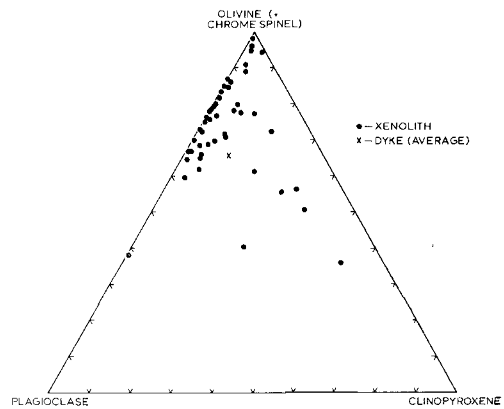


FIG. 1. Modal compositions of xenoliths from dyke 1. An average composition of the host rock is shown for comparison.

The majority of the xenoliths present in the dykes are feldspathic peridotites (90 % > olivine > 50 %; plagioclase > pyroxene) with dunites (olivine > 90 %) and peridotites (90 % > olivine > 50 %; pyroxene > plagioclase) less common. Allivalite (olivine < 50 %; pyroxene virtually absent) and picrite (50 % > olivine > 20 %) comprise less than 10 % of the xenoliths. In addition to the mineralogical variations, the xenoliths exhibit a variety of textures and grain sizes, and brief petrographical accounts of some of the more common types are given below.

Dunites. There are two main types of dunite xenolith. The first is composed of subhedral-euhedral olivine crystals, which may be as long as 1 cm, although the majority are between 1 and 5 mm in length. Traces of plagioclase and clinopyroxene occur in the interstices between the olivine and spinel crystals. In the second type the olivine crystals are smaller, the largest being approximately 2 mm long. There are large numbers of anhedral grains less than 0·2 mm in diameter, which impart a granular texture to the rock. With an increase in plagioclase content the dunites grade into feldspathic peridotites.

Feldspathic peridotites. The most abundant type of xenolith in the dykes is a feldspathic peridotite containing between 70 and 90 % olivine and less than 2 % pyroxene with the olivine poikilitically enclosed by plagioclase crystals up to a centimetre long. Four sub-types can be distinguished by the size and shape of their olivine crystals, although a few xenoliths have been observed that are gradational between these sub-types. In the first sub-type the euhedral to subhedral olivine crystals are mostly between 0·5 and 2 mm long and the elongate crystals exhibit a very strong parallelism. The second sub-type is basically similar to the first, but the olivine crystals are larger (1–5 mm long) and the parallelism of elongate crystals is much less prominent. The third sub-type exhibits no preferred orientation of the olivine crystals, which are subhedral and between 1 and 5 mm long. In the fourth sub-type the olivine occurs mainly as anhedral grains less than 0·5 mm in diameter although a few larger subhedral crystals are also present. Where the olivines in this type of xenolith are closely packed the rock appears to be transitional to the granular dunites described above. In all four sub-types the small amounts of pyroxene are interstitial to the plagioclase crystals.

A second type of feldspathic peridotite xenolith, which differs from the first mainly in its higher pyroxene content, is also common in the dykes. In examples transitional from the first type the interstitial pyroxene crystals are much smaller than the plagioclase crystals, but as the amount of pyroxene increases the crystals become larger, subophitically intergrown with the plagioclase, and frequently enclose olivine crystals poikilitically. With further increase in pyroxene content they grade into peridotites.

In the *peridotite* xenoliths the pyroxene crystals may be as long as 1 cm and are subophitically intergrown with the plagioclase crystals, which tend to be slightly smaller than those of pyroxene (i.e. the reverse of the relationship in the feldspathic peridotites).

Picrite xenoliths are basically similar to the second type of feldspathic peridotite xenolith apart from their lower olivine content. The olivines are poikilitically enclosed by subophitically intergrown crystals of plagioclase and pyroxene, which may be as long as 7·5 mm. A few picrite xenoliths have been observed that are very rich in pyroxene and are almost olivine pyroxenites. These are generally only an inch or two long and consist of a few very large crystals of faintly greenish clinopyroxene poikilitically enclosing crystals of olivine and plagioclase between 0·5 and 2·5 mm long.

The *allivalite* xenoliths consist of subhedral olivines less than 1·5 mm long poikilitically enclosed by plagioclase crystals up to 7·5 mm long. Traces of interstitial pyroxene are generally present.

Banded xenoliths. A relatively common variety of xenolith is composed either of alternating bands of the two types of feldspathic peridotite (i.e. the difference is in the pyroxene content) or of bands of the first type of feldspathic peridotite in which the olivine content varies from one band to another. Individual bands are rarely more than a few inches thick.

Arborescent feldspathic xenoliths. A much rarer type of xenolith is one in which a single very large arborescent plagioclase crystal encloses abundant smaller olivine crystals. These xenoliths are almost certainly broken fragments of larger arborescent plagioclase crystals and may be analogous to the 'harrisitic' olivine cumulates described by Wadsworth (1961, pp. 37–9).

Mineralogy

With the exception of the pyroxene in some of the picrite xenoliths, which is greenish in contrast to the faintly brown colouration of the dyke pyroxene, the olivine, clinopyroxene, and plagioclase of the xenoliths cannot be distinguished optically from the corresponding minerals in the dykes.

The compositions of a number of olivine, pyroxene, and plagioclase crystals in four xenoliths from dyke 1 have been determined by electron probe analyses and the results are presented in table I. Data for the corresponding minerals in the central part of the host dyke are given for comparison.

The olivine crystals in each of the xenoliths exhibit a range of compositions but in each case the variation is less than 2 % Fa. The electron probe analyses suggest that some of the individual crystals may be slightly zoned but, if so, the extent of the zoning is less than 1 % Fa. It is noteworthy that the compositional range exhibited by the olivine in each of the xenoliths in table I is slightly different and that all are slightly less magnesian than the unzoned cores of the olivine crystals in the host dyke.

TABLE I. *Compositions of the principal minerals in the xenoliths and their host*

	Olivine Fa %	Clinopyroxene			Plagioclase An %
		Wo	En	Fs	
Xenolith FG4	13–15	44	46	10	85
„ FG77B	13½–14	44	48½	7½	84 zoned to 78
„ FG77C	12½–13	43½–45	48–9	7–7½	— zoned to 68
„ FG77D	14–15	42	50	8	—
Dyke 1 (centre)	11	43	48½	8½	85 zoned to 52½

The compositions of the clinopyroxene crystals do not vary greatly within a single xenolith although a few crystals have been observed which are slightly zoned.

Many of the plagioclase crystals are normally zoned but the true extent of the zoning is unknown and the figures given in table I can only be regarded as minimum values.

From the results presented in table I it appears that no compositional discrimination between the pyroxene and plagioclase in the xenoliths and the corresponding phases in the host dyke can be justified but there are undoubtedly small compositional differences between the olivines in the xenoliths and the olivine in the enclosing dyke rocks.

Chemistry

One of the xenoliths (FG4) has been chemically analysed and the results of this analysis are given in table II and compared with an analysis of the host dyke.

The principal differences between the two analyses are that the xenolith has much higher contents of Al_2O_3, CaO, and Na_2O and lower MgO, FeO, Fe_2O_3, Cr_2O_3, and TiO_2 contents than the dyke. These discrepancies do not indicate any basic difference between the xenolith and its host rock but merely reflect the fact that the xenolith is much richer in plagioclase than the dyke rock and hence the elements that occur in the mafic minerals are depleted with respect to those in the feldspar. The normative plagioclase is considerably more calcic than the actual plagioclase but this can be attributed to the presence of nepheline in the norm.

Contact relations between the xenoliths and their host rocks

Because of similarities in grain-size and mineralogy between the xenoliths and dyke rocks it is often difficult to locate the boundaries of the xenoliths in thin section.

However, where the enclosing dyke rocks are much finer-grained than the xenoliths, e.g. near the margins of most of the dykes (Gibb, 1968), the junctions between the xenoliths and their hosts are readily discernible and the relationships between the two have been studied at a number of these junctions.

The junction between a xenolith and the enclosing rock is invariably sharp. Crystals of all three of the principal minerals in the xenoliths are frequently broken (figs. 2 and 3) and the broken edges are in juxtaposition with the dyke rock. No evidence of reaction between the xenolith and dyke material has been observed and only occasionally do small stringers of dyke rock penetrate the xenoliths.

TABLE II. *Chemical analyses and norms of a xenolith and its host* (*Anal. F. G. F. Gibb*)

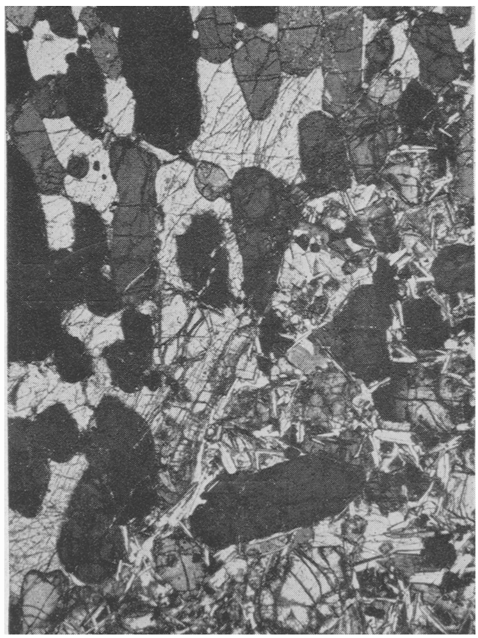
	1	2			Norms (wt %) 1	Norms (wt %) 2	Mineral compositions (normative)	1	2
SiO_2	41·74	40·29	Qtz		—	—	*Plagioclase*		
TiO_2	0·02	0·28	Or		0·41	0·53	Or	0½	2
Al_2O_3	15·87	5·41	Ab		4·43	3·30	Ab	5½	12
Cr_2O_3	0·06	0·39	An		38·83	12·75	An	94	86
Fe_2O_3	1·36	1·93	Ne		1·95	—	*Clinopyroxene*		
FeO	5·50	8·16	Wo	Cpx	2·54	2·41	Wo	50	50
MnO	0·10	0·16	En	Cpx	1·96	1·18	En	44½	45
MgO	22·55	35·46	Fs	Cpx	0·32	0·27	Fs	5½	5
CaO	9·08	3·77	En	Opx	—	2·89			
Na_2O	0·95	0·39	Fs	Opx		0·42	*Olivine*		
K_2O	0·07	0·09	Fo	Ol	37·97	58·53	Fo	89	90
H_2O^+	1·64	2·21	Fa	Ol	6·76	9·41	Fa	11	10
H_2O^-	0·15	0·23	Mt		1·97	2·80			
CO_2	0·45	0·70	Il		0·04	0·53			
P_2O_5	0·02	0·03	Crt		0·09	0·60			
Total	99·56	99·50	Ap		0·05	0·07			

1. FG4, a feldspathic peridotite xenolith from dyke 1.
2. Centre of dyke 1.

The complete lack of corrosion or reaction at the edges of xenoliths, composed partly of pyroxene and plagioclase, which were suspended in a magma from which almost identical minerals subsequently crystallized, implies that the interval between the incorporation of the xenoliths and the onset of plagioclase crystallization from the dyke magma must have been relatively short and, further, that the temperature of the dyke magma at the time they were incorporated was not much above the olivine–plagioclase cotectic. These implications impose severe limitations on the distance the xenoliths could have been transported and would appear at first to be inconsistent with the presence of rounded xenoliths in the dykes. However, although the boundaries of some of the xenoliths are rounded macroscopically, they are irregular and angular on a microscopic scale and consequently they cannot be regarded as indicating that substantial rounding occurred during the intrusion of the dykes.

Distribution

Field observations indicate that the distribution of ultrabasic xenoliths is very irregular. The xenolith content varies considerably from dyke to dyke, between outcrops of the same dyke and even within a single outcrop. Where a dyke contains abundant xenoliths they appear to decrease significantly in amount only very near the edges of the dyke. In order to test this observation quantitatively the following method was devised.



FIGS. 2 and 3: Fig. 2 (left). Photomicrograph (under crossed nicols) showing broken crystals of olivine and plagioclase at the edge of a xenolith where it is in contact with finer-grained dyke rock. $\times$ 19. Fig. 3 (right). Photomicrograph (under crossed nicols) of the contact between a xenolith and finer-grained dyke rock. The part of the xenolith shown consists of a single clinopyroxene crystal poikilitically enclosing numerous olivine crystals. Both pyroxene and olivine crystals are truncated against the dyke rock. $\times$ 19.

Large specimens collected at intervals across the dyke were cut along three mutually perpendicular planes, two of which were vertical, one parallel to, the other perpendicular to the strike of the dyke. The resulting faces were polished to make the xenoliths more conspicuous. Outlines of these faces and the xenoliths exposed therein were traced on to graph paper and the volumetric content of xenoliths determined. Small discrepancies occur between the results obtained from different faces of the same specimen but these are almost certainly due to the sampling error. They cannot be attributed to any preferred orientation (of xenoliths), which, according to Shaw and Harrison (1955), would not produce such discrepancies.

The average xenolith contents of four specimens from the 30-ft wide dyke 1 are:

5 in. from the SW. contact, 17·2 %; 4 ft 10 in., 26·3 %; 7 ft 6 in., 25·2 %; and 30 ft (at NE. contact), 1·2 %. Four xenolith contents are insufficient for the preparation of a distribution curve but the results appear to confirm the field observation that the xenolith content decreases towards the extreme edges of the dyke.

Mainly from the field evidence, therefore, it appears that the distribution of ultrabasic xenoliths is random with local concentrations and there is a tendency for the extreme edges of the dykes to contain fewer xenoliths than the centres.

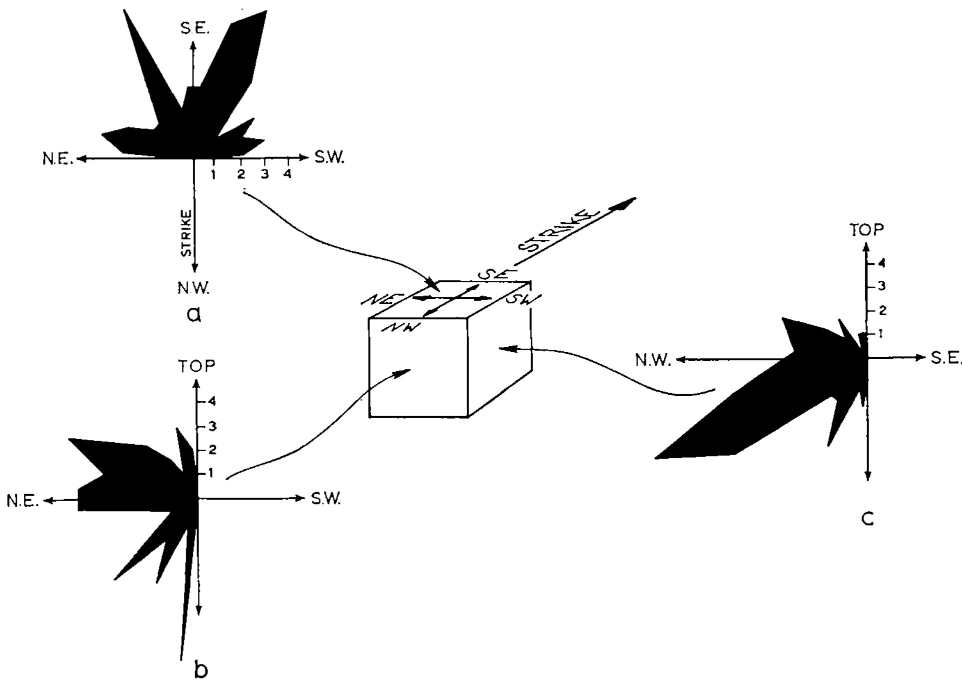


FIG. 4. Rose diagrams showing the orientations of the long axes of the cross-sections of elongate xenoliths from dyke 1 (see text for full explanation).

Orientation

On many of the weathered faces, particularly those subparallel to the margins of the dykes, there appears to be a tendency towards a preferred orientation of elongate xenoliths. In an attempt to confirm this the orientations of the long axes of the cross-sections of the xenoliths exposed on each of the three mutually perpendicular planes have been determined for the specimens from dyke 1. The results for the corresponding planes from each specimen have been combined to produce the orientation diagrams presented in fig. 4. In the vertical plane parallel to the strike (fig. 4*c*) there is a strong preferred orientation of the elongate xenoliths and, since no similar preferred orientation is apparent in either of the planes perpendicular to this one (figs. 4*a* and *b*), the orientation of the xenoliths must be linear rather than planar, with the intermediate and short axes randomly oriented in the plane perpendicular to the long axes. The plane represented in fig. 4c is almost parallel to the walls of the dyke (dyke 1 is not quite vertical) and the data presented in fig. 4 are interpreted as indicating that there is a preferred orientation of the long axes of the elongate xenoliths at an inclination of 20–30° to the horizontal in the plane parallel to the walls of the dyke.

Discussion

The motions of tabular and irregularly shaped solid bodies during laminar flow of concentrated suspensions have not been studied in any detail and even the behaviour of more regular bodies such as prolate and oblate spheroids, rods, and discs is the subject of some controversy. For dilute suspensions it was predicted (Jeffrey, 1923) and demonstrated experimentally (Taylor, 1923) that in a uniform shear flow an ellipsoid of revolution will rotate about its long axis, which will tend to adopt a preferred orientation perpendicular to the direction of flow within the flow plane. Despite this, a linear parallelism of prismatic or lath-shaped crystals in lavas has long been attributed to flow, with the parallelism corresponding to the direction of flow and more recent work on the flow of suspensions tends to support this interpretation. Goldsmith and Mason (1967) have suggested that for relatively concentrated suspensions the effects of particle collisions and interactions will tend to produce a preferred orientation of elongate particles such as rods and prolate spheroids with their long axes within the flow plane but parallel to the flow direction rather than perpendicular to it as suggested by Jeffrey and Taylor. If the extrapolation of Goldsmith and Mason's results to the case of the xenoliths is valid, a linear parallelism of the long axes of the type observed should have occurred during the intrusion of the dykes. It seems, therefore, that the preferred orientation of the xenoliths is a flow structure and that the orientation is parallel to the direction of flow.

The inference that the long axes of the xenoliths and, therefore, the direction of flow are inclined to the horizontal is particularly significant, since it indicates that dyke 1 flowed both upwards and in a south-easterly direction. This is in accord with the previously suggested hypothesis (see Gibb, 1968, p. 436) that the dykes of the Ben Cleat type diverged from the centre of the Cuillin plutonic complex.

It has already been demonstrated (Gibb, 1968) that the efficiency of the axial migration of olivine crystals in the dykes increased with the size of the crystals. Since the xenoliths are much larger than the largest of the olivine crystals, axial migration of the xenoliths should have been much greater than that of the olivine crystals and consequently, the xenoliths should be concentrated in a very narrow axial zone. However, although the extreme edges of the dykes contain fewer xenoliths than the rest of the dyke, it is evident that no extreme axial concentration of this type has occurred.

For axial migration to take place it is essential that the migrating body is able to rotate in, and move laterally through, the suspending medium. There is little doubt that the olivine crystals migrated through the suspending liquid, often until they became so concentrated that mutual interference prohibited any further movement. The xenoliths, however, would have had to move through a mush of olivine crystals, which, even before the differentiation of the dykes, could rarely have consisted of less than 40 % solid material, and movement of the xenoliths under such conditions appears highly improbable. Since many of the elongate xenoliths evidently aligned their long axes parallel to the flow, some rotation must have been possible but the longitudinal forces that orientated these xenoliths would have been much stronger than the transverse forces tending to produce axial migration, and it does not follow that since the xenoliths rotated they should have migrated axially. Nevertheless, the impoverishment in xenoliths of the extreme margins of the dykes is evidence that some axial migration did occur and it appears highly significant that this migration was confined to the parts of the dyke where the olivine concentration was lowest; one implication being that such migration as occurred did so after the differential distribution of olivine was established within the dyke.

It may therefore be concluded that, despite the much greater size of the xenoliths relative to the olivine crystals, the distribution of xenoliths was virtually unaffected by flow differentiation because of the relatively high viscosity imparted to the suspending magma by its content of olivine crystals.

Origin of the ultrabasic xenoliths

The ultrabasic xenoliths in the dykes differ in several respects from the olivine nodules frequently found in basalts and kimberlites and believed to have been derived from the upper mantle. Although occurring throughout the world, these olivine nodules are invariably composed of olivine, enstatite, chrome diopside, and chrome spinel (Ross, Foster, and Myers, 1954; Forbes and Kuno, 1967). The xenoliths in the dykes, on the other hand, although formed mainly of olivine and spinel, have not been observed to contain enstatite and always contain plagioclase. Consequently, there seems little doubt that the ultrabasic xenoliths in the dykes are not fragments of the upper mantle.

Ultrabasic xenoliths identical with those in the dykes occur in the nearby Sgurr Dubh intrusion and have been attributed by Weedon (1965, p. 65) to autobrecciation, although he does consider external derivation as a possible, albeit less probable, alternative. Although most of the xenoliths in the Sgurr Dubh intrusion can be matched with rocks forming parts of that intrusion, those in the dykes are seldom similar to any part of the host dyke and it is evident that the ultrabasic xenoliths must have been introduced into the dykes. Only the xenoliths in a few of the highest dykes (Gibb, 1968, fig. 1) could possibly have come from the Sgurr Dubh intrusion and, consequently, this is a very unlikely source of the xenoliths in the dykes. Since there must therefore have been a source of ultrabasic xenoliths other than the Sgurr Dubh intrusion, the possibility that the xenoliths in both the Sgurr Dubh intrusion and the dykes were introduced from a common external source cannot be ruled out. Indeed, such an origin could account for the presence of xenoliths in the highest level of the Sgurr Dubh intrusion and the features described by Weedon (1965, p. 65). [Despite earlier suggestions (Harker, 1904; Bowen, 1928) of a considerable disparity in age between these dykes and the Sgurr Dubh intrusion, investigations by the writer (Gibb, 1966), supported by recent clarifications of age relations in the Cuillins (Weedon, 1961, 1965; Hutchison, 1966 and pers. comm.), indicate that the ultrabasic dykes of the Ben Cleat type were emplaced approximately contemporaneously with the Sgurr Dubh intrusion.]

The range of rock types occurring as xenoliths in the dykes and the presence of relatively abundant banded xenoliths suggest that the ultrabasic xenoliths were produced by mechanical disintegration of layered ultrabasic rocks similar to those occurring in the Rhum and Sgurr Dubh intrusions (Brown, 1956; Wadsworth, 1961; Weedon, 1965). The only other indication of the origin of the xenoliths is the evidence that they were incorporated in the magma for a relatively short time and, consequently, are believed to have originated comparatively close to the present position of the dykes. Only a very tentative hypothesis concerning the origin of the xenoliths can be advanced on the basis of the available evidence and this hypothesis is outlined below.

Prior to the intrusion of the dykes (and possibly the Sgurr Dubh intrusion) part of a suspension of olivine crystals derived by partial fusion of a peridotitic source rock was mobilized and emplaced at a level below the point from which the dykes diverged. The complete or partial crystallization of this part of the suspension produced a small layered intrusion. Subsequent intrusion of the main part of the suspension via the same conduit ruptured the small layered intrusion with the consequent incorporation of the fragments in the dykes (and possibly the Sgurr Dubh intrusion, which could have been at or below its present level).

The above hypothesis is based on a number of assumptions for which no direct evidence is available but it does not seen inherently improbable and it is consistent with the observed dissemination of the xenoliths throughout the various intrusions and the short interval in both time and space between their incorporation in the magma and the onset of plagioclase and pyroxene crystallization in the dykes. In addition, a slight cryptic variation in the composition of the olivine in the layered intrusion might account for the small differences between the compositions of the olivine in the xenoliths and in the dykes. Whether or not the proposed petrogenetic hypothesis is correct, it appears highly unlikely that the xenoliths were derived accidentally from the Sgurr Dubh intrusion or any other ultrabasic body whose existence is, as yet, unknown, and consequently the xenoliths may justifiably be regarded as being of cognate origin.

Acknowledgements. The writer is extremely grateful to Dr. H. I. Drever and Mr. R. Johnston for stimulating discussion on the subject matter and to the latter for his constructive criticism of the manuscript.

REFERENCES

Bowen (N. L.), 1928. *The Evolution of the Igneous Rocks*. Princeton University Press.

Brown (G. M.), 1956. The layered ultrabasic rocks of Rhum, Inner Hebrides. *Phil. Trans. ser.* B, **240**, 1–53.

Drever (H. I.) and Johnston (R.), 1958. The petrology of picritic rocks in minor intrusions, a Hebridean group. *Trans. Roy. Soc. Edinb.* **63**, 459–97.

—— —— 1967. *Picritic Minor Intrusions*, in *Ultramafic and Related Rocks*, ed. Wyllie, (P. J.). New York (J. Wiley).

Forbes (R. B.) and Kuno (H.), 1967. *Peridotite inclusions and basaltic host rocks.* in *Ultramafic and Related Rocks*, ed. Wyllie (P. J.). New York (J. Wiley).

Gibb (F. G. F.), 1966. Ph.D. Thesis. University of St. Andrews.

GIBB (F. G. F.), 1968. Flow differentiation in the xenolithic ultrabasic dykes of the Cuillins and the Strathaird Peninsula, Isle of Skye, Scotland. *Journ. Petrology*, **9**, 411–43.

GOLDSMITH (H. L.) and MASON (S. G.), 1967. *The Microrheology of Dispersions*, in *Rheology-Theory and Applications*, **4**, ed. Eirich (F. R.). New York (Academic Press).

HARKER (A.), 1904. The Tertiary igneous rocks of Skye. *Mem. Geol. Surv. U.K.*

HUTCHISON (R.), 1966. Intrusive tholeiites of the western Cuillin, Isle of Skye. *Geol. Mag.* **103**, 352–63.

JEFFREY (G. B.), 1923. The motion of ellipsoidal particles immersed in a viscous fluid. *Proc. Roy. Soc. ser.* A, **102**, 161–79.

ROSS (C. S.), FOSTER (M. D.), and MYERS (A. T.), 1954. Origin of dunites and of olivine rich inclusions in basaltic rocks. *Amer. Min.* **59**, 693–737.

SHAW (D. M.) and HARRISON (W. D.), 1955. Determination of the mode of a metamorphic rock. Ibid. **40**, 614–23.

TAYLOR (G. I.), 1923. The motion of ellipsoidal particles in a viscous fluid, *Proc. Roy. Soc. ser.* A, **103**, 58–61.

WADSWORTH (W. J.), 1961. The layered ultrabasic rocks of south-west Rhum, Inner Hebrides. *Phil. Trans. ser.* B, **244**, 21–64.

WEEDON (D. S.), 1961. Basic igneous rocks of the southern Cuillin, Isle of Skye. *Trans. Geol. Soc. Glasgow*, **24**, 190–212.

—— 1965. The layered ultrabasic rocks of Sgurr Dubh, Isle of Skye. *Scot. Journ. Geol.* **1**, 41–68.

[*Manuscript received 31 March 1969*]