Myrmekite and myrmekite-like intergrowths

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Summary. Myrmekite-like intergrowths in the Lewisian gneiss and the igneous complex of Loch Borolan are described. The intergrowths are of diverse mineral composition but have many features in common with myrmekite and it is shown that they result from the constriction of a previously existing mineral during the growth, in the solid state, of the host mineral. More than one stage of intergrowth is often found and these stages can be correlated with geological events.

ALTHOUGH the term myrmekite applies strictly to an intergrowth of vermicular quartz and plagioclase, similar-textured intergrowths of vermicular quartz in a variety of other host minerals have been described. In some examples the vermicular mineral is not quartz. Myrmekite and the other vermicular textures all appear to lack any specific crystallographic or lattice co-relationship between the vermicular and host mineral, as reported by Drescher-Kaden (1948, p. 64) and confirmed in those cases tested by the present writer. By contrast, the two minerals in graphic type intergrowths show definite crystallographic relationships with each other. In the vermicular textures there is, however, a purely geometrical relationship between the included mineral and the growth directions of the host mineral. This fact is the major clue to the origins of myrmekitic intergrowths. As will be seen from the following descriptions, this relationship is the common factor of a large number of intergrowths of variable mineral composition, and leads to the conclusion that they have a common origin, related to the physical conditions of growth.

Examples from the Lewisian gneiss

The Lewisian gneiss of the Scourie and Laxford regions has been described by Sutton and Watson (1951). Charnockites formed during a Scourian period of metamorphism were transformed, during a later period of metamorphism and granitization, into gneisses, the more acid of which consist of varying proportions of hornblende, epidote, biotite, plagioclase, K-feldspar, and quartz. Sutton and Watson noted vermicular intergrowths of quartz in epidote in the Laxfordian Acid Gneisses, and they are so abundant in some of the specimens collected by the writer that they constitute most of the rock.

Dr. R. G. Park brought the writer's attention to similar intergrowths in the Gairloch area. Here, as at Laxford, the intergrowths occur in the shear zones of Laxfordian age, which affect the older Ialltaig gneisses of Scourian age (Park, 1964, pp. 405–7). Intergrowths between vermicular quartz and amphibole are common in the Ialltaig rocks and also occur at Laxford.

The form of the epidote of the intergrowths ranges from plug-like outgrowths to perfectly shaped euhedral wedges. The plug-like forms (fig. 1*a*) are very similar to the characteristic plugs of true myrmekite: the vermicules of quartz, groups of which have a common extinction position, fan outwards, tending to lie perpendicular to the outer surface of the plug. The wedge-shaped forms have a more regular arrangement of the quartz in intergrowth: the quartz is not always perfectly vermicular and there is a tendency to form plates parallel to the crystal faces; some of the plates radiate at the edges of the crystal (fig. 1*b*). In some rocks, the crystal form appears to have been initiated by a skeletal growth, and completed by an infilling of the skeleton, only the later infilling enclosing quartz (fig. 1*b*).

The intergrowth occurs between the grains of any mineral but only in rocks with free quartz. For example, in one specimen of Ialltaig gneiss, the abundant clusters of epidote grains are full of vermicular quartz (fig. 2*a*), and quartz is an abundant constituent of the remainder of the rock. In contrast, another specimen shows similar clusters of epidote without vermicular quartz (fig. 2*b*), and no other quartz is present in the rock.

An examination of some of the intergrowths with the universal stage revealed no relationship between the orientation of the quartz and epidote. The vermicular mineral proved to be feldspar in some rare cases.

The amphibole–quartz intergrowth is best developed in the Laxfordian sheared Ialltaig gneiss. Two generations of amphibole occur. In one sample, both generations form the margins of pyroxene crystals, and are probably replacing them, the earlier being darker in colour and without vermicules (fig. 3). Another sample lacks pyroxene but contains dark green and brown pleochroic amphibole surrounded by a pale amphibole filled with vermicular quartz (fig. 4*a*). The vermicules of

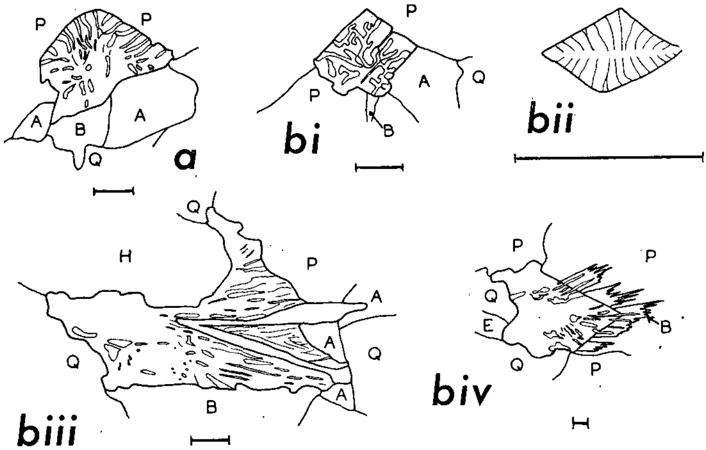


FIG. 1. (*a*) A plug-like intergrowth of epidote and radiating vermicules of quartz. (*b*) Wedge-shaped forms of epidote with vermicular quartz: *bi* illustrates quartz following a rather rectangular pattern related to the outline of the epidote crystal; *bii* is an example in which the quartz vermicules radiate in regular fashion at the edges of the epidote crystal; in *biii* a V-shaped skeletal crystal of epidote is overgrown by epidote and vermicular quartz which follows a regular pattern around and in the 'V'; the regularly radiating quartz in the epidote of *biv* continues in the surrounding biotite. The biotite has a radiating form and appears to have continued the growth directions of the epidote indicated in the orientation of the included quartz (the cleavage of the biotite is parallel to the irregularities at its edge). The scale bar represents 0·1 mm. A = amphibole, B = mica, E = epidote, H = hole in slide, P = plagioclase, Q = quartz. Grid references giving location of the specimens are as follows: *a* and *bi*—193491; *biii*—232483; *biv*—236491; *bii* is from the Ialltaig gneiss.

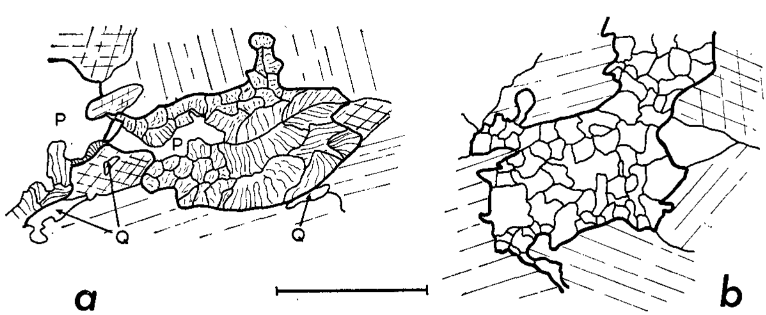
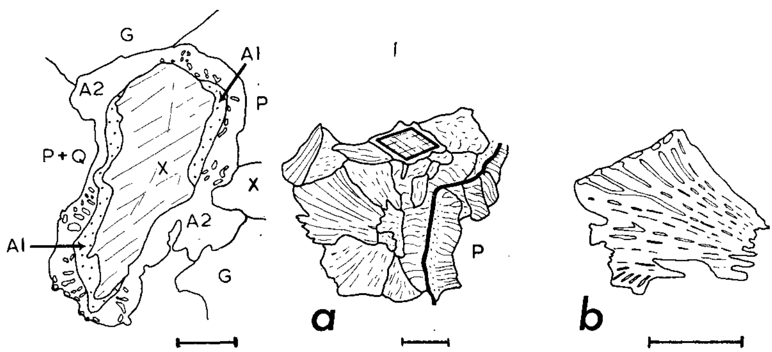


FIG. 2. (*a*) Cluster of epidote grains with vermicular quartz more or less surrounded by amphibole. P = plagioclase, Q = quartz. (*b*) Cluster of epidote grains without vermicules in quartz-free rock. The surrounding mineral is amphibole. The scale bar represents 0·5 mm. The figures are somewhat diagrammatic.

quartz radiate in characteristic fashion in the sheaf-like growths of amphibole. This intergrowth is in turn surrounded by vermicular quartz–epidote intergrowths. The quartz vermicules in the clusters of amphibole grains do not extend from one grain to the other (although some quartz is present along the grain boundaries) each grain having its individual set of vermicules, usually with some clear relationship with



FIGS. 3 and 4: FIG. 3 (*left*). Two stages of amphibole growth (A1 and A2) surrounding a pyroxene crystal. G = garnet, P = plagioclase, Q = quartz, X = pyroxene. The scale bar represents 0·2 mm. FIG. 4 (*centre and right*). (*a*) A euhedral crystal of dark amphibole (top centre and cleavage shown) surrounded by clusters of pale amphibole crystals with vermicular quartz (represented diagrammatically by lines). The pale amphibole is in turn surrounded by epidote–quartz intergrowth (to right of thick line). P = plagioclase. (*b*) Detail taken from the left of fig. 4*a* of a sheaf-like amphibole with discontinuous vermicules of quartz. The scale bar represents 0·1 mm.

the external form of the amphibole (as in the sheaf-like form). Furthermore, the vermicules are discontinuous in some examples (fig. 4*b*)—this will be discussed in the section concerning the syenitic rocks of Loch Borolan.

More than one generation of the epidote–quartz intergrowth is present in some samples. In a specimen from near the junction of the main Laxford road and the small road to Skerricha (Grid Ref. 239504), three generations of the epidote–quartz intergrowth, as well as similar generations of amphibole–quartz intergrowth, can be distinguished. The first and second generations, which are not readily separated, occur as the inner and outer zones respectively of large distinctly pleochroic crystals with coarse blebs of quartz. Close examination reveals a sharply defined inner zone to the crystals, separated from the outer zone by traces of a green mineral (fig. 5*a*). Growing on the margins of these crystals, as irregular encrustations and plug-like forms, are paler crystals of third generation epidote containing fine vermicules of quartz (fig. 5*b*). The early generation of amphibole crystals in the specimen, which are deeply embayed and do not contain vermicular quartz, was subsequently overgrown by a new generation of amphibole containing fine vermicules (fig. 5*c*).

Origin of the intergrowths. The amphibole and epidote of the intergrowths resulted from the Laxfordian recrystallization of pyroxene

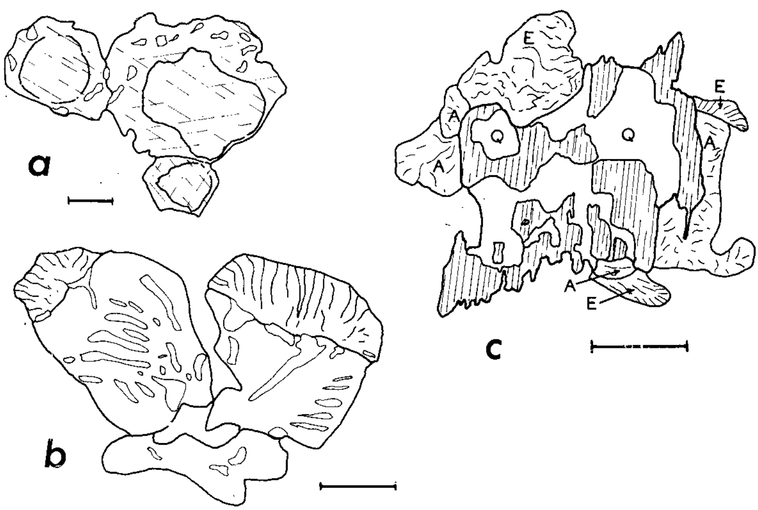


FIG. 5. (*a*) Three crystals of epidote the upper two of which include coarse blebs of quartz. Each crystal consists of two zones, which are optically continuous but separated by an irregular trace of a green mineral. (*b*) Three crystals of epidote with coarse vermicules of quartz and at the upper margins of the top two of these crystals is an encrustation of late generation epidote, which contains very finely vermicular quartz (represented by fine lines). (*c*) Deeply embayed amphibole (lined) overgrown by amphibole (A) and epidote (E) with vermicular quartz. Q = quartz. The scale bar represents 0·2 mm.

granulites (Sutton and Watson, 1951; Park, 1964). There are, however, three distinct possibilities for the timing of the development of the vermicules and the origin of the quartz: at a later date than the formation of the host mineral and as a result of corrosion by siliceous solutions; formation simultaneously with the host mineral as a result of chemical reaction or eutectic crystallization; presence prior to the host mineral but incorporation in the host mineral at the time of its growth.

The quartz is unlikely to be later than the host mineral. From energy considerations, corrosive siliceous solutions would be expected to follow the grain boundaries rather than to form vermicules. Some specimens show corrosion but the host mineral is embayed along the grain boundary and the vermicules enlarged (fig. 7*a*), this probably accounting for the coarseness of the early intergrowths; the corrosion is evidently secondary to the formation of the vermicules. Further, corrosive solutions would be expected to affect the minerals of an earlier generation, but the vermicules of the intergrowth do not give evidence of this. As in the Lundy granites (Shelley, 1966), second generation vermicules start at the new growth boundary and never extend below it. It is unlikely that any process involving exsolution of quartz in the host mineral would produce forms of quartz that mimic the growth directions of the host (see below and fig. 6). Further, some consistency in the relative volumes of quartz and host mineral and some crystallographic control between them might be expected if exsolution had taken place.

The second and third possibilities both involve simultaneous crystallization of the two minerals in the intergrowth. The second, postulating either reaction simultaneously producing the two minerals or eutectic crystallization, is not tenable, because of a complete lack of consistency in the relative volumes of quartz and host mineral. The third possibility is that the quartz was present prior to the host mineral but was incorporated in it during its growth. This is supported by the development, in those rocks in which quartz is not an essential constituent, of epidote in identical manner to that of the intergrowth, but without vermicular quartz (fig. 2). As with myrmekite (Shelley, 1964), the quartz (and feldspar in some rare cases), at the time of growth of the host mineral, must have been undergoing recrystallization, in this case as a result of Laxfordian shearing.

The essential point concerning the development of the geometry of the intergrowths is the constriction of the recrystallizing quartz by the growing host mineral. The constriction results from the increase in volume in the immediate vicinity of the new site of growth of the host mineral. In the case of the characteristic plug- or sheaf-like intergrowths, the force of crystallization was presumably equal in all directions perpendicular to the direction of growth, so that vermicules resulted (fig. 6*a*). However, the type of constriction imposed during the growth of wedge-shaped crystals would have been different, so that the vermicules tended to be flattened parallel to the crystal faces of the host, as well as being more regularly arranged in the crystal (fig. 6*b*). Correspondingly, in micaceous minerals, if the mica grew essentially in all directions in the basal planes, the quartz would take the form of irregular plates and blebs in the basal cleavage (fig. 6*c*). Such intergrowths are common in the Laxfordian-affected gneisses (fig. 7*b*) and it seems probable that their origin is the same as that of the more vermicular texture. There are examples (fig. 1*b* iv) in which the biotite appears to have continued the same growth directions as the epidote.

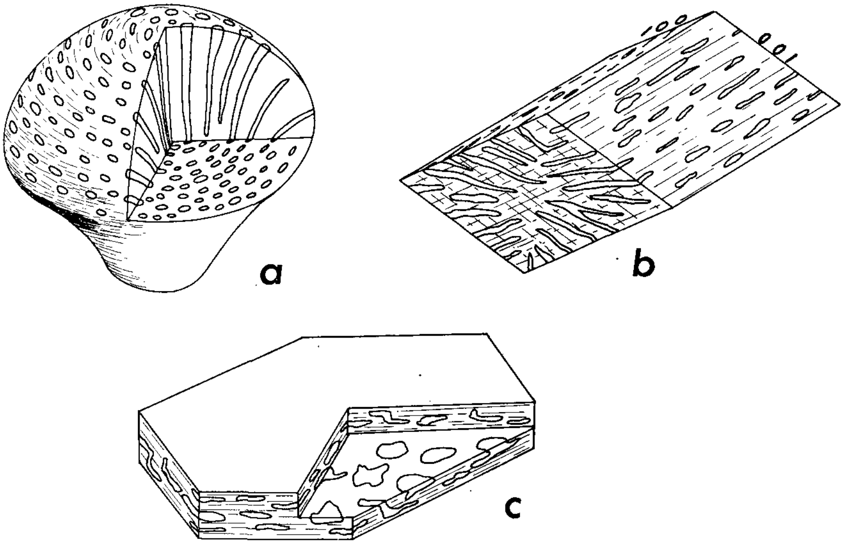


FIG. 6. Diagrams illustrating the relationship in three dimensions between the geometry and disposition of the included quartz and the shape and growth direction of the host mineral. (*a*) Plug or sheaf-like intergrowth; (*b*) Wedge-shaped intergrowth; (*c*) Micaceous intergrowth.

Geological significance. A detailed study of the vermicular intergrowths in the Lundy granites led to a more detailed chronology of geological events (Shelley, 1966). Although a similar detailed correlation has not been made in the Lewisian gneiss, the three generations of vermicular intergrowth may indicate three separate periods of metamorphism or shearing. This may further substantiate the proposed division of the Laxfordian into more than one episode (see discussion at the end of Park, 1964). Some support is also given by the two or more generations of growth of blastic plagioclase in the gneiss (fig. 7*c*).

Examples from the Loch Borolan region of north-west Scotland

The complex of alkaline igneous rocks at Loch Borolan has been described in some detail by Shand (1910, 1939) and by Woolley (1965). Essentially, the rocks pass upwards from melanite–pyroxene syenite into quartz syenite, although the exact nature of the change is still

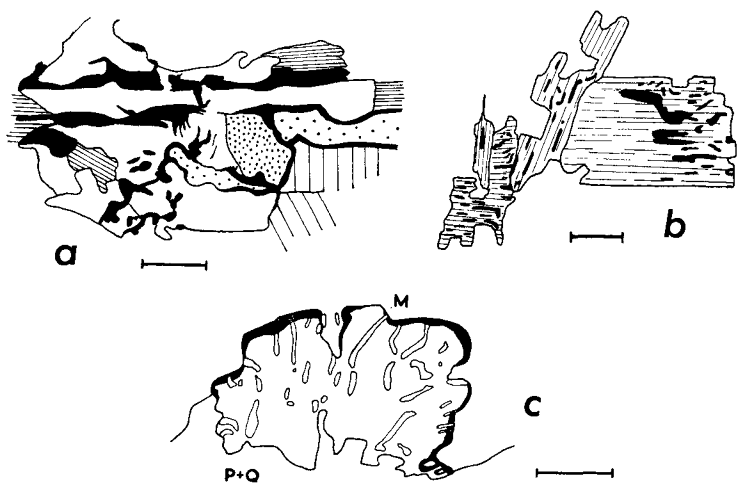


FIG. 7. (*a*) Siliceous solutions have penetrated the minerals along the grain boundaries and have enlarged some vermicules. Black—quartz (nearly all of which has a single orientation); close lines—biotite; wide lines—plagioclase; wide stipple—microcline; close stipple—apatite; blank—epidote. (*b*) Biotite–quartz intergrowth. (*c*) Old cloudy myrmekite has been corroded leaving some vermicules isolated; a later growth of clear albite has overgrown the myrmekite and the isolated vermicules. M is microcline, P and Q are plagioclase and quartz. The scale bar represents 0·2 mm. Grid references giving location of the specimens are as follows: *a*—228477; *b*—239501; *c*—236491.

uncertain owing to discontinuous and poor exposures. The emplacement, however, took place at the same time as the post-Cambrian thrusting of the area, some parts of the complex being sheared, other parts unsheared (Bailey and McCallien, 1934; Woolley, 1965). Woolley thought that shearing stress was important throughout and that the early intrusions were still hot at the time of thrusting (p. 285).

The rocks commonly contain intergrowths of vermicular nepheline in K-feldspar. The nepheline has been replaced in many instances by muscovite. Mention of the intergrowths was made by Horne and Teall (1892) and Shand (1906) described them in some detail. Similar intergrowths of vermicular nepheline in feldspar from various parts of the world have been described by Tilley (1958).

The writer's specimens are from poor exposures along the Ledbeg River just north of the Elphin Road. The intergrowth is very abundant and constitutes more than half of some of the specimens. In thin section, the rock shows many bands of microbreccia, and veins of carbonate with occasional patches of quartz are numerous. Mica has entirely replaced the nepheline of the intergrowth and has also replaced some of the K-feldspar.

Shand (1906, p. 430) describes the vermicules as lacking any relationship with the crystallographic or outline directions of the orthoclase. Nevertheless the typical examples figured here show a very definite relationship between K-feldspar and vermicule: the very symmetrical feathery forms of intergrowth as in fig. 8*a* are directed along the *c* axes[1] of the host feldspar and are in contact with each other along definite lines of mutual interference; fig. 8*c* shows a rather more orthogonal pattern related precisely to the crystal axes of K-feldspar. The more altered examples commonly have discontinuous vermicules (fig. 8*c* and *d*), which all stop and start precisely along the same line. There is no indication that the vermicules disappear from the plane of thin section and then reappear, and no vermicules elsewhere have ever been seen to do this. In some examples only a mere suggestion of the presence of the vermicules is seen (fig. 8*d*).

Origin of the intergrowth. Tilley (1958) thought the vermicular nepheline in feldspar resulted from metasomatism, the nepheline replacing feldspar. Woolley (1965) agreed with Tilley and correlated the development of the texture with a proposed period of nephelinization in the Borolan complex (based on chemical work). However, the feathery vermicules are typical of growth forms and the fact that the feather axes are, in many cases, related to the crystal axes of the feldspar argues strongly in favour of simultaneous crystallization rather than replacement (the crystal axes of the feldspar being probable growth directions). Unfortunately, the evidence against replacement found in examples showing more than one generation of growth, as in the Lewisian gneiss and the Lundy granites (this paper and Shelley, 1966), is not present

[1] The principal axes of many feathers, as seen in two dimensions in thin section, usually lie in a plane containing the β optic directions of the feldspar. Therefore, it is likely that the true axes of the feathers in three dimensions are parallel to the *c* crystallographic axes of the feldspar. There are some instances in which the long axes are subparallel to the γ optic direction and some in which no relationship was established.

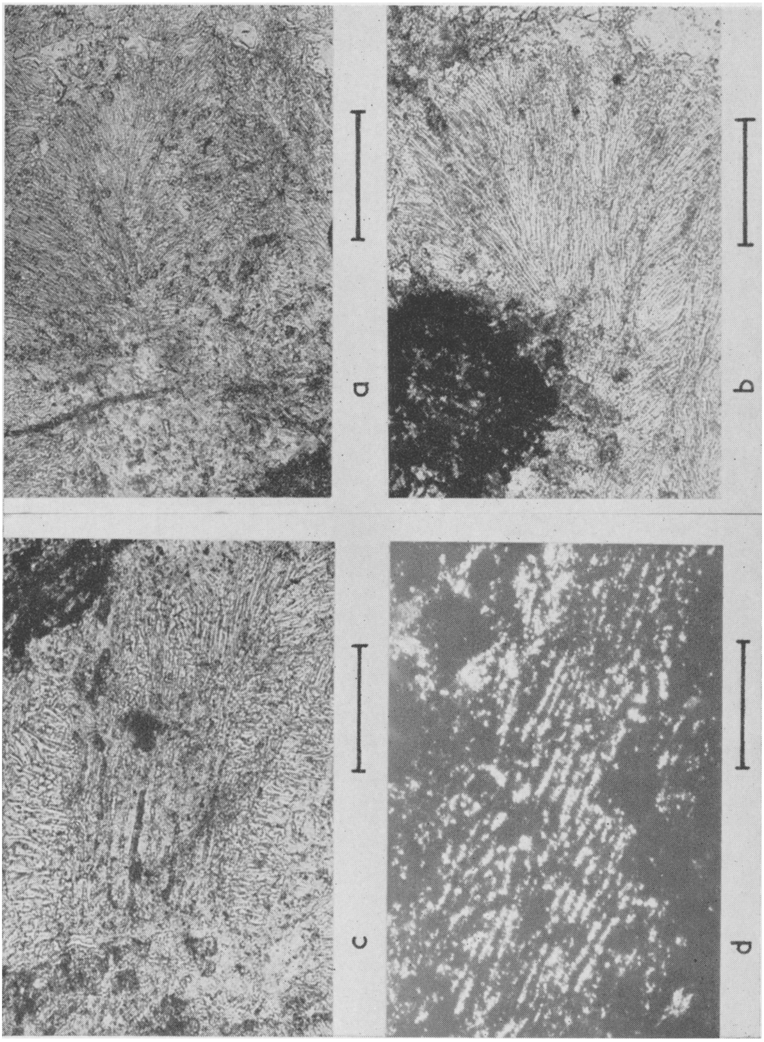


Fig. 8. (*a*) A feathery form of intergrowth. The line of contact with another 'feather' can be seen in the bottom right of the photograph. (*b*) Sheaf-like intergrowths similar to myrmekite and directed in the same direction as the feathers. (*c*) The nearly vertical vermicules are subparallel to the *c* axis of the feldspar and those at right angles are subparallel to the *b* axis. (*d*) This photograph was overexposed in order to emphasize the presence of the discontinuous vermicules in the feldspar. They are much more difficult to see in fact. The scale bar represents 0·2 mm.

here but the similarity of the other features is striking. Nephelinization may have been important at some stage in the development of the rocks but cannot easily be argued to be the cause of the texture.

The discontinuous vermicules (fig. 8*c* and *d*) may be simply explained in terms of a potash and silica metasomatism as follows: formation of normal and continuous vermicules; replacement of the already formed vermicules by K-feldspar which in some cases (fig. 8*d*) virtually eliminated the vermicules;[1] the metasomatism continued in these particular examples and resulted in the replacement of the nepheline by mica. It is possible, especially in the light of work by Parsons (1965) on the Loch Ailsh complex, that the K and Si metasomatism occurred during the post-Cambrian thrusting movements. If this is correct, then there was a combination of shearing and K–Si metasomatism, which must have led to recrystallization and volume increase of K-feldspar with respect to nepheline.

It seems probable, therefore, that the two minerals recrystallized simultaneously and that the vermicules were the result of constriction of the recrystallizing nepheline by K-feldspar, which was increasing in volume.

An example from the Aberdeenshire gabbros

Some mention can be made of another well-known intergrowth of similar type, namely, that between opaque iron-ore and pyroxene in the Aberdeenshire gabbros. Although only a brief examination has been made of some thin sections of specimens from Auchenbradie and Cairnhill, the intergrowths appear to be associated with strain features, and, in a similar manner to that proposed for the Lewisian and Borolan examples, there seems to be a possible correlation between the development of the intergrowth and the deformation and folding of the gabbros proposed by Shackleton (in discussion of Read and Farquhar, 1956) and by Stewart and Johnson (1961).

Discussion

Certain features are common to all the various myrmekitic and myrmekite-like intergrowths:

First, the vermicules are disposed along growth directions of the host mineral, their exact shape being presumably a consequence of the particular constriction imposed on them during growth.

[1] A similar replacement can be seen in the Lewisian examples (fig. 4*b*), where the formation of the amphibole evidently required silica, this requirement being met in some instances by the already formed vermicules.

Second, there is no consistency in relative volume of host mineral to vermicular mineral in individual rock masses, some specimens containing abundant vermicules, others none (fig. 2). This is also evident in most examples of myrmekite the writer has previously studied: some growths of plagioclase have abundant vermicular quartz, others in the same specimen, apparently identical in origin and form, have only a few vermicules or none at all; this last case is especially common where the plagioclase has grown onto included grains in orthoclase, quartz being available only along shear planes or grain boundaries (e.g. Shelley, 1966, fig. 7*a*).

Third, detailed petrography has shown many cases of more than one stage of development of the intergrowths. Early growths often suffer secondary changes not directly related to their origin: for example, those of myrmekite, usually being associated with granitic activity, are often enveloped in later crystals of orthoclase (Shelley, 1964) and the early vermicules are commonly enlarged by later corrosion. The recognition of the stages of development is of great importance since the intergrowth can only be interpreted once these stages have been placed within a sound geological framework. Some recent authors (e.g., Hubbard, 1966) do not, in the writer's opinion, take proper regard of this factor in their interpretation.

Most important from a geologist's point of view is that the intergrowths provide useful markers in the development of the texture of the rock and can often be correlated with the recrystallization following periods of deformation.

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