A petrographic and geochemical study of back-veining and hybridization at a gabbro–felsite contact in Coire Dubh, Rhum, Inverness-shire

By A. C. Dunham, M.A., D.Phil., F.G.S.

Department of Geology, South Road, Durham

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Summary. Field, petrographic, and chemical data are presented which make it possible to follow the course of back-veining of felsite by a gabbro ring-dyke. The remelted felsite back-veined the chilled margin of the gabbro, then acidified the partly crystalline basic mush within the chilled zone and finally mixed with the mainly liquid basic magma farther inside the dyke to produce hybrids of marscoitic aspect. Spectrographically determined trace-element data, with data on some major elements, illustrate these changes. The veins are shown to have a composition nearer the ternary minimum in the system Ab–Or–Qz–H_2O than the parent felsite, while culminations of soda and iron in the acidified gabbros and hybrids suggest that metasomatism has accompanied the mixing of the partly liquid end members. This study confirms the earlier suggestion that the gabbro post-dates the felsite.

The island of Rhum, in the Small Isles parish of Inverness-shire, has long been famous for its layered ultrabasic rocks. However, to the north and south of the eastern mass of layered ultrabasics (Brown, 1956) are two areas of minor intrusions of acid and basic rocks (Hughes, 1960), the whole area of igneous intrusion being contained within a ring fault (Bailey, 1945).

In Coire Dubh, in the northern area, Harker (1908) was the first to notice acid veining from felsite in the enveloping gabbro around the ultrabasic rocks. He accordingly assigned a younger age to the felsite. Harker also believed the gabbro (eucrite in his terminology) to be a sheet dipping south-westwards conformably with the layers of allivalite and peridotite. Bailey (1945), however, concluded that the gabbro was essentially steeply bounded but with sheets coming off to the south and he also concluded that from the way in which the gabbro cuts across the other boundaries it must be the younger intrusion, in spite of the difficulties of the acid veining. Brown (1956) agreed with Bailey as to the age relation, but distinguished two types of enveloping gabbro; the 'marginal gabbro' and the 'fine-grained gabbro'. Brown shows the 'marginal gabbro' running all round the northern and eastern margins of the ultrabasic rocks with the 'fine-grained gabbro' between the 'marginal gabbro' and the ultrabasic rocks on Cnapan Breaca. He also demonstrated the similarity of petrographical type of the sheets of gabbro within the ultrabasic rocks and the 'fine-grained gabbro'. Hughes (1960) records similar veining from the Southern Mountains area, where a peripheral gabbro to the ultrabasic rocks cuts felsite.

The object of the present investigation, part of a resurvey of the north-eastern margin of the igneous complex, was to study the veined zone in detail to try to elucidate its origin.

Field relations

The exposure of the zone adjacent to the ultrabasic rocks is very poor, but only one type of gabbro has been found within the present area lying between the ultrabasics and the other rock types. This corresponds to Brown's 'fine-grained olivine gabbro' (Brown, 1956). On Cnapan Breaca it forms a dyke 500 ft wide with an outward dip on the northern margin. On Meall Breac it has thinned to 210 ft, while 1800 ft west of the col on Meall Breac it dies out altogether. Thus it is not believed that there is a continuous strip of gabbro running along the northern margin of the ultrabasic rocks then continuing northward between Loch Gainmhich and Loch Bealach mhic Neill (as shown on the Geological Survey 1″ sheet 60). Also the way in which the gabbro crosses Coire Dubh (fig. 1) suggests that it is dyke-like in form, not a sheet as Harker suggested (1908, fig. 4, p. 11).

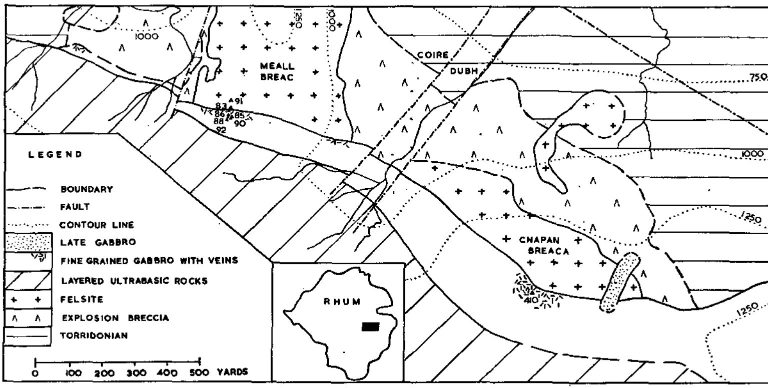
The veined zone within the gabbro occurs next to the felsite with the veins emanating from the felsite. On Cnapan Breaca the zone is 150 ft wide while on Meall Breac the width is only 27 ft. Cone sheets on Cnapan Breaca cut the felsite but do not cut the gabbro; a similar relation was found by Hughes (1960) in the Southern Mountains area. Near to the gabbro the cone sheets are extensively net-veined.

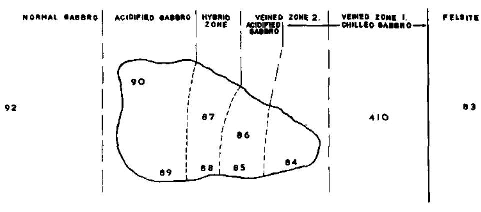
As the veined zone is traced into the gabbro the margin of each vein becomes less and less distinct until eventually it merges into a light-coloured hybrid rock. This hybrid rock may be free from dark basic xenoliths or as on Cnapan Breaca there may be many of these blocks set in a hybrid matrix.

The cross-cutting relationship, the chilled margin, and the absence of cone sheets in the gabbro suggest very strongly that the gabbro post-dates the felsite (Bailey, 1945; Hughes, 1960).

Petrography

The veined and hybrid zones have been further subdivided on the basis of their field and microscopic characteristics. The sequence of rock types from felsite into the ring dyke is shown in fig. 2. Superimposed





FIGS. 1 and 2: FIG. 1 (top). Geological sketch map of Coire Dubh, central Rhum. The inset map shows the area covered by the sketch map. FIG. 2 (bottom). Plan of the traverse on Meall Breac to show the sequence of zones and the positions of the analysed specimens. The relative position of specimen 410 is shown as it comes from Cnapan Breaca.

on this scheme are two types of veins; the first type running from the felsite into the acidified gabbro and the second within the outer acidified gabbro up to the hybrid zone, the first type grading into the second.

Felsite. The detailed petrography of the felsite has been described elsewhere (Hughes, 1960) so only a brief description will be given here. The rock weathers to a light grey colour on which phenocrysts of feldspar and quartz are conspicuous. In thin section glomeroporphyritic groups and separate phenocrysts of plagioclase (An_{34-18}), pyroxene, and magnetite, with separate high-quartz paramorphs are seen set in a cryptocrystalline groundmass of quartz and feldspar. The pyroxene is almost always pseudomorphed by amphibole and iron ore. Typical modal analyses are given in Table I.

A sequence of rocks was collected on Meall Breac up to the margin of the felsite. The only noticeable change is an increase in the grain size of the groundmass starting between 50 and 35 ft from the felsite margin (table I). On Cnapan Breaca a xenolith of felsite shows the plagioclase to have been altered to anorthoclase (a change paralleled

TABLE I. Modes and grain-size variation of felsites.

Spec. no.	Distance from gabbro contact ft	Plagio-clase %	Quartz %	Pyroxene %	Ore %	Ground-mass %	Grain size mm
429*	1500	30·1	2·9	3·7	1·9	61·4	—
91*	100	14·2	3·6	2·8	1·4	77·5	—
13	100	25·6	2·4	3·8	1·1	66·9	0·007
12	50	22·1	2·5	6·0	1·6	68·0	0·008
11	35	—	—	—	—	—	0·012
10	20	19·2	3·3	2·1	1·9	73·5	0·014
9	10	—	—	—	—	—	0·014
30	3	21·8	2·4	4·1	1·8	69·9	—
32	3	17·1	2·4	1·5	1·1	77·9	—
83*	3	19·8	2·1	3·2	1·1	73·8	—
8†	1	23·1	3·4	2·5	2·5	68·2	0·031
31†	1	—	—	—	—	—	0·047

* Analysed rocks, see table III.
† Vein 1 ft within gabbro.

in the granophyre and also noted by Hughes (1960) in the Southern Mountains area). The groundmass shows extensive recrystallization to bundles of quartz and feldspar laths, with strings of small granular pyroxenes between the bundles.

Veins. Two types of veins can be distinguished on the basis of their textures. The veins of zone 1 are indistinguishable from normal felsite except that the groundmass grain-size has increased fivefold from the normal (table I). The analysed vein from this zone (410) carries a smaller percentage of phenocrysts than normal felsite.

Veined zone 2 is characterized by veins with granophyric texture and few plagioclase phenocrysts. The margins of these veins are very indistinct in contrast with veined zone 1. The veins are further characterized by the virtual absence of ferromagnesian minerals.

Gabbro. The 'fine-grained olivine gabbro' on Meall Breac and Cnapan Breaca shows a well-chilled margin against felsite, and the grain-size increases inwards, though in the central portion of the dyke it is variable. In thin section two types of variation within the gabbro are apparent; the first depending on proximity to the margin of the dyke and the second on proximity to the hybrid zone. The variation with proximity to the margin will be described first.

A sample of gabbro from well within the dyke (92) consists of plagioclase (An_{61-57}) in small elongate laths enclosed by both olivine (Fo_{79}) and clinopyroxene ($Ca_{41.5}Mg_{43}Fe_{15.5}$).[1] The augite shows an ophitic

TABLE II. Modes of gabbros and hybrid rocks (volume per cent).

Spec. no.	Plagio-clase	Clino-pyroxene (Cp)	Ortho-pyroxene (Op)	Olivine (Ol)	Ore	Micro-pegmatite	Cp/(Op+Ol)
85*†	38·0	10·4	4·8	—	8·2	38·6	2·3
89†	40·8	21·4	1·1	—	7·8	28·8	19·4
90*†	45·0	30·6	2·7	—	7·2	14·3	11·6
6‡	53·1	25·8	11·9	—	3·8	5·5	2·2
31‡	44·5	48·3	—	—	7·2	—	—
7‡	45·5	28·7	21·5	—	4·3	—	1·4
84‖	47·8	30·9	13·1	3·4	4·8	—	1·9
92*‖	56·6	27·3	—	15·3	0·8	—	1·8

					Groundmass	
	Oligoclase	Andesine	Pyroxene +ore	Quartz	Feldspar	Quartz
88*§	11·0	3·2	12·2	trace	48·4	25·2

* Analysed rock, see table III. ‡ Veined gabbro.
† Acidified gabbro. ‖ Gabbro.
§ Hybrid rock.

texture towards the olivine. This rock is almost identical to Brown's analysed sample of 'fine-grained gabbro' (1956, p. 47), although it carries a little more olivine and a little less augite (table II).

A series of specimens was collected from 92 up to the edge of the dyke on Meall Breac. A most striking change is observed in grain-size towards the margin (fig. 3). This change applies to all rocks of both types of variation. Estimates have been made of the overall maximum size and the average long diameter of the pyroxenes and of the plagioclase. The convergence of the average and maximum sizes towards the margin is noteworthy.

There is also a striking variation in the mineralogy and the modes of

[1] Olivine determined by the method of Yoder and Sahama (1957); d_{130} 2·7809 Å. Clinopyroxene determined by the method of Brown (1960); $a \sin\beta$ 9·366 Å, b 8·930 Å.

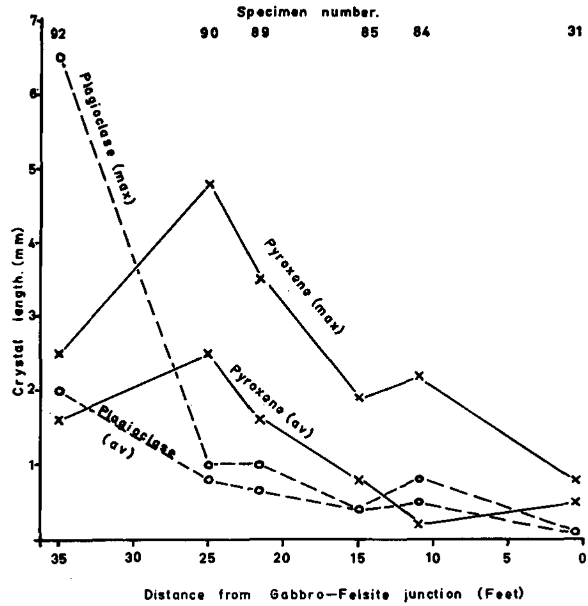


FIG. 3. The variation of the maximum and average grain-sizes observed towards the margin of the 'fine-grained gabbro' ring-dyke.

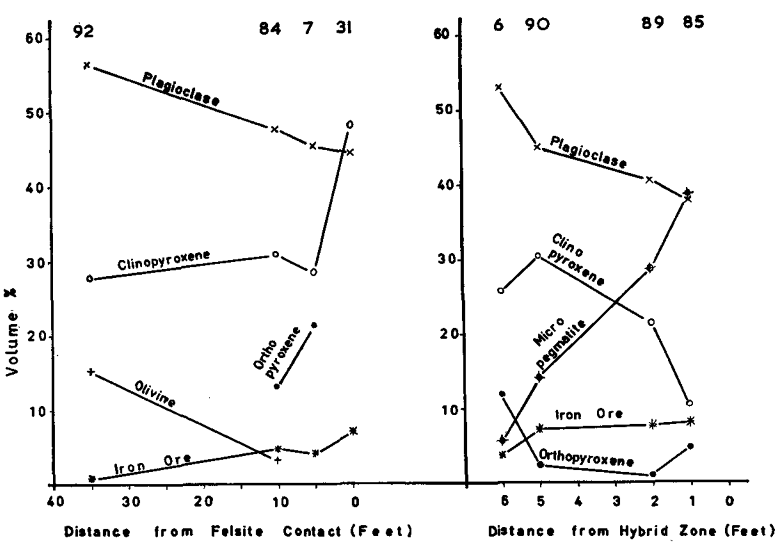


FIG. 4. Variation in modes with proximity to the gabbro–felsite junction (left side of diagram) and to the hybrid zone (right side of diagram). The figures along the top of the diagram are specimen numbers.

the rocks (fig. 4 and table II). Olivine and plagioclase decrease towards the margin while clinopyroxene and iron ore increase, and orthopyroxene appears ($2V_\alpha$ 61°). However, the ratio of clinopyroxene/(orthopyroxene+olivine) varies very little (table II). The core compositions of the plagioclases in all these rocks are very similar (An_{67-61}) and they show little normal zoning.

The second type of variation is related to the proximity of the hybrid zones, and the rocks are characterized by increasing amounts of micropegmatite (fig. 4, table II) and a progressive change in the feldspar composition towards more sodic types. This change affects the cores, which move from An_{63} to An_{51} in the rock with the most micropegmatite (85), and the zoning becomes very much more pronounced, reaching An_{24} in the most extreme case.

The character of the interstitial quartz and feldspar changes progressively with increasing amount. In sample 6 (table II) the acid material is in the form of small patches of *micropegmatite* between the plagioclase grains. In 90 and 89, however, a rim of clear albite often surrounds the plagioclase grains and the quartz appears as irregular grains within larger alkali feldspar grains. Apatite also occurs within the alkali feldspar. Finally in 85 the quartz is euhedral and several grains extinguish together.

Hybrids. On Meall Breac this zone consists of dark-grey rocks of homogeneous nature with a few dark-coloured basic inclusions. On Cnapan Breaca, however, there are many more basic inclusions surrounded by the same homogeneous grey rock.

In thin section the hybrids consist of two kinds of plagioclase phenocrysts, both types associated with pyroxenes, with rare quartz phenocrysts set in a groundmass of turbid alkali feldspar and quartz. The largest feldspars are oblong in outline, although frequently broken, with a composition range An_{30-20}. They often occur in glomeroporphyritic groups with iron ore and clinopyroxene. The second type of plagioclase is smaller, more elongate and is strongly zoned from An_{60} to An_{45}. Clinopyroxene is often associated with this type of feldspar also, but it is usually more granular than the augite with the sodic feldspar. Two or three quartz phenocrysts have been found with embayments very similar to those in the felsite.

The groundmass of the hybrids consists of quartz and turbid alkali feldspar. While many of the quartz blebs extinguish together, a regular granophyric texture is not developed. Iron ore and apatite also occur.

An example from Cnapan Breaca (414) shows typical hybrid material surrounding blocks of basic material that have been partly acidified. The pyroxenes have broken down to granular aggregates, the feldspar has been albitized, and a considerable amount of micropegmatite is

TABLE III. Spectrographic analyses. Major elements in weight per cent, trace elements in parts per million. Optical spectrographic determinations made using the variable internal standard method on a Hilger large quartz and glass spectrograph. Na_2O and K_2O determined by the flame photometer.

Specimen	429	91	83	410	86	88	85	90	92
Fe	3·9	3·1	3·9	1·7	2·0	4·4	7·5	7·5	5·5
MgO	0·7	0·4	0·6	0·5	0·9	1·5	2·7	4·3	4·6
CaO	2·7	1·9	2·1	2·8	1·7	4·2	6·7	8·7	10·3
TiO_2	0·6	0·57	0·52	0·47	0·47	0·97	1·78	1·7	0·53
Na_2O	4·82	4·26	4·30	3·75	3·35	3·34	3·72	3·42	2·70
K_2O	2·99	3·33	3·11	4·47	4·35	2·93	1·65	1·12	0·17
Ga	24	24	28	23	18	26	22	23	23
Cr	5	49	57	65	9	62	41	240	433
V	21	15	17	27	31	104	300	311	114
Li	41	17	24	38	24	30	20	25	7
Ni	4	3	4	8	14	13	19	58	233
Co	6	1	3	3	3	9	42	38	68
Cu	9	13	9	5	20	27	166	88	257
Sc	12	9	10	4	6	13	27	29	25
Zr	266	335	336	329	243	296	216	196	40
Mn	710	685	840	280	304	760	1173	1190	805
Sr	245	215	230	78	120	237	226	283	279
Ba	1078	1255	1247	830	992	1118	514	359	111
Rb	130	115	123	264	143	131	32	46	6
La	59	87	83	—	33	74	51	41	—

429 Felsite, Meall Breac. 1500 ft from gabbro contact.
91 Felsite, Meall Breac. 100 ft from gabbro contact.
83 Felsite, Meall Breac. 3 ft from gabbro contact.
410 Felsitic vein, Cnapan Breaca. 50 ft within gabbro.
86 Granophyric vein, Meall Breac. 15 ft within gabbro.
88 Hybrid, Meall Breac. 17 ft within gabbro.
85 Acidified gabbro, Meall Breac. 15 ft within gabbro.
90 Acidified gabbro, Meall Breac. 23 ft within gabbro.
92 'Fine-grained olivine gabbro', Meall Breac. 35 ft within gabbro.

present. Although the margins of these xenoliths are sharp in hand specimen they are very much more diffuse in thin section.

Chemistry

A suite of rocks representing the felsite, the veins, and the acidified gabbros and hybrids have been analysed by optical spectrographic methods for certain major elements and fourteen trace elements, and Na_2O and K_2O in all these rocks have been determined by flame photo-

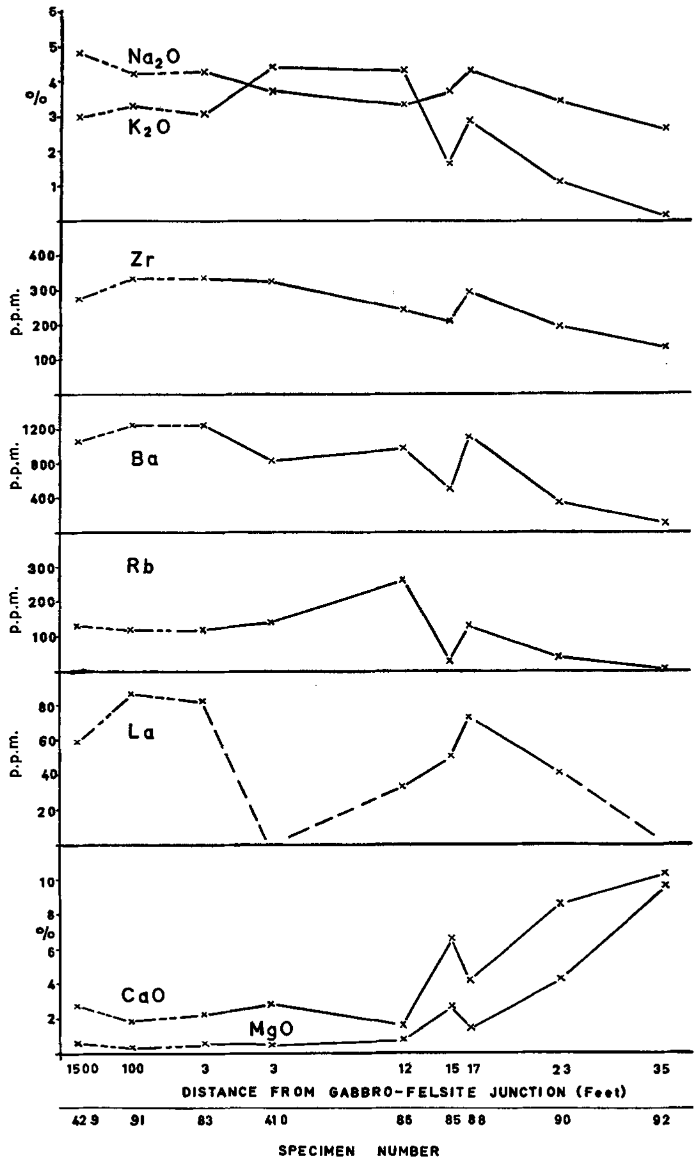


FIG. 5. The variation of certain major and trace elements from within the felsite mass to within the gabbro ring-dyke. 429, 91, and 83, felsite; 410, felsitic vein; 86, granophyric vein; 88, hybrid; 85 and 90, acidified gabbros; 92, 'fine-grained olivine gabbro'.

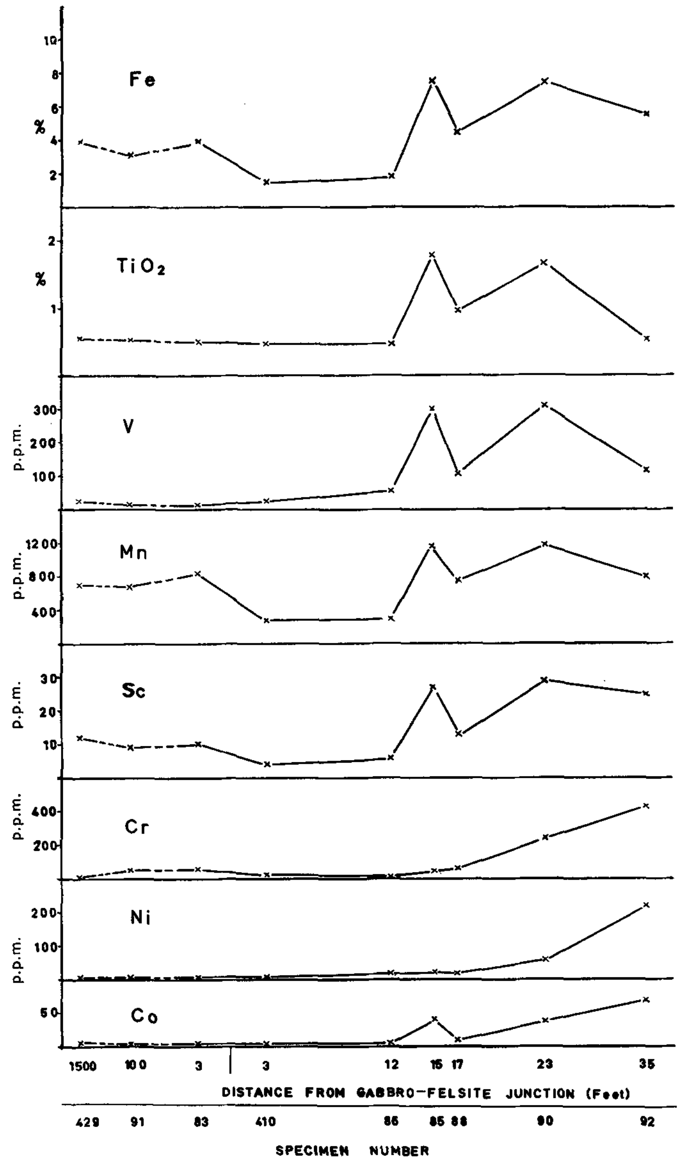


FIG. 6. The variation of certain major and trace elements from within the felsite to within the gabbro ring-dyke.

metry (table III). No claim is made for an accuracy greater than $\pm 0{\cdot}5\ \%$ for the major elements determined by spectroscopy. However, with this limitation it is believed that the trends displayed are real (figs. 5 and 6).

Felsite and veins. The felsite from its field relations and petrography is the parent of the veins so the changes from the felsite to the veins will be discussed first. Although no complete analysis of the felsite of Meall Breac has been made, the soda and potash values of the three rocks analysed are very similar to analyses of other felsites of Rhum (Harker, 1908; Hughes, 1960).

There is no significant change in the concentration of any element towards the margin of the felsite, but in the veins there are several important changes. In the felsite soda is dominant over potash but in the veins this position is reversed, and the weight percentage of total alkalis increases. Amongst the trace elements Zr, Ba, and La follow the distribution of Na_2O, while Rb follows K_2O. CaO and MgO are small in all the analysed samples and show no systematic variation. Fe, Mn, and Sc all fall off in the veins while Ti, V, Ni, Cr and Co remain roughly constant.

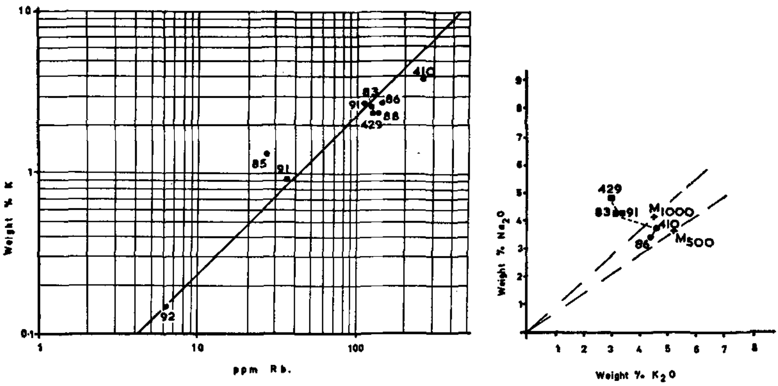
Gabbros and hybrids. A typical uncontaminated 'fine-grained gabbro' that has been analysed by Brown (1956, p. 47) is very similar to the rock analysed in this study (92). The sequence from this gabbro through acidified gabbro to hybrid shows some striking changes. Fe, Ti, V, Sc, and Mn all show a culmination in the acidified gabbros (85 and 90). This can be observed in the rocks as an increase from *c.* 1 % of iron ore in the 'fine-grained gabbro' to *c.* 8 % in the acidified gabbros. MgO, CaO, Cr, Ni, Co, and Cu all decrease towards the hybrids, whilst Na_2O, K_2O, Ga, Zr, Ba, Rb, La, and Li all increase towards the hybrids. The K/Rb ratios of all these rocks fall on the trend for normal igneous rocks (Ahrens *et al.*, 1952; Taylor, Emeleus, and Exley, 1956) (fig. 7).

Petrogenesis

This study was begun to try to resolve the conflicting opinions as to the relative ages of the felsite and the 'fine-grained gabbro' (Harker, 1908, and Bailey, 1945). The field relations are quite clear that the gabbro postdates the felsite. However, veins from the felsite cut the chilled margin of the gabbro; a paradox noted at other acid–basic contacts (e.g. Ardnamurchan, Butler, 1961; Mull, Bailey *et al.*, 1924; Antrim, Harris, 1937; Finland, Kahma, 1951; South Africa, Walker and

Poldervaart, 1949; etc.). Thus, to anticipate the main conclusion, it is apparent that the gabbro has provided enough heat on cooling to remelt partially the adjacent felsite, which back-veined the gabbro.

The chemical data on the veins confirms this hypothesis. In a plot of weight percentage Na_2O against K_2O (fig. 8) it can be seen that there is an increase of K_2O in the veins. Also plotted in this diagram are the



FIGS. 7 and 8: FIG. 7 (left). The variation of K and Rb. See fig. 5 for rock types. Trend line for normal igneous rocks from Taylor, Emeleus, and Exley (1956). FIG. 8 (right). Values of Na_2O and K_2O (weight %) found in the felsites and veins on Meall Breac and Cnapan Breaca. M_{500} and M_{1000} are the ratios for the ternary minima in the system Ab–Or–Qz–H_2O at 500 and 1000 kg/cm² water-vapour pressure, calculated from the data of Tuttle and Bowen (1958).

calculated positions of the ternary minima in the system Ab–Or–Qz–H_2O (Tuttle and Bowen, 1958). It can be seen that the veins plot between the constant-alkali-ratio lines for 500 and 1000 kg/cm² water-vapour pressure, i.e. much nearer the minima than the original felsite. This suggests that only the groundmass of the veins has been melted and mobilized. The position of the veins on this diagram also suggests that the maximum water-vapour pressure under which this remelting could have occurred is approximately 750 kg/cm², and was probably less, for some of the soda in the analyses is contributed by unmelted plagioclase. No tridymite has been observed, so the water-vapour pressure was probably greater than 200 kg/cm² (Tuttle and Bowen, 1958).

The distribution of the trace elements in the veins reflects their very simple mineralogy. Rb is the only one to show any pronounced enrichment compared with felsite, but the K/Rb ratio is still that found in most igneous rocks. The enrichment of Rb observed in certain more potash-rich acid rocks (Taylor, Emeleus, and Exley, 1956) has not been observed.

Recent work by Brown (1963) on the melting of granophyres from Rhum (Papadil granophyre) and Skye under hydrothermal conditions has shown that in the case of the Papadil granophyre (identical in composition to the felsite) the plagioclase was the last phase to melt. It is believed that these experiments have reproduced what happened to the felsite when heated by the cooling gabbroic magma.

This new magma was formed when only approximately 6 % of the gabbro had completely solidified (from the ratio of the width of unacidified gabbro adjacent to the felsite contact, 12 ft, to the total width of the ring-dyke in the same place, 210 ft). It was able to penetrate into cooling-cracks in the chilled margin, possibly aided by the expansion (approximately 10 %) when a solid rock becomes molten. If the estimate of the water-vapour pressure quoted above is correct, then the melting envisaged could take place within the temperature range 750–800° C (Tuttle and Bowen, 1958). This is a significantly lower temperature than that of the entirely molten gabbroic magma, for the data of Yoder and Tilley (1962) suggest that even if the magma rose from a depth of four or five kilometres from the local magma source it would have a temperature of approximately 1150° C and would be entirely solid at 1000° C under the much smaller confining water-vapour pressure near the surface.

The new acid magma was thus able to penetrate the quickly-crystallized outer margin of the gabbro, and the veins in the zone nearest the contact have sharp margins. However, as they are traced inwards their character changes from felsitic to granophyric and their margins become less well defined. In this latter zone it is suggested that the gabbro had not entirely crystallized, for there is a progressive increase in the amount of micropegmatite, the degree of albitization of the feldspars, and the modal amount of iron ore. These effects are probably due to the introduction of acid magma that mixed with the liquid contained in the crystal mush. The amount of acid material added increased inwards and the mode of the most acidified gabbro examined suggests that approximately 40 % of acid material has been added.

The reason for the culmination in iron is not clear. The non-linear character of the variation diagrams (figs. 4 and 5) contrasts strongly with the linear relationship shown by the mixing of acid and basic magma in the Gardiner River area, Wyoming (Wilcox, 1944). It may be that the introduction of acid magma altered the oxidation state of the basic magma, causing iron to crystallize as the oxide rather than go into the pyroxene lattice, for example. However, the presence of a culmination in iron means that iron must have been removed from the surrounding basic magma by diffusion, for the veins carry even less iron than the felsite.

The hybrid rocks represent this mixing process carried even further, with a dominating contribution from the acid magma. Thus, recognizable phenocrysts from both end members are present: quartz and oligoclase with pyroxene pseudomorphs from the felsite, labradorite–andesine and pyroxene from the gabbro. It is possible to calculate the approximate contribution of acid and basic magma to form rock 88 (table II) in the following way: The mode of the rock shows 25 % quartz; this would be associated with approximately 40 % alkali feldspar in the felsite (Dunham, in press). In addition to this, 11 % of the rock is oligoclase phenocrysts from the felsite, which would be associated with approximately 2 % of iron ore and pyroxene. Thus the total contribution from the felsite is at least 78 %. This simple calculation does not take into account the material added to the basic plagioclase on acidification, but since this is probably more or less balanced by the amount of resorption of the acid plagioclase crystals, we probably have a fair estimate of the proportion involved. The chemistry of the hybrids bears this out, for the values are much nearer to felsite than to gabbro. However, as was the case in the acidified gabbros, straight mixing is not the only process to have occurred, for it is not possible to draw a linear subtraction diagram between gabbro or acidified gabbro and the felsite or the veins. Metasomatic diffusion must have operated to upset the simple addition. On such a diagram (and table III) it can be seen that relative to the veins (86 and 410) and the gabbro (92) the hybrid (88) shows a culmination in Na_2O while Fe and TiO_2 show strong positive deviations from the linear plot (higher than expected), and amongst the trace elements Ga, Ba, and possibly La show culminations, while V, Li, Zr, Mn, and Sr show positive deviation, and Cr, Ni, Co, and Cu show negative deviations. These remarks apply assuming a mixture of 78 % acid magma and 22 % basic magma. Many of the deviations are relatively small, however, and the values of MgO, CaO, H_2O, and possibly Sc are in good agreement with this figure for the relative proportion of acid to basic material.

Thus there is good evidence for metasomatic transfer of Na_2O, Fe, and TiO_2 into the hybrid during the mixing process with possible additions of those elements showing positive deviations and subtractions of those elements showing negative deviations. The source of these elements must have been the basic magma, and it is well known that soda metasomatism often accompanies the intrusion of basic rocks (e.g. Agrell, 1939). The iron metasomatism is more unusual and as already suggested may be controlled by a change in the oxidation state of the mixed magma.

The exposures on Meall Breac, from which most of the analysed rocks were taken, show relatively homogeneous hybrid rock, but the hybrid rocks on Cnapan Breaca are crowded with basic xenoliths. These are all acidified gabbros, very similar to the rocks already described but enclosed within hybrid material.

A feature of the ring-dyke that requires further investigation is the change in mineralogy of the uncontaminated sequence of gabbros, from the margin of the intrusion to the centre. Olivine increases towards the centre of the dyke, although the ratio of clinopyroxene to orthopyroxene plus olivine remains roughly constant in this series. The total amount of ferromagnesian minerals also decreases towards the centre of the intrusion.

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