The significance of granophyric and myrmekitic textures in the Lundy Granites

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Summary. Zonal myrmekitic and granophyric intergrowths in plagioclase and K-feldspar phenocrysts are described. There are two such zones in the feldspars of the Late Granite, G2, but only one in the Early Granite, G1. The zonal granophyric intergrowths are the end-product of the replacement of myrmekitic plagioclases by K-feldspar. Transitional stages of this replacement, which took place in the solid state, are represented in numerous examples. The zones of myrmekite, which also represent growth in the solid state, occur between zones of magmatic plagioclase, which is oscillatory-zoned. It is concluded that the granites evolved at depth under the influence of at least three phases of volcanic activity. Each of these phases resulted in the partial melting of the country rocks with subsequent magmatic crystallization, followed further, under the slow cooling conditions, by extensive reaction in the solid state. During each of the final two phases, some of the granite was intruded as a crystal mush to form G1 and G2, in which the phenocrysts retain evidence of their evolution at depth whilst the ground-mass gives evidence of the final magmatic crystallization.

Lundy is the southernmost site of igneous activity in the Atlantic Tertiary province. The island is composed primarily of granite although a group of Palaeozoic slates, into which the granite was emplaced, outcrop at the southern end of the island. A swarm of Tertiary basalt and trachyte dykes cuts both granite and slate.

Dollar (1941) has made the most recent field study of the granite and concluded that there are two distinct granites. The earlier, G1, is domed up and broken by the later, G2, which shows a chilled margin against the former. There is also a late dyke phase, G3. The Tertiary age of the complex was not demonstrated until three years ago when Dodson and Long (1962) and Miller and Fitch (1962) showed G1 to have an Eocene age.

Bott *et al.* (1958), from their gravity measurements, suggested that the granite mass has an approximate form of a cylinder with a diameter of 4·8 Km and a depth of 1·6 Km. They calculated that there is an overall regional positive anomaly that can be interpreted in terms of the presence of a body of dense rock in the vicinity of the island.

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They pointed out the similarity of the Lundy Granite to the Mourne Granite, which is 1·2 Km thick and near which there is also an unexposed mass of basic rock to which the Mourne Granite is probably genetically related.

In the present paper, certain petrographic-textural characters of the Lundy Granite are examined. Abundant throughout the granite are intergrowths between K-feldspar and vermicular quartz, which have been termed granophyric. The term granophyric (micrographic) is poorly defined and is usually applied to all fine intergrowths between quartz and K-feldspar. The quartz of granophyric intergrowths has been referred to as cuneiform, leaf-like, flower-like, frost-crystal-like, or plumose. Intergrowths in which the quartz is vermicular have also been termed granophyric. A distinction can be made between the vermicular and non-vermicular types. There can be little doubt that the latter type is produced in some circumstances by simultaneous eutectic crystallization of quartz and K-feldspar, since the texture has been produced in the laboratory (Schloemer, 1962), although petrographic evidence shows that the texture may also be the result of the penetration of quartz along planes of weakness in K-feldspar (Drescher-Kaden, 1948, and Augustithis, 1964). The vermicular quartz and K-feldspar intergrowths cannot be so easily explained. The origin of the vermicular development of quartz in intergrowths with plagioclase has never been satisfactorily explained by replacement or simultaneous crystallization from a liquid. It has been recently suggested (Shelley, 1964), that vermicules are formed during the physical constriction of recrystallizing quartz in plagioclase that is in the process of exsolution from K-feldspar. When, however, the vermicular quartz occurs in K-feldspar, as in the Lundy Granites, further explanation is needed and is attempted in this paper.

Forty-five thin sections were prepared from over 30 specimens of the two Granites, G1 and G2, which were collected at scattered localities on the island and are therefore representative of the Granites as a whole.

Petrographic features of G2

In the field the rock has a mottled appearance and consists of phenocrysts of bipyramidal quartz (often black in hand specimen), K-feldspar, and plagioclase, set in a fine-grained mass of K-feldspar, plagioclase, and quartz. The K-feldspar phenocrysts are more abundant than those of plagioclase.

K-feldspar phenocrysts. The most striking feature of these phenocrysts is the existence of at most two zones with quartz vermicules or quartz blebs within them. The zones are almost invariably present, are continuous around the crystal (fig. 1), and have a sharp inner boundary and a diffuse outer boundary. Groups of vermicules within a zone often have an identical optical orientation. The development of vermicules

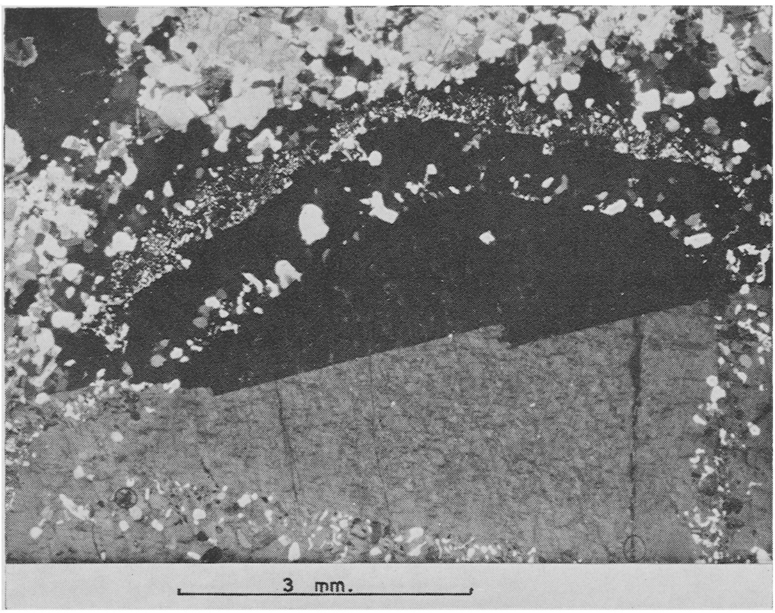

FIG. 1. A K-feldspar crystal from G2 that clearly illustrates two zones of vermicular and bleb-like quartz.

as opposed to the inclusion of non-vermicular quartz is irregular as is the presence of the zones at all. Usually the inner zone is less vermicular than the outer zone. Frequently, in any one zone, the vermicular quartz develops outwards into non-vermicular quartz but never vice-versa (fig. 2*a*).

The K-feldspar often has the optics of high-temperature sanidine (2V approaching zero and the absence of multiple twinning). Exsolution lamellae and irregular patches of plagioclase are almost invariably present and will be discussed later.

Plagioclase phenocrysts. These are less common than the K-feldspar crystals but their features are remarkably similar to those of the

K-feldspar. The crystals, which are oligoclase, include zones of quartz vermicules or blebs. There are again no more than two zones and they have the same features as those in the K-feldspar.

Whereas the K-feldspar crystals are generally homogeneous (apart

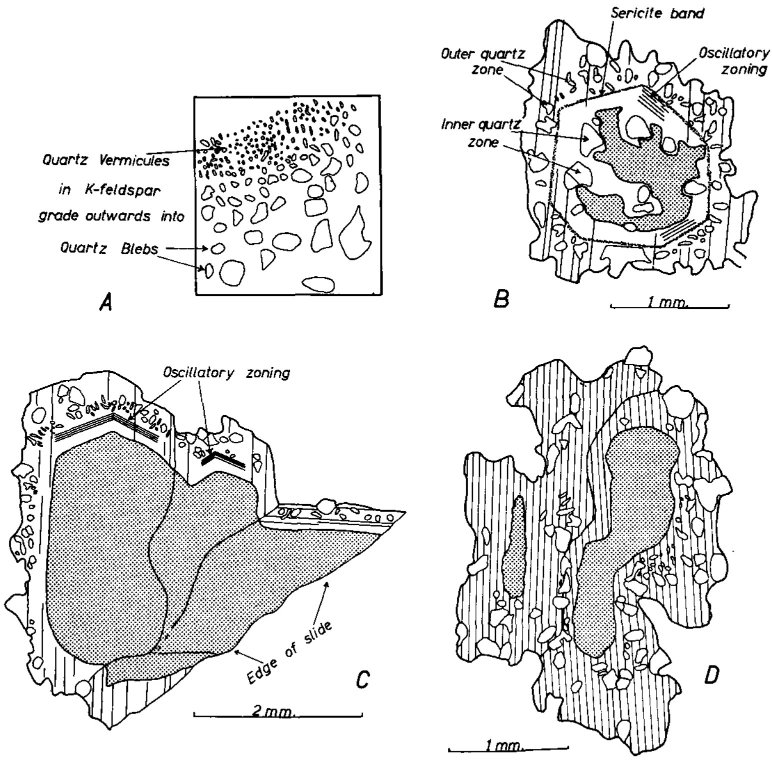

FIG. 2. *a*: Detail of an intergrowth between quartz and K-feldspar. *b*, *c*, *d*: Various examples of zones of quartz vermicules and blebs in plagioclase feldspars from G2. The stippled areas represent highly sericitized and altered plagioclase. Feldspar twinning is represented diagrammatically.

from quartz inclusions and perthite), the plagioclase crystals show distinct growth features. There is normally an intensely altered core, which in the field appears as a soft centre to the crystals. The alteration is usually so intense as to make the plagioclase core unidentifiable in thin section. Flakes of biotite scattered amongst the alteration products impart a red colour to the cores. The altered core is surrounded by a zone with quartz inclusions that are more often blebs rather than vermicules and are set in optically homogeneous oligoclase. Oscillatory-zoned oligoclase follows and is in turn surrounded by a second zone with quartz inclusions that are more often vermicules rather than blebs (fig. 2*b*).

Sometimes the inner core seems to be completely absent and elsewhere the other growth features cannot be recognized. For example,

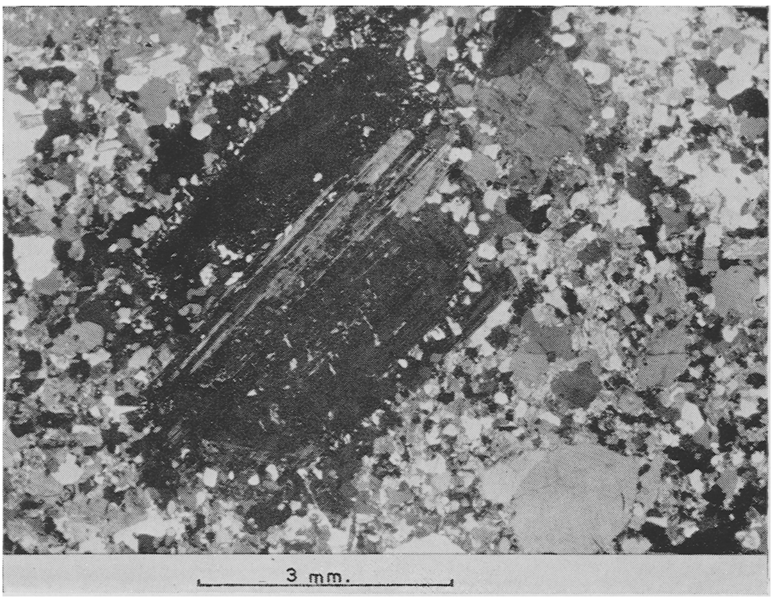

FIG. 3. A plagioclase crystal from G2, which apparently has a single zone of quartz vermicules.

the inner zone with quartz blebs is missing from the crystal illustrated in fig. 2*c* and a further example (fig. 3) shows only one zone of vermicular quartz and, probably as a result of cut effect,[1] neither the inner zone nor the altered core appear in the section. However, a crystal showing all the above features can usually be found in any specimen.

In some examples, the core has embayed margins suggesting that the plagioclase was strongly corroded prior to the crystallization of further plagioclase or inclusion of quartz (fig. 2*d*).

[1] This term (Schnitteffekt) has been used by Sander and other workers on petrofabrics for the inadequate representation of three-dimensional features in a thin section; the inner zones of crystals, for example, will often appear to be absent.

Although the similarity between the K-feldspar and oligoclase crystals is quite remarkable, the vermicules are often better developed in the K-feldspar than in the plagioclase and this feature will be discussed later.

Replacement of plagioclase by K-feldspar. The similarity between the K-feldspar and oligoclase crystals clearly requires an explanation. The simultaneous growth of the plagioclase and K-feldspar is unlikely since the plagioclase provides evidence of a complex history in having a highly altered and corroded core and zones of oscillatory-zoning whereas the K-feldspar shows no signs of such a history. A likely explanation is that the K-feldspar has replaced some of the plagioclase phenocrysts and has retained the quartz zones formerly present in the plagioclase. This resolves the problem of the quartz vermicules into that of the formation of myrmekite (the vermicular quartz–plagioclase intergrowth).

The replacement suggested here can be demonstrated by the presence of transitional stages in various phenocrysts. For instance, in a typical example (fig. 4*a*), in which there are two zones of vermicular quartz, the K-feldspar occupies principally the inner part of what appears as a replaced plagioclase. The first zone with blebs of quartz is in the K-feldspar although there is a small irregular patch of plagioclase. The second zone of blebs and vermicules is partly within the K-feldspar and partly in a discontinuous 'zone' of plagioclase. On the clinopinacoid, the discontinuous zone of the plagioclase forms the rim to the combined plagioclase–K-feldspar crystal. The zone of plagioclase is especially discontinuous in directions at right angles to the twin lamellae thus implying that these were the channels of replacement by the K-feldspar. The quartz vermicules and blebs do not change in character from one feldspar to the other. More frequently, mere selvedges of the plagioclase exist on either side of the K-feldspar suggesting that replacement along the twin planes was stronger. In one example the core has not been affected (fig. 4*b*) and in another (fig. 4*c*), the plagioclase appears to have been replaced without reference to the growth structures leaving 'islands' of plagioclase in the replacive K-feldspar.

It has already been noted that the quartz has a somewhat less vermicular form in the plagioclase. There are perhaps two reasons for this. Firstly, there are many examples showing that the quartz vermicules have slight projections along the twin planes of the plagioclase producing 'Christmas-tree' forms (fig. 5*a*) thus implying the mobilization of quartz in the plagioclase. The vermicules enclosed in the K-feldspar show no such signs of mobilization. Presumably, this phenomenon is an effect of the selective replacement of the quartz with respect to each feldspar. Therefore, contrary to expectation, the vermicules are better preserved in the replacive K-feldspar than when they remain in the

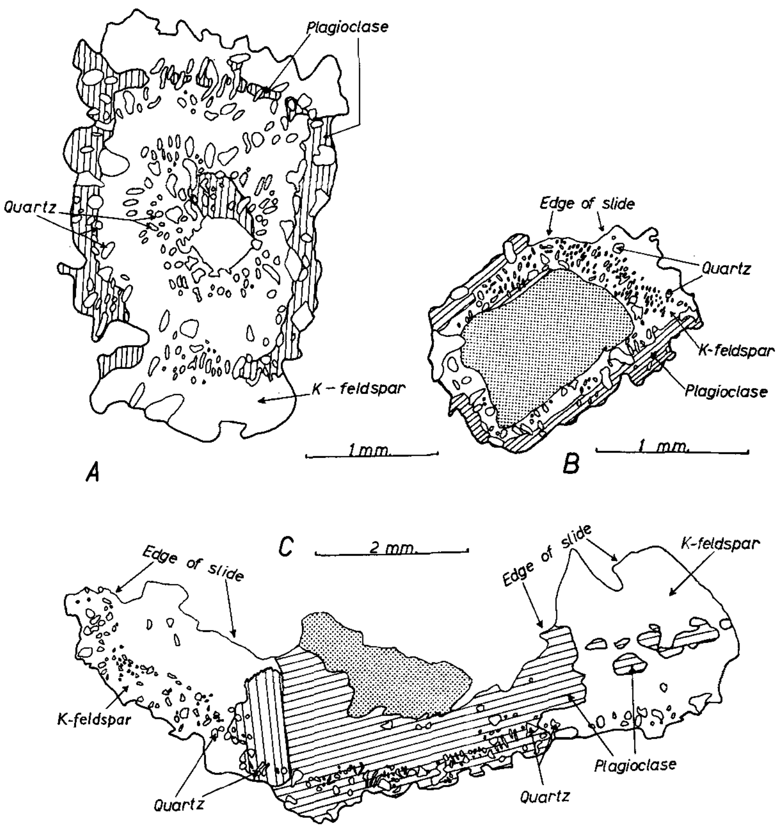

FIG. 4. Three examples of crystals that show transitional stages in the replacement of myrmekitic plagioclase by K-feldspar.

plagioclase. Secondly, in a few examples where the K-feldspar has only partially replaced the plagioclase, the quartz in the K-feldspar is strikingly more abundant and vermicular than that in the plagioclase and it may be that the K-feldspar selectively replaced those plagioclase crystals most rich in quartz inclusions.

Many K-feldspar crystals have abundant patches of perthitic plagioclase within them. These patches are often intensely sericitized whereas the K-feldspar is not. The perthitic plagioclase shows very fine, complex twinning and is cracked in the same way as the large plagioclase phenocrysts. Fine albite-twin lamellae are considered by many workers (Vance, 1961) to be secondary, and in association with fracturing are the result of deformation. The K-feldspar shows little or no sign of deformation, implying that the patch-perthite is the remains of an earlier and replaced plagioclase crystal. The same crystals as show the

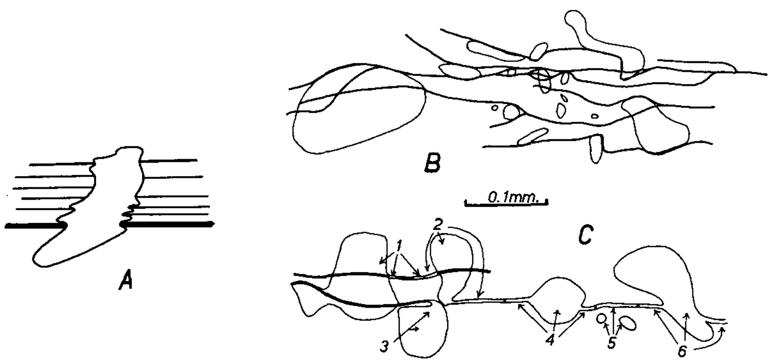

FIG. 5. *a*: Mobilized quartz vermicule in plagioclase. *b*, *c*: Quartz vermicules and blebs that are cut by and have been mobilized in association with red micaceous veins (thick black lines). The numbers in *c* refer to six different orientations of the quartz.

patch-perthite have fine, untwinned lamellae of plagioclase within them and these can reasonably be regarded as exsolution lamellae from K-feldspar.

Other features, such as the inclusion of disoriented plagioclases in the K-feldspar, can be matched with similar inclusions in the plagioclase phenocrysts and can be accounted for by a process of replacement. Similarly, the highly irregular inner margin to the zone of quartz inclusions in an otherwise completely homogeneous K-feldspar crystal (fig. 6) represents, after replacement, the embayed plagioclase core such as that illustrated in fig. 2*d*. The red micaceous material, which is included in the altered cores of the plagioclase, forms veins in the K-feldspar that cut the quartz vermicules (fig. 5*b*). In places the affected quartz recrystallized along continuations of the veins in optical continuity with the nearest quartz bleb (fig. 5*c*).

It is assumed that the replacement of plagioclase occurred at high temperature since the K-feldspar often has a small negative 2V characteristic of sanidine. Since, however, the quartz vermicules have remained essentially undisturbed (only occasionally do they appear to have been moved and packed together) it does not seem possible that any liquid was involved in the process of replacement and replacement

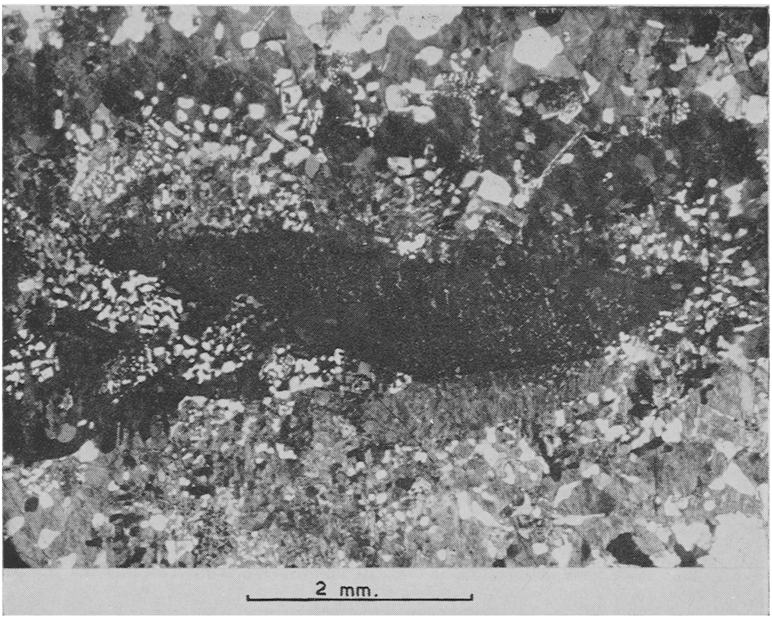

FIG. 6. Vermicular quartz in K-feldspar. Note the corroded appearance of the inner core of the K-feldspar (see text).

in the solid state has to be invoked. Therefore, the presence of sanidine does not necessarily imply molten, magmatic conditions.

Ground-mass myrmekite. In nearly all specimens of G2, there are small patches of common myrmekite in the ground mass. The myrmekite is usually plug-like in form, is associated with K-feldspar and has grown only at the principal grain boundaries. It is one of the final features of the development of G2. The plagioclase, originating presumably by exsolution, has also grown onto included quartz grains etc., but here it has not incorporated any quartz as myrmekite (fig. 7*a*).

Quartz bipyramids. Most of the quartz bipyramids are fractured. The fracturing occurred prior to the final crystallization of the granite since fragments of the bipyramids are separated by the fine-grained ground-mass. The margins of the bipyramids were recrystallized and protrude into the ground mass (either by actual protrusion or as a result of corrosion by the ground mass). Very rarely, examples have been found in which the quartz of myrmekite has the same orientation as that of an adjacent quartz bipyramid. It appears that the quartz of the bipyramids and that of the vermicules recrystallized simultaneously to attain a common orientation.

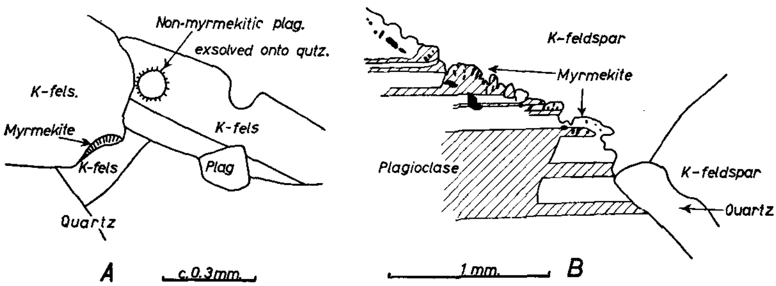

FIG. 7. *a*: Fine-grained ground-mass myrmekite in G2. *b*: Boundary myrmekite in G1. An enlargement of the area indicated in Fig. 8.

Petrographic features of G1

Although this granite has a similar composition to G2 it is more homogeneous, and it has not the mottled appearance of G2, neither has it the fine ground-mass nor the quartz bipyramids. However, the textures of the feldspars are remarkably similar to those in G2 except that instead of two zones of quartz inclusions in the feldspars only one has been found. The quartz zone in the plagioclase follows immediately on an intensely altered core.

To avoid repetition only one example is described here (fig. 8). A fine myrmekite is developed on the boundary between the plagioclase and K-feldspar crystals (enlarged in fig. 7*b*). This, as was the case for the groundmass myrmekite in G2, is one of the final features in the development of the granite. The boundary myrmekite is fresh, uncorroded, and plug-like in form. The growing plagioclase had in some places, though not in others, taken on the twin orientations of the host plagioclase. One can note the earlier quartz inclusions around the altered plagioclase core.

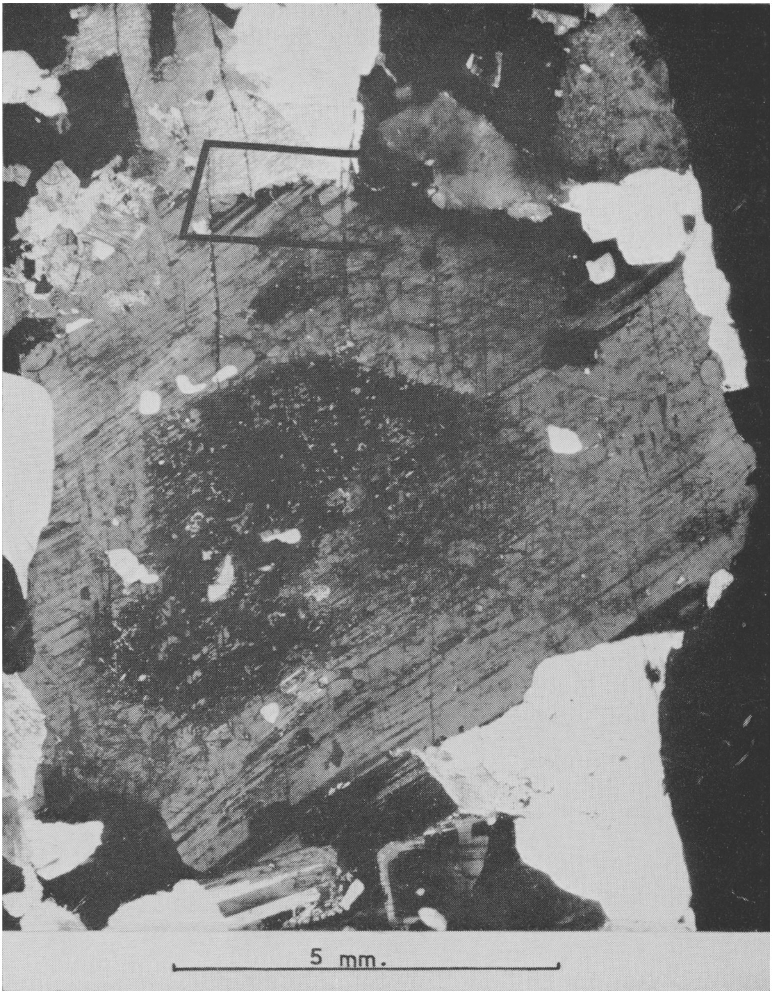

FIG. 8. A plagioclase crystal from G1 illustrates an altered core surrounding which is a poorly developed quartz inclusion zone. This is followed by oscillatory-zoned plagioclase, whilst fine-grained myrmekite is developed at the boundary of the crystal (enlarged in Fig. 7*b*).

Significance of the myrmekite

The arguments for and against various theories for the origin of myrmekite have been stated elsewhere (Shelley, 1964). Suffice to say that the characters of the intergrowths in the Lundy Granite are incompatible with the theory of Drescher-Kaden whilst the volume of quartz present in most of the intergrowths (fig. 6, for example) is far in excess of that required by Schwantke's or Becke's hypotheses. These hypotheses do not explain the rod-like nature of the quartz. All the characters of the intergrowths are, however, possible features of the author's theory in which the recrystallizing quartz is physically constricted in plagioclase growing in the solid state. In the case of the Lundy Granite however, it is evident that the quartz sometimes completely recrystallized prior to its total or even partial inclusion in plagioclase, thus resulting in the vermicular quartz grading outwards into non-vermicular quartz (fig. 2*a*, for example), and that the volume of plagioclase in the zonal intergrowths is so large as to render unlikely its formation as a result of exsolution from cooling K-feldspar. A source for the large volume of unzoned plagioclase in the intergrowths is in fact found readily in the neighbouring plagioclase phenocrysts, which have been either partially or totally replaced by K-feldspar in the solid state.

Discussion

To summarize the foregoing, the following five conclusions can be reached:

Oscillatory-zoned and non-myrmekitic plagioclase probably represent stages of magmatic crystallization.

The plagioclase crystals are replaced by K-feldspar in the solid state. Clearly this replacement leads to migration of material elsewhere, resulting in the blastic growth of plagioclase on adjacent plagioclase crystals, as unzoned material.

The zonal nature of the textures in the feldspars indicate cyclical changes in the conditions of crystallization causing the repetition of a characteristic sequence of zones.

The fine-grained boundary and ground-mass myrmekite represent the final phase of the evolution of both G2 and G1.

And the fact that G2 has a chilled margin against G1 suggests that it has been in part a molten mass. The sanidine feldspars in G1 and G2 and the quartz bipyramids in G2 force one to conclude that both granites originated at high temperatures. It is now widely accepted (e.g. Brown, 1963), that similar granites in other Atlantic Tertiary centres are the result of the partial melting of the country rock by hot basic masses, and such a mass is indicated by Bott *et al.* (1958) for Lundy.

Both granites have virtually identical chemical compositions (Dollar, 1941) and have clearly originated from the same magmatic source.

The complex zonal features in the plagioclase feldspar phenocrysts of G2 are equally well developed throughout the mass. Even the plagioclase feldspar phenocrysts present in the chilled margins against G1 show precisely the same sequence of zonal development. This phenomenon implies that all such phenocrysts originated before the granite achieved its present position in the crust. The similar phenocrysts in G1, which have a somewhat less complex texture but are otherwise identical, must also have originated at depth. The presence of only one zone of quartz blebs and myrmekite in G1 phenocrysts as distinct from two such zones in the G2 phenocrysts can be explained by suggesting that the former phenocrysts, as compared with the latter, underwent a shorter period of growth in the parent magma, at depth.

On the basis of these arguments it is possible to propose the following model of evolution (fig. 9). Granite was formed at depth in association with the intrusion of gabbro. Cooling of the granitic magma between phases of basic intrusion resulted in the magmatic crystallization of plagioclase, later to be corroded and replaced during the crystallization of K-feldspar. By this time most of the acid magma was solid. The plagioclase material released as a result of replacement of early phenocrysts grew in the solid around the unreplaced phenocrysts and incorporated the surrounding quartz, which was often in the state of strain as a result of cooling, to form the myrmekitic zones. After the second phase of gabbro intrusion and before the granitic magma had completely crystallized or before blastic growth of plagioclase had begun, some of the granite was separated and intruded as a crystal mush of relict plagioclase phenocrysts and K-feldspar phenocrysts into the present position of G1. The stresses set up in the final stages of crystallization and cooling resulted in a slight deformation of the quartz, exsolution of plagioclase and hence the production of the boundary myrmekite. The boundary myrmekite of G1 is essentially equivalent in age to the outermost zone of quartz inclusions in G2, which continued to evolve at depth. During a third cycle, more granite was separated and intruded so that G2 was formed. In other words, the myrmekitic zones can be used as time markers in constructing a model of evolution for the granites.

In conclusion, it may be said that, in what had previously been thought to be a relatively simple and intrusive granite, the textures give clear evidence of a complicated, but cyclical, sequence of events.

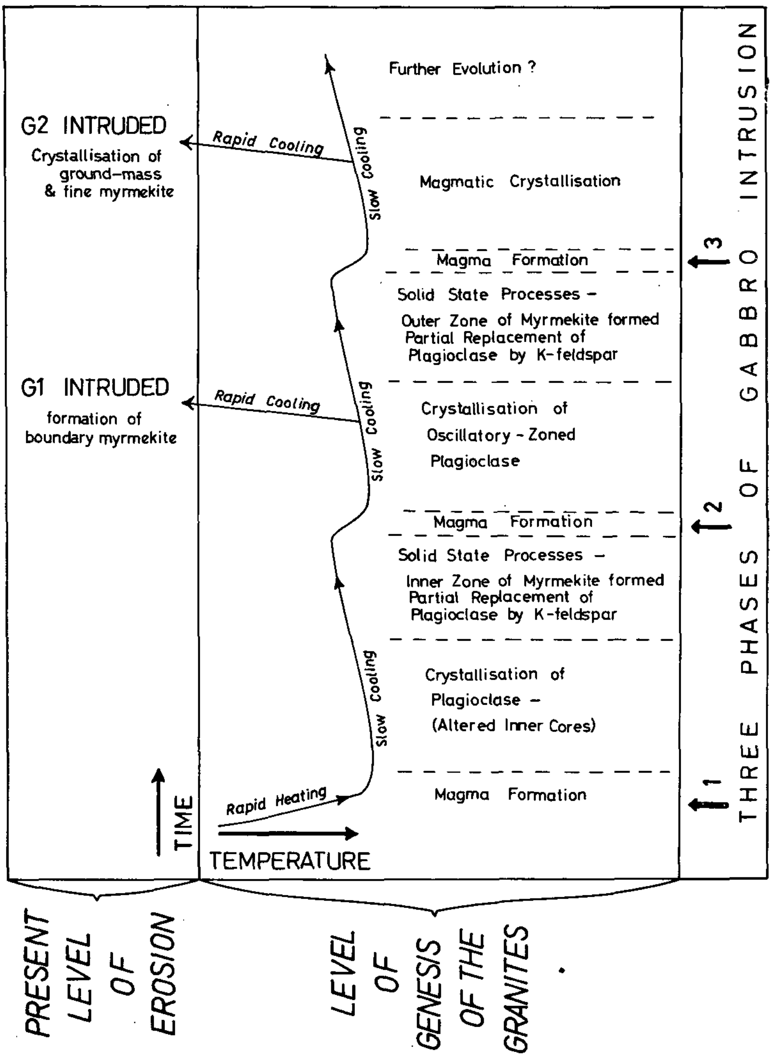

FIG. 9. Diagrammatic representation of the evolution of the Lundy Granites showing the relationships between two depth zones, temperature, volcanic activity and time.

The Lundy Granites were doubtless mobile at times and actual magma is strongly suggested by chilled margins, a fine-grained ground-mass to G2, and oscillatory-zoned plagioclases. On the other hand, solid-state processes can be invoked for the replacement of plagioclase by K-feldspar and the blastic growth of the plagioclase in the myrmekitic intergrowths. The solid-state processes only had noticeable effects at depth where cooling was slow and the temperatures remained high for relatively long periods of time.

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References

AUGUSTITHIS (S. S.), 1964. Spec. Bull. Inst. Petrogen. Geochem., Athens, p. 1.
BOTT (M. H. P.), DAY (A. A.), and MASSON-SMITH (D.), 1958. Phil. Trans., ser. A, vol. 251, p. 161.
BROWN (G. M.), 1963. Min. Mag. vol. 33, p. 533.
DODSON (M. H.), and LONG (L. E.), 1962. Nature, vol. 195, p. 975.
DOLLAR (A. T. J.), 1941. Quart. Journ. Geol. Soc., vol. 97, p. 39.
DRESCHER-KADEN (F. K.), 1948. Die Feldspat-Quartz-Reaktionsgefüge der Granite und Gneise und ihre genetische Bedeutung, Springer, Berlin.
MILLER (J. A.), and FITCH (F. J.), 1962. Nature, vol. 195, p. 553.
SCHLOEMER (H.), 1962. Radex-Rundschau, vol. 3.
SHELLEY (D.), 1964. Amer. Min., vol. 49, p. 41.
VANCE (J. A.), 1961. *Ibid.*, vol. 46, p. 1097.

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