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Demonstrations in petrogenesis from Kiloran Bay, Colonsay.

I. The transfusion of quartzite.

(With Plates XI and XII.)

By Doris L. Reynolds, M.Sc., F.G.S.

Lecturer in Geology, University of Durham.

With analyses by Agnes Gibbs and others.

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1. Introduction.

In 1911 Dr. W. B. Wright[1] briefly described the felspathized quartzite blocks in the hornblendite of Port Easdale, Kiloran Bay, Colonsay, Hebrides. He showed that the exposures provide a conclusive demonstration that the action of hornblendite magma on quartzite xenoliths was to convert them to alkali-felspar and quartz, so that

[1] W. B. Wright and E. B. Bailey, The geology of Colonsay. Mem. Geol. Surv. Scotland, 1911, p. 29.

in the final stage 'one can recognize in numerous angular and rounded patches of felspathic material, without visible xenolithic core, the ghosts of former masses of quartzite'.

Twenty-five years have elapsed since the publication of Dr. Wright's account, yet the importance of the record appears to have passed unnoticed. The purpose of this paper is, therefore, to recall the occurrence; to amplify Dr. Wright's description with additional observations and petrological and chemical detail; and to emphasize the petrological significance.

Stimulated by Dr. Wright's description, Dr. Holmes and I paid a preliminary visit to Colonsay in 1934. Finding much of interest we returned in 1936 and, in order that no detail should be overlooked, remapped the small intrusions of Port Easdale on the scale of 54 inches to the mile. For this purpose the coastline, with its disconnected rocky outcrops, had to be remapped. As a result of our visits much additional evidence of first-class petrological importance has been obtained. We propose to deal with this evidence in a series of papers of which the present communication, restricted to the phenomena attending the transfusion of quartzite, forms the first.

2. Geological Setting.

The sedimentary rocks, which constitute the major part of the island of Colonsay, consist of a folded, crumpled, and cleaved series of phyllites, limestone, mudstones, grits, and conglomerates, regarded by Wright and Bailey as of Torridonian age. Kiloran Bay breaches and occupies the centre of a structural basin in this series, the shores of the bay being margined by the Staosnaig phyllites, the youngest beds of the succession. The latter are in turn margined by the Colonsay limestone and successively older members of the sedimentary sequence.

On the northern shore of Kiloran Bay the Staosnaig phyllites are pierced by three small composite intrusions consisting of hornblendite, appinite, and syenite. Two of these form the northern and southern shores of Port Easdale, whilst the third outcrops in the higher ground directly to the north. Each of the three intrusions comprises an elongated mass of syenite, trending in a W.–E. or NW.–SE. direction, together with marginal phases of hornblendite and appinite (hornblende and alkali-felspar). Further, the marginal phases of each intrusion contain abundant angular and rounded blocks of

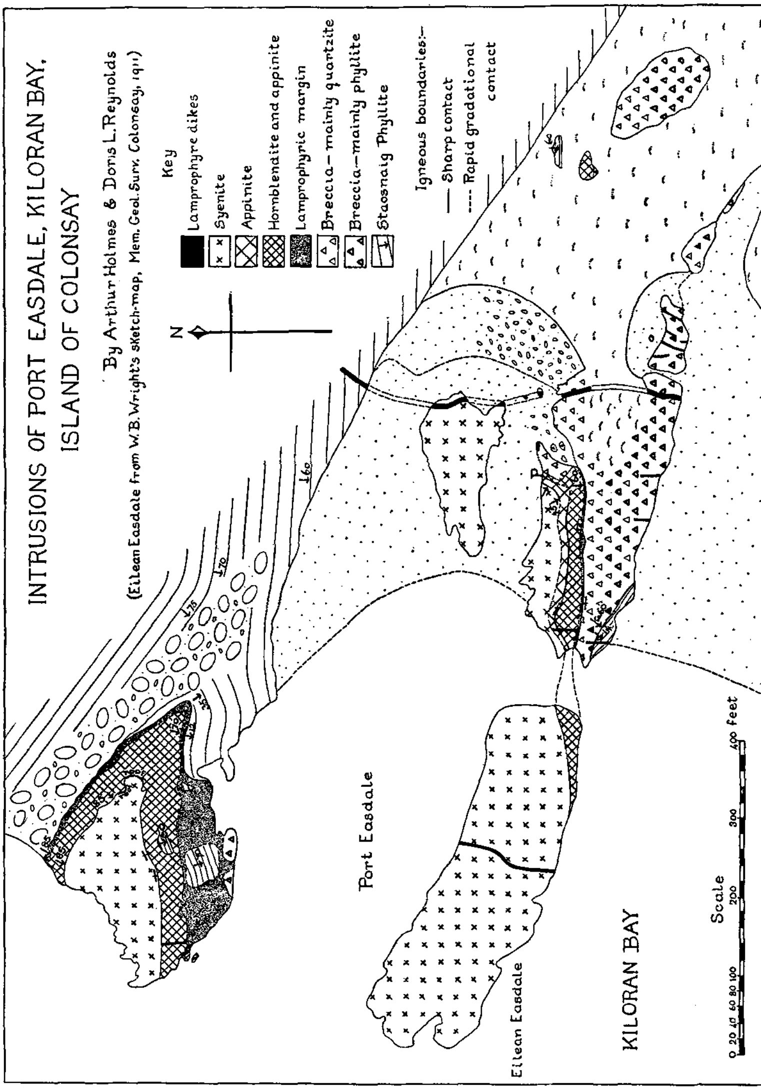


FIG. 1. Geological map of the intrusions of Port Easdale. The strike lines of the Staosnaig phyllites are diagrammatic, except where observations of dip are recorded. The arrows on the igneous types and on the breccia refer to the dip of the contact planes. P indicates the locality of the syntectic pegmatite veins (pl. XI, fig. 4).

quartzite which are to be seen in all stages of conversion to both syenite and appinite.

The most southerly of the three intrusions throws light on the origin of the xenolithic quartzite blocks. Only the southern limb of this intrusion is exposed, its northern margin being concealed beneath the sand of the bay. The intrusion is elongated from west to east and the exposed portion consists of successive zones, from north to south, of syenite, appinite, hornblendite (showing gradations to appinite throughout its mass), lamprophyre, and sedimentary breccia (developed by magma pressure). The distribution and ascertained relations of these various types are shown on text-fig. 1.

In the present connexion the breccia is of importance. It shows a sharp contact against the Staosnaig phyllites and is as much an intrusion as are the igneous types. At its outer margin, where it adjoins the phyllites, it is formed almost completely of closely interlocking angular blocks of similar phyllite. A few feet in from the margin, however, angular and occasional rounded blocks of white quartzite, sometimes two feet or more across, are also present, together with rarer blocks of limestone. The latter, as Wright suggested, is probably the Colonsay limestone which margins and dips under the phyllites of Kiloran Bay. Away from the margin the proportion of quartzite blocks increases until the igneous contact is reached. There the breccia is composed almost completely of rounded and angular blocks, together with much larger masses, of white quartzite. The latter, measurable in yards, are obviously representatives of a massive quartzite horizon. The blocks vary from a few inches up to two or three feet across, and the proportion of rounded relative to angular members increases greatly towards the igneous contact.

No quartzite formation outcrops in the island, although it was noted by Wright that similar quartzite occurs as small pebbles in conglomerate beds at two horizons in the local Torridonian and also as xenoliths in some of the lamprophyre dikes. The facts indicate that the quartzite represents a formation older than the exposed country-rocks.

That the breccia results from magma pressure is evidenced by its restriction to the igneous margin. That it represents upheaval is evidenced (*a*) by the dip of the contact plane against the phyllite (text-fig. 1), and (*b*) by the disposition of the rock types within the breccia, the oldest variety occurring in contact with the igneous rocks.

It remains to account for the rounding of some of the quartzite blocks in the breccia. So striking is this rounding that Wright was led to regard the blocks as water-worn boulders, derived from a loose surface formation, which had fallen into a fissure or pipe. Dr. Holmes and I discovered, however, that many of the boulder-like forms in the breccia have pink felspathic rims, sometimes two or three inches broad, similar to those of the xenolithic quartzite blocks in the hornblendite and appinite of the intrusion. The inference is that the rounded blocks in the breccia have undergone a form of magmatic attack similar to that experienced by the xenoliths in the basic magma. It will be shown later in the paper that felspathic material developed from the quartzite may become palingenetic magma. If this occurred in the breccia, under conditions of high stress, mobile material formed around the periphery of the blocks would readily squeeze away, and rounded forms would result. It seems probable that the quartzite blocks thus attacked were once directly in contact with the hornblendite magma. Indeed, the hornblendite is still roofed, at one point along the contact, by a slab of quartzite, about one foot thick, which is margined against the hornblendite by a felspathic layer two or three inches thick. The fact that a few rounded forms occur towards the outer margin of the breccia may be accounted for by the greater ease with which such bodies, possibly lubricated by magmatic material, could slip through the heaving mass.

The massive quartzite adjoining the igneous intrusion at its eastern extremity has the appearance of being turned up on edge, as though punched upward by the rising intrusion. This, together with the intrusive contact exhibited between the breccia and the Staosnaig phyllites, is indicative of the enormous upward pressure exerted by the rising magma.

Further evidence of magma pressure is obtainable from the intrusion which margins the northern shore of Port Easdale. Here the invaded phyllites have been forced outwards, as is evidenced by the curve of the strike lines round the intrusion (text-fig. 1). Both the northern and southern limbs of the intrusion are exposed in this case, and breccia is seen to be developed only on the southern margin. The breccia, moreover, consists of fragments of phyllite only.

3. Field Description.

(a) *Metasomatized Quartzite Xenoliths.*

In all three intrusions the major part of the hornblendite and appinite is thickly sprinkled with blocks of white quartzite similar to that in the breccia which margins the southern intrusion. The largest blocks, which are up to two and a half feet long, are frequently of roughly rectangular form, whilst the smaller examples are usually rounded.

In the southern intrusion the quartzite xenoliths are fairly evenly distributed through the exposed portions of the hornblendite and appinite. In the hornblendite cliffs to the north of Port Easdale, however, there is some evidence that they are concentrated in the upper part of the intrusion, since a level charged with quartzite blocks passes downwards to one which is almost free from such inclusions. The distribution is, however, by no means uniform, for patches of hornblendite free from such inclusions, sometimes six feet or more across, are surrounded by zones heavily charged with xenoliths.

Whereas a few of the quartzite xenoliths in the upper part of the intrusion are unaltered, the great majority are in some degree changed to syenite or appinite (pl. xi, fig. 1). The varied appearances which they present are as follows:

1. In the apparently less altered xenoliths a core of white quartzite is sharply margined by a narrow felspathic rim, up to 1 cm. in width. The latter, which is usually pink, but locally white, may be quite free from ferromagnesian minerals or may contain sparse small crystals of hornblende. Where it adjoins the quartzite, the felspathic rim commonly becomes rich in mafic minerals. This melanocratic zone is extremely narrow, generally being 1 or 2 mm. across but occasionally swelling out to 5 mm. Blebs of quartz are sometimes visible in the felspathic rim.

2. More completely replaced xenoliths sometimes exhibit a core of quartzite surrounded by a narrow inner felspathic zone, like that just described, and a broad outer zone of appinite or syenite. There is a sharp boundary between the quartzite core and the felspathic rim, and between the latter and the appinite or syenite. In the outer zone the hornblende is frequently blade-like and occasionally, in zones of appinite, it reaches a length of 6 cm., thus contrasting strongly with the stumpy prismatic hornblende of the hornblendite (text-fig. 2).

3. In other examples, a quartzite core is directly surrounded and sharply bounded by a rim of appinite or syenite without the intervening felspathic zone. In such cases the hornblende is evenly distributed throughout the felspathized region. The percentage of hornblende varies, however, from one example to another, and in the more leucocratic varieties of syenite it is absent, chlorite being the characteristic mafic mineral.

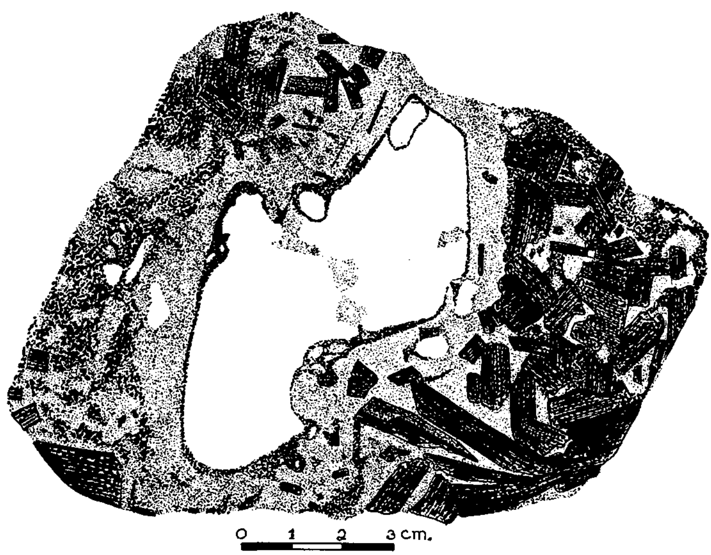


FIG. 2. Metasomatized quartzite xenolith, described in the text under type 2. A narrow mafic zone, which adjoins the residual quartzite, is followed successively outwards by a pink felspathic zone and an appinitic zone.

4. Many of the xenoliths have been completely replaced by appinite or syenite. Leading up to this type there are examples in which small isolated relics of quartzite still remain; the latter are surrounded by elongated hornblendes with a stellate arrangement.

Whatever form the replacement may take, one of the most striking phenomena in the metasomatized quartzite xenoliths is the invariable sharpness of the contact between the residual quartzite and its metasomatized portion. Moreover, where the quartzite core is surrounded by two successive zones (type 2 above) the boundary between these is also sharp. If seen on a large scale in the field such boundaries would inevitably be interpreted as intrusive contacts. From the well-defined replacement rim lobe-like forms composed of felspar frequently penetrate the quartzite. Again, sharp contacts are seen, although the blunt endings of the vein-like projections testify to the replacement origin of the latter.

Such sharp boundaries are at first surprising. Reference to experimental work on replacement structures in metals, however, shows that actually they are to be expected when replacement results from compound formation dependent on diffusion through a solid. According to Desch,[1] in the study of diffusion in metals it has been found that: 'When an intermetallic compound is formed by diffusion, the boundary of the new phase is perfectly sharp, and such sharpness may be taken as an indication of compound formation.' In the present case the development of the compound felspar results from the introduction of potassium, sodium, and aluminium into quartzite.

Although the metasomatized xenoliths present so many different appearances, yet the following facts, relating to the diffusion of felspar-forming and cafemic materials into the quartzite, stand out clearly.

(*a*) Felspar-forming materials only have in some cases been introduced into the xenoliths, as evidenced by type 1 above.

(*b*) Felspar-forming materials have in some cases advanced a short distance farther into the xenoliths than the cafemic materials, as evidenced by types 1 and 2 above.

(*c*) Felspar-forming and cafemic materials have in some cases advanced the same distance into the xenoliths, as evidenced by types 3 and 4 above.

(*d*) Ferromagnesian minerals, within a felspathic zone, sometimes form a narrow green rim against quartzite, but are separated from the main hornblende-bearing region by a felspathic rim. This is exemplified in some of the cases described as types 1 and 2 above.

(*e*) Ferromagnesian minerals have in no case been introduced into the xenoliths beyond the limit of felspathization.

These facts appear to indicate that the process of metasomatism takes place in two successive, but overlapping, stages: (1) introduction of felspar-forming materials, (2) introduction of cafemic materials for forming ferromagnesian minerals. Case (*c*) suggests that a certain amount of ferromagnesian material may travel with the vanguard of potassium, sodium, and aluminium, the main introduction of cafemic material following slightly later.

Against the enclosing rock the boundaries of the metasomatized

[1] C. H. Desch, The chemistry of solids. 1934, p. 112.

xenoliths may be sharp (as is invariably the case in type 1), ill-defined, or merging. In the last case the original quartzite xenoliths are now represented by felspathic patches or schlieren. Where the hornblendite is free from xenoliths it is also free from felspar, but in the neighbourhood of felspathized quartzite blocks it becomes felspathic and is then better termed appinite. Similarly, where appinite is the enclosing rock it becomes more felspathic around felspathized quartzite xenoliths and approaches syenite.

(*b*) *Syntectic Veins.*

Some of the felspathized quartzite xenoliths have meteor-like tails of felspathic material which pass out from the metasomatized blocks in various directions through the hornblendite. In some cases these 'tails' are broad and short, whilst in others they are vein-like in their proportions, being many yards long, although they may be less than an inch wide (pl. XI, fig. 2). The appearance indicates that the felspathic material, resulting from the metasomatism of quartzite, has in these cases become magmatic. At one point, near the seaward end of the southern limb of the intrusion margining the northern shore of Port Easdale, such felspathic material is locally so abundant that it cuts the hornblendite in a roughly rectangular network of veins (pl. XI, fig. 3). Indeed, the hornblendite now appears as rounded inclusions in a pink felspathic matrix. Without the evidence of the complete exposure, this small portion would hardly fail to be interpreted as resulting from the invasion of solid hornblendite by felspathic magma. The appearance is reminiscent of the Arran gabbro-granite complexes; the dolerites veined with granophyre in Ardnamurchan; the hornblendite veined with leucocratic material on Garabal hill; and the peridotite veined with felspathic material at Crocknafoyle, in the Newry complex. Yet here, in Colonsay, there is conclusive evidence that the hornblendite magma itself generated such vein material from sediment. The vein material was in fact syntectic magma.

The roughly rectangular character of the vein network suggests that the felspathic material migrated along the contraction joints in the hornblendite, indicating that the felsic syntectic magma had a lower crystallization temperature than the hornblendite magma.

At the extreme eastern end of the intrusion to the south of Port Easdale, the hornblendite is seen for two or three feet in vertical contact with quartzite. Along the contact the quartzite is felspathized in an irregular zone which has a maximum width of about two inches. From this felspathic margin several veins of pink pegmatite extend into the hornblendite and beyond it into the appinite (pl. XI, fig. 4). The veins, which are about 6 or 8 inches wide, have, in places, irregular margins against the hornblendite. The irregularities are seen to result from a certain amount of mixing of the two types. One vein in particular has a highly irregular upper margin above which the hornblendite, for a distance of several inches, contains small patches or blebs of pink felspar. The heterogeneous appearance is reminiscent of an emulsion in which the felspar forms the disperse phase. The facts indicate that the syntectic pegmatite veins were injected into the hornblendite whilst the latter was still fluid, and that blebs of the felspathic magma began to rise up through the hornblendite magma. Lack of complete mixing, evidenced by the emulsion-like structure, is suggestive of high viscosity. Around the felspathic patches there are blade-like crystals of hornblende sometimes several centimetres long.

4. Petrology.

(a) *Hornblendite.*

Where free from inclusions of quartzite, the hornblendite is a medium-grained dark-green rock consisting essentially of stumpy euhedral to subhedral crystals of amphibole which average about 4 to 5 mm. in length. In thin section the amphibole crystals are found to be composite, in that they consist of several varieties which are associated both in zonal fashion and as replacements one of the other. The optical characters of the varieties are set out in table I.

Table I. Optical data of amphiboles in the hornblendite.

	γ'.	$\gamma-\alpha$.	$\gamma:c$.	2V.
Brownish-green hornblende ↓	1·657	0·019	20°	Negative and close to 90° throughout.
Green hornblende	1·643	0·020	18°	
Actinolite ↓	1·638	0·025	18°	
Tremolite	1·634	0·027	15°	

The limit of error of γ', measured on cleavage flakes, is $\pm 0{\cdot}002$, except in the case of tremolite for which γ' is correct to the third place. $\gamma-\alpha$ was determined with a Berek compensator.

The central part of the crystals, which is brownish-green hornblende with γ green $>\beta$ brownish-green $>\alpha$ pale brownish-green, merges outwards in a very irregular but gradual manner to a green variety.

The latter may closely resemble the brownish hornblende in its optical characters, but where zoning is most conspicuous $\gamma : c$ decreases outwards to 18° at the margin of the crystal, there being a concomitant increase in birefringence and decrease in refractive indices. The optical characters appear to indicate gradation to an actinolitic hornblende. The irregular form of the zones, which are not always bounded by crystallographic planes, possibly indicates that each zone is in part a replacement of earlier amphibole.

These crystals are usually terminated by outgrowths of tremolite, or of pale actinolite followed outwards by tremolite. In some examples there is a complete outer zone of tremolite which is very narrow in the prism zone, often barely visible, and of considerable extent on the terminal faces. The outgrowths of tremolite, or of actinolite and tremolite, are sharply separated along crystallographic planes from the rest of the crystal. Where both varieties are present, they, in turn, may be sharply bounded one against the other, or they may show rapid gradation.

Commonly there has been replacement of the zoned hornblende by tremolite. The latter, in such cases, embays the margins of the amphibole and also occurs in irregular areas within it (pl. XII, fig. 1). Tremolite also replaces the hornblende either along its cleavages or as fine veinlets in the green marginal zone. In both cases it commonly spreads out into rounded lobe-like areas on entering the central brownish hornblende, the latter evidently being the most unstable variety. In regions of replacement small relics of the earlier amphiboles, in optical continuity with the original crystal, often remain. Occasionally a pale-coloured actinolite, similar to that of the marginal outgrowths, also replaces the hornblende in a vein-like manner.

The zonal and replacement textures of the amphibole show that the crystallization sequence was brownish hornblende $\rightarrow$ actinolitic hornblende $\rightarrow$ actinolite $\rightarrow$ tremolite, indicating a progressive decrease in alumina, soda, and iron.

Associated with the tremolite is a pale-coloured optically positive pennine, with $\alpha = \beta$ very pale green $> \gamma$ very pale yellowish-green ; β between 1·587 and 1·588 ; $\gamma - \alpha$ 0·004 ; and 'ultrablue' or weak grey interference tints. It sometimes occupies the central portion of tremolite replacement-veinlets in the hornblende. Moreover, where brownish hornblende is replaced by lobes of tremolite the latter is commonly associated with pennine and calcite. In such cases pennine appears to have replaced tremolite to some extent, since disconnected relics of the latter, optically continuous with the main tremolite, remain embedded in the pennine.

Large crystals of an almost colourless pennine sometimes contain central cores or isolated relics of biotite. In this case the pennine ($\beta < 1{\cdot}588$) evidently replaces biotite, and it contains strings of a dense whitish material, resembling leucoxene, which follow the cleavage traces. Pennine with relics of biotite is sometimes enclosed within the hornblende.

Locally the hornblendite is rich in biotite, which is partly enclosed by and partly encloses hornblende. It is of a dull brown to greenish-brown colour, commonly becoming greener towards the margin of the flakes. The flakes average about 1·5 mm. across, but in patches they reach a size of 2 or 3 cm. They are particularly characterized by sharp crumpling.

Interstices between the amphibole and biotite or pennine crystals are occupied by large anhedral crystals and finely-granular aggregates of calcite; radiating tufts of pennine; and fibres of tremolite. The latter penetrate both pennine and calcite. In many instances calcite is also interlaminated with tremolite.

Finally, there has been replacement of the earlier minerals by calcite, which cuts across all the other constituents in veinlets, and sometimes occupies considerable areas in which small isolated residuals of optically continuous amphibole remain.

Accessories consist of apatite, as large stumpy prisms, and sparse pyrite and iron ore.

The crystallization sequence of the hornblendite, as indicated by zoning and replacement textures, was as follows: hornblende and biotite; amphiboles successively less aluminous than the original hornblende; actinolite; tremolite; pennine; calcite. The crystallization periods of the last three minerals appear to have been in part simultaneous; the final mineral deposited, however, is always calcite. The sequence indicates crystallization from a magma which became progressively less rich in alkalis and alumina, and in which magnesia and lime became concentrated.

(*b*) *Appinite.*

The appinite of the marginal intrusions differs from the hornblendite in containing varying amounts of albite, perthite, and quartz, the quartz commonly being intergrown with the felspars as micropegmatite. In addition apatite is more abundant than in the hornblendite. As in the hornblendite, biotite is locally abundant, and the hornblende shows outgrowths of, and replacement by, tremolite and actinolite. There are patches in which the hornblende is largely or wholly replaced by chlorite. The characteristics of the minerals are similar to those—described in the following pages—of corresponding minerals in the metasomatized quartzite xenoliths. As in the metasomatic rims, patches of quartz which appear isolated in thin section are sometimes optically continuous. The felsic constituents, including apatite, are partially replaced by calcite, being much dissected by veinlets of this mineral.

(c) *Quartzite Xenoliths.*

The quartzite xenoliths consist almost entirely of a fine-grained mosaic of quartz grains in which a few larger individuals of quartz are embedded. The quartz is characterized by strain shadows. Felspar is present in very small amount, and it is impossible to tell whether it is an original constituent or the result of introductions. Both albite and perthite are represented; they have characteristically crystalloblastic outlines with curved re-entrants around quartz grains, and are usually clouded with an exceedingly fine brown substance. Perthite sometimes encloses optically continuous blebs of quartz, thus simulating a rude micrographic intergrowth. Calcite, chlorite, and pyrite are present in small amount, and sparse rounded detrital grains of zircon are characteristic.

The quartzite cores, in partially replaced blocks, are crossed by streams of minute bubbles which extend into the quartzite from the metasomatized rim. Sometimes such streams of bubbles, which pass from one quartz individual to another, cut through felspar, their passage being marked by a clear band in the latter. This band is optically continuous with the remainder of the felspar, but is completely cleared of inclusions, so that it contrasts sharply with the clouded neighbouring portions.

Here and there along the course of bubble-streams short veinlets of calcite replace quartz. The veinlets may cut across the centre of quartz grains or extend along their boundaries. In the latter case calcite projects, in minute antennae-like structures, from the sides of the veinlet along the boundaries of neighbouring quartz grains—a typical replacement texture. Such calcite veinlets begin and end abruptly in thin section, being continued at either extremity by a stream of bubbles. Similar streams of bubbles, which locally pass into veinlets of calcite, or rarely quartz, are also present in the metasomatized rims, and from the latter they are sometimes traceable into the quartzite.

Veinlets of felspar (perthite and albite) with which chlorite is occasionally associated, extend into the quartzite from the metasomatized rims. They usually take a highly sinuous course, since they are generally developed along the boundaries of quartz grains. Like the calcite, the felspar fingers out from the sides of the veinlets along the boundaries of neighbouring quartz grains (pl. XII, fig. 6), indicating that it replaces quartz. Occasionally felspar veinlets cut across large individuals of quartz. Here again the felspar fingers out on either side of the veinlet, but in this case it extends into a quartz crystal instead of along intergranular boundaries. As a consequence of this invasion, the quartz shows lines of stress radiating from each felspathic finger.

(*d*) *Metasomatized Quartzite.*

As already described in the field section (p. 372), most of the quartzite xenoliths are partially or wholly altered to varieties of syenite and appinite, the syntectic rock types occurring either separately or in concentric zones in individual xenoliths. In the latter case syenite adjoins the centrally placed residual core of quartzite.

(i) *Minerals and Textures.*

In the syntectic rocks, perthite, albite, hornblende, actinolite, tremolite, chlorite, epidote, allanite, apatite, pyrite, sphene, and calcite have developed as a result of metasomatic introductions. In addition, quartz and zircon are present, having persisted from the original quartzite. The quartz has usually recrystallized, whilst the zircon generally retains its detrital form.

The syntectic rocks form a series, ranging from micropegmatite and quartz-rich syenite to melanocratic appinite, the various members of which differ in the relative proportions of mafic to felsic constituents. Moreover, whereas hornblende is characteristic throughout the greater part of the series, chlorite is the common mafic mineral, usually to the exclusion of hornblende, in the more leucocratic varieties. A wide range of textures are developed, and much variation is sometimes shown within a single rim. It should, however, be stressed at the outset that the rocks constituting the rims have an igneous aspect, and that in no case, without the complete evidence, would they be suspected of having originated as replacements of pre-existing rock.

Felspars. Perthite occurs both as subhedral to anhedral crystals and in micropegmatitic intergrowths with quartz. The potash-felspar of the perthite shows simple twinning of Carlsbad type only. Albite is present in the potash-felspar in irregular areas at the margin, and in minute discontinuous veinlets and patches, optically continuous with the marginal albite, within the crystal. In some instances the veinlets are directly continuous with the marginal albite, and have the appearance of being outgrowths from the latter. Dependent on the orientation of the section, the albite veinlets either extend parallel to the vibration-direction of the slow ray in the potash-felspar or make an acute angle with that direction, the maximum angle measured being 30°. The data indicate that the veinlets extend parallel to the intersection of the basal plane and one of the primary prism faces. In some sections the albite appears as small patches which tend to have straight margins parallel to the *c*-axis, but are otherwise of irregular outline. The albite is usually untwinned, but it may show an occasional patchy development of albite lamellae. More rarely, albite is present in the potash-felspar as larger and less frequent patches in which albite lamellae are easily visible and are often of 'chess-board' type.

The ratio of albite to potash-felspar in the perthite varies within wide limits. From the examples described above there are gradations, through varieties in which potash-felspar is almost completely margined by albite, to a type in which potash-felspar is present only as disconnected patches in albite. Finally, there are examples in which potash-felspar appears as very small and sparse patches within euhedral or subhedral albite. The albite in these cases does not develop albite lamellae, except in rare small patches, but, like the potash-felspar, it exhibits twinning of Carlsbad type.

The relations exhibited between albite and potash-felspar in the perthitic intergrowths suggest that the former replaces the latter (cf. the 'patch perthite' of Andersen [1]). Further, the fact that in the rare instances where albite lamellae are present their development is of 'chess-board' type is significant, since this texture commonly results from replacement. It cannot, however, be overlooked that

[1] Olaf Andersen, The genesis of some types of feldspar from granite-pegmatites. Norsk Geol. Tidsskrift, 1928, vol. 10, p. 170, pl. 3, figs. 2 and 3.

the felspars are here known to replace quartz, and it is therefore possible that the textural features displayed by the perthitic intergrowths may result from the simultaneous growth of potash-felspar and albite in a solid medium, being in fact a crystalloblastic development. Albite is also present, however, as euhedral to subhedral crystals in which no trace of potash-felspar has been observed. Such crystals stand in strong contrast to the albite of the perthite, since in them albite lamellae are well developed; the lamellae are commonly persistent across the crystals, but are occasionally of 'chess-board' type. In the forefront of the replacement rim the polysynthetically twinned albite is sometimes seen to be directly replacing quartz. It is therefore possible that the twinned albite results from replacement of quartz, whereas the untwinned variety replaces potash-felspar.

The ratio of albite (well-twinned variety) to perthite varies from one specimen to another. Usually albite is considerably less abundant than perthite. In some instances, however, it is as abundant as perthite, and occasionally it is the more abundant felspar. It is often micropegmatitically intergrown with quartz and two types of such intergrowth have been recognized. In one, quartz, and in the other, albite appears to form the host mineral. Similar micropegmatitic relationships between albite and quartz, in reconstituted xenoliths from the Dartmoor granite, have been recorded and figured by Brammall.[1]

Both the untwinned albite of the perthite and the twinned crystals exhibit a faint brown clouding due to the presence of minute opaque inclusions, some of the larger of which can be seen to be ragged flakes of haematite. In the well-twinned albite the clouding is sometimes arranged in bands parallel to the albite lamellae. The potash-felspar of the perthitic intergrowths, although it contains sparse inclusions of a similar kind, is relatively clear.

Occasionally both perthite and twinned albite are crowded with sericite[2] flakes. This development of sericite is quite sporadic and cannot be correlated with any particular position in the replaced xenoliths. Aggregates of sericite, in which no felspar is visible, are locally developed. Both perthite and twinned albite are sometimes rendered opaque by the presence of a grey substance, associated with

[1] A. Brammall and H. F. Harwood, The Dartmoor granites: their genetic relationships. Quart. Journ. Geol. Soc. London, 1932, vol. 88, pp. 205, 207.

[2] The term sericite is used throughout this paper without implication as to the potassic or sodic character of the mica.

sericite. In such instances the felspar is visible only in small clear areas near the margin, the actual margin being clouded with a fine brown substance.

Where a core of quartzite remains in the metasomatized xenoliths the limit of general felspathization can be seen, in thin section, to be sharp. The felspar of the replaced portion, however, extends into the quartzite in minute antennae-like processes which are frequently developed along the margins of adjacent quartz grains (pl. XII, fig. 6; see also pl. XIII, fig. 4 of the following paper[1]). This fact indicates that the felspar-forming materials penetrated the quartzite most readily along intergranular boundaries. In places felspathization has spread in this way along the boundaries of neighbouring quartz grains for a short distance in advance of the limit of general replacement. In such examples the quartz grains may have the appearance of being embedded in a sparse felspathic matrix, or, with a greater development of felspar at the expense of quartz, they may appear as rounded poikilitic inclusions in a felspar crystal. Narrow vein-like forms of felspar sometimes extend from the metasomatic rim into the quartzite. They, like the rim itself, are margined against the quartzite by antennae-like processes of felspar which extend between adjacent quartz grains (pl. XII, fig. 6).

The antennae-like outgrowths of felspar are not, however, restricted to the intergranular boundaries. Where a large quartz grain margins the replaced portion, it is penetrated by such felspathic outgrowths which terminate bluntly within the grain (text-fig. 3). Sometimes large quartz grains are in this way much dissected. Not infrequently large quartz grains lie across the metasomatic boundary, one part being in the quartzite and the other in the felspathized zone. In such cases the felspathization can often be seen to take place along definite crystallographic directions, the quartz becoming cut up into rhomb-shaped portions, of roughly similar size, which exhibit straight extinction with the diagonals of the rhombs (text-fig. 4). This suggests that the felspar-forming materials penetrate quartz most readily along rhombohedral planes, and is possibly an indication that quartz has a coarse rhombohedral mosaic structure.

Quartz. The percentage of quartz in the metasomatized quartzite xenoliths is very variable. In some cases quartz is absent, whereas in others it is present in amount comparable to that of granitic

[1] A. Holmes, Transfusion of quartz xenoliths in alkali basic and ultrabasic lavas, south-west Uganda. Min. Mag., 1936, vol. 24, p. 421.

rocks. For the most part the quartz has recrystallized so that the grain-size has become considerably coarser than that of the quartzite cores. In many examples it forms micropegmatitic intergrowths with the felspars; in others it is associated with the felspars in granitic fashion; and in others again it is interstitial. Where it exhibits granitic texture or occurs interstitially, neighbouring isolated portions are often optically continuous.

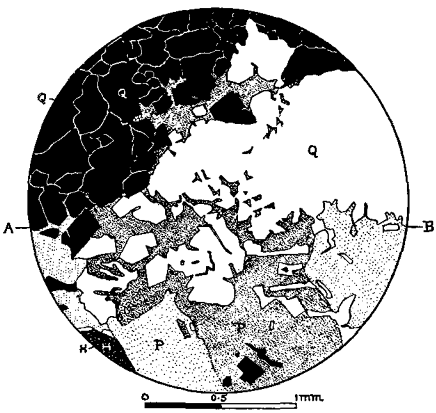


Fig. 3.

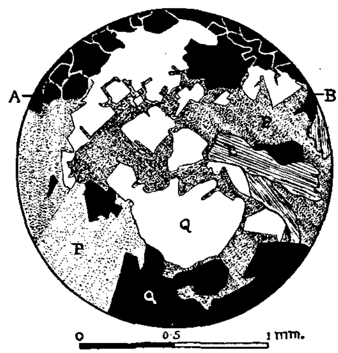


Fig. 4.

Fig. 3. Contact between the residual quartzite and the replaced portion of a xenolith. A–B marks the limit of general felspathization, Q = quartz, P = perthite, and H = hornblende. The quartz shown white is all part of one individual, which has been partially felspathized. A replacement veinlet of felspar extends, from the zone of general felspathization (below A–B), along the margin of this large grain, penetrating the latter and spreading into the adjacent smaller grains via their intergranular boundaries.

Fig. 4. Contact between the residual quartzite and the replaced portion of a xenolith. A–B marks the limit of general felspathization. Q = quartz, P = perthite, and C = chlorite. The quartz shown white is all part of one individual, which has been partially felspathized, the felspar mainly following rhombohedral planes.

The anhedral quartz almost always shows strain shadows, the shadows, in every observed case, extending parallel to the vibration-direction of the slow ray. This appears to indicate that the strain is developed in planes parallel to the *c*-axis. Occasionally the strain gives an appearance of lamellar twinning parallel to the *c*-axis, alternate lamellae extinguishing simultaneously at a small angle with *c*. The strained quartz is distinctly biaxial.

In the micropegmatite the quartz sometimes, but not always, shows strain. Where intergrown with albite the direction of the strain lamellae makes a high angle with the albite lamellae in all observed cases.

The quartz is crossed by lines of dot-like inclusions which include both gas bubbles and minute irregular specks of an opaque material.

Hornblende of the same type as that which characterizes the hornblendite is present in the metasomatic rocks. It shows similar, though less conspicuous, zoning in which the brownish-green variety ($\gamma : c = 20°$, γ' 1·657 $\pm$ 0·002, $\gamma - \alpha$ 0·019, negative, 2V close to 90°) occurs centrally, and merges outwards to green hornblende ($\gamma : c = 18°$, γ' 1·643 $\pm$ 0·002, $\gamma - \alpha$ 0·020, negative, 2V close to 90°). The latter also builds independent but relatively small crystals which particularly characterize the forefront of replacement rims. Outgrowths of tremolite and actinolite are less common than in the hornblendite, but replacement of the early hornblende by these two amphiboles has often taken place. Felted aggregates of actinolite are sometimes present, and appear to replace leucocratic constituents as well as earlier hornblende.

The hornblende occurs both as isolated crystals and in aggregates. It often builds euhedral crystals which vary in habit from stumpy to elongated prismatic. Subhedral forms are also evident in which prism and clinopinacoid faces are usually well developed, while the terminations are irregular, and not infrequently have a frayed appearance. More rarely the faces of the prism zone show an irregular development. Simple twinning parallel to (100) is not uncommon.

The hornblende exhibits a variety of textures. In cross-section it sometimes has the appearance of being only half developed. Such an appearance is usually taken to indicate that the crystal is broken. In the present instances, however, where the hornblende results from metasomatic introductions into solid rock, such an interpretation is untenable, and the appearance probably results from irregular growth of hornblende in the vertical zone. Curved crystals are common. In addition to the frayed terminations, already mentioned, embayed margins and sieve-like inclusions of quartz, felspar, and micropegmatite are occasionally exhibited (text-fig. 5). Crystal zones often have the appearance of being abruptly truncated against the leucocratic constituents. In some examples the crystals have the appearance of being split apart, along cleavage planes, by lamellae of quartz or felspar which are optically continuous with neighbouring crystals (text-fig. 6). Portions of hornblende, which may be exceedingly small, are in places isolated from, although optically continuous with, the main crystal. These textures, several of which are commonly regarded as evidence of corrosion, can here only be interpreted as crystalloblastic developments, dependent on the fact that crystallization has taken place in an essentially solid medium.

FIG. 5.

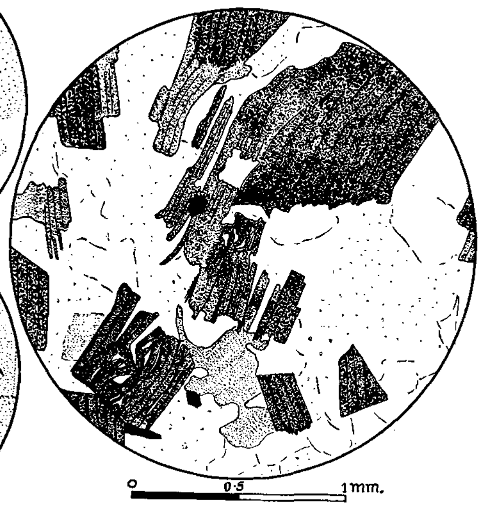


FIG. 6.

FIG. 5. Crystalloblastic developments of hornblende in the replacement rim of a quartzite xenolith, illustrating textures commonly attributed to corrosion.

FIG. 6. Hornblende from the metasomatized rim of a quartzite xenolith, showing replacement textures which simulate mechanical distortion and 'splitting apart' along cleavage planes.

It must not be supposed, however, that such crystalloblastic textures are always the most characteristic. Just as commonly—even in the same slides—the hornblende exhibits euhedral or subhedral form. Where this is the case the rock would not, without the excellent field evidence, be suspected of having originated in any way other than by crystallization of magma. It should be stressed that hornblende, even when it is euhedral, may be either entirely enclosed within felspar, quartz, or micropegmatite, or it may cut across the boundaries of these minerals.

Chlorite is present both as a replacement of hornblende, which is sometimes completely pseudomorphed, and as a direct replacement of quartz and felspar. It has $\alpha = \beta$ bluish-green $>$ γ very pale green, and is optically positive with 2V very small. In measured examples from a rim of appinitic composition β is about 1·589 and $\gamma - \alpha = 0{\cdot}0045$. The data indicate that it is clinochlore not far from pennine in composition.

Where it replaces hornblende, the chlorite is commonly fibrous, in which case it extends along the cleavage planes; in some examples, however, it builds aggregates of small spherulites. Where chlorite replaces quartz and felspar it often builds aggregates of small spherulites which exhibit bulbous boundaries towards the replaced minerals. From the spherulites, vermicular chlorite commonly fingers out into both quartz and felspar. In some examples, more noticeably in syenitic types of replacement and in the forefront of the replacement rims, chlorite which replaces felsic constituents develops crystal form and exhibits lamellar twinning parallel to (001).

In rare instances, chlorite encloses felspar and euhedral crystals of hornblende, the latter sometimes terminated in toothed outgrowths of tremolite.

Chlorite is also present in little veinlets which are situated along the boundaries of quartz and felspar. Such veinlets are in places traceable into calcite veinlets.

Allanite is common in the syntectic syenite and rare in the syntectic appinite. It builds small euhedral crystals (usually about 0·13 mm. across, and rarely reaching a size of 0·3 mm.) in which (100), $(10\bar{1})$, and (001) are developed. It is strongly zoned, the darker zones occurring in the centre of the crystal, and has γ dark brown $>$ α pale brown; $\alpha : c = 36°$, and the birefringence is low. The allanite is sometimes intergrown with or surrounded by epidote. The latter mineral also occurs separately, in which case it is sometimes, but not always, associated with chlorite.

Calcite is common both as large anhedral crystals, intergrown with the other minerals, and in veins which cut through the other minerals. The large crystals are in some cases seen to antedate the aggregates of chlorite spherulites. This is inferred from the fact that the chlorite fingers into the calcite, and occurs within it as vermicules, just as it does in the quartz and felspar.

From the large crystals of calcite, antennae-like structures extend along the boundaries of neighbouring individuals of quartz and felspar, or actually penetrate these minerals. In some instances veins of calcite extend from the crystals, and from the sides of the veins calcite fingers into the felsic constituents. Some of these veins terminate as single or bifurcating veinlets of quartz. The large individuals of calcite exhibit lamellar twinning, and the lamellae are in many cases curved.

Apatite has been introduced both as abundant needles, sometimes of minute dimensions, and as crystals which may be much elongated in habit or short prismatic. The crystals either occur enclosed within quartz, felspar, and hornblende, or they cut across the boundaries of these minerals. They are frequently clouded with swarms of minute rod- and dot-like forms of an opaque mineral. The needle-like apatite is often highly concentrated in quartz and felspar.

Apatite reaches its maximum development in the appinitic type of replacement. It is sometimes sporadic in its occurrence, tending to segregate at certain points. Although commonly perfectly formed, it occasionally has finely crenulate margins and fingering terminations. In many instances the crystals are curved, and elongated crystals are not infrequently disconnected parallel to the base, the isolated portions being either in line or in echelon.

Pyrite is common, and reaches its maximum development in the appinitic type of replacement. It occurs within both felsic and mafic minerals and, although it often develops cubic form, it sometimes exhibits typical replacement textures, antennae-like processes of pyrite extending from an anhedral central mass, along the intergranular boundaries of neighbouring quartz and felspar. In some instances compact crystals of pyrite poikilitically enclose apatite and hornblende.

Sphene is one of the less common minerals. It usually builds euhedral crystals, most of which are small, though occasional large examples, up to 0·5 mm. across, are present.

Zircon, with a rounded detrital form, as in the quartzite, persists in the metasomatized portions. It occurs as inclusions in quartz and felspar, some of which lie across the mineral boundaries. Very rarely it is crystalloblastic in its development, when it exhibits curious sigmoid forms.

(ii) *Rock Types.*

The various products of replacement, regarded as rock types, may now be briefly described:

Micropegmatite, which may be devoid of mafic minerals or may contain hornblende and/or chlorite, is common in the forefront of the replacement rims around residual cores of quartzite (pl. XII, figs. 4 and 6). The felspathic rims described on p. 372 of the field description under types 1 and 2 usually consist of micropegmatite. In some of these felspathic rims, however, only the innermost margin consists of micropegmatite; away from the quartzite this passes into leucocratic syenite or quartz-syenite.

Syenite. Under this term is included a series of rocks which ranges between micropegmatite and appinite. There are leucocratic quartz-free syenites which fall within Phemister's [1] delimitation of perthosite, and closely allied to these are varieties gradational towards leucocratic micropegmatite. The latter varieties of syenite differ from perthosite only in the presence of a little quartz; they may be termed quartz-perthosite. The mafic minerals of the perthosites and quartz-perthosites, chlorite, allanite, and epidote, are present only in accessory amount. By the incoming of hornblende the perthosites grade through hornblende-syenite, which is usually quartz-bearing, to appinite. The various types of syenite respectively characterize different xenoliths; they also occur, in some instances, in association within a single xenolith.

The analysed syenite (table II, no. 3), collected from a large xenolith that is almost completely replaced by pink syenite, is a quartz-perthosite characterized by albite, perthite, and quartz, with accessory chlorite, allanite, epidote, calcite, sphene, zircon, apatite, and pyrite. Texturally it varies from roughly equi-granular to seriate-granular (pl. XII, fig. 3). The felspars tend to develop form, whilst the quartz occurs interstitially or intergrown in granitic fashion with the felspars. In many instances portions of quartz, though completely isolated in thin section, are optically continuous. Chlorite is subhedral to anhedral in form, and sometimes shows crystalloblastic development. In the latter case, it has outlying optically-continuous portions and, rarely, is sieved with inclusions of the leucocratic constituents. In the sections examined, the

[1] J. Phemister, The geology of Strath Oykell and Lower Loch Shin. Mem. Geol. Surv. Scotland, 1926, p. 47.

chlorite does not appear to replace an earlier ferromagnesian mineral. Sericite is sparsely dispersed through the felspars, and calcite replaces the felspars in small veinlets and irregular patches.

In perthosite, which is free or almost free from quartz, the felspars, although they are mutually intergrown, show an approximation to rectangular outline in thin section. Crystalloblastic textures are sometimes developed; in some instances, for example, twinned albite, with crenulate margins, has optically-continuous outlying portions.

In the syenites which are rich in quartz, micropegmatite is developed. These rocks grade from a variety which contains mafic minerals in accessory amount only to quartz-bearing hornblende-syenites. Both the quartz-rich syenites and the micropegmatites exhibit textures which characterize micropegmatite-bearing rocks in general. The micropegmatite may be coarse in texture or of a finer feathery variety. Euhedral crystals of felspar are sometimes optically continuous with the felspar of the surrounding micropegmatite. Anhedral quartz is similarly sometimes optically continuous with the quartz of neighbouring micropegmatite. In some instances a single quartz crystal is intergrown with two or more differently orientated crystals of felspar. In short, there is no textural clue from which it could have been suspected that the metasomatic micropegmatite did not arise as a result of the crystallization of magma.

A point of special interest in the syenitic type of replacement is the relation between quartz and felspar. In the forefront of the replacement rim, felspar develops along the margins of quartz grains, the latter sometimes remaining as inclusions in felspar crystals. Farther into the replacement rim the quartz has generally recrystallized. If it is present in only small amount it is interstitial, whereas when present in greater amount it is either micropegmatitically intergrown with the felspars or, less commonly, is associated with them in granitic fashion. The relationship between quartz and felspar is thus dependent in part on position in the replacement rim and in part on the proportion of quartz present.

As noted in the field section under type 1, p. 372, there is commonly a narrow green zone, generally 1 or 2 mm. wide, situated at the contact between leucocratic felspathic rims and residual quartzite cores. In thin section this is found to differ from the main leucocratic zone in the abundance of ferromagnesian material. Chlorite is the most common mafic mineral, but green hornblende is sometimes present. A block of quartzite with a felspathic rim from the marginal breccia appears to throw light on the origin of this narrow green frontal zone. The quartzite of the block contains fairly abundant biotite, yet the marginal felspathic rim is of leucocratic micropegmatite rich in 'chess-board' albite. Immediately at the contact with the quartzite, the micropegmatite contains chlorite together with a few flakes of biotite which have persisted from the quartzite. Away from the margin, however, chlorite is rare in the micropegmatite, and biotite, partly chloritized, is very rare, whilst rutile needles are common (pl. XII, fig. 5). The evidence suggests that the constituents of the biotite from the quartzite became mobilized during the felspathization process, the Mg and Fe being carried forward to the forefront of the zone of replacement.

Appinite. The appinites, which are all quartz-bearing, range from hornblende-syenite to varieties which differ from the hornblendite only in the presence of a little felspar and quartz. They contain hornblende of the brownish and green varieties which characterize the hornblendite; actinolite and tremolite, which are present both as replacements of and outgrowths from hornblende, the actinolite sometimes being present also as irregular aggregates; perthite; albite; quartz; chlorite; calcite; apatite; pyrite; and rare allanite and epidote. The characteristics of these minerals have already been described.

Quartz is often micropegmatitically intergrown with the felspars, but it also occurs interstitially and associated in granitic fashion with the felspars. As in the syenites, isolated portions of quartz are in many instances optically continuous.

The appinites vary in grain from medium to coarse, and are practically always coarser in grain than the associated syenites. The analysed appinite (table II, no. 2) contains blade-like crystals of hornblende up to 6 cm. long, which are embedded in a pink quartzo-felspathic matrix. In common with many examples of the apinitic type of replacement, small druses, margined by calcite crystals which exhibit form towards the cavity, are present.

(*e*) *Syntectic Veins.*

The pegmatite veins, which arise from the narrow felspathic zone developed at the margin of the quartzite against the hornblendite (p. 376 and pl. XI, fig. 4) and penetrate the latter rock, show rapid variation from point to point. One such vein about six inches wide, from which the analysed specimen (table II, no. 5) was collected, varies, in a single hand-specimen, from quartz-perthosite of equigranular texture to leucocratic micropegmatite-bearing syenite. There are, moreover, patches in the vein which are rich in chlorite (prochlorite with β about 1·61) and epidote. The chlorite usually replaces and often retains cores of biotite, the latter with crumpled cleavage traces. The epidote, which is associated with the chlorite, is more strongly coloured than that in the replacement rims. Iron ore is a common associate of chlorite.

The felspars are albite and perthite, the latter with a patchy development, as in replacement rims. In chlorite-rich regions the felspars are commonly crowded with flakes of sericite, amongst which apatite is often segregated. The apatite characteristically develops acicular crystals up to 3 mm. long. These are sometimes curved or arranged in echelon. The rock contains large patches of calcite, up to a centimetre across, and where it adjoins the hornblendite it contains hornblende similar to that in the latter rock but of bladed habit and up to several centimetres in length. So far as could be judged, the analysed specimen was free from hornblende, but it contained some chlorite and epidote.

Texturally the pegmatite is closely similar to the corresponding rocks of the replacement rims and, except that epidote is considerably more abundant and the chlorite is prochlorite instead of clinochlore or pennine, there are no obvious criteria by which it could be distinguished from these.

The syntectic veins which form a network in the hornblendite (p. 375) are of the composition of appinite or mafic syenite. They are composed of hornblende, a little tremolite, and actinolite, chlorite, perthite, albite, and quartz, together with accessory apatite, epidote, sphene, pyrite, and calcite. The characteristics of these minerals are similar to those of the corresponding minerals in the replacement rims. The hornblende is for the most part euhedral, but it occasionally has frayed margins, re-entrants, and sieve-like inclusions of the felsic minerals. It sometimes has outgrowths of tremolite and actinolite and may be partially replaced by chlorite. The quartz is in part interstitial, in part intergrown with the felspars in granitic fashion, and in part a constituent of micropegmatite. In the two former cases neighbouring patches of quartz are sometimes optically continuous. This latter texture, together with those suggestive of crystalloblastic development exhibited by the hornblende, probably indicates crystallization in a highly viscous medium. Indeed, as in the case of the pegmatite, there is, in thin section, no obvious criterion which distinguishes these veins from the replacement rims. As in the latter, calcite replaces the other minerals to some extent.

In the 'tails' which extend from metasomatized quartzite xenoliths (p. 375, pl. XI, fig. 2 and pl. XII, fig. 2) the minerals and textures are again essentially similar to those which characterize the replacement rims; allanite is occasionally present.

(*f*) *Syenite.*

No systematic petrological investigation of the syenite of the main intrusions has yet been made, but the following notes, made from a study of a few thin sections, indicate their similarity to the rocks of the replacement rims.

The syenite of the two intrusions of Port Easdale consists of perthite, albite, quartz, abundant chlorite (prochlorite with β 1·612 $\pm$ 0·002), and epidote, together with accessory apatite, pyrite, allanite, and calcite. The chlorite and epidote, in the thin sections examined, have no appearance of having replaced earlier ferromagnesian minerals. The texture is seriate-granular with the constituents ranging from subhedral to anhedral. Neighbouring patches of quartz, which are isolated in thin section, are in many instances optically continuous. The syenite of the intrusion on the hill to the north of Port Easdale contains hornblende, which is partially altered to chlorite.

Mineralogically and texturally, the syenite of the main intrusions is very similar to parts of the pegmatite veins. Moreover, the presence of allanite indicates consanguinity with the rocks of the replacement rims and the syntectic veins derived from them.

5. Chemistry.

In tables II and III the chemical analyses and norms of the rock types are listed. The hornblendite (1) was collected from a zone free from quartzite xenoliths in the intrusion which margins the northern shore of Port Easdale. It is typical of the felspar-free hornblendite which characterizes both the Port Easdale intrusions. It differs from analysed hornblendites of other areas in being richer in magnesia and poor in alkalis.

The quartzite (4) is the residual part of a typical quartzite xenolith from the southern intrusion.

The appinite (2) and the syenite (3) were collected from relatively large metasomatized quartzite xenoliths, which retain residual cores

TABLE II. Chemical analyses.

	1.	2.	3.	4.	5.	6.
SiO_2	42·54	52·30	66·04	95·17	68·38	57·66
Al_2O_3	9·00	15·23	17·68	3·45	14·00	12·86
Fe_2O_3	1·84	2·29	0·33	0·12	1·10	5·60
FeO	7·80	5·30	0·94	0·09	0·54	3·38
MgO	19·41	5·77	0·20	0·04	0·51	2·90
CaO	10·82	7·85	1·81	0·38	4·00	5·08
Na_2O	0·53	2·16	4·95	0·01	5·49	3·57
K_2O	0·33	3·00	5·16	0·37	3·78	4·64
H_2O+	4·61	1·76	0·80	0·08	0·48	1·76
H_2O-	0·17	0·09	0·11	0·07	0·06	0·06
CO_2	1·81	0·90	0·97	nil	0·86	0·71
ZrO_2	nil	nil	0·15	0·14	0·02	0·007
TiO_2	0·74	0·72	0·11	0·09	0·09	0·38
P_2O_5	0·08	1·11	0·18	0·06	0·26	0·70
Cl	0·01	n.d.	n.d.	n.d.	n.d.	n.d.
S	0·15	1·37	0·06	0·06	0·06	0·33
Cr_2O_3	0·08	trace	nil	n.d.	n.d.	n.d.
V_2O_3	0·05	0·04	0·02	n.d.	n.d.	n.d.
NiO	0·10	0·17	nil	n.d.	n.d.	n.d.
MnO	0·18	0·14	0·02	trace	0·03	0·08
SrO	nil	0·02	nil	trace	0·08	0·05
BaO	nil	0·09	0·15	nil	0·09	0·07
Li_2O	trace	n.d.	n.d.	n.d.	n.d.	n.d.
	100·25	100·31	99·68	100·13	99·83	99·83
Less O	0·06	0·51	0·02	0·02	0·02	0·12
	100·19	99·80	99·66	100·11	99·81	99·71

1. Hornblendite. Northern shore of Port Easdale. Analyst, L. S. Theobald.
2. Appinite. Rim of quartzite xenolith. Southern shore of Port Easdale. Analyst, Agnes Gibbs.
3. Syenite. Rim of quartzite xenolith. Southern shore of Port Easdale. Analyst, Agnes Gibbs. A second analysis made on another sample of material from the same specimen gave SiO_2 65·85, Al_2O_3 18·30.
4. Quartzite xenolith. Southern shore of Port Easdale. Analyst, Agnes Gibbs.
5. Pegmatite. Syntectic vein in hornblendite. Southern shore of Port Easdale. Analysis by Messrs. Imperial Chemical Industries Ltd., Research Dept., Billingham, Co. Durham.
6. Syenite. Intrusion south of Port Easdale. Analysis by Messrs. Imperial Chemical Industries Ltd., Research Dept., Billingham, Co. Durham.

of quartzite; both are from the southern intrusion. The appinite is a somewhat leucocratic variety transitional to hornblende-syenite. The syenite falls within Phemister's (loc. cit.) delimitation of perthosite, except that it is quartz-bearing. The latter fact accounts for its lower alkalis and alumina, relative to silica, as compared with the perthosite of Loch Ailsh.

The appinite and syenite which result from the transfusion of quartzite xenoliths are chemically, as well as mineralogically and

TABLE III. Norms of analyses in table II.

		1.	2.	3.	4.	5.	6.
Q ...		—	7·16	15·71	92·96	17·85	9·88
C ...		—	—	3·20	2·56	—	—
Z ...		—	—	0·22	0·20	0·04	0·02
or		1·89	17·75	30·50	2·13	22·32	27·44
ab		4·51	18·25	41·89	0·11	46·45	30·20
an		21·20	23·01	2·03	1·26	2·39	5·37
di	$CaSiO_3$	8·59	1·65	—	—	1·47	4·82
	$MgSiO_3$	6·26	1·18	—	—	1·28	3·97
	$FeSiO_3$	1·48	0·33	—	—	—	0·26
wo		—	—	—	—	3·07	—
hy	$MgSiO_3$	15·13	13·19	0·50	0·10	—	3·25
	$FeSiO_3$	3·59	3·79	1·19	—	—	—
ol	Mg_2SiO_4	18·87	—	—	—	—	—
	Fe_2SiO_4	4·90	—	—	—	—	—
cm		0·11	—	—	—	—	—
mt		2·66	3·31	0·48	—	1·37	8·12
h ...		—	—	—	0·13	0·16	—
il ...		1·76	1·72	0·21	0·06	0·17	0·91
tn		—	—	—	0·20	—	—
ap		0·20	2·62	0·37	0·14	0·60	1·65
pr		0·25	2·56	0·11	0·11	0·11	0·62
cc		4·11	2·05	2·21	—	1·96	1·61
water		4·78	1·85	0·91	0·15	0·54	1·82
		100·29	100·42	99·53	100·11	99·78	99·94

texturally, normal igneous rocks. In text-fig. 7 their constituents are plotted on a variation diagram together with those of the hornblendite and quartzite. The diagram turns out to be of a common type, such as is frequently interpreted as evidencing crystal differentiation, yet here the process was one of migration of various constituents from hornblendite magma into quartzite.

Comparison of the chemical analyses, or their diagrammatic representation on text-fig. 7, reveals the following important facts with regard to the syntectic appinite and syenite.

(1) They do not represent admixtures of hornblendite and quartzite.

(2) All the constituents, with the exception of SiO_2 and ZrO_2, appear to have been provided almost entirely by the hornblendite magma. The concentration of ZrO_2 in the quartzite and syenite

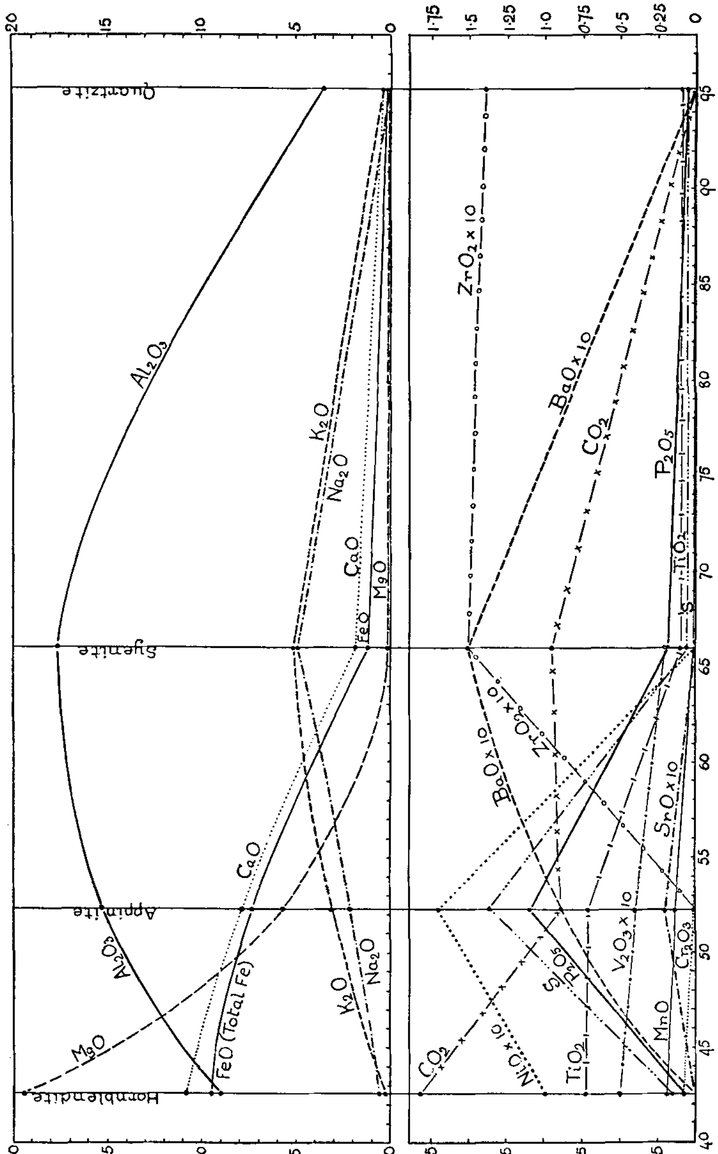


FIG. 7. Variation diagram for the series hornblendite–rim-appinite–rim-syenite–xenolithic quartzite.

tallies with the observation that practically all the zircon in the syenite exhibits a detrital form.

(3) Certain constituents, i.e. Al_2O_3, K_2O, Na_2O, P_2O_5, S, NiO, BaO, and SrO, have actually become concentrated in the appinite and syenite, Al_2O_3, K_2O, Na_2O, and BaO reaching a maximum in the syenite, and P_2O_5, S, NiO, and SrO in the appinite. BaO is of particular interest since, although it is absent from both the hornblendite and the quartzite, it is present in both the syenite and appinite.

(4) Soda is more abundant than potash in the hornblendite, yet in the appinite and syenite potash is more abundant than soda.

It is evident, from the concave and convex curves of the variation diagram, that the constituents of the hornblendite magma were introduced differentially into the quartzite xenoliths. It is, however, not at present apparent how the migration was effected; even to discuss the migratory units in terms of oxides is to make an assumption. Remarks will therefore be restricted to the behaviour of individual elements. It is particularly noteworthy that, although Mg is by far the most abundant metallic element in the hornblendite, it was the least diffusible, as shown by the downward slope and concave form of the curve representing MgO in text-fig. 7. Potassium, on the other hand, which is now poorly represented in the hornblendite, was amongst the most diffusible elements, as shown by the upward slope and convex form (as far as the syenite) of the curve representing K_2O in text-fig. 7. Similarly, barium, which is now actually absent from the hornblendite, was one of the most diffusible elements from its magma.

The migratory elements can be classified, for this area, as follows:

Most diffusible.	*Less diffusible.*	*Least diffusible.*
Al	Fe	Mg
K	Ca	
Na	C	
P	Ti	
S	Cr	
Ni	V	
Ba	Mn	
Sr		

It will be recalled that the order of mineral formation in the hornblendite indicates crystallization from a magma which became impoverished in alumina and alkalis. The loss of the magma is thus balanced by the major gains of the quartzite.

The circumstances which contributed towards the present distribution and relative concentration of the elements in the tranfused xenoliths probably include: (*a*) sequence of introduction into the xenoliths; (*b*) relative rate or power of diffusion through the xenoliths; (*c*) sequence (in both space and time) of fixation by the xenoliths. The various zonal arrangements of rock types in the transfused xenoliths (see pp. 372–3) suggest that (*a*) was an important factor, potassium, sodium, and aluminium having been introduced before the cafemic-forming constituents entered in force.

The analysed pegmatite (5) was collected from one of the 6-inch syntectic veins described on p. 392 and figured on pl. XI, fig. 4. Chemically it is a somewhat soda-rich quartz-syenite. Although it had a similar origin to the syenites of the replacement rims, it is chemically remarkable in that it differs from the analysed rim-syenite in containing more soda than potash.

The analysed syenite (6) was collected from the intrusion to the south of Port Easdale. Chemically it is related to plauenite; alumina is low, however, and iron high. Except for the low alumina and high iron it very nearly fits the curves for the metasomatic rocks on the variation diagram text-fig. 7.

6. Comparable Examples.

Ontario.—Quartzite xenoliths which have been similarly felspathized and changed by a process of transfusion into rocks of igneous composition have been described by Collins from diabase sills. In 1913 he recorded the presence of light-coloured red patches, of coarser grain than the normal diabase, in the sills of the Gowganda district.[1] The patches vary in size from about an eighth of an inch in diameter up to several hundreds of feet in length. No evidence as to their origin, however, was found in this district. Later, in a study of the gabbro sills of the north shore of Lake Huron, the origin of similar leucocratic patches was discovered.[2] At Blind River, for example, the gabbro contains many patches which are more leucocratic and coarser in grain than the normal gabbro of the sill. Some of these contain cores of quartzite which are obviously remains of xenoliths

[1] W. H. Collins, The geology of the Gowganda mining division. Mem. Geol. Surv. Canada, 1913, no. 33, p. 63.

[2] W. H. Collins, North shore of Lake Huron. Mem. Geol. Surv. Canada, 1925, no. 143, p. 80. See also T. T. Quirke, Espanola district, Ontario. Mem. Geol. Surv. Canada, 1917, no. 102, p. 51.

derived from the neighbouring Mississagi quartzite. All stages of alteration have been found in the sills from blocks of quartzite which are only marginally corroded to others which are represented by patches of gabbro conspicuously lighter in colour and coarser in grain than the normal sill rock. In some cases the inclusions are bordered against the sill rock by a dark rim, varying from less than an inch up to more than a foot in width, composed mainly of hornblende. In other examples, the altered inclusions merge insensibly into the normal gabbro. They are composed of an intimate intergrowth of hornblende, intermediate plagioclase, which is commonly graphically intergrown with quartz, and some epidote.

The inclusions in one of the sills near Sudbury have been investigated by Jones.[1] In this intrusion there are lens-shaped and irregular bodies of white rock, with dimensions varying from a few feet up to 100 by 40 feet, some of which have a central core of quartz. One such patch, about 42 feet in diameter, was studied in detail with chemical analyses. It has a marginal zone consisting of hornblende and bytownite and an inner zone, adjoining central quartz, of andesine and quartz. In the outer zone the hornblende and bytownite exhibit textural relationships similar to those of the normal sill rock. The hornblende crystals attain their greatest size towards the middle of the outer zone, where they reach a length of 10 inches. From this region towards the centre of the mass they become smaller and sparser, finally dying out. With the disappearance of hornblende the plagioclase changes from bytownite to andesine.

Jones concludes that the change in the xenolith took place in an essentially solid state by diffusion into it of various constituents from the gabbro magma. From the zonal character of the transfused inclusions he deduces that the various constituents had different penetrative abilities. Alumina, soda, and lime penetrated farther into the xenolith than magnesia and iron.

Felspathized xenoliths of quartzose sediment have been recorded by Fenner[2] from the gabbro of the Sudbury lopolith. In places the xenoliths are surrounded by a zone of rock which is similar to the granophyre of the upper part of the intrusion, whilst in other cases they are so digested as to have almost disappeared. In explanation

[1] W. A. Jones, A study of certain xenoliths occurring in gabbro at Sudbury, Ontario. Toronto Univ. Studies, Geol. Ser., 1930, no. 29, pp. 61–73.

[2] C. N. Fenner, Journ. Geol. Chicago, 1926, vol. 34, pp. 735–736.

of phenomena of this type Fenner suggests 'that before and during assimilation of the quartzose body it was soaked with volatile material emanating from the magma, and that a modification of the composition of the magma and the sediment was thus effected, much of the material lost by the magma being retained by the sediment.'

Bushveld, Transvaal.—Daly[1] has described, with chemical analyses, successive stages in the alteration of quartzite xenoliths in the mafic quartz-syenite and granite of the Bushveld complex. The chemically unaltered quartzite is grey or white in colour and generally contains little else besides quartz, the average silica percentage of four analysed varieties being 95·5. Descriptions of three xenoliths, as follows, illustrate the various stages in the alteration.

(*a*) A slightly altered xenolith from the mafic quartz-syenite is pink in colour and contains 17 per cent. by weight of cloudy felspar, consisting of soda-rich orthoclase and oligoclase-albite (Ab_{92}) in about equal proportions. Subordinate constituents are rare granules of diopsidic augite and magnetite and a few blades of green hornblende.

(*b*) A more altered xenolith, from the same rock, is redder in colour, about half of the rock being composed of felspar. The felspars are similar to those in the last example, but the orthoclase, which is less rich in soda, is more abundant than plagioclase. The rock contains a few shreds of biotite and a little magnetite. Texturally it differs from the last example in that it contains some feathery micropegmatite. In spite of the intense felspathization, the rock retains its cross-bedding, indicating that the alteration took place while the xenolith remained essentially in the solid state. Chemical analyses show that alumina, potash, and soda were introduced into the quartzite; the process was, therefore, one of metasomatism.

(*c*) An even more altered xenolith, enclosed in coarse red granite, shows no trace of original bedding. It contains about 40 per cent. of quartz arranged in clumps; 50 to 55 per cent. of felspar; small proportions of biotite and of hornblende with occasional cores of diopsidic augite; a few needles of apatite and very rare specks of iron ore. The felspars are perthite, in which orthoclase and practically pure albite are intergrown, and subordinate plagioclase. The analysis shows the rock to be a normal acid granite. Daly remarks that 'In the field all of the five geologists, including Dr. Hall, were impressed

[1] R. A. Daly, Bushveld igneous complex of the Transvaal. Bull. Geol. Soc. America, 1928, vol. 39, pp. 746–750.

with the igneous look of the xenolith. To explain it one of the working hypotheses used is that the present state of the xenolith may be the result of ultra-metamorphism. The secondary magma may, however, never have been quite homogeneous, but may have held in it, undissolved, many grains of quartz, such as now appear in thin section as rounded individuals, separate and in clusters.

Illimausak, Greenland.—Inclusions of sandstone, surrounded by a zone of soda-granite, have been described by Ussing[1] from the augite-syenite of the Illimausak region, Greenland. From the descriptions of the evidence, this appears to provide an example of transfusion closely analogous to that in Colonsay. The augite-syenite contains numerous inclusions of sandstone; the largest is over 100 metres long and 50 metres broad. All the fragments, large as well as small, are surrounded by and separated from the augite-syenite by a zone, from a half to two metres wide, of soda-granite, which frequently contains a large number of very small rounded fragments of sandstone. From the soda-granite rim small apophyses extend into the sandstone, and the syenite, in the neighbourhood of the sandstone inclusions, is cut by veins of soda-granite.

Ussing's description of the rim is as follows: 'Directly surrounding the sandstone there is always a black zone, not more than ½ a centimeter broad and containing exclusively black-green pyroxene or black hornblende in short prisms which lie at right angles to the surface of contact; then comes a slightly broader, white zone, which consists of large anhedra of felspar and quartz with a relatively small amount of black minerals, and outwardly the white zone passes into the more uniform soda-granite. The size of grain of the latter is sometimes variable, so that coarse grained portions may alternate with fine-grained in the most irregular manner, even within one and the same hand-specimen. . . . As a rule the junction between the soda-granite and the surrounding augite-syenite presents a sharp line; the augite-syenite retains its normal character right in to the contact.' It is perhaps a point of petrological significance that chemically the soda-granite of the rims is very similar to the large granite body of Illimausak.

Microscopically, at the contact between soda-granite and sandstone, the region of felspathization is seen to be advancing into the sandstone along the margins of the quartz grains.

[1] N. V. Ussing, Geology of the country around Julianehaab, Greenland. Medd. om Grønland, 1912, vol. 38, pp. 51-54 and 116-118.

A point of special interest in the Illimausak occurrence, which is paralleled in Colonsay, is the evidence that the syntectic soda-granite became magmatic and remained fluid longer than the augite-syenite which generated it, since, in the vicinity of sandstone fragments, the augite-syenite is cut by veins of soda-granite.

Glen Coe, Scotland.—An example of felspathization of quartzite xenoliths has been recorded by Bailey[1] from the porphyrite fault-intrusion of Glen Coe. The porphyrite is described as often being 'not only richly charged with xenoliths of baked mica-schist and quartzite, but also loaded with quartz grains separated from the quartzite'. Moreover 'the quartzite, where it retains its individuality, is frequently saturated with pink felspar from the porphyrite'.

In his petrological description of these metasomatized xenoliths Bailey records that the felspars developed in the quartzite are orthoclase and albite or albite-oligoclase. I am indebted to the Director of the Geological Survey for allowing me to examine the thin sections of the altered quartzite xenoliths. It is a point of special interest that here, as in Colonsay and the Illimausak region, the felspathization of the quartz takes place most readily along intergranular boundaries.

That the quartzite xenoliths served to fix migratory alkalis is clear from Bailey's observation that the 'portion of the Fault-Intrusion which developes the permeation phenomena . . . differs from the more coherent portions of the same intrusion in being much richer in alkali'. At the time of writing, Bailey himself clearly realized the importance of this observation for he adds, 'There is a tempting field here for further careful work, and one which is likely to yield pregnant suggestions in regard to magmatic differentiation.'

General comments.—This section cannot be concluded without reference to a recent paper by Collins[2] in which he reviews various examples, including those discussed in the previous pages, of alteration of xenoliths by diffusion into them of material from magma in which they were enclosed. He finds (*a*) that in specific examples diffusion is not uniform for all constituents, some penetrating farther than others and being concentrated differently, as indicated by zonal arrangements; and (*b*) that the penetrative power of various consti-

[1] E. B. Bailey, The geology of Ben Nevis and Glen Coe. Mem. Geol. Surv. Scotland, 1916, pp. 112, 164.

[2] W. H. Collins, Derivations of granitic rocks. Report XVI Internat. Geol. Congress, Washington, 1933, 1936, vol. 1, pp. 271–282.

tuents varies from one locality to another. With regard to the alkalis, for example, in one of the cited instances, potash penetrated farthest and in greatest abundance, and in another soda. He concludes that the process involved molecular transfer of highly mobile material and chemical reaction, rather than a mechanical soaking into the solid rock of the adjoining magma or a fluid portion of it. The present investigation confirms these conclusions, but I can see no reason for believing that the transfer was molecular rather than atomic or ionic. In Colonsay not only has there been differential introduction of various constituents into the xenoliths, but the latter have actually been converted to felspar-rich types although immersed in a magma which, on crystallization, gave rise to an ultrabasic felspar-free rock. Although the felspar-forming material penetrated most readily along the boundary of quartz grains, it appears to have been capable of passing through the crystal mesh of quartz (see p. 383), a fact which suggests ionic introductions. It is a point of interest that sodium ions have been experimentally passed through quartz parallel to the *c*-axis.[1]

7. Summary and Petrological Conclusions.

At Port Easdale, Colonsay, micropegmatite, syenite, and appinite have been developed by replacement of quartzite xenoliths engulfed in hornblendite magma. The syntectic rock types occur either separately or in concentric zones in individual xenoliths. In the latter case micropegmatite or syenite adjoins the centrally placed residual core of quartzite. The syntectic rocks also occur in the hornblendite as leucocratic patches and rarer schlieren without visible residual cores of quartzite. The process involved the differential diffusion of the various magmatic constituents into the quartzite; of the major constituents, aluminium, potassium, and sodium appear to have been introduced first. Chemically, the rocks thus developed do not represent a mixture of hornblendite and quartzite; Al_2O_3, K_2O, Na_2O, P_2O_5, S, NiO, BaO, and SrO have actually become concentrated in the metasomatic varieties. Moreover, there is more potash than soda in the metasomatic rocks, whereas the hornblendite contains more soda than potash.

The rocks which result from the transfusion of quartzite present an igneous appearance, and without the field evidence it would not be possible to deduce that they are not 'igneous' in the common sense of the term.

[1] C. H. Desch, The chemistry of solids. 1934, p. 115.

Finally, the process of transfusion gave rise to syntectic magma of syenitic and appinitic composition. This is represented by pegmatite veins developed from felspathized quartzite along the contact of of the intrusion; by veins of syenite and appinite which emerge from transfused quartzite xenoliths; and locally by an intricate network of such veins in the hornblendite, so that the latter appears as mafic xenoliths in a relatively leucocratic matrix.

Arising out of the Colonsay evidence, the following points of outstanding petrogenetic significance may perhaps be emphasized.

(1) A field association of melanocratic and leucocratic rocks does not in itself constitute evidence of crystal differentiation as the mode of origin of the types concerned. Nor does such an association, even though all gradations between the extreme types be represented, constitute evidence that the whole of the rock materials once formed part of a homogeneous magma.

The necessity for stressing this latter point is made apparent in several recent discussions of which one, by Kennedy and Read,[1] may be taken as an example. A dike of markfieldite, which they describe, is characterized on the one hand by patches, schlieren, and veins of a leucocratic variety, and on the other by irregular patches and schlieren of a more mafic variety, the three rock types concerned being linked by a complete series of transitional types. The statement, based on these field relations (loc. cit., p. 118), that 'there is no escape from the conclusion that the heterogeneous nature of the intrusion results from splitting or differentiation of an originally homogeneous magma' goes far beyond the evidence. The data presented in the present communication provide one means of escape.

(2) Sharp contacts do not necessarily indicate intrusive contacts, they may equally well represent diffusion limits.

(3) The facts that a rock exhibits an 'igneous' appearance, both in hand-specimen and microscope section, and is of igneous composition do not constitute evidence that it crystallized from a magma. It should be specially emphasized that rocks which many petrologists have tacitly assumed to be of igneous origin may be metasomatic replacements.

(4) The enclosure of crystals, even though they are euhedral, in other minerals does not constitute evidence that the enclosed mineral

[1] W. Q. Kennedy and H. H. Read, The differentiated dyke of Newmains, Dumfriesshire, and its contact and contamination phenomena. Quart. Journ. Geol. Soc. London, 1936, vol. 92, pp. 116–145.

was the first to crystallize; its constituents may have been introduced at a later stage.

(5) Micropegmatite does not necessarily result from the crystallization of magma of eutectic or other composition. This point has already been emphasized by many writers.

(6) The presence of abundant apatite is frequently taken as evidencing a concentration of volatile constituents and, in consequence, of indicating that the rock in which it occurs crystallized from a highly fluid magma. In the appinite of metasomatic origin described in the present communication, apatite is highly concentrated, particularly in the felsic constituents, occurring both as fine needles and prismatic crystals. Yet the rock has never existed in a state other than essentially solid.

(7) Curvature of crystals or their twin-lamellae does not necessarily indicate external stress; it is a characteristic replacement texture.

(8) Strain shadows in quartz do not necessarily result from external stress; they may also result from strain dependent on metasomatic introductions. This point and those referred to under 2, 3, 4, 7, 9, and 13 are the more necessary of emphasis in that such structural, textural, and chemical features of certain of the rocks of the Killarney area, Ontario, have been presented by Jones[1] as if they were evidence unfavourable to Quirke's[2] conclusions that the rocks result from the transfusion of quartzite. Actually, however, not one of the facts cited by Jones is inconsistent with such a metasomatic origin.

(9) The fact that a mineral has the appearance, in thin section, of being only half developed is not necessarily an indication that it is a broken crystal. In Colonsay, hornblende which results from introductions into rock which was essentially solid sometimes has this appearance.

(10) Crenulated and frayed margins, sieve-like inclusions, and 'splitting apart' of minerals along their cleavages are not necessarily indicative of corrosion. Nor are sieve textures necessarily indicative of contact alteration. Minerals which develop as the result of metasomatic introductions may exhibit such textures, e.g. hornblende in the rocks described in this paper.

(11) Ability to construct a normal variation diagram for a rock

[1] W. A. Jones, The petrography of the rocks in the vicinity of Killarney, Ontario. Toronto Univ. Studies, Geol. Ser., 1930, no. 29, pp. 39–60.

[2] T. T. Quirke, Killarney gneisses and migmatites. Bull. Geol. Soc. America, 1927, vol. 38, pp. 753–770.

series does not constitute evidence of crystal differentiation. A perfectly normal variation diagram can be constructed for the hornblendite and the rocks resulting from the transfusion of quartzite.

(12) The fact that in an association of rock types one variety is chemically the equivalent of a mixture of two or more other varieties does not constitute evidence that the former represents the parent magma from which the other rocks arose as a result of differentiation. Such evidence is adduced by Kennedy and Read (loc. cit., p. 131), to quote a recent paper, as confirmative of crystal differentiation. In the case described in the present communication, the syntectic appinite, which results from the transfusion of quartzite, is chemically equivalent to a mixture of the syntectic rim-syenite and hornblendite.

(13) Finally, the fact that a rock exhibits intrusive contacts and shows signs of having flowed and at one time existed in what is normally regarded as a magmatic state, does not constitute evidence that its magma originated in the hidden depths. Syntectic magma, developed at observed levels, may give rise to rocks with just such appearances, as witnessed by the pegmatite veins in the Colonsay hornblendite, and by the network of veins with which the latter is locally dissected.

In conclusion I should like to express my great indebtedness to Lady Gibbs and to thank her for her generous collaboration on the chemical side.

Description of Plates XI and XII.

Micro-sections of rocks from Port Easdale, Colonsay, Argyllshire.
(Photomicrographs, Plate XII, by G. W. O'Neill.)

Plate XI, Fig. 1. Quartzite xenoliths with metasomatized rims in the hornblendite of Port Easdale. Reproduced from Plate IV of the Geology of Colonsay, Mem Geol. Surv. Scotland, 1911, by permission of the Controller of H.M. Stationery Office.

Fig. 2. A felspathic tail-like vein extending from the metasomatized rim of a quartzite xenolith. The vein is slightly touched up, in order to ensure reproduction.

Fig. 3. Hornblendite cut by a network of leucocratic veins of syntectic origin. Western end of the intrusion margining the northern shore of Port Easdale.

Fig. 4. Syntectic pegmatite veins developed from the felspathized margin of the quartzite (back) and penetrating the hornblendite (front). Southern shore of Port Easdale, locality marked P on text-fig. 1.

Plate XII, Fig. 1. Hornblendite, showing replacement of hornblende by tremolite. Ordinary light, × 11. (See p. 377.)

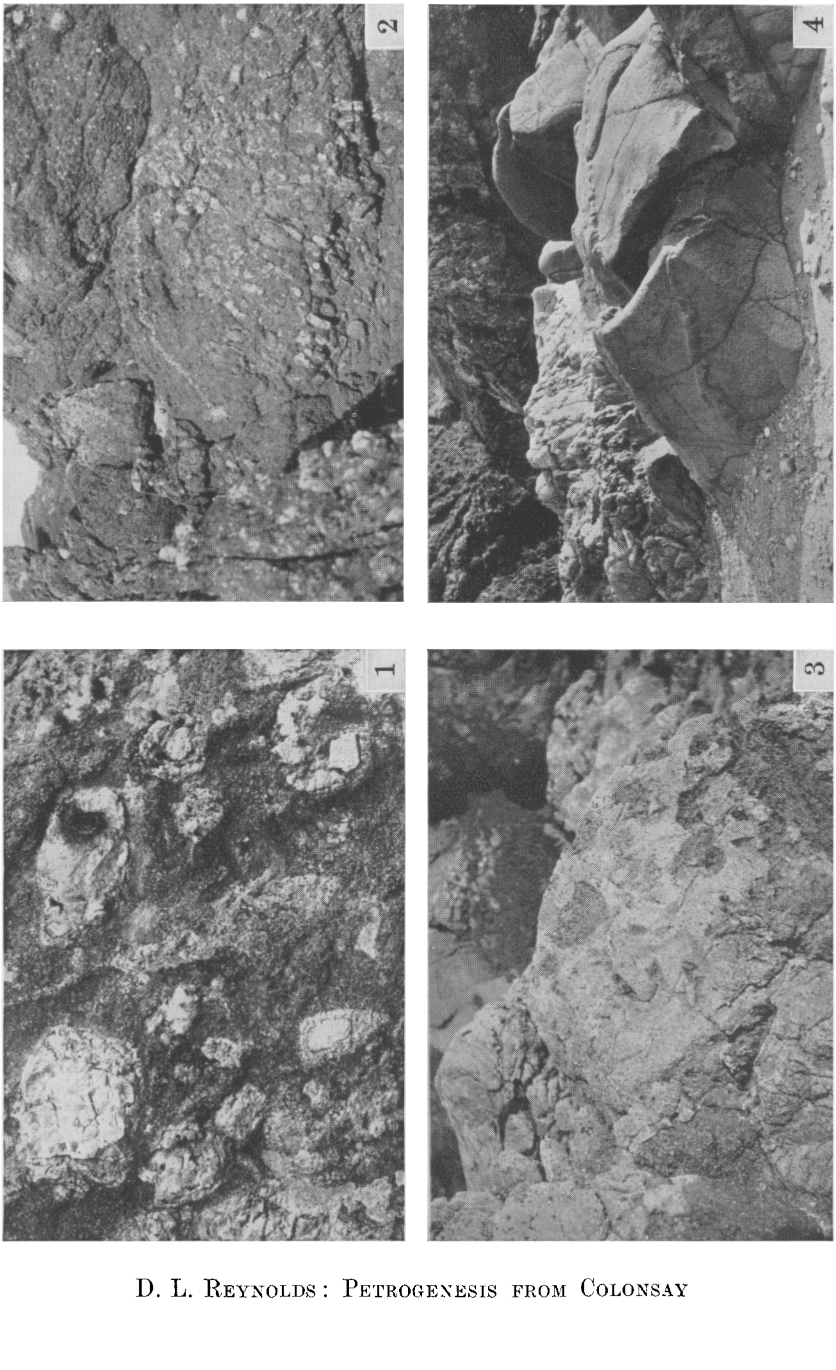
Fig. 2. Syntectic appinite from a vein projecting from the metasomatized rim of a quartzite xenolith. As in the hornblendite, the hornblende is partially replaced by tremolite. Ordinary light, × 26.

Fig. 3. Syntectic syenite, metasomatized rim of a quartzite xenolith. Nicols crossed, × 15. Analysed specimen.

Fig. 4. Micropegmatite from the metasomatized rim of a quartzite xenolith. Nicols crossed, × 13.

Fig. 5. Micropegmatite, metasomatized rim of a quartzite block in the breccia which margins the intrusion to the south of Port Easdale. The needle-like mineral is rutile. Ordinary light, × 13.

Fig. 6. Contact between a residual core of quartzite and its metasomatized rim. The region of felspathization is seen to be advancing into the quartzite in minute antennae-like processes which extend along the intergranular boundaries. A felspathic vein has developed, along intergranular boundaries, in advance of the limit of general felspathization. Ordinary light, × 13.



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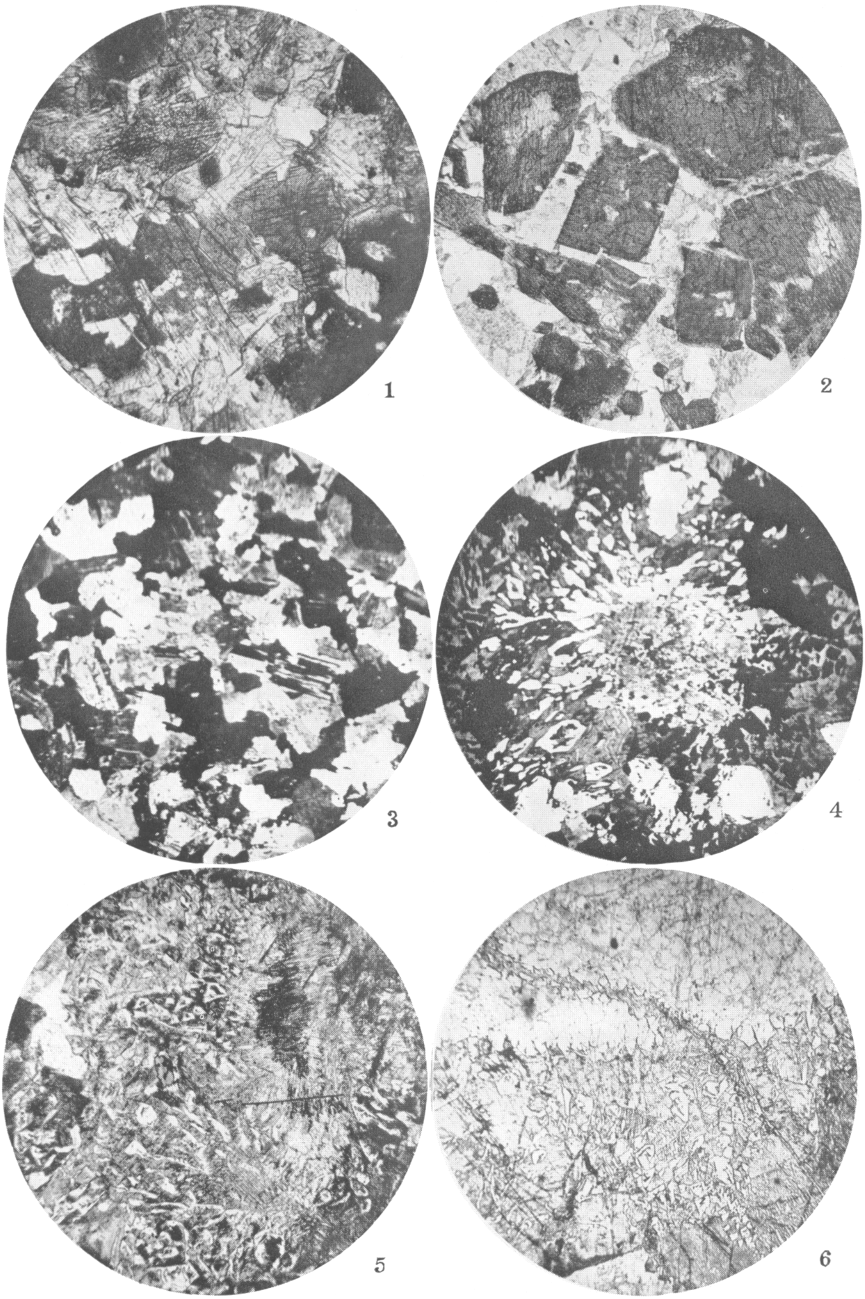

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